SPARTAN SUPERWAY

A Solar Powered Automated Public Transportation System

San Jose State University
Mechanical Engineering Department
ME195B Final Report
May 21, 2015

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Executive Summary

The Spartan Superway project is a multi-year and interdisciplinary project that is currently in its third year in an academic environment. The Spartan Superway project is an effort to develop and demonstrate the technology of an Automated Transit Network (ATN) that is powered by solar energy. Starting off as 25 students, the students organized themselves into Management, Manufacturing, and Design teams. The management team oversaw and ensured the teams' success by enforcing weekly meeting, meeting agendas, and encouraging team communication. In addition, the management team and team treasurer were responsible for handing the project's expenses. Lastly, the management team was responsible for team outreach. During the 2014-2015 year, Spartan Superway was able to present to Norman Mineta, former U.S. Secretary of Transportation, at the Stanford Precourt Energy Conference, and to Jeff Zhou, CEO of MiaSolé, at Maker Faire. The Manufacturing Team oversaw the Spartan Superway Machine Shop and workspaces, provided consultation concerning manufacturing of models, and assured the safety of their fellow teammates. For 2014-2015, there were four distinct design teams: Full Scale, Scale Model, Cabin, and Solar teams. The following sections will summarize the accomplishments of each design team.

Full Scale

The main purpose of the Full Scale Team this year was to create and manufacture a modular full scale prototype that can adequately represent the benefits and feasibility of an ATN system to both the public and to any potential sponsors of Spartan Superway. The full scale prototype should closely resemble an actual full scale implementation to the extent that it serves as an adequate proof of concept. This results in the significant dimensions and size of the prototype to be full scale, but the overall strength and load capacity reduced to allow for ease of transport and to reduce cost. The team this year focused specifically on making improvements to the guideway, implementing vehicle propulsion, adding a Y-shaped switch track section, and adding a switching mechanism to the bogie, so that it could demonstrate the ability to switch from one guideway to another.

In order for the 2015 Full Scale Team to meet its design goals, the previous year's challenges and issues had to be identified, in order to build off previous work. The Full Scale Team was divided into three sub-teams each of which focused on a different aspect of the project including guideway, propulsion, and bogie switching. Each of these teams focused on their specific tasks and encountered their own issues. Ultimately, each sub-team had common challenges of designing to minimize cost, ease of fabrication, incorporating systems with existing hardware, and designing to sufficient strength to avoid failure while still fulfilling the purpose of the project.

The guideway team developed three new guideway sections based on the previous year'. The first section, as shown in Figure 1-1:1: Single-Sided Guideway Section, most closely resembles the guideway of the previous year, sharing the same asymmetrical cross section. The two other sections designed were a double sided track section and a switching track section. In contrast to the work done last year, the structurally significant members of all guideway sections this year consist of tube steel. This was done to significantly reduce weight, size, and allow for ease of transport and assembly for events such as the Maker Faire.

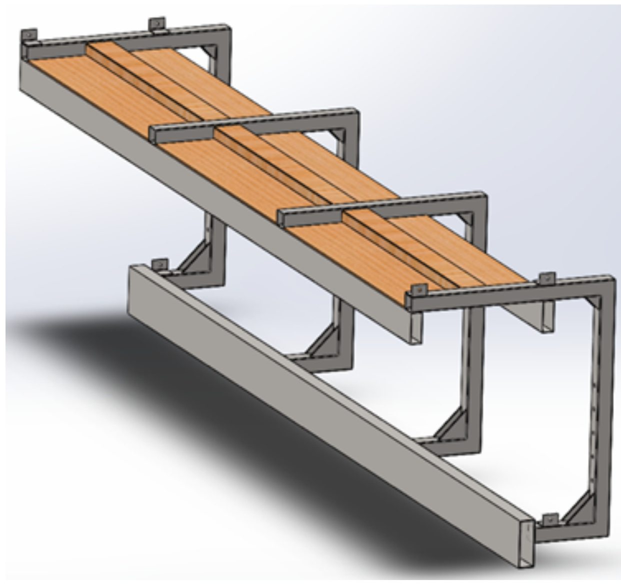

Figure 1-1:1: Single-Sided Guideway Section

The propulsion team designed a mechanism that would incorporate a hub motor with a lever mechanism, to press the motor to the guideway ceiling, to propel the vehicle at a specified velocity, as shown by Figure 1-2:2: Bogie Propulsion Mechanism. All appropriate calculations were done to determine the requirements for the selection of the motor. A moment arm was implemented to press the drive wheels against the guideway ceiling interface and apply the traction needed for movement.

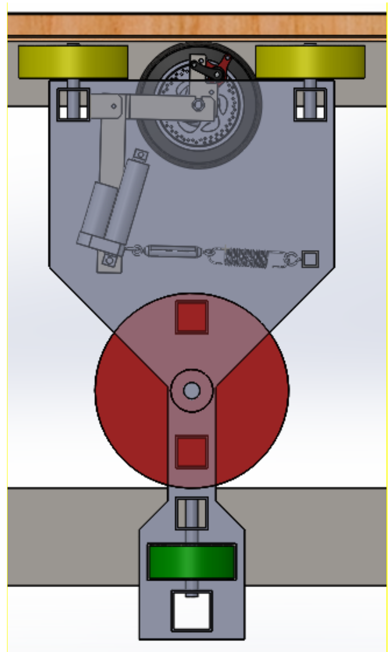

Figure 1-2:2: Bogie Propulsion Mechanism

The bogie switching mechanism, as shown in Figure 1-3:3: Bogie Switching Mechanism consists of two mechanisms to allow wheels to rotate into position and attach the bogie to one side of the track or the other. The mechanism is controlled by two electric actuators that are mounted to the bogie frame. There are two of these mechanisms on each bogie, one in the front and back, to fully constrain the bogie while moving through the switch.

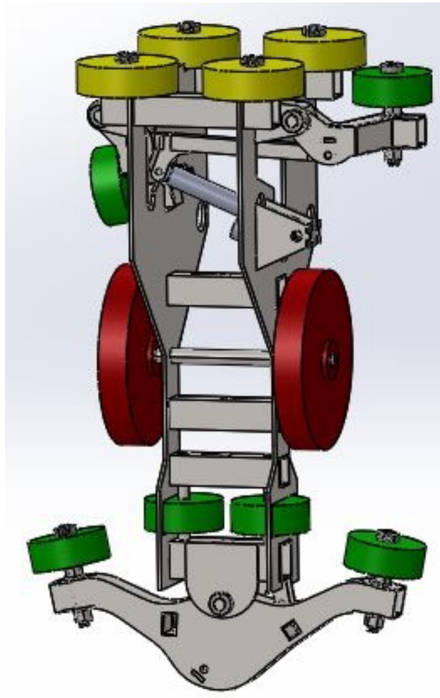

Figure 1-3:3: Bogie Switching Mechanism

The fabrication process began begin with the single sided guideway section and alteration of the bogie. This served as a verification of the design functionality. As all components were fabricated, they were combined into the total assembly for the entire Full Scale Team, as shown in Figure 1-4:4: Complete Assembly of all components.

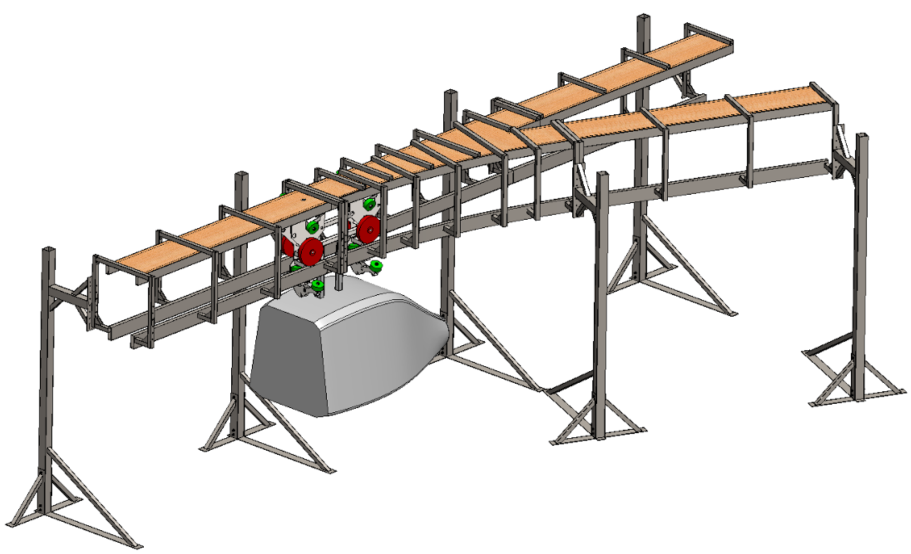

Figure 1-4:4: Complete Assembly of all components

<u>Cabin</u>

The purpose of the cabin team is to design the cabin for the ATN and build a mock-up version of a cabin for Maker Faire. The design of the cabin should be structurally sound, aesthetically pleasing, and have a low drag coefficient. The cabin design is intended to be the basis for what could be used in service. The cabin design is intended to be the basis for what could be used in service. From previous years, the cabins were large and difficult to transport. The mock up cabin this year will be made for people to be able to experience what it would be like to ride in a real ATN vehicle. The mock-up will be stationary and not go on the Guideway. It will also be easy to assemble, disassemble, and transport.

Since the cabin team is creating a new design, we could not use the work done by previous teams. The design from last year could be improved and there was no mock up cabin preserved to show for Maker Faire.

The Cabin team planned on designing a new interior, exterior, and frame. The support of the cabin was designed to be a rib-liked shape; consequently taking on the shape of the exterior. The cabin team built the structure and exterior to be integrated together and added curvature to the cabin. Bondo was used to cover the curved sections and transition it to the flat sides. The interior for the mock up cabin was intended to have different accessories that could be in the real cabin such as a touch screen, and lights but was not implemented.

The Cabin team designed a structural frame with a mass of 341 kg but was unable to complete the analysis of supporting 1370.7 kg. The drag coefficient of the exterior shell was 0.03. The HVAC system requires 1.8KW to maintain at 23 ^{0}C.

Future work would be to use a master drawing on SolidWorks to keep the designs of the frame, exterior, and interior together. Designing a full cabin with doors is the biggest goal so people could sit and walk around the cabin. Applying an analysis on the cabin not just the frame would be another goal. Having material such as metal and plastic outsourced would make it look professional and closer to the real pod.

Scale Model

The 2014-2015 Scale Model Team focused on several important aspects of the Superway project. The team learned from the previous year’s design and throughout the academic year. The main task of the scale team was to redesign the track and bogie while considering a few stipulations. The new track design also allowed the team to simplify the assembly of the track. This design was seen as a solution to the reliability concerns since the bogie would not be getting stuck in the track gaps. The track is composed of simple aluminum bar that is made into modular sections of guideway. These modular sections will look similar to the Full Scale model and ultimately close the gap between Full Scale and Scale model. The final piece of the improvements has to do with supplying power to the bogies. Batteries are being replaced by wayside pickup using multiple power supplies powering electrical rails around the track. The bogie will use this available power without the need to store it on board.

The new design emphasized ease of use and reliability. The controls team designed the main hub for the system, and wrote the pod control and communication control codes from scratch. The system was completely functional by the end of the semester but due to mechanical failures, the team was not able to test the controls with the pods on the track.

Future work would include redesigning the bogie in order to make it go smoothly around the track. The switching mechanism can be polished a bit more to make it more reliable and simple. The controls portion of the project could use optimization through the use of API mode. The python script can also use a little work to make it more efficient. Cyclic Redundancy Checks (CRC) could be implemented instead of the complicated handshakes included in the current system. It would be nice to designate one person for all the hardware hookups so that every detail is accounted for. If the current schematic is satisfactory, future teams should consider getting a Printed Circuit Board (PCB) made for a cleaner look on the cabin. The track can also be modified to include higher tolerances for smoother travel; current design requires extreme precision, or else nothing will function correctly.

Solar Team

The solar panel implementation is a major contributor to the overall effectiveness of such a system. The 2014-2015 Solar Team's goal is to design and fabricate of a lightweight functional solar tracking system and stationary design which showcases thin film flexible panel donated by Miasolé. In addition, the solar team designed the models for ease of assembly and maintenance and minimal power usage. In order to accomplish this goal, three models were built: Tracker for the Scale Model, Tracking Capable Frame Model for Full Scale, and Miasolé Model for Full Scale.

Just like the previous year, the solar panel frame assembly design was split up into two separate models to be demonstrated at Maker Faire Bay Area: a Scale model and a Full Scale model. Thus, the objective for this year's solar team includes the following: (1) design a lightweight single-axis solar tracking frame assembly, (2) successfully rotate the solar panel assembly, (3) minimize the power required to track the sun, and finally, (4) come up with a design that is both easy to assemble and maintain. However, only objectives (2) and (4) will be demonstrated in the Full Scale Model, because with all successful designs, it is important to design and build at a small scale before moving onto the actual implementation in a revenue producing ATN full-fledged model.

The Tracker for the Scale Model, depicted in Figure 5e-1, uses the inputs from two photo resistors in order to determine the optimum position to collect solar power. An Arduino controller board is used to take the inputs from the photo resistors and drive the servo in the appropriate direction. The servo is attached to a coupler and the drive shaft. As the servo rotates, the drive shaft, solar panel frame, and solar panels rotate with it. This model demonstrates real-time tracking and is automatically positioning. The Arduino is powered by the Voltaic Systems portable solar panel and charging system. In order to collect data, a voltmeter connected to the custom Miasolé thin film flexible solar panel so that panel voltage data can be collected while the tracker model is active.

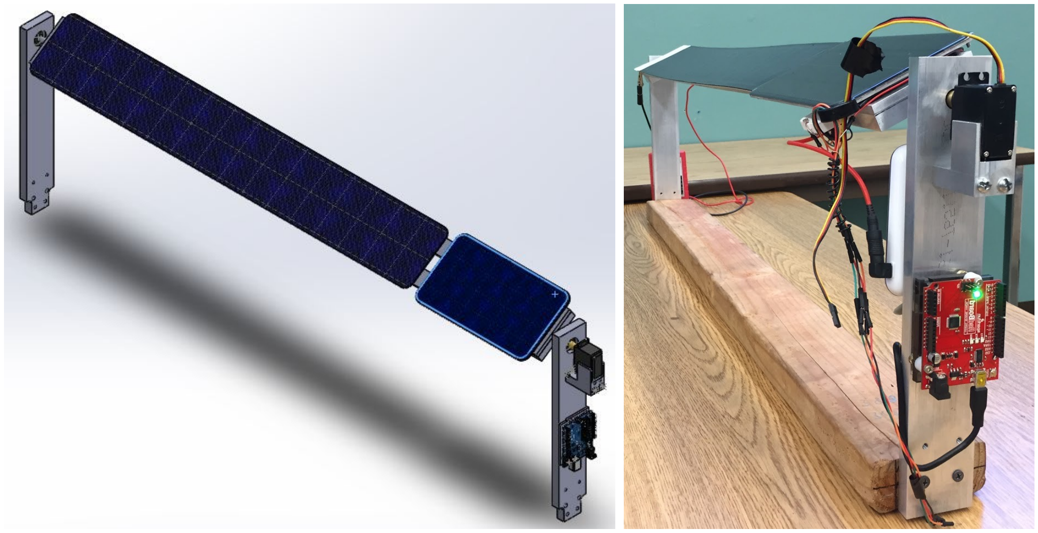

Figure 1-5:5: Tracker Model for the Scale Model holds a custom Miasolé Thin film Flexible Panel and is powered with a Voltaic Portable Solar Panel+ Charging System.

The Tracking Capable Frame model (TCF) for the Full Scale Guideway rotates and showcases Stion Modules on a newly retrofitted frame made from recycled aluminum tubing (see Figure 1-6:6). The TCF rotates 70 degrees to 115 degrees and is driven with a 180 lbf. ServoCity linear actuator. Two mounted sleeve bearings are used to assist in the rotation and assure the frame is supported by the full-scale column supports. As a result, this more robust design enables optimum solar power efficiency throughout the day compared to the stationary (i.e. static) solar panel frame that was designed by last year's team.

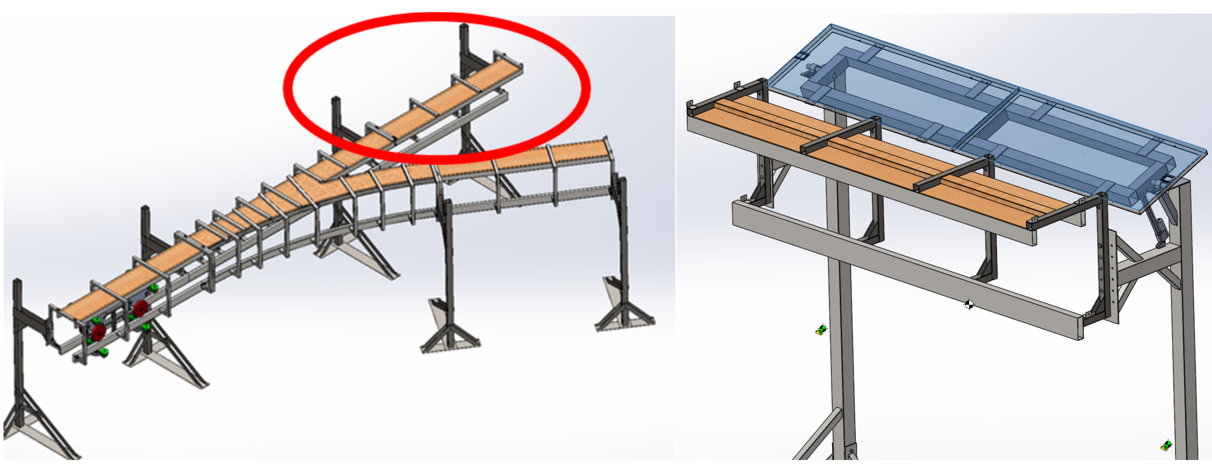

Figure 1-6:6: For the Full Scale Model, the Tracking Capable Frame with Stion Solar Modules utilizes a programmable microcontroller and is driven and controlled by an actuator and Wii nunchuck controller, respectively.

The last model, Miasolé Model for Full Scale (MMFS), utilizes 80/20 extruded aluminum modular framing to create an adjustable frame, which showcases the thin film flexible panels; see Figure 1-7:7. As a result, this more robust design which utilizes modular lightweight framing allows for quick and easy assembly and modification.

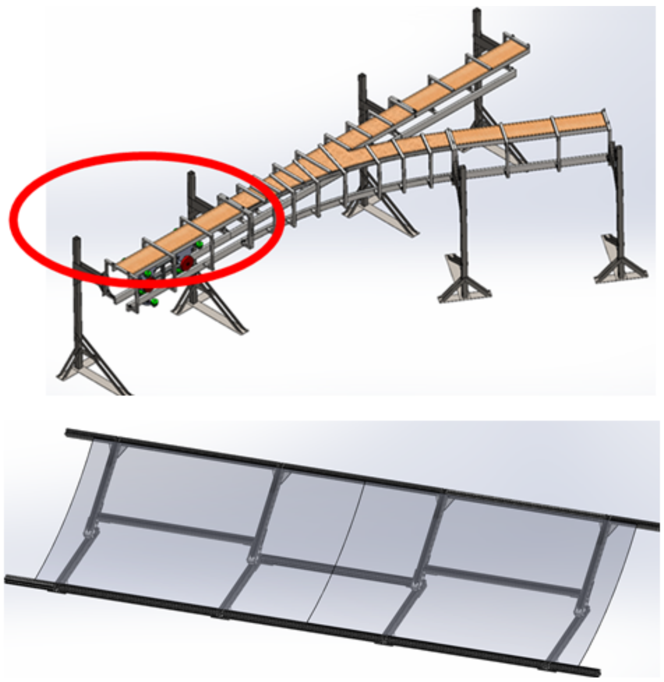

Figure 1-7:7: For the Full Scale Model, the 8020 AL Frame showcases MiaSolé's Flexible Thin Film Solar Panel.

Acknowledgements

We would like to thank our mentors for providing assistance throughout this semester, and for any help they may provide us in the future. The team would like to offer special thanks to Dr. Burford Furman, Ron Swenson, Paul Albulet, Sam Ellis, and Anuradha Munshi for guiding this project and assisting with constructive suggestions. In addition, we would like to thank our generous sponsors.

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Chapter 1: Setting the Stage

Communication and travel are two key areas that require such reformation in thinking. In the article “Benefits and Transportation-Related Reductions in Greenhouse Gas Emissions in the San Francisco Bay Area”, Neil Maizlish says, “Greenhouse gas emissions linked to global warming and climate change are the most significant threat confronting public health in the 21st century. Approximately 7% of US GHGE are generated in California, which is the 12th largest emitter worldwide. California's transportation sector is the single largest source (38%), and personal passenger vehicles account for 79% of that sector's GHGE. The State of California has enacted legislation to achieve a 2050 goal of reducing GHGE to 80% below its 1990 level.” [1-solar] Transportation is a major problem in the Bay Area; San Jose State University’s Spartan Superway senior project aims to provide a solution to the south bay area’s roadway congestion and excess emissions problem. The team achieves this by using solar power as an alternative power source and implementing a personal autonomous transit network.

Traffic congestion is inevitable when commuting to and from dense urban areas during rush hour. Currently no alternative type of transportation has been integrated in urban areas that are able to avoid traffic congestion. There are many problems caused our impacted roadways such as wasted time, traffic accidents and injury, and air pollution. This report discusses one potential solution to all of these problems, in addition to addressing other issues such as increasing quality of public transportation and the high cost of vehicle ownership, the Spartan Superway Project

The Spartan Superway is a solar powered Automated Transit Network (ATN) that creates an efficient, reliable, and fast transportation system that makes use of vertical space, reduces congestion, improves safety, and runs on renewable energy. ATN has multiple public transportation vehicles operating simultaneously and autonomously. There is no operator but is controlled through one control center. The vehicle is able navigate from origin to destination without stopping at other stations or interfering with other vehicles. The vehicles are suspended below a guideway so less material is needed to extend the guideway. Solar energy is used to operate the vehicles 24/7 through solar panels mounted on top of the guideway. The goal of this project was to design a better alternative way of public transportation that can be implemented in urban areas.

For the Spartan Superway project, the students were divided into Full Scale, Scale Model, Cabin, and Solar teams. The Full Scale team is responsible for creating a full-scale model version of the guideway and boogie. The models represent how an actual bogie is supported on the guideway through a straightaway and a switch section. The Scale team’s purpose is to develop the controls system and demonstrate how the vehicle will navigate through the guideway. It also serves as a model for advertising our project for future presentations. The Solar team is responsible for harnessing and using solar energy to operate the vehicle. Lastly, the Cabin team is responsible for designing the cabin’s structural frame, exterior and interior, and the HVAC system.

Day after day, traffic congestion fills the highways in multiple cities and streets including the city of San Jose, which leads to increased time-frames between travel destinations. Thus, there is a great demand for an alternative system of travel for those individuals who are caught in bumper-to-bumper traffic and sit eagerly in their cars for long time-periods while traveling from point A to point B. According to the United States Census Bureau, the average person takes 25.1 minutes to get to work. If we look at a total of five days a week, and four weeks a month, that equates to an eight hour work day. By freeing up the commuter by automating their form of transportation, they can become more productive by utilizing commute times for alternate tasks. This would increase an individual's daily time allowance thereby freeing them up to achieve far more.

A raised and extended guideway with by pod cars or cabins that pick up commuters and take them to a user-defined destination point is one such alternative system of travel that has not yet been introduced to the city of Silicon Valley. Also known as an Automated Transit Network (ATN), such a system offers a plethora of advantages over more traditional transit modes such as light rail, metro, buses, and other modes of transit.

For the City of San José, opportunities to make advancements toward ATN technology are being addressed, in hopes of the implementation of the much-needed technology. According to the United States Environmental Protection Agency (EPA), 27% of the United States' total Greenhouse Gas Emissions in 2012 were from the Transportation sector. Transportation sector includes all air, marine, and rail transportation and highway vehicles. The change in climate due to global warming, depletion of fossil fuels, and increase of traffic are three influences that have led Spartan Superway, a solar powered personal autonomous transit network. Over the Spartan Superway's life cycle, the solar powered personal autonomous transit network is the solution to the problems mentioned above and would alleviate traffic by providing a solution that uses a renewable sustainable source of energy. The use of solar panels to provide power will help secure the earth's natural resources. Every year, just in the United States, transportation systems account for about five million barrels of oil. This will help tremendously in cutting those five million barrels of oil the United States is currently using.

Chapter 2: Full Scale

Summary of Model System

As the work this year was a continuation of the work last year, a fair amount of time was spent reviewing this work. Any fabricated components this year must had to be compatible with the work done last year, unless sufficient alterations were made.

The guideway section fabricated last year was a wooden prototype of a straight track section, which can be seen in Figure 2-1:8: Previous and Current Full Scale Prototype for Bogie and Guideway. The section was supported by two vertical supports attached at two separate points. The dimensions for this track, as available in last year's report, were the foundation for the work done this year on the single sided straight section (Cowley, 2014). The design itself is based on the designs of Bengt Gustaffson of Beamways. However, there was no significant level of work done for the development of a switch section.

Figure 2-1:8: Previous and Current Full Scale Prototype for Bogie and Guideway

Additionally, there was minimal work done for the development of a switching mechanism or propulsion for the bogie, the carriage that rides along the track and supports pods below. The only work done was theoretical, had no supporting calculations or analysis, and had no actual design proposed. Again, the guideway dimensions provided from the 2013-2014 report provided the foundation for developing a switching mechanism this year. Actual implementation of the switching mechanism was not accounted for as the wooden guideway is incompatible with such a system, since the wall of the guideway would physically block such a mechanism.

Objectives

The main goal of this year's full scale team was to further expand upon the efforts of the full scale team from last year. To give some context, the team last year designed and built the first iteration of the full scale guideway system. The result was the 16 foot wooden guideway held by two steel support structures, and a bogie consisting of two individual “half-bogies” connected by an H-bar allowing for the support of a simulated vehicle cabin as shown in Figure 2-1:8: Previous and Current Full Scale Prototype for Bogie and Guideway. The goals for this year included designing a more robust guideway, switch section, switching mechanism, and propulsion mechanism. Each of these objectives were handled by a separate sub-team within the full scale team to allow for effective use of time. The specific objectives for each sub-team are dependent on their exact scope of the project and are discussed in their respective section.

Guideway

Objectives

The focus of the full scale guideway team is to revise the design presented by the guideway team from 2013-2014. This includes further development of additional track sections that were not designed for a prototype, such as the switch section and double-sided straight section. The specific objectives for the team this year are to:

- Redesign the straight section to be easier to fabricate, transport, and be less costly without sacrificing structural integrity and allows for the operation of the switch mechanism and propulsion system
- Design a robust switch track section that allows for the vehicle to change the route it takes, operate safely, and allows for the proper function of the switching mechanism
- Design a double sided straight section to be placed before a switch guideway section to allow the switch mechanism to actuate sufficiently early before the switch section is encountered
- Revise the support columns to allow for easier fabrication and transport

Design Requirements and Specifications

BOE = Basis of Estimate (D =Design Specification, A = Analytical Estimate, T = Verified by Test)				
Parameter	Value	Units	BOE	Guidance/Comments
Track Section Length	10	ft	D	(3.05 m) Allows for ease of transport/ assembly
Support Structures per Length Track	1	per 10 ft (3.05 m)	D	Similar to previous year, allows for less material waste
Desired Incline	0	%	D	No Elevation Changes
Bogie Maximum Weight	550	lbs	D	(226 kg)
Switch Section Curve Radius	315	in	D	(8 m) Defined from last year

Table 1-1:1: Guideway Key Specifications

Table 1-1:1: Guideway Key shows a condensed list of the major technical specifications of the guideway design. Additional information regarding the other influencing technical specifications is available in the propulsion and bogie sections.

In addition to the aforementioned design requirements, there are additional requirements pertaining to the other subsystems. These exact requirements, regarding the propulsion mechanism and the switch mechanism, are discussed in their respective sections. The guideway must allow for the operation of the bogie at all of these maximum conditions, which were taken into account in the design process. The guideway must be designed in English units as stock materials available are in English units.

Design Concepts

The final design for the guideway required many iterations and improvements upon the original concepts from last year. The original design of the guideway, as shown in Figure 2-2:9: Track Cross Section, was that of wood, had a total length of 16 feet (4.87 m), and a total weight of approximately 460 lbs (208 kg). Though this was a good starting point for the design this year, the existing design has some major conflicts with the desired changes for this year. The central aspect of the design was to maintain the track cross section locations consistent, which would allow for the bogie to continue to operate.

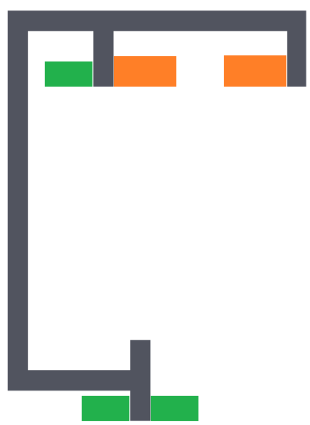


Figure 2-2:9: Track Cross Section

Using this design as a basis, the final design was ultimately reached, as shown in Figure 2-3:10: Single-Sided Straight Section. This particular iteration was the lightest out of all the previous designs, at only 195 pounds (88 kg) per section, only about a third of the weight of the wooden guideway section. This design also included points to attach individual guideway sections together, as shown by the mounting brackets at either end of the guideway section. The double sided straight section, as shown in Figure 2-4:11: Double-Sided Straight Section, uses essentially the same rib design, but with the addition of a support on the opposite side. Little iteration occurred in the design of the double sided straight section, as the design was already refined in the process of developing the single sided straight section. The double sided section is necessary in the design as it allows the switching mechanism to safely operate prior to a switch section, making it an integral part of the design work this year.

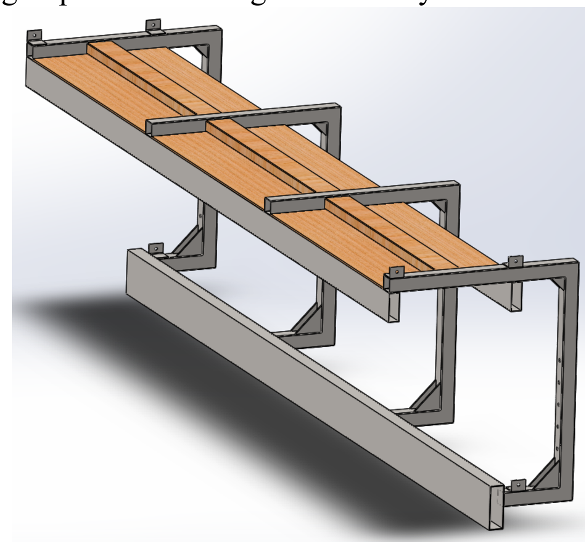


Figure 2-3:10: Single-Sided Straight Section

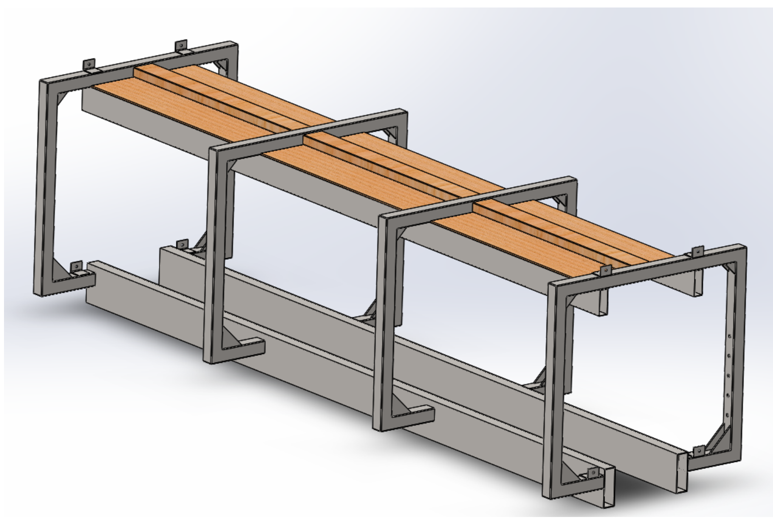


Figure 2-4:11: Double-Sided Straight Section

The guideway switch section, as shown in Figure 2-5:12: Switch Section, was designed in a similar fashion as the straight sections, using the same support ribs as before, only modified in length. Like with the straight sections, the model is designed with tube steel so that it is lightweight, but also very resistant to deflection, due to the material farthest away from the neutral plane of stress being kept.

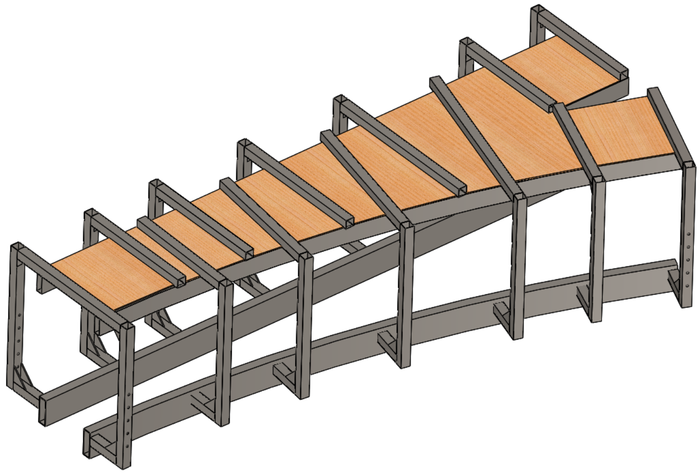


Figure 2-5:12: Switch Section

Analysis & Concept Selection

A majority of the iterations occurred with the single sided straight section. This was for simplicity purposes and allowed for rapid iterations and analysis, but also as any guideway system will primarily consist of straight sections, it is imperative to make the design for this particular guideway type as effective as possible. Nearly ten iterations occurred before the final design was reached, even though many are not shown. Even at this stage, there is room for revision and improvements, but in its current configuration, the design can safely support the maximum load and is considerably lighter than the wooden guideway.

Regardless of the bogie being loaded at the center or edge of the guideway, the track can safely support it. Figure 2-6:13: Static Loading at edge of Guideway shows the stresses associated with the bogie being located at the edge of the section, and it has a maximum Von Mises stress of 12,600 psi (86 MPa). The edge loading case results in the highest possible stresses, so the analyses at other conditions are less important. Far more analysis was run to ensure the guideway would operate properly.

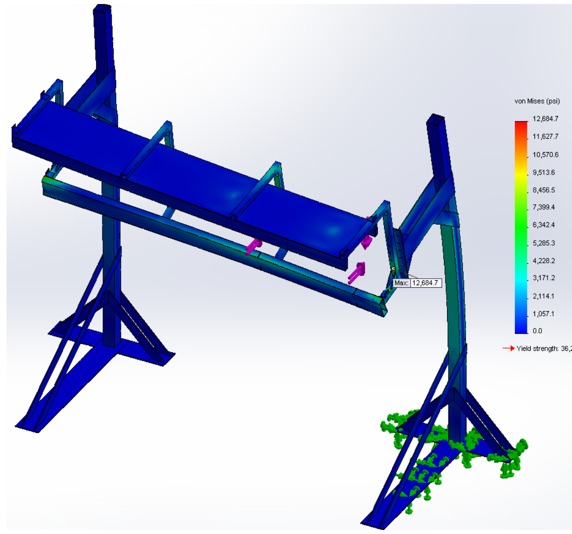


Figure 2-6:13: Static Loading at edge of Guideway

Additionally, a deformation analysis was done at all extreme locations. Figure 2-7:14: Relative Deformation of Guideway shows the results of the deformation analysis at the edge position and only with respect to the track. Incorporating the support columns in this analysis would have given an inaccurate estimation of the deformation the bogie experiences. The support columns are able to elastically deform without affecting any vehicles on the guideway. However, the relative deformation with respect to the track is significant and is worth calculating. Additional deformation analysis was done for other cases to verify this was the extreme case.

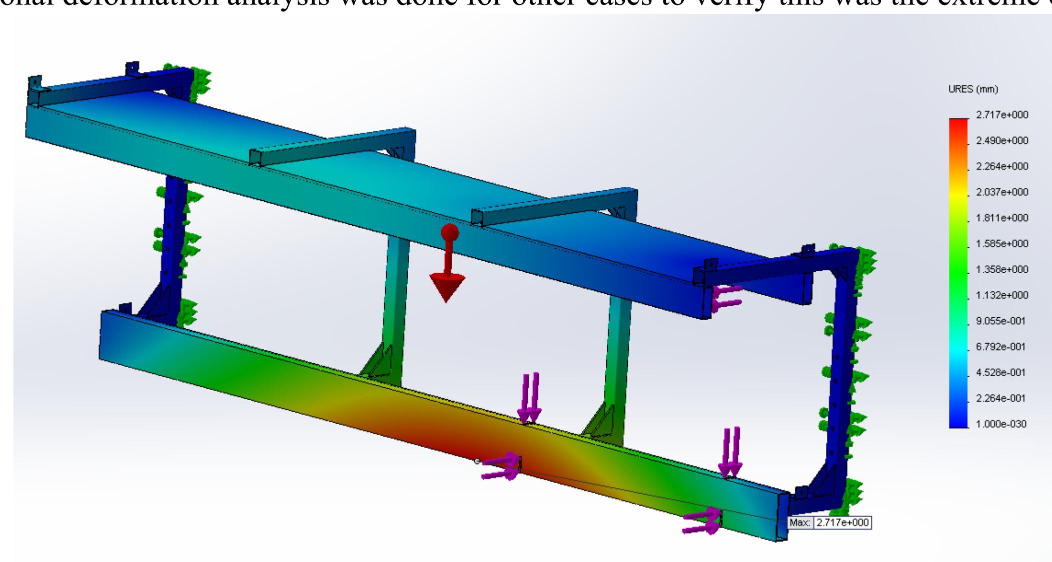


Figure 2-7:14: Relative Deformation of Guideway

A fatigue analysis was for normal operational loads, and shows that the guideway will not fail due to cyclic loading, assuming it is fabricated properly and is not subjected to corrosion. Fatigue analysis was also done for the case of elevated loads, and showed that the guideway would eventually fail. However, since this is not the intended loading, it is not an issue, though it would be addressed in a full scale practical implementation. Factor of safety plots were generated for all major loading conditions, and showed a minimum factor of safety of 1.8. This would allow for a maximum load of 900 pounds (408 kg) before failure. However, this is only for the case of the guideway being supported on its own, without being connected to other guideway sections and distributing their loads to those members. If that is the case, the factor of safety jumps considerably. Regardless, the guideway must be able to support the bogie with sufficient factor of safety while not connected to any other members. If it passes that condition, it will pass any other connected configuration. Additionally, a buckling analysis was run for several cases, and was determined not to be an issue.

The analysis for the double sided section is mostly redundant of the single sided section and for the most part will not be addressed. The only instance that the loading is different is when the bogie is fully loaded on the side opposite of the support columns. This would result in the highest possible stresses the guideway would experience, and warrants additional analysis.

Figure 2-8:15: Static Loading of Double Sided Section shows the maximum stresses experienced by the guideway double sided section. The stresses are slightly higher than the similar case of the single sided guideway section, which is to be expected. The stresses experienced by the guideway double sided section had a maximum of 23,000 psi (180 MPa).

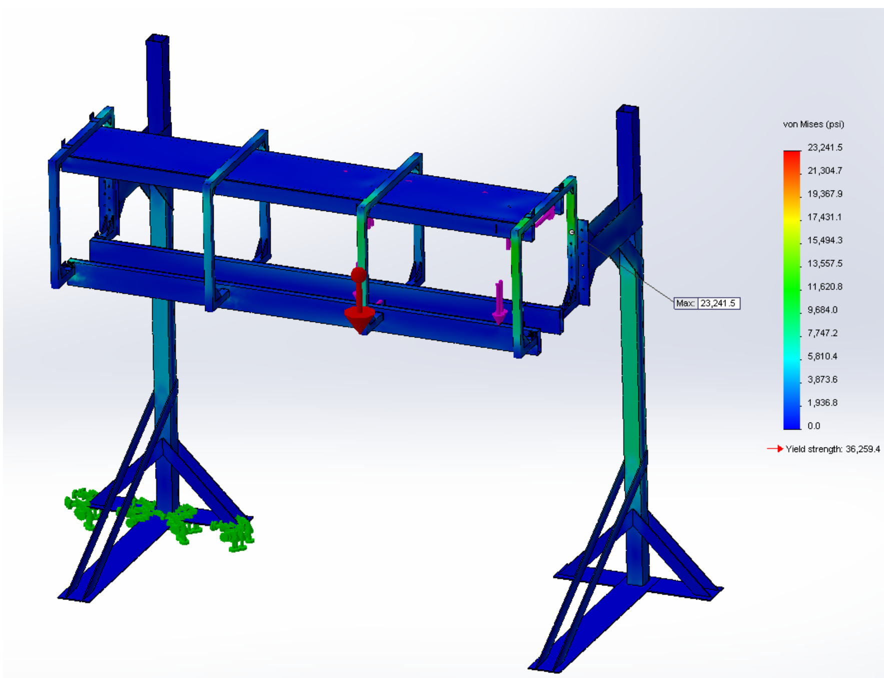


Figure 2-8:15: Static Loading of Double Sided Section

Additionally, the relative deformation of the guideway track was determined, as shown in Figure 2-9:16: Relative Deflection of Double Sided Section. As expected, the deflection in this case is slightly higher than that of the previous case. However, it is still within an acceptable level and will still allow for safe operation. Additionally, when the guideway is connected to another track section, the deformations that occur would be even lower. A fatigue analysis was done, as shown in Appendix B, revealing that the current configuration would eventually fail less than 10^5 loading cycles. However, under normal operating conditions, this section would be connected to additional track sections, reducing stresses and increasing the life of the assembly.

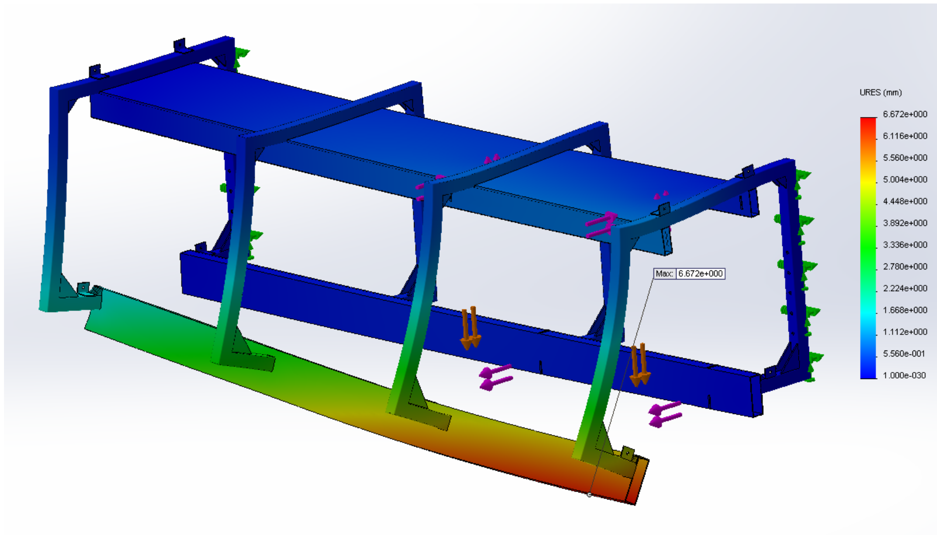


Figure 2-9:16: Relative Deflection of Double Sided Section

The guideway switching section is the portion of the overhead rail system that will require the bogie to direct the cabin along an either straight or curved path. As the bogie approaches the switch section, it will alter the arrangement of the guide wheel in order to facilitate the chosen action. This will change the points at which the guideway will offer support to the bogie and cabin. In order to ensure that the guideway could support the bogie during this section, analysis was run in a similar fashion as the previous sections. While the bogie will technically be moving during this time, the low speeds at which we will be running the full scale model eliminate the need for a dynamically loaded situation.

The full scale model is designed with support columns placed at ten foot intervals. For this reason, during the switching section, the guideway will experience a maximum stress situation at two critical points. The first critical position occurs along the path generated when the bogie carries the cabin straight through the switching section. At this time the bogie will support itself through a wheel positioned on the outer portion of the upper rail. The upper rail on the opposite side of this wheel will curve and lose contact with the bogie. This change in wheel configuration will allow the bogie to rely on only one upper rail. Because of this the supporting upper rail will need to counteract any moment generated by the center of gravity of the cabin being offset from the load-wheel on the bogie. The critical point lies at the furthest distance from the two support columns supporting the straight side of the guideway. The second critical position is the one in which the bogie carries the cabin through the turning section of the switch. The same conditions as in the straight section are applied, but now the rail is curved, and there is a force applied due to the changing inertia of the system. However, due to the very low speeds at which the bogie will be running on the full scale model, approximately 1 ft/s, this inertial force can be neglected, and the analysis run as a static analysis. The critical point in this section lies at the furthest distance from the two support columns supporting the curved side of the guideway.

Figure 2-10:17: Straight Portion Critical Loading displays the results obtained from an FEA analysis, run with Solidworks, on the most recent model of the switching section. In this situation, a safety factor of two was applied to the loads during the first critical position. The figure displays that the deformation experienced by the guideway is .19 inches (4.82 mm) at a maximum.

Alternatively, when the analysis is run under normal loading conditions, the maximum experienced deflection is .09 in (2.31 mm). The deflection ratio produced by the loads in these two scenarios runs true to the elastic (linear) region of deformation caused by appropriate loading.

During a scenario in which the bogie carries the cabin along the curve of the switch section, the deflection will be highest near the joint of the guideway, where the straight section and curve meet. The maximum deflection at this point is 0.11 inches (2.79 mm) under normal loading conditions.

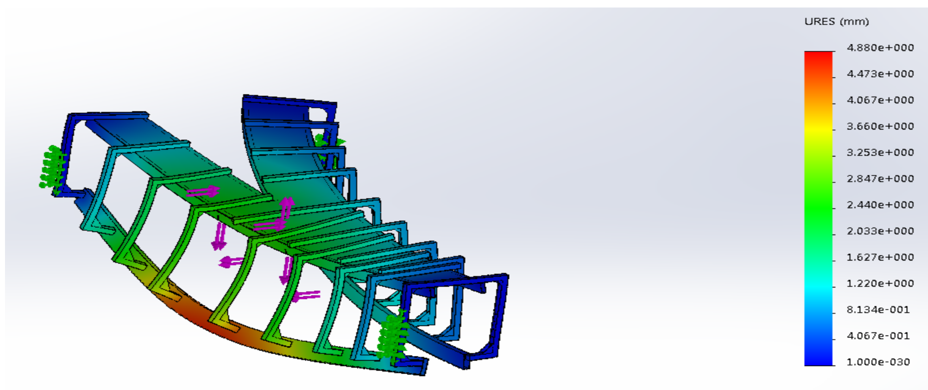


Figure 2-10:17: Straight Portion Critical Loading

The loads applied to the model illustrated directly above are of the same magnitude as the forces used for the straight portion (SF 1). The locations of the loading points on the curved section vary slightly from those in the straight portion due to the curve. The only critical point behind the difference in location for the loads lies in the fact that, the bogie is now angled to accommodate the turn. This results in a slight "shortening" of a projected side view of the bogie and brings the load wheels closer together. However, the expected maximum deformations for both the straight portion (0.09 in) and the curved portion (0.11 in) are considered acceptable for our application.

The total mass for this portion of the guideway is estimated to be about 698 lbs, using the Solidworks mass evaluation tool. The top portion of the guideway was selected as cedar, for properties closest to that of the plywood we will be using. The metal portions of this section were all modeled as ASTM A36 steel.

<u>Fabrication Methods</u>

The guideway was fabricated in stages and took place over several weeks. To begin, only one single sided straight section was fabricated. This allowed for some amount of testing to take place, mostly for verification that the existing bogie would fit. After verification, additional sections were fabricated. As all of the structurally significant parts of the guideway are steel, fabrication involved significant amounts of welding. Temporary tack welds were used in most cases to allow for minor changes to be made if necessary, should parts be not within specifications. A framing table, as shown in Figure 2-11:18: Fabrication of Parts on Framing Table , was used throughout the fabrication process as it allowed for individual pieces to be precisely secured prior to welding. This allowed for the required level of precision needed to make the switch section possible.

Figure 2-11:18: Fabrication of Parts on Framing Table

In addition to the guideway sections, several support columns were fabricated similar to the design from last year. These columns were slightly redesigned to be easier to fabricate, take less space in transit, be lighter, and be more rigid. A total of six support columns were fabricated to allow for all four guideway sections to be held properly. The design for these columns can be seen in Appendix A.

Outcomes

The guideway was fabricated and allowed for the proper operation of the bogie as desired. With the assistance of a fork lift, the entire guideway can be assembled by only two people, though it goes much faster with three to four. From start to finish, the entire guideway can be completely assembled in less than two hours. There is sufficient built-in wiggle room to allow the rails to be aligned despite variations in the ground, supports, or other track sections. With the built-in modularity, the track sections can be assembled in any correct orientation; however, due to the limited number of sections and section types there are a limited number of safe configurations.

Discussion

The single-sided straight section of the guideway design this year shows the most progress, as it can be directly compared to last year. It is less than half the weight and significantly smaller, allowing for better manipulation, setup, and fabrication. Even though the switch and double sided sections have no direct comparison, the progress made on them is still significant. The success in these designs is likely attributed to the care that was taken in the design process. Many iterations were examined over the course of several weeks, to find a design that would minimize cost, weight, fabrication time, and allow for a high level of precision. Additionally, care was taken in the fabrication stage because of this high level of precision, further contributing to the design's success.

Propulsion

Objectives

The purpose of the propulsion system is to move the vehicle at the maximum performance requirements. The propulsion system must generate the traction force required at the wheel to accelerate the vehicle. The system must also exert the required normal force allowing the vehicle to receive the required traction. The propulsion team was working on the design and analysis of the theoretical model and prototype model in parallel. The concepts of the theoretical model were to be developed, and the concepts were to be implemented in the prototype model. Development of the theoretical model is mostly concerned with its performance and feasibility. The goal of the prototype model was to develop a concept that would be implemented in Maker Faire in the spring semester. Development of this concept was more concerned with simplicity and cost than performance. The goals of the project are summarized below.

- Analyze of requirements/specifications for theoretical and prototype models
- Develop propulsion system of theoretical model
- Design propulsion system for prototype
- Generate fabrication plan and budget for Maker Faire

Design Requirements and Specifications

Development of the prototype model is more concerned with cost and simplicity than performance. The speed is to be fast enough to allow onlookers to observe its operation, while also being slow enough to prevent collisions with objects or people and reduce the cost of components. The assumed conditions and performance requirements are summarized below.

Table 2-2:2: Specifications of Propulsion

Parameters	Value	Units	BOE	Comments
Vehicle Weight	250	kg		550 lb
Nominal Speed	1	ft/sec	D	
Maximum Acceleration	1	ft/sec^2	D	
Grade	0	%	D	
Propulsion:				
Traction Force Max	115	N	A	25.748 lb
Peak Torque	11.637	Nm	A	
Continuous Torque	3.9172	Nm	A	
Revolutions Per Minute	28.648	rpm	D	
Peak Power	34.911	W	A	
Continuous Power	11.752	W	A	
Normal Force	164	N	A	36.783 lb

Design Concepts

Figure 2-12:19: Model of Propulsion System shows a model of the traction system on the prototype. Figure 2-14:20: Unattached model of Propulsion System shows an unattached model of the system to better observe its operation. The vehicle is accelerated by an 8 inch hub motor. The braking system consists of mechanical disk brakes (not shown), which are to be actuated. The traction system consists of an L lever attached to a spring, which is to be connected to a pin located at a horizontal distance. The spring is to be connected to a turnbuckle, which is connected to a pin on a mounting bracket welded on the bogie. The pin is shown unattached, and its location should be chosen to allow flexibility in spring size and extension. The L lever is hinged to a bracket welded on the upper rectangular bars of the half bogie.

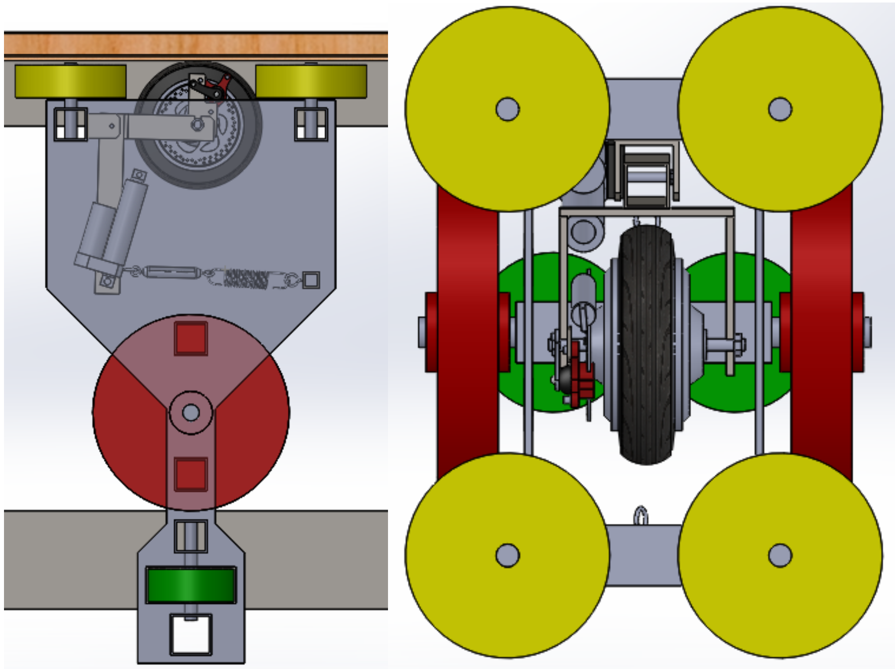


Figure 2-12:19: Model of Propulsion System

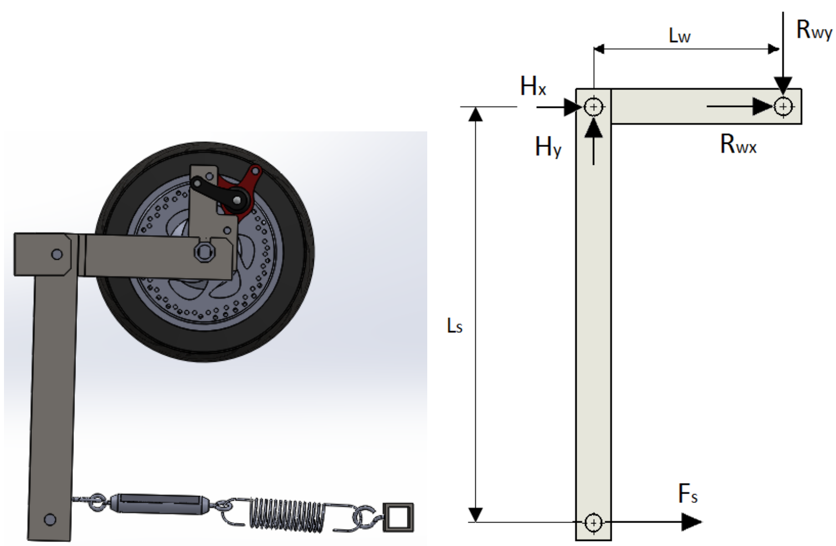


Figure 2-14:20: Unattached model of Propulsion System

When the spring pulls on the long arm of the lever, it generates a vertical force on the end of the short arm, due to the moment at the hinge. It is desirable to make the transmitted force adjustable, due to slip from unforeseen conditions. Therefore, a turnbuckle and a stronger than necessary spring is preferred to allow adjustability of the spring extension, and thus normal force on the wheel.

Analysis and Concept Selection

A published Matlab file "Estimations of Prototype Traction Requirements" was used to generate the specifications of the prototype model and the motor requirements. The results of the analysis and specifications are summarized in Table 2-2:2: Specifications of Propulsion. The analysis on the structural integrity of the lever was done with hand calculations. Table 2-3:3: Verification of Stresses on Traction System shows the results of the stress calculations of each component, as well as the assumed materials and yields. The analysis was carried out assuming one double shafted drive motor in order to accommodate the case of a malfunction of one motor. This geometry yields an acceptable safety factor.

Table 2-3:3: Verification of Stresses on Traction System

Stresses on Link	Horizontal Link Shear Max	Horizontal Link Stress Max	Vertical Link Shear Max	Vertical Link Stress Max	Bolt Shear Max	Link Tearout Max	Bearing Stress Max
Material	ASTM A36 Steel				Low Carbon Steel		
Analytical Estimate (psi)	1718	2001	70.3	1009	688	827	2160
Yield (psi)	26250	35000	34500	46000	15225	15225	20300
Safety Factor	15	17	491	46	22	18.4	9.4
Critical Load	8170 lb						
Max Deflection	-0.00057 in						

The results of the calculations showed that the spring must at minimum supply a force of 24.8 lb with one drive motor and half this load with two. The following relationship may be used to experimentally determine the spring constant (k) of any store bought spring, and the necessary extension.

$$F_s = k(\textit{final length} - \textit{initial length}) \quad (1)$$

An Arduino Mega, a wireless Wii Nunchuck, and two hub motor kits are used to control the bogie. The kits include a motor controller capable of bidirectional control, and a disc brake and caliper for braking. The motor is driven with a pwm signal from the Arduino, which is connected to the throttle signal of the motor controller. Two TCRT5000 sensors operate as encoders to monitor the speed of the bogie. A striped pattern is attached to the inner shaft the support wheels on each side of the half bogie, to determine the speed of rotation of the wheel. The position of the bogie is determined by a reed sensor, which senses magnets placed on the track. The magnets are to be placed on the lower track plate, and a reed sensor is placed on both sides of the half bogie. The disc brake caliper is mounted on a bracket, and the brakes are activated with a linear actuator, which is attached to the vertical column of the traction link. If the disc brake ever proves inefficient, brake pads may be mounted on the actuator and pressed on the guideway as an alternative braking system. The bogie is powered with a set of 3, 12V batteries in series for the motor with a separate, standalone 12V battery for the Arduino and linear actuators.

Fabrication Methods

The moment arm for the electric motor was fabricated with similar techniques as the guideway and the bogie. The moment arm was connected to the bogie upon its completion, along with all necessary wiring and electronic components.

Outcomes

The outcome of the propulsion team was a workable propulsion system. The bogie was able to move along the track under its own power. During fabrication of the bogie and track, the controls were initially mocked up on a test stand with all features implemented. However, when testing on the track began, the system was found to be inconsistent in its response. These inconsistencies were assumed to be hardware related since software functions that were initially verified ceased to function for unknown reasons. The system was simplified in order to secure consistent function within the time constraints. The Nunchuck controls were replaced with a toggle switch to initialize a loop that would have the bogie move forward and backward before switching. Instead of closed loop feedback control, the motor was set to hardcoded value for the initial start, and after a set period of time, would revert to a lower value to travel slowly to the end of the track where it would coast to a stop rather than brake. Due to time constraints speed control was not implemented and only one of the two planned motors was used. This system often required adjustment of the hardcoded values but still demonstrated the basic functions of the propulsion system.

Initially, the motor signal needed to be relatively high in order for the motor to consistently start. Replacing the PWM output with a true analog signal from a digital-to-analog converter (DAC) allowed the motor to move at a much slower rate. The DAC chip however used the I2C pins on the Arduino, which were initially utilized by the Wii Nunchuck and removed this option of control. The reed sensors were too fragile and were replaced with hall sensors to sense the magnets at the stop points. The disc brake proved to be unreliable and was initially disabled since the actuator functioned inconsistently. Even with the modifications done to remove obstructions to the caliper, the bolts connecting the disc brake to the motor would come loose after continuous use of the motor, and the caliper would also become loose and wobble. These obstructions may cause the brake to interfere with the movement of the motor. These components are difficult to access for readjustment and were removed entirely for a more consistent performance.

There are areas where the propulsion system needs work. The single motor does not start moving the bogie consistently and requires the system to be restarted. Implementing the second motor may solve this problem. This problem may be related to lack of cooling of the components, so a 140mm computer fan was added during the demonstration at Maker Faire to cool the controller. A proper cooling system should be implemented to cool all of the components. The lack of speed control means that factors such as wind, battery capacity, and track grade need to be compensated for by manually tweaking the program. The lack of brakes means that if those factors are not compensated for properly, then the bogie can hit the hard stop at the end of the track. Currently, the status of the program is outputted to the serial monitor, but this requires a computer to be connected to the Arduino. A separate screen on the vehicle would be helpful for checking on the program status and troubleshooting.

There are areas where the propulsion system needs work. The motor inconsistently stalls and requires the system to be restarted to resend a second signal. Implementing the speed control would likely solve this problem by accomplishing this programmatically. This would also remove the need to manually adjust the program to account for factors such as wind, battery capacity, and track grade. A proper cooling system should be implemented to cool all of the components and resolve any related problems. The brake caliper should be welded on the traction link to prevent wobble and the caliper should be further modified to prevent obstruction. If further modification proves to be burdensome, a new caliper, drum brakes, or brake pads may be utilized to install a more consistent system. Currently, the status of the program is outputted to the serial monitor, but this requires a computer to be connected to the Arduino. A separate screen on the vehicle would be helpful for checking on the program status and troubleshooting.

Although more work needs to be done, the propulsion team met its goals of designing and implementing a working prototype propulsion system.

Discussion

The prototype concept was developed to allow for easy fabrication of the traction system. This allows adequate time in the spring semester to develop the controls system for the prototype. However, more effort should have been made to develop this system in time to provide a better budget estimation for the system, and predict problems that may occur during its development. Development of a controls system was the priority of the beginning of the spring semester. This task is crucial for building a self-propelling vehicle in time for demonstration.

Bogie

Objectives

Last year the bogie team made considerable progress in determining the locations of the fixed wheels of the bogie, which make contact with the guideway. There was little thought though on the implementation of a mechanism which would allow the bogie to choose which track to follow during switching sections. Since the requirements of an autonomous transportation network are that the track must be fixed, it is necessary for the bogie to determine which course it will follow. The objectives of this year’s team are as follows:

- Design switching mechanisms for the top and bottom rail which will keep the bogie securely attached to the guideway
- Design a system to actuate the switching mechanism automatically

Design Requirements and Specifications

Table 2-4:4: Bogie Technical Specifications

BOE is Basis of Estimate (D =Design Specification, A = Analytical Estimate, T = Verified by Test)				
Parameter	**Value**	**Unit s**	**B/O/E**	**Guidance/Comments**
Minimum Turning Radius	8	m	D	Defined last year
Upper Steering Force	249.54	N	A	56.1 lb (Safety Factor 2) *
Lower Steering Force	1107.61	N	A	249 lb (Safety Factor 2) *
Drive Wheel Force	222.41	N	D	50 lb
Switching Section Length	3.048	m	D	10 ft
Available Track Length For Switching	2.1336	m	D	7 ft for leading bogie
Bogie Speed	0.3048	m/s	D	1 ft/s
Maximum Actuation Time	7	s	A	
Cabin Estimated Weight	1779.29	N	D	400 lb **
Bogie Maximum Weight	1334.47	N	D	300 lb For both bogies **
Maximum Wind Speed Normal to Path	56.327	kph	D	35 mph ***
*These forces do not take into account drag forces from the wind **Estimated weights are higher than anticipated for an added safety factor ***Maximum estimated wind speeds for San Mateo County taken from chart in Appendix A				

The requirements of the bogie switching mechanisms are largely dependent on the other areas which are being developed this year, primarily the thicknesses of the upper and lower rails of the guideway, the radius of the turn during the switching section, the length of the straight section entering the switching section, the speed which the bogie will be traveling, and the force that the drive wheel exerts on the ceiling of the guideway. Determining the forces that the steering mechanisms will experience is required for each of the three different sections, seen below in Figure 2-14:21: Critical Locations for Steering Mechanism Force Analysis.

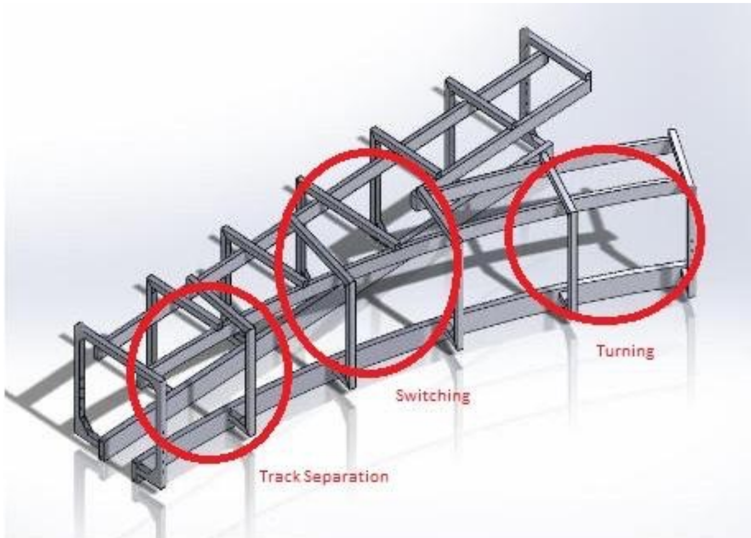


Figure 2-14:21: Critical Locations for Steering Mechanism Force Analysis

There are three areas which will be focused on this year. The first is moment when the two parallel track sections begin to separate. In the reference frame of the bogie the track which it is not following is moving away from the track which it is trying to follow. For the bogie to stay on the track which is desired the steering mechanisms must be able to overcome the friction force experienced between the support wheel, and the track which the bogie is not following.

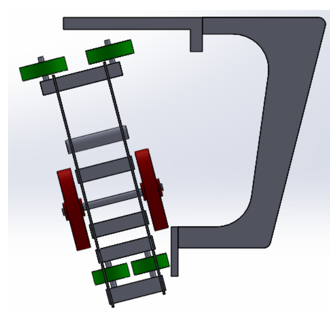


Figure 2-15:22: Bogie Falling off Guideway during Switching

The representation of the cross section of the guideway and bogie during switching can be seen above in Figure 2-15:22: Bogie Falling off Guideway during Switching to illustrate the problems which can be encountered during switching, and is the second point which will be analyzed. The weight of the bogie and cabin create a moment at the bottom wheels which want to rotate the bogie off the track. During normal straight sections the contact between the opposing upper guide wheel and the guideway create a force which opposes this moment. During switching this section of track is no longer in contact with the guide wheel so the steering mechanisms must provide this force to counter the moment.

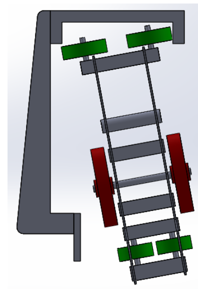


Figure 2-16:23: Bogie Rolling off Guideway during Cornering

Figure 2-16:23: Bogie Rolling off Guideway during Cornering above illustrates the final situation which must be analyzed. During cornering the centripetal acceleration of the bogie causes the bogie to want to swing out in a radial direction. This can cause the bogie to roll out of the guideway as seen in the image. The steering mechanism will need to counter these forces to keep the bogie in firm contact with the guideway.

<u>Design Concepts</u>

When generating the design concepts it was the goal to keep the designs as close to what would actually be produced in the final product as is possible given our limited abilities for fabrication. The theoretical model is subjected to much greater forces than the prototype will be subjected to so all of the designs are scaled down to reduce cost. There were two main topics which were considered when generating the design concepts, the steering arms, and actuation components.

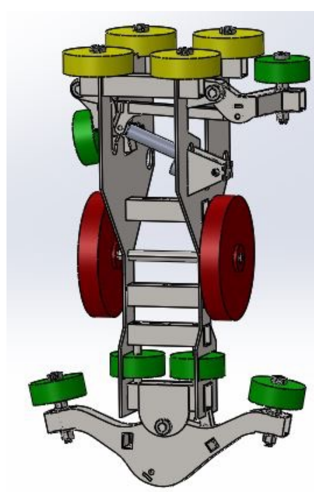


Figure 2-17:24: Single Link for both bottom wheels and 4-bar for top

One of the final options considered for the steering mechanism was a single link for the bottom wheels, and a 4-bar link for the top wheel, shown in Figure 2-17:24: Single Link for both bottom wheels. These arms would be controlled by a single actuator on the top and a single actuator on the bottom.

There has been less design work accomplished in the other two aspects. There were three types of actuators considered, either pneumatic, hydraulic, or electric. Each of these pose their own benefits which will be discussed in the next section.

Analysis & Concept Selection

To begin the analysis, hand calculations were done to determine the forces necessary to keep the bogie in control during the three critical sections discussed in the previous section. For the analysis it was assumed that the bogie would be traveling at 1 ft/s, the minimum radius was 8 m, the center of the mass of the cabin was 8 feet below the bottom of the support wheels, and the center of mass of the bogie was located at the top of the support wheels. In reality the center of mass of the cabin will likely be higher than 8 feet, but calculations were done with 8 feet since any shorter distance would reduce the forces experienced by the steering wheels. The appendix shows the free body diagram, and forces experienced during the moment when the tracks begin to separate. From this analysis the upper steering member will need to withstand 41 lb or 182.5 N, and the bottom steering member will need to withstand 259 lb or 1152 N. Next the moment during switching when the opposing track is no longer there was analyzed; this analysis can be seen in the appendix. From this analysis the upper steering member will need to withstand 56.1 lb or 249.5 N, and the lower steering member will need to withstand -430.3 lb or -1914 N. During cornering the forces experienced by the steering members were analyzed. Due to the presence of both upper rails of the guideway during this section there are no forces experienced by the upper switching mechanism during cornering, the lower steering mechanism experiences a force of -459.4 lb or -2043.5 N.

The negative forces experienced by the lower steering mechanism during cornering and switching indicate that the support wheels inside the track will be subjected to those forces. At the speeds the bogie will be traveling the weight of the bogie and cabin supply enough of a moment about the pivot point to keep the bogie securely fastened to the desired rails. Of the three cases the greatest forces experienced by the upper and lower steering links were used to analyze the stress in the components of the steering mechanisms. The upper steering mechanism experiences its greatest force of 56.1 lb or 249.5 N during the switching period, and the lower steering mechanism experiences its greatest force of 259 lb or 1152 N during the time when the two tracks begin to separate right at the entrance to the switching section.

The majority of the fabricated components were designed using 11 gauge cold rolled Steel, with the mounting plates being made from ¼ inch A36 steel plate. An electric actuator was chosen for a few different reasons, one is it is cheaper. With pneumatic and hydraulic actuators other hardware such as pumps, valves, and compressors are needed which add cost and weight to the project. The other is that pneumatic and hydraulic systems are prone to leak over time, while air leak will decrease the efficiency of the system, a hydraulic leak could potentially be hazardous to the environment.

Once the design of the components was completed analysis was run using the Finite Element Method using Solidworks simulation. The forces calculated previously incorporate a safety factor of 2, and were used as the loads for the analysis. The results from this analysis can be seen below in Figure 2-18:25: Switching Stress Analysis in both Configurations, from the analysis both the upper and lower switch arms experienced stresses much lower than the yield strength of the materials.

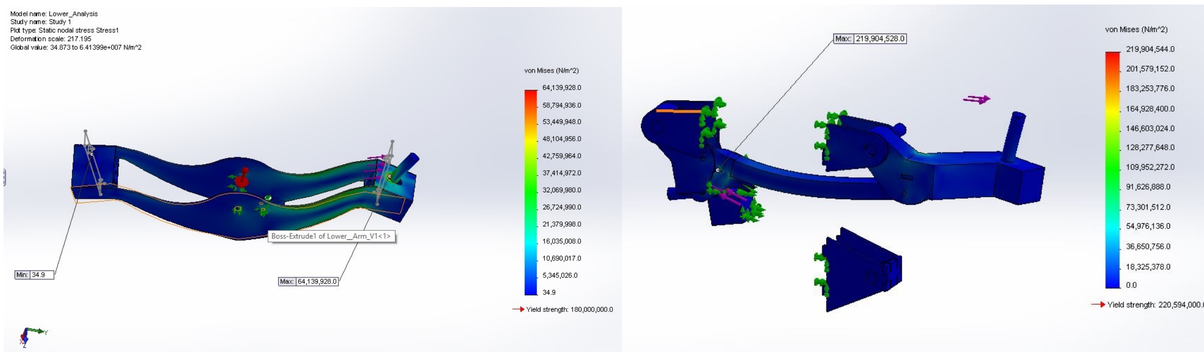


Figure 2-18:25: Switching Stress Analysis in both Configurations

<u>Fabrication Methods</u>

The design used in this year's prototype was specifically created to be fabricated for low cost, with the means that the team had at their disposal. The 11 gauge sheet metal parts were cut on a laser cutting machine, and the ¼ inch plate was cut on a water jet. All of the tubing pieces were cut on the band saw in the workspace, and the holes were drilled on a mill in the student machine shop. Once all the pieces were cut the pieces were carefully aligned and tacked in place. Once all of the pieces were tacked in place the bogies were tested on the new track sections to ensure proper alignment with the support rails. Once it was verified that the bogies fit on the tracks as designed, and that the steering mechanisms operated as intended then the components were welded the rest of the way.

<u>Outcomes</u>

The overall performance of the switching mechanism was satisfactory. The steering mechanisms were able to successfully keep the bogies on the tracks at all times while traveling through the switching section. There are a few problems with the design which became evident during testing and demonstration. First of these is that there needs to be some sort of mechanical locking system to keep the steering mechanisms engaged once the actuators put them into their position. Currently the design relies on the static load bearing capacity of the actuators to keep the steering mechanisms engaged. Although the actuators were below their reported static load capacity the first pair of upper actuators allowed the steering mechanisms to slowly disengage from the track while traversing the switching section. Replacing the actuators solved this problem for the time being, but does not guarantee that the problem will not return, and adding a mechanical lock will add a redundant safety feature. In addition the actuators which control the steering mechanisms have a relatively slow travel rate, which makes the steering take a long time to engage, specifically the upper steering. Faster travel actuators would make the operation of the switching mechanism not halt the demonstration of the bogie for so long. Although all of the objectives of the bogie team were satisfactorily completed, there is room for improvement in all areas of the design.

Discussion

There were some substantial obstacles to overcome with the design of the steering mechanisms. The first was that initially there were no 3D models of the bogie available, once we did finally get the 3D models the dimensions of the models we were provided did not match the physical prototype. The second problem is that the chassis of the prototype is not true, meaning that during welding the welders allowed the metal to reach too high of temperatures which caused the metal to warp, it was for this reason that the bogie was remade, with more care taken to align the components, and prevent distortion from welding. The obstacle to the progress of the steering mechanism is its reliance on the designs of both the guideway team, and the propulsion team, to determine the forces experienced by, and the locations of the steering wheels. Once that information was available from the other teams the current iteration of the steering arms was designed and fabricated. For the reasons explained in the previous section it was decided to go with electric actuators for the steering arm. The upper and lower steering arms are going to be joined by steel cables to synchronize their motion. There is one additional concern about the current design of the steering mechanism. The wheels on the steering mechanism, although adjustable do not offer any type of active adjustment to hold them securely to the track, in next year's iteration it would be nice to see some sort of system designed which will keep the steering wheels firmly pressed against the surface of the track.

Full Scale Team Conclusion

The full scale prototype project is a massive undertaking. Many hours were spent going over design revisions and making calculations. The guideway team designed an entire new guideway using all steel construction. Many design iterations were completed before the current design configuration was reached. FEA modeling was performed on the all sections of the guideway design to ensure that they would function as desired and there would be no risk to the user.

The propulsion team succeeded in developing a system for moving the prototype bogie along the track. Extensive calculation and analysis was performed to determine the requirements for the components of the system. Hub motors and electrical components that met the required specifications were chosen as components for the assembly. The propulsion system developed for the prototype is scaled down substantially from the actual idealized production assembly to reduce cost and make fabrication feasible.

The bogie team iterated through several design concepts before settling on an upper and lower steering mechanism consisting of a single link for both steering wheels. Hand calculations were performed to analyze the forces experienced during three critical sections. These sections are: when the tracks begin to split, after one of the support wheels is pulled off of the track during the switching section, and cornering. The greatest forces experienced by the upper and lower steering arms were used to perform a preliminary analysis of the von-Mises stresses in the respective components. This information was used to aid in the estimation of necessary materials. The arms will be actuated with electric linear actuators mounted to the chassis. There are more parts that need to be analyzed, and optimized. A mechanism needs to be created which will synchronize the motion of the upper and lower steering mechanisms.

Ultimately, the primary goal was achieved, to produce a modular, functioning full scale mockup, as shown in Figure 2-19:26: Complete Full Scale Prototype. Even with the progress made this year, there is still additional work to be done such as further design of a passive safety system, expansion joints, wayside pickup, and more robust position and velocity detection and control. As work continues in the future, these will likely be addressed and resolved.

Figure 2-19:26: Complete Full Scale Prototype

Chapter 3: Cabin

Introduction

As cities develop over time, there is an increase in traffic going in, through, and out of urban areas. Commuters have no choice but to sit in the traffic wasting valuable time. Currently there is no solution to bypassing traffic. Even with energy efficient cars, carpooling, and buses, they all must wait in traffic. People are willing to find other means of commuting as proven in the 2014 Silicon Valley Index. Over the past three years, there has been a 26.5% increase in Caltrain riders and a 38% increase of VTA riders from 2012 to 2013. However this is still a small percentage of how overall workers get to work as seen in Figure 1 below.

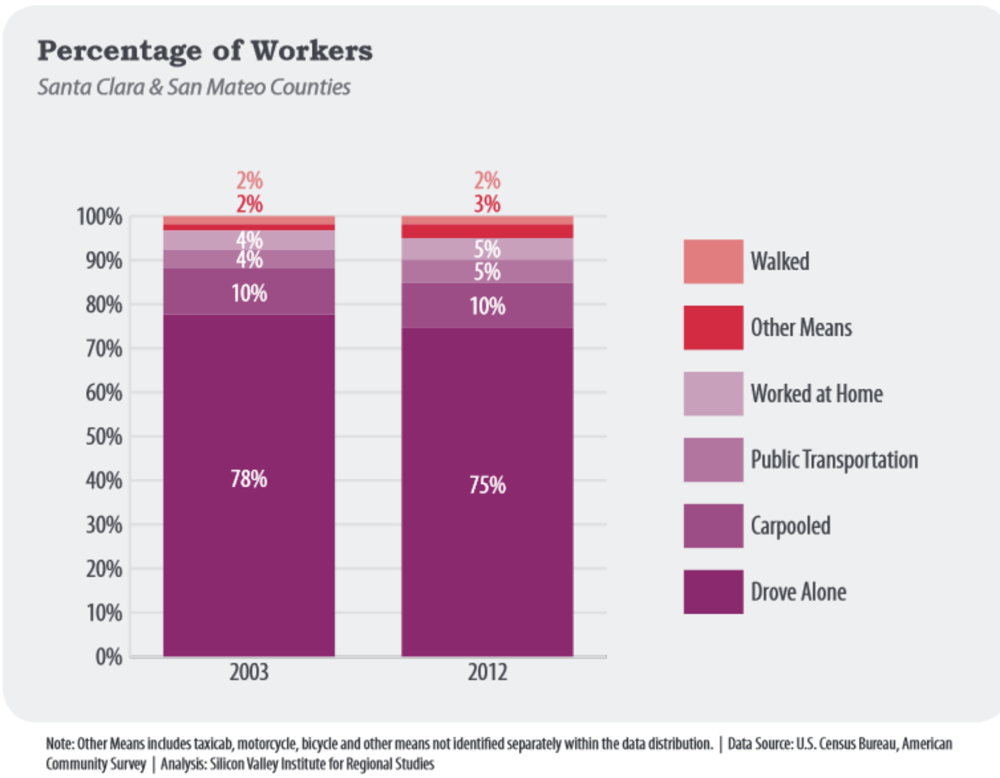


Figure 3-1: 27: Percentage of how workers commute to work in 2003 and 2012.

With a combined 85% of people driving alone and carpooling to work in 2012, it is shown that driving is and has been the main source of transportation. With the Spartan Superway project, traffic can be avoided by riding above street level. The controls would avoid crashing into other pods providing safe travel. The 100% electric run system will reduce the air pollution from operating cars. Future riders will appreciate all of the experiences of the ATN by riding in the cabin. With that goal in mind the cabin team sets out to design a cabin that would be comfortable, aesthetically pleasing, and functional.

Goals and Objectives

The objective for the cabin team was to design a structurally sound, aerodynamic, and comfortable cabin for the Spartan Superway. Designing and fabricating a full scale cabin was too large of a scope. Instead, the cabin team focused on a few specific areas to design. This was accomplished by dividing the tasks into the following: HVAC analysis, designing the frame and body, and designing interior layout. With these tasks, the Cabin team focused on creating a functional and comfortable cabin to ride in.

The HVAC is required to maintain the cabin at a comfortable temperature range independently of the weather outside. This is important so people feel comfortable on their ride in the cabin. On cold days and hot days the cabin should be at around 23 ◦C which is in the comfort range for humans. The sizing of the HVAC unit is important otherwise it could be too small to cool or heat up the space. The other side if it is too big of a HVAC unit where it is spending more energy than is required to cool and heat. To ensure the correct size is picked for the cabin a HVAC analysis was conducted on the cabin being designed.

The load on the grid due to the HVAC has to be minimal if the Spartan Speedway is to be efficient. The goal of the Spartan Speedway is to be as efficient as possible and have no impact on the grid. The HVAC unit takes a big amount of energy to run so it is important that a highly efficient unit is found so as to no impact the energy being supplied by the solar panels. If there are going to be multiple pods on the track it is imperative that HVAC units use as little energy as possible.

The frame and shape of the cabin play the largest roles in the efficiency and safety of the cabin, and need to be designed with those factors in mind. The decision for the design was to design them for a real world implementation, rather than for next fabrication next semester. Since this is an ongoing project, this will give next year's team a better starting place than designing for fabrication.

The design of the frame should focus on distributing the stress of the cabin effectively while maintaining structural integrity. The material choice needs to have a high enough strength to handle the loads, but not be overly dense and heavy. The dimensions of the frame also need to align with the interior dimensions, and the shape of the cabin needs to be integratable with the design.

The shape of the cabin correlates to the drag force experienced by the cabin. A high drag force will reduce the efficiency of the cabin, so the shape should be as streamlined as possible and be constructible with the frame design. The focus will be in designing the cabin shape around that of a streamlined body, because this will help achieve the low drag coefficient.

The design of the interior layout will be used as a starting point for fabrication, so this will focus more on the overall concept, rather than small details. The dimensions of the interior layout should be compatible with the frame design. There are also regulations from the ADA that need to be complied with, to ensure that those with disabilities can access the cabin.

Design Requirements and Specifications

- HVAC
  - The HVAC needs to be able to handle up to 6 people in the cabin and also keep them in a comfortable temperature range of 22° C-24° C.
  - To stay efficient it has to be a 2 KW HVAC unit.
  - The HVAC unit should be 1m x 0.30m, small enough fit inside the cabin design without altering the frame or design.
- Frame and Body
  - The frame should be able to withstand a stress up to 26689.33 N
  - The safety factor of the frame must be at least 2 or higher.
  - The shape of the cabin should have a drag coefficient of less than .3
  - The weight of the cabin should be less than 902 kg
- Interior
  - The space between seat edges should be no less than 1.22 meters
  - The doorways will be at least 72" high and 32" wide, to comply with ADA regulation §38.53
  - There will be an open space of at least 32" by 48" for wheelchair mobility, as per ADA regulation §38.57

Literature Review

There are many Personal Rapid Transit (PRT) systems that have already been implemented around the world. A study of different PRT cabins was done to gain knowledge of existing designs; UltraGlobal PRT, Morgantown PRT, and Vectus PRT's cabins were all studied. Most of the available information about these PRT cabins is on the layout, track, and propulsion of the cabins; there is little information about the frame or drag coefficient of the vehicles. Therefore, the designs of these cabins were mainly studied for ideas of shape and layout.

UltraGlobal PRT is a supported podcar system currently in operation at London Heathrow Airport. It is a small system, and currently only operates at the airport; it has 21 pods and operates on a track that is 3.9 km in length. The pods for this system are electric, and run on four car batteries. They are capable of travelling up to 40 km/h. Being that UltraGlobal PRT is a supported podcar system, the frame and body shape of the cabin were not compatible with the suspended style of the Spartan Superway. However, the pods can still be studied to gain design ideas and insight. The system's cabin design was studied because its interior layout reflected that of what the cabin team had in mind, because it maximizes space, and has inward facing seats; it can be seen in Figure 3-2.

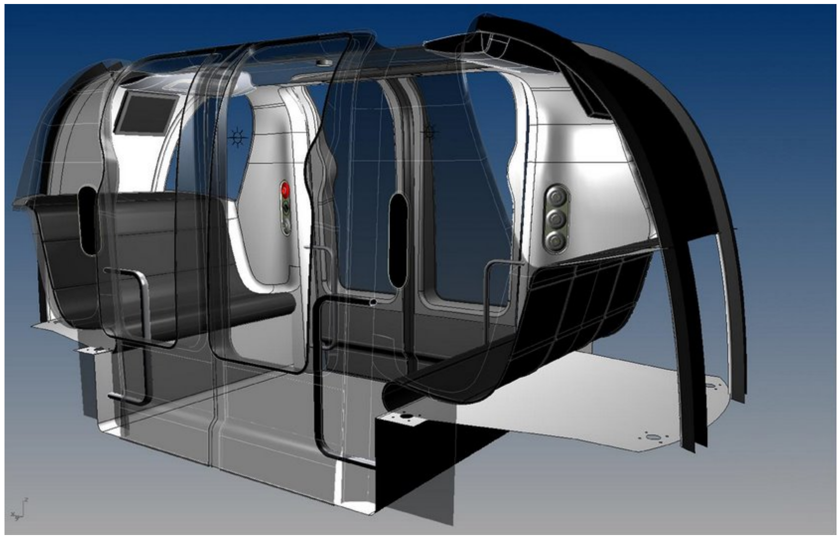


Figure 3-2: 28: Interior of UltraGlobal PRT pod car

The Morgantown PRT was installed in the 1970's in the West Virginia campus. It is not considered a true PRT due to it being able to hold 20 people at once. However, it is a great system for the Spartan Speedway to look at for inspiration. It has a massive cabin which allows a vast amount of people to ride it at once. The system also has a HVAC system to keep people comfortable. The Morgantown PRT does not function like a typical PRT. It feels more like an automated bus with set stops. Also as seen in Figure 3-3 below the cabin rides on top of the guideway which is not what the Spartan Speedway is aiming for. Lastly the cabin is to massive as it tries to fit around 20 people inside of it while the Spartan Speedway is aiming for a much lower number.

Figure 3-3: 29: Morgantown PRT at station

Vectus PRT was installed in Korea and has been operating since April of 2013. Vectus has accomplished many of the goals that the Spartan Superway aims to achieve. The vehicles are not piloted and fully automated, runs on a static guideway, and has a central control station to name a few. The Vectus PRT cabin is the ideal cabin for an ATN as seen Figure 4 below.

Figure 3-4: 30: Vectus cabin on track

The cabin is 3500 mm long, 1900 mm wide, and 2240 mm in high. It can fit up to four people and is also wheelchair accessible. There are dual LCD screens and a HVAC system. There are many things the Vectus PRT cabin has that the Spartan Superway also plans to implement. The interior layout is similar having four seats however the Spartan Superway plans to have the seats fold up so a wheelchair can fit and not take up more than one seat. Also, since the Vectus PRT travels on top of the guideway, the framework is quite different not having to suspend from the top. The main difference between the Vectus PRT and the Spartan Superway design is that the Spartan Superway cabin is suspended from the guideway. The framework to support the cabin from the bogie would be

2012-2013 Team overview

The Cabin Team of 2012-2013 mainly focused on the seating arrangement. They made sure they could fit 6 people inside the cabin by showing different seating arrangements and also they looked into which type of seats they would use. They designed the cabin to follow the ADA codes for wheelchair accessibility. They were able to also compute the drag coefficient of their design which came out to be 0.80. They assumed the front of their cabin was an angled cube. To get this they designed their cabin to be 108 in by 56 in so they could fit six people and also bike and wheelchairs. They really looked into how to optimize the seating inside to make the passengers comfortable. The seats they looked up and the seating arrangement where they face each other were incorporated into our design. The reason for using the seats and seat layout is due to it being in line with what was envisioned for the interior of the cabin. The HVAC that was calculated for the cabin design will not be used for this current iteration. The cabin is different from our current design so a new HVAC analysis needs to be performed.

2013-2014 Team Overview

The 2013-2014 Cabin Team chose to use a trapezoid shape as their design. They increased the length of the cabin from the previous design by 50%. The cabin was 3.048 meters long by 1.83 meters wide. This was because they wanted to have more room for the riders to sit as well as stand. The structure itself needed improvement and was why the current Cabin Team decided to design a new cabin. The top of the frame where the structure attached to the bogie would be under high stress. The platform could deform since it was connected in the middle of the frame. Also the drag coefficient they used was from the semester before which was 0.8. This drag coefficient and drag force of 551.6 N were not reliable since they were based on a different design. The current team could not use the data and must calculate a new drag force based on the new design. The interior of the design has two chairs facing each other, which is what the current layout of the cabin is. The interior layout of the previous team could be mimicked but in a smaller area since the current cabin is smaller.

Design Concepts

HVAC units come in different sizes, and shapes. There are HVAC units that are packaged for offices and others for automobiles. They are both feasible options for the PRT being designed. The first choice is to see if either one of these units would work with the cabin design so as to cut cost but if there is no match in the market for what we need a custom unit would be an option. The input would be near the ceiling and the return would be close to the ground. Cool air would gravitate from the input towards the ground as warmer air rises.

The frame concept was designed in order to better distribute stress. Since the issue with the previous design was the heavy stress in the area of attachment to the bogie, the team decided to take a different approach. The structural design of a gondola lift, shown in Figure 3-5, was used as a starting point for frame design. This structure was studied because of the way it distributes the stress to the four corners of the cabin, rather than just the center.

Figure 3-5: 31: The frame of the ski gondola is a part of the exterior four corners

Previous designs of the cabin built straight frames and an exterior around it. This current cabin team wanted to blend the frame with the exterior like how the frame of a car is in the shape of its exterior. The ski gondola has minimal material as the frame and exterior and that was our initial goal.

The first concept for the frame shown in Figure 6 has the cross section rib-like supports that take on the shape of the exterior.

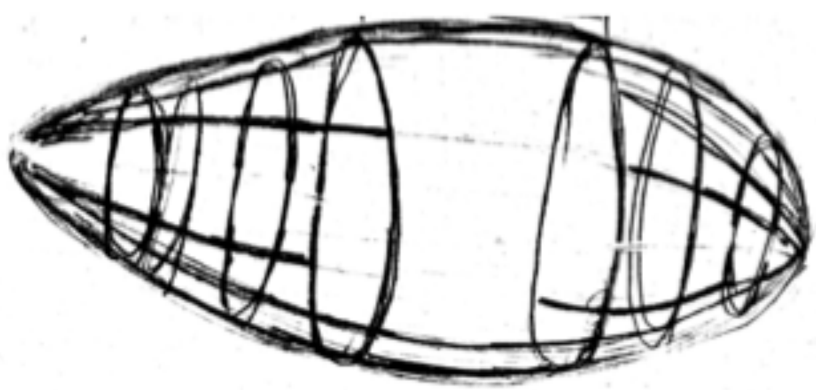


Figure 3-6: 32: The first design concept revolved around the idea of having multiple circular cross sections as supports.

Once basic dimensions had been given to the interior, the size of the frame was modeled around that space. The corners were kept rounded, in order to for the frame to be compatible with the shape design.

The past team recommended Chromoly Steel as the material choice for the frame, and the team decided to continue using that material. Chromoly Steel is frequently used in vehicle frames, because it has a high strength to weight ratio. It does require pre and post processing when welded, which could add cost to fabrication. More information on this material can be found in Appendix B. This material may be varied during analysis, to see if a different steel alloy gives better results without being too heavy. The frame differs from vehicle frames because vehicle frames are designed to collapse in a specific during a collision. The frame of the cabin is designed to hold the weight of the cabin from the bogie. The initial frame design was designed similarly to the ski gondola.

The initial shape was kept in mind as the frame was being laid out however the initial design could be focused on that of a streamlined body. Modern cars have a lower drag coefficient than most cars on the market, and this is because of their more streamlined design. However, a car is limited in how streamlined it can be, due to the fact that it needs all four tires on the ground. Since the cabin will be suspended from the guideway, there are more options when it comes to its design as seen in Figure 3-7.

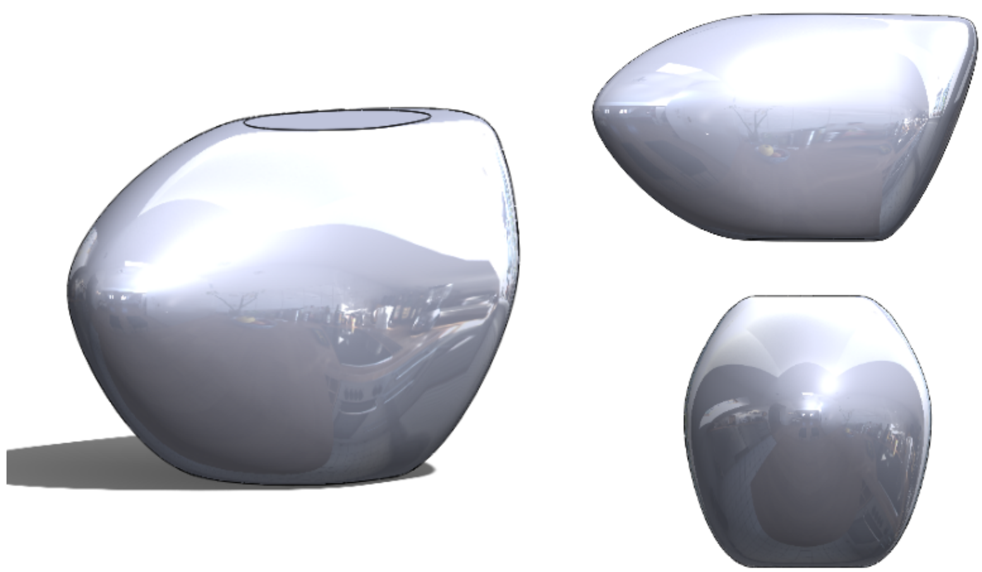


Figure 3-7: 33: The exterior of the cabin with a streamlined design.

The interior layout concept was chosen after studying past teams work, and looking at the layout of the UltraGlobal PRT cabins. The team decided to continue with the design of bench seats facing inward. Since the design of the past team's frame was not being used, a new set of interior dimensions could be chosen to better suit the visions of the current cabin team. The extra space in the between the benches could be used for another rider to stand or to place a bicycle.

Analysis/Concept Selection

The HVAC has to be able to cool the enclosed capsule with 6 people inside while also using less than 2KW to achieve this. To verify that an HVAC could work with less than 2KW of energy and could still maintain the temperature in a relative comfortable level the software Trace 700 was used. As seen in Appendix B, it was found that with the dimensions of the cabin and 6 passengers the load would be 995W and would only require about 1.8KW to operate. The reason that it takes 1.8KW to operate is because the fan, pump, and condenser add to the power generated. So it takes roughly half of its power to be able to keep people comfortable in the cabin.

The frame was more concisely designed and modeled using the CAD program Solidworks. After research into the material, the frame was initially modeled with 1” circular pipe, because that is what it most commonly comes in. The weight of this cabin was found to be 150 kg, which is well under the specification of 350 kg. Using Solidworks simulation, it was found that this was not strong enough to support the structure. The displacement and safety factor were higher than desired, so the team took another approach.

It was then modeled using a .051 m square cross section steel pipe with welded joints. The square cross section was intended to improve the safety factor by providing more material to distribute the stress. The flat sides of the square also provide more weld-able area, which should increase the strength of bonds. The addition of so much new material also increased the weight of the cabin to 350 kg. This new frame can be seen in Figure 3-8.

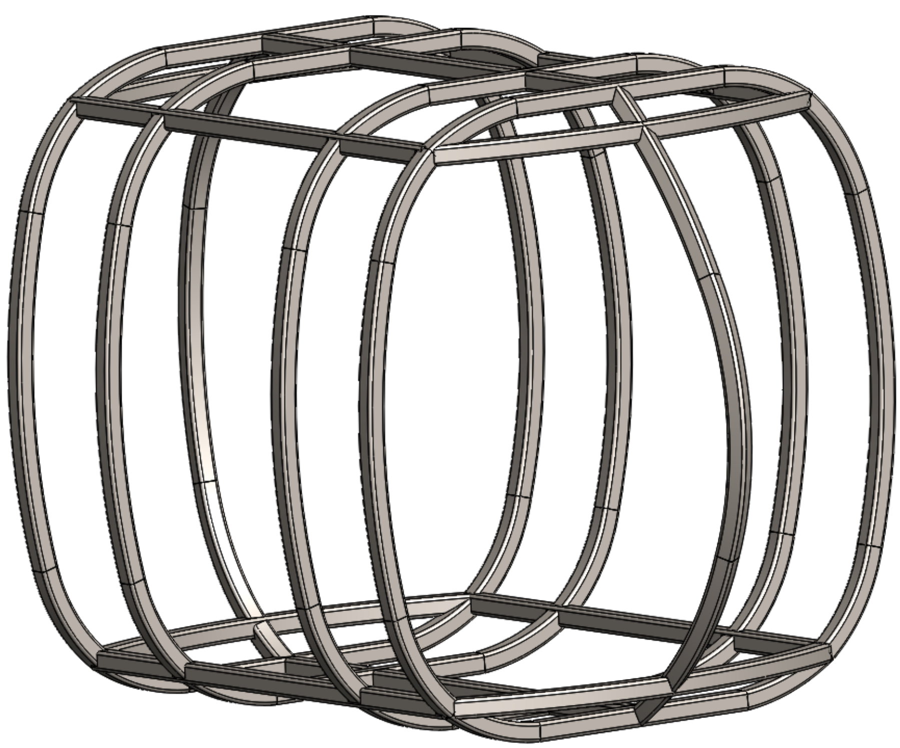


Figure 3-8: 34: Design of new frame with steel tubing with a square cross section.

The work in fall semester on the frame was continued in the spring semester, and a structural analysis of the frame was completed. The frame was modelled out of 4340 Steel pipe, with a cross-sectional diameter of 1.5 inches. This material was chosen because of its high strength to weight ratio; it is commonly used for frame construction. The final weight of the frame is 498 kg, which meets the design specification.

The total deformation can be seen below in Figure 9. The maximum displacement occurred at the bottom center of the frame, where it is least vertically supported. The maximum displacement of 14 mm is within the design specifications.

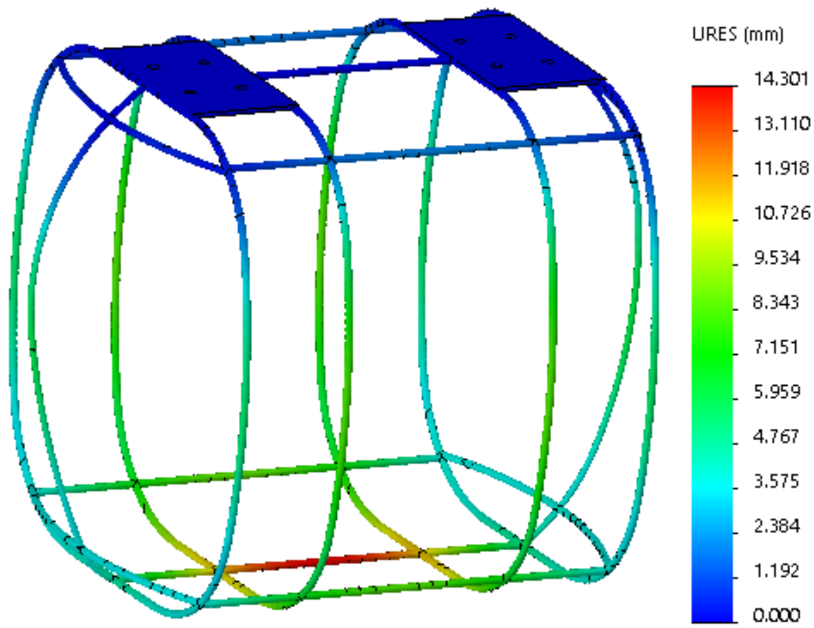


Figure 3-9: 35: Total deformation for the cabin frame. Boundary conditions were top frame fixed with 20,000 N downward force.

The next analysis done was a study of distribution of stress, to see if any of the stresses seen within the frame could cause failure. The maximum Von-mises stress seen at any point was 246.5 Mpa; this amount is below the yield strength of the material of 710 Mpa. This means that failure is unlikely to yielding of the frame. An additional analysis for safety factor was run, in order to determine to verify that everything was within the strength limits. The analysis showed a minimum safety factor of 2.9, located at the corners of the frame. These results can be seen in figure 3-10 and figure 3-11 on the following page.

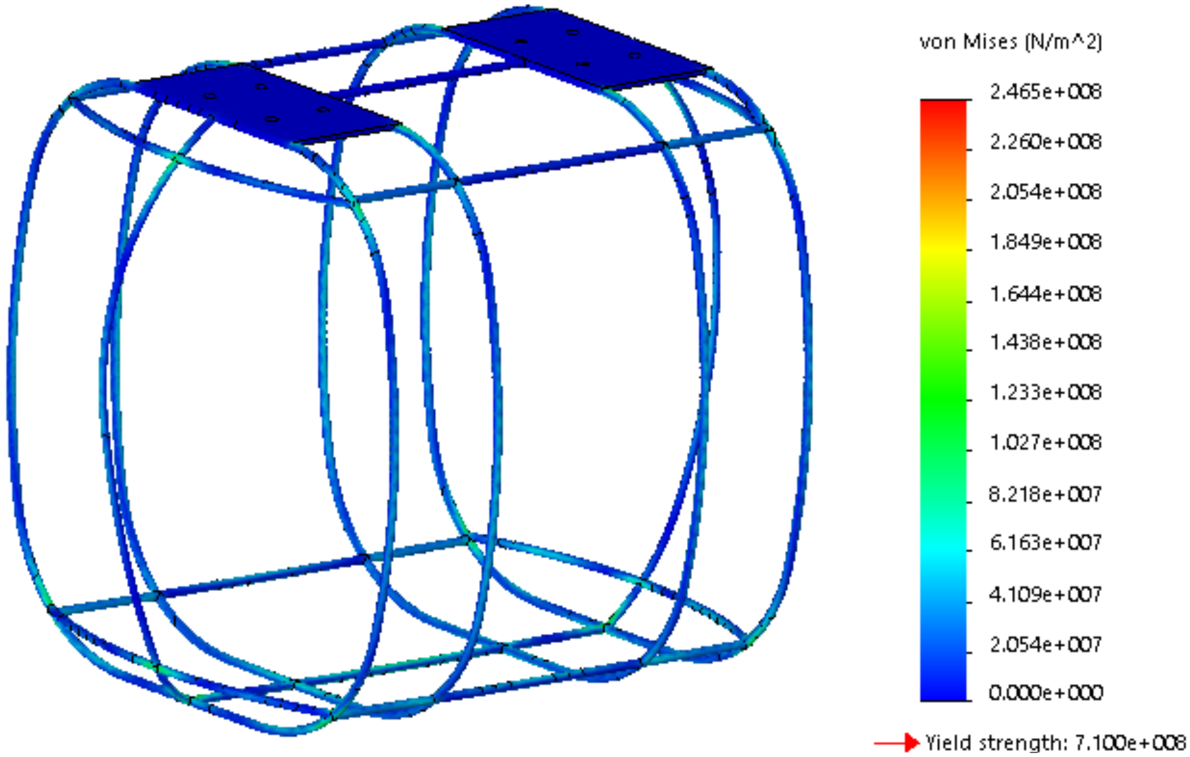


Figure 3-10: 36: Von-mises stress distribution in the frame. The maximum stress occurs at the bottom joints.

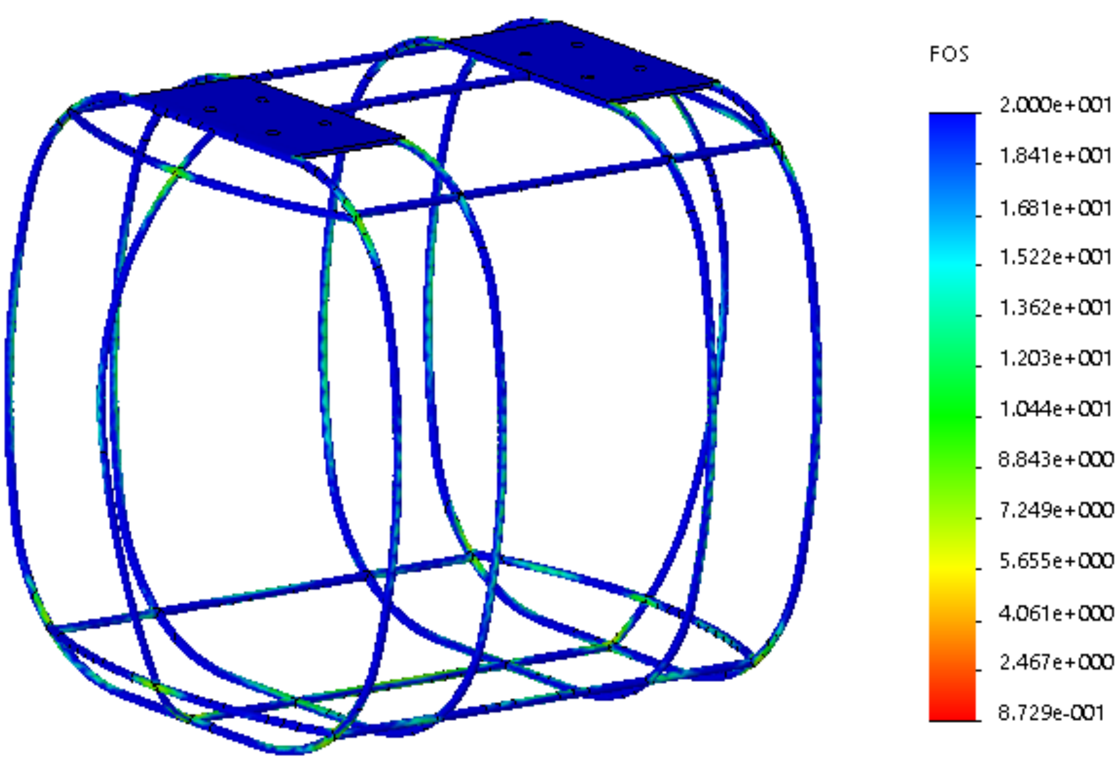


Figure 3-11: 37: Minimum safety factor of the cabin is 2.9

The drag coefficient was determined by the equation below:

1. cD=FD0.5V2A

where F_D is the drag force, is the mass density of the fluid, V is the velocity of the fluid, and A is the reference area. The drag coefficient was determined using Solidworks Flow Simulator because the drag force was also unknown. The mass density of air is 1.225 kg/m^3. The velocity of air was set at 17.88 m/s (40 mph) and the area selected was the frontal portion of the cabin. The frontal normal force of 59 N was determined through Solidworks and used as the drag force. Figure 3-12 below shows the airflow as it flows past the cabin.

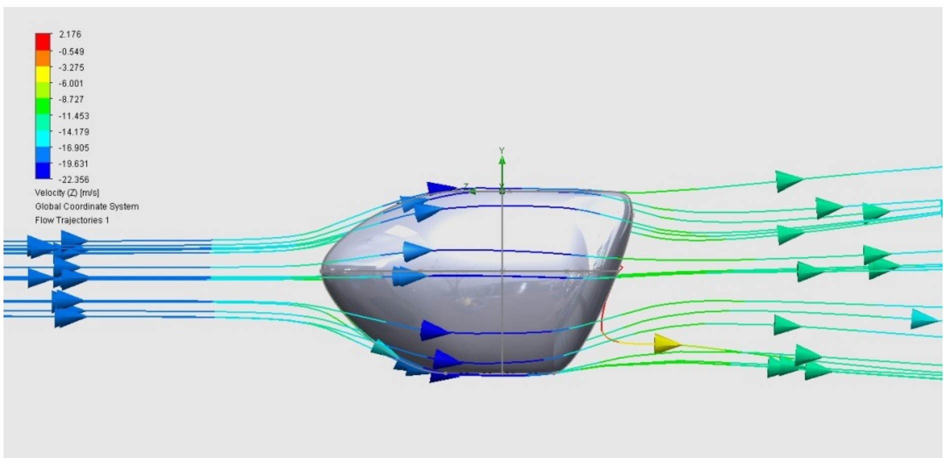


Figure 3-12: 38: The arrows in blue show maximum air velocity and the arrows in red show little to no velocity. The design provides airflow up to 22 m/s around the cabin.

The drag coefficient was low due compared to safety factors of cars which is about 0.3. However the drag force of a streamlined body is 0.04 and our model was designed to simulate a stream lined body.

The layout was tested first through trial and error. The team used chairs and a desk to simulate different layout scenarios, in order to determine what some nominal dimensions should be. The initial design specification that was worked tested was the 1.20 m of space between chair edges. When two people sat across from each other, however, it was found that more than 1.20 m was needed in order to accommodate a range of typical heights. A distance of 1.50 m was chosen instead, and that distance, coupled with an added 0.60 m on either side for seats, made for a total length of 1.80 m. The doorway was modelled at 1.83 m high by 0.91 m wide, and the interior height is roughly 2.13 m to better accommodate taller people. The distance, door to door, was chosen at 1.52 m. A top view can be seen in Figure 3-13. These dimensions also allow for the compliance of ADA regulations.

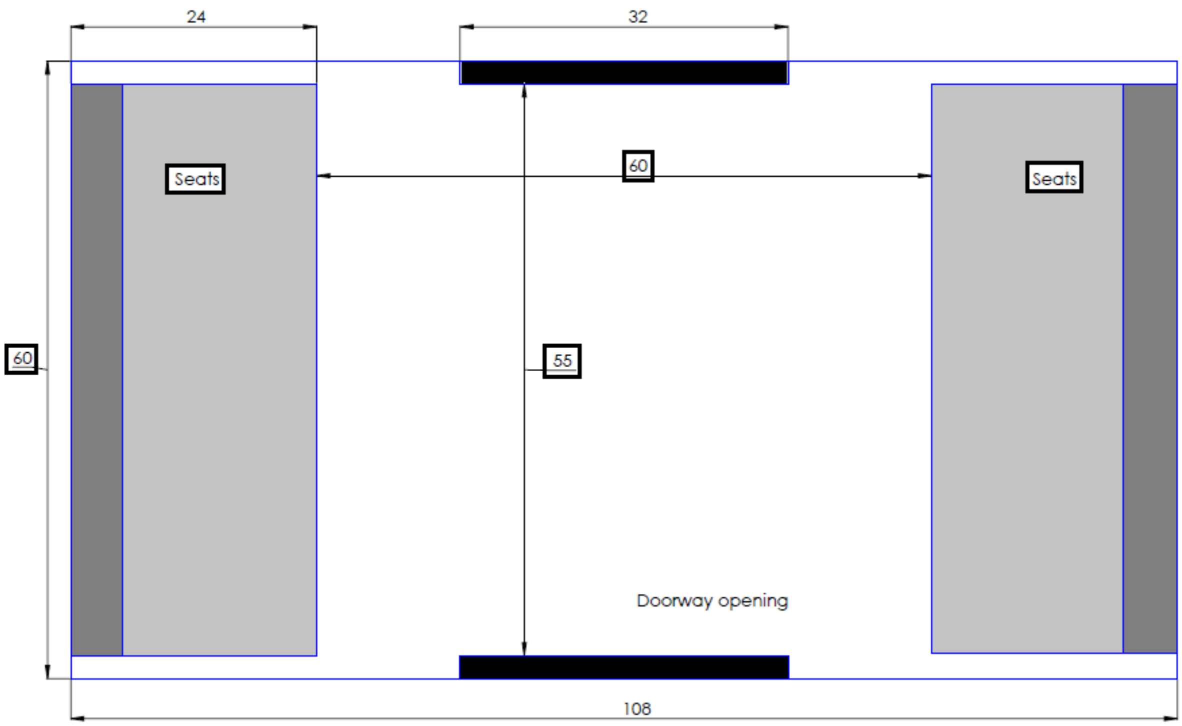


Figure 3-13: 39: The dimensions, in inches, of the interior layout, top down view

The mock up cabin will be a half cabin for Maker's Faire. There will not be a top cover so the cabin will be about four feet high. The focus of this cabin is to have a memorable experience so people will be able to come in, sit down, and watch a promotional video of our project. The screen will be mounted on one side of the cabin and the entrance on the opposite side. The base is 2.44 meters by 1.52 meters made out of ply wood and multiple two-by-four pieces used for support. The flooring will be made out of a hard rubber similar to the material used in VTA light rail. The base will have wheels to transport the cabin easily. The side walls will have two-by-fours as the frame. For the front and back of the cabin, there will be a curved section as it would be for the real design.

The fabrication of the exterior of the cabin was a slow and methodical process that involved multiple steps to complete. To start creating the exterior of the cabin the frame first needed to be constructed. The frame was constructed using 2x4 pieces of wood to make the frame of the cabin. Once the frame was constructed the next step was to create the curves that are present at the ends of the cabin. To get the ends of the cabin to be curved, the plywood had to be cut out in a crescent shape. The height of the plywood crescent is one meter while the distance from the frame to the end of the crescent is 0.45 m. Figure 3-14 seen below shows how the crescent plywood are attached to the frame. The curve was created by bending a flexible metal rod and tracing the curve.

Figure 3-14: 40: Crescent shaped plywood

The crescent shapes are attached to the frame on the bottom with L brackets. This ensures the plywood stays in place for the next step of creating the curves on the ends of the cabin. The next part for the creation of the curve is to attach chicken wire onto the plywood crescents.

To get the chicken wire onto the frame it was cut in half so it would create the correct curvature around the plywood crescents. The chicken wire was attached with a staple gun so it would be flush on the surface. Chicken wire was proven to be necessary to have a sturdy foundation to apply the bondo. After the chicken wire is attached to the plywood crescents the next step was to attach linen cloth on top of the chicken wire. Linen was chosen due to the roughness of the fabric so it would adhere better to the resin. Also the reason cloth would take the shape that was laid out with the plywood crescent and also with the chicken wire. The initial idea of using fiber glass cloth would be too messy and the more time consuming. The strength of the curved ends were not important since it is for looks. With the plywood crescents, chicken wire, and lastly cloth the shape of the curve is starting to take shape. Figure 3-15 below shows how the curve is starting to take shape with the addition of the cloth.

Figure 3-15: 41: Cloth attached tightly onto chicken wire.

The final part for creating the desired curve is to add a resin on the surface of the linen cloth. The resin that was used to create the desired effect was bondo auto body filler. Bondo by itself is nothing more than a gooey plastic but once the hardener is added to the resin a chemical reaction starts where the resin will start to harden. Depending on how much hardener is added to the bondo it could take 3 minutes to harden or up to 10 minutes to harden. The chemicals are very dangerous so it is best to use it in open and well circulated areas because the fumes that are released are very dangerous. For the curve it takes two layers of bondo to get the desired strength and curve. The first layer is mostly to soak the cloth in bondo and to harden it. After it had hardened the bondo must be sanded to remove any bumps or imperfections. Then a second layer is attached to it so further give the shape that is desired. Figure 3-16 shows how the finished bondo looks after two layers and sanding is done for paint to be applied.

Figure 3-16: 42: Final layer of bondo applied.

Once the final layer of bondo is attached it must dry and then be sanded one last time. The last sanding is to remove imperfections, bumps, ridges, and to roughen up the bondo so paint can then be used over it without peeling. As can be seen in Figure 3-16 the curve is not a natural curve but rather it is a complex 3d curve which is the reason why bondo was used. Bondo is applied and can take the shape of the surface. This will give the cabin a unique shape that will be memorable for people when they first glance at it. After the bondo dries, primer and paint will be added to the exterior and interior of the cabin.

The design of the chairs was created with the idea that they needed to be fully functional when down, but compact when folded up to permit space for wheelchairs or other large items. The design can be seen below in Figure 3-17 the image on the left shows the chairs in the folded down position; this would be when they are being sat on. The picture on the right shows the chairs in the folded up position, which is when they would not be in use. The back hinges are attached to the frame of the cabin, using bolts. The seats were covered in dark blue vinyl. Vinyl was chosen as the material because it is known for its durability, yet it is also easy to maintain and clean (Vinyl).

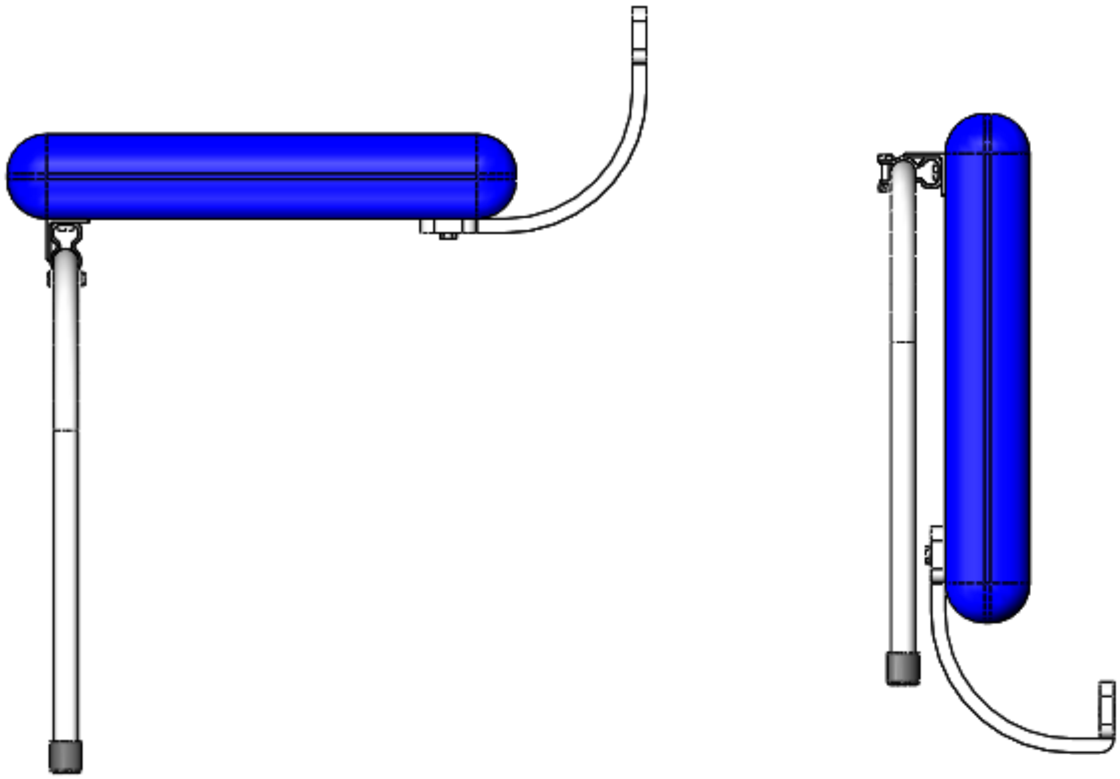


Figure 3-17: 43: The image on the left shows the chairs in a folded down position. The image on the right shows the chairs when they are folded up.

The chairs were constructed out of multiple materials, both used and new. The seats cushions themselves were taken from a truck at a local scrap yard. The seat structure was already reinforced with a steel pipe running along the outside edges. The steel pipe was utilized by attaching aluminum L-shaped plates to with screws along the front. This was important, because it provided a secure location to attach the front legs. It also prevents the chair legs from swinging too far out, which can be seen in Figure 3-18.

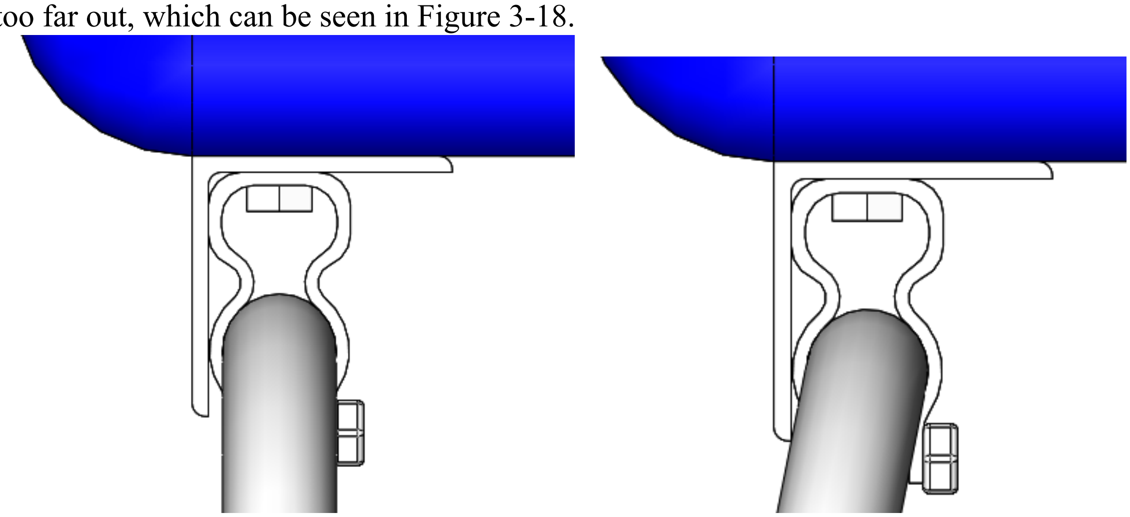


Figure 3-18: 44: These two images show the maximum movement of the legs when in the folded down position; it can be seen that the aluminum plate greatly limits the range of motion of the legs

The front legs needed to be free swinging, but not in such an uncontrolled way that it would be unsafe. The solution was to make the legs out of a single piece of conduit, with corners bent to a six inch radius. They are attached to the aluminum plate using conduit clamps. The clamps can be tightened enough so they induce friction against the legs, preventing them from swinging too freely. The final assembly of the chairs in the model can be seen below in Figure3-19.

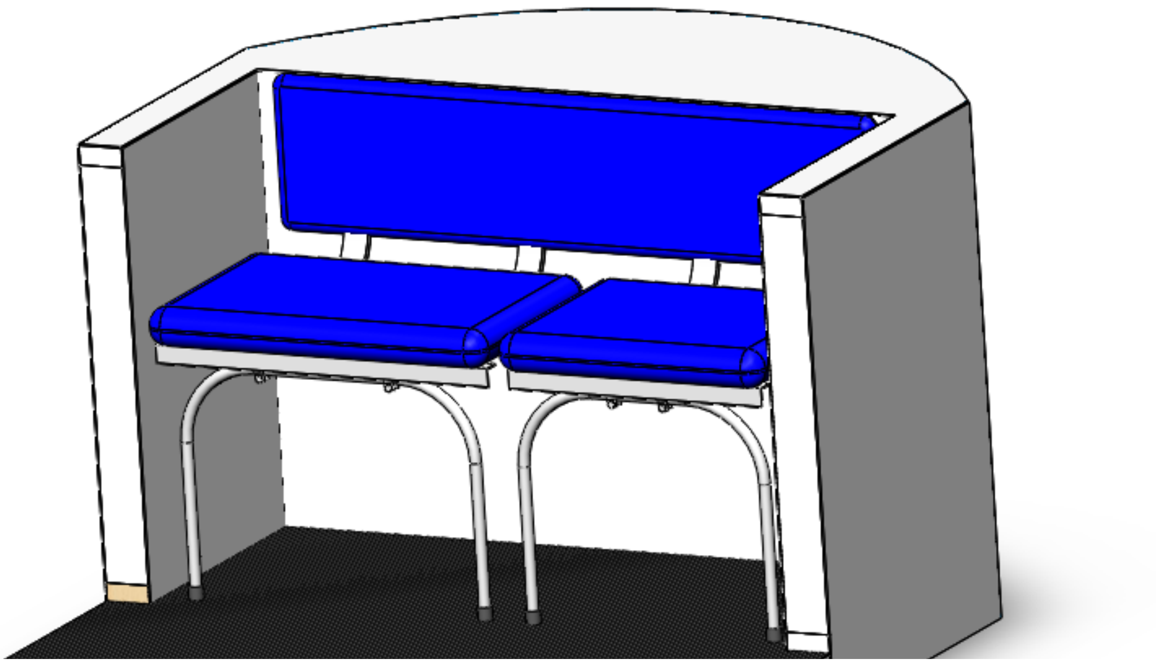


Figure 3-19: 45: The chairs installed on one side of the cabin.

This design both helps support the chair and creates space for a wheelchair. The seat already has a mount on the hinge so we will attach mount to the metal frame. Since the seat will support the weight of people, the seat frame and support frame were analyzed.
A 15” two-by-two was analyzed as the frame that the seat is mounted onto. Assuming there is a 1334.47 N (300 lb) load on the seat the stress, there is a moment of 508.43 N-m (4500 lb-in). The moment of inertia for the rectangle was 0.033 m^4 (1.33 in^4). The bending stress was calculated using the equation:

$$\sigma =$$

$$\sigma = 23.28 \text{ MPa } (3375.84 \text{ psi})$$

The max stress for a two-by-two is 30.34 MPa (4,400 psi) which is only a safety factor of 1.3. A two-by-two wood block would work but we would want a higher safety factor since people could be hurt if it did fail. We plan to either use a thicker wood piece or aluminum.
The diagonal support bar was also analyzed to see if it would buckle. When the seat is folded down, the support bar was considered fixed at both ends and as pressured was applied from the top, it would be vulnerable to buckling. Assuming that the diagonal bar is at 45 degrees, the 1334.47 N would be separated into forces in the x and y directions. The compressive stress of aluminum is 240 MPa, the Euler Buckling formula was used:

$$=$$

is the critical buckling load, p is the applied load (943.6 N), E is the Modulus of elasticity (70 GPa), I is the moment of inertia (0. 0021082 meter), and is the effective length of the bar. The moment of inertia equation was based off of a hollowed square tube where a is the outer length of 0.0254 meters and b is 0.00158 meters.

I =

The critical load was 145818 MPa and the critical buckling stress is the critical load divided by the area, which is 1. The bar will not buckle under a load of 943.6 N since the yield stress of 240 MPa will be reached first before the critical buckling stress of 145818 MPa.

<u>Results and Discussion</u>

For HVAC, the results show it is possible to have a small 1.8 KW HVAC unit attached to the cabin that is being designed. It would also not take up a lot of energy so as to put a strain on the solar panels or the grid. This shows that no specially designed HVAC needs to be built. The HVAC could be a small commercial unit that are used in offices, RV's or even car HVACs. This would cut back on unnecessary R&D time and money. The goals were achieved for the semester but that does not mean it was perfect. More time should have been spent on optimizing the design so the HVAC numbers could be lower. If more time had been dedicated to the analysis a smaller more efficient HVAC could have been found.

The frame proved to be harder to design once more specific design aspects were implemented.. The total mass of the cabin was found to be 350 kg, which meets the design specification exactly.

Although the drag coefficient of 0.03 is relatively low, it is in the close to the drag coefficient of a streamlined body of 0.04. Using Solidworks to setup the input parameters could be adjusted to achieve a more accurate drag coefficient. Some factors that may have resulted in a low drag coefficient were selecting the drag force and frontal surface area. The normal force on the front of the cabin was selected as the drag force, there may be other methods in achieving the drag force. The surface area was selected through Solidworks and since the front of the cabin was a unique shape, there was no way to verify if the surface area selected was the area desired. A more accurate drag coefficient could be calculated with more research in Solidworks but the drag coefficient equation would be the same.

This interior layout design serves as a fundamental starting place for the upcoming semester's fabrication plan. As the frame and shape will not be constructed this semester, the interior design will be expanded upon to include possible features. The dimensions and layout will reflect that which was designed

The current fabrication plan is to construct the interior design layout of the cabin with modifications to keep it mobile and reduce its size. Seats will be moved closer together, because people won't be spending much time inside of the cabin. A frame similar to the one designed may extend up from a base, but only the bottom half of the cabin is being constructed. The bottom half walls will keep the rounded shape of the cabin design, but this cabin will likely be symmetrical to eliminate unnecessary design challenges.

A plywood base will be constructed from a plywood board and a two-by-four frame. The base foot print will be 1.22 m by 2.44 m. This is slightly smaller than the floor that was designed, but it was decided to use a commonly available size. This may be accommodated for, however, by other design choices. The base will be mounted on 4 lockable caster wheels. Multiple metal poles will be attached to the frame and will curve away at a certain radius; the tops will be secured with a frame lock. This curvature will add volume to the interior of the cabin, making up for the smaller floor size. The chairs are hoped to be sourced cheaply, such as junk car lot, but may have to be bought new. A Bill of Materials can be found in Appendix B. The concept design can be seen in Figure 3-20.

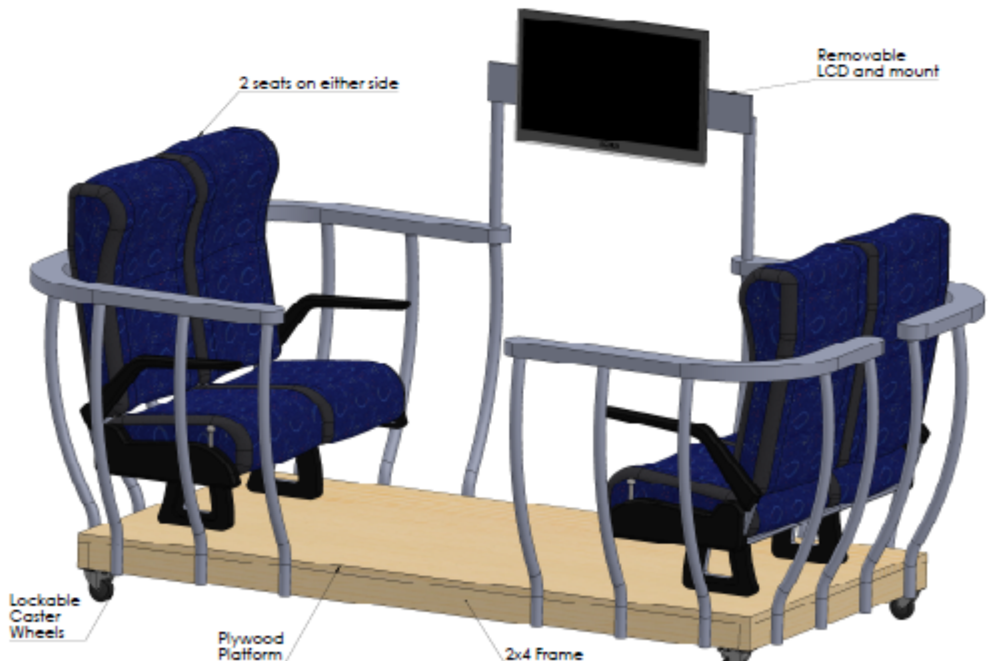


Figure 3-20: 46: First frame concept design.

Conclusions

The design of the cabin's structural frame was a success. The final dimensions and specifications can be seen in the Appendix B. The frame was designed to meet the specifications initially set out by the cabin team: limited deformation, reasonable safety factor, and under 500 kg. While this frame was not fabricated this semester, it will serve as a great starting point for teams in the future. It would not have been practical for the small cabin team to fabricate the frame, and instead the focus was on an interactive cabin. Design of the cabin fabrication model was designed around the dimensions of the frame, and final results all align how they should. Figure 3-21 demonstrates how the cabin model fits with the frame, by superimposing them on the same image.

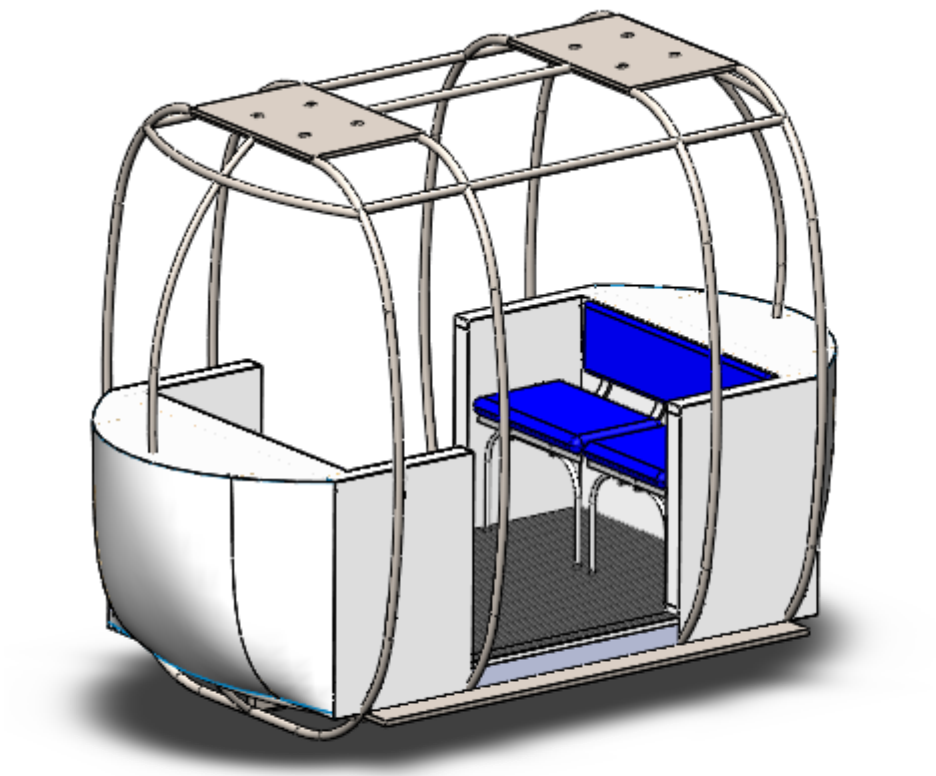


Figure 3-21: 47: Final cabin design.

With our cabin built we hope that future teams could improve on our design or take something from it. Some ideas for building the frame would be to use steel for good strength to weight ratio. Our purpose is to have people feel and believe that they could one day be in a cabin similar to our model riding on the ATN.

Chapter 4: Scale Model

Description of the Subteam and Objectives

The scale team is focused on creating a working model of the full-scale Automated Transit Network (ATN). Due to the large scope of the project and budget and time constraints, it is somewhat impossible to design and build a full-scale prototype of the system. In order to prove that the concept is viable, it is important to have the scale model. Fancy animations are fun to look at but it is difficult to convince an audience without a physical model. Thus, the team has adopted the slogan "Seeing is Believing" because this model will be presented at exhibitions to demonstrate how the actual system would work. Through successful completion of this model, the project will gain more momentum and support from potential sponsors as well as customers.

As with any project, there were several issues that needed to be resolved. Consistency was a real concern in the previous years' model, and thus that was one of the key focuses throughout the design process. For the Fall semester, the team's objectives were to quickly iterate three designs, construct a prototype of the scale model, complete a redesign of the scale guideway, implement wayside pickup, match the full scale design within reason, and to interface the code provided by the Computer Engineers.

In prior years, there had been issues in the switch sections of the track causing the bogie to jerk at the interface. While conducting tests, batteries would also run out very often, creating a need for wayside pickup. Many such issues needed immediate attention so the team quickly got to work. Initially, the team split up into three sub-teams in order to work efficiently and generate more ideas. Implementing a divergent-convergent work process, the sub-teams were able to come up with several concepts of their own and then narrow it down to one design. Each subteam was in charge of quickly prototyping its idea for the track and bogie for further analysis. The entire scale team then met up to discuss the strengths and weaknesses of each of these ideas and to come up with a final design that would make use of the strengths from all of the iterations. Certain standards had to be met and the team attempted to match the full-scale design as much as possible, but also made adjustments as necessary for the scale model. The next section will talk about the engineering specifications that the project had to meet.

Design Requirements

- Support 24.5 N

It has been decided to build a bogie and track that will support up to 24.5 Newtons. This works out to about 5.5 lbs. This target weight of 24.5 N will include the bogie, cabin, and all necessary hardware or electronics for operation. With this weight, track deflections should not exceed a vertical deflection of 3mm and a torsional deflection of 2mm. FEA will be used in the upcoming semester to determine these numbers are met.

- Move up to .5 m/s

One half meter per second was chosen as the max speed for the bogie. This was decided because it will accurately represent a scaled down full scale operating speed of 35 mph. There are certain standards that need to be pertained to. These standards come from the American Society of Civil Engineers (ASCE). Within the ASCE is a system of codes and regulations that the Automated People Mover Standards Committee (APM) uses to determine safe operating speeds for automated people movers. Additional standards limit the rate of acceleration that can be used. For linear acceleration the standard states that it cannot exceed 0.35g and for lateral acceleration that number cannot exceed 0.25g. Lateral acceleration would come into effect around any curves in the track. The curves forming the track will involve 0.5m and 1m radii sections. In order to meet these requirements PID code will be written which will maintain safe operation. Even if the bogie has the ability to accelerate faster or operate at a higher speed, it will be kept down. This speed will require a relatively fast switching mechanism. It has been decided that the switch will need to occur in 0.5 seconds. If the switch occurs in 0.5 seconds than the bogey will have only traveled 0.25 meters at a speed of 0.5 m/s.

- Build at least 3 bogies

It will be necessary to have at least three bogies operating on the track at one time in order to correctly demonstrate operation of the system. Three bogies will allow the system to demonstrate a variety of different things. If a bogie is being called to a station, the closest one will respond to it. If one bogie is merging onto a track with another one approaching, it will either speed up or slow down depending on what the safest operation would be. Having three bogies will also force the master controller to know where each one is at any specific time. This will keep them from crashing into each other or from practicing unsafe operation. It has been determined that a minimum operating distance of at least 20cm must be maintained between each bogey.

- Design track with at least 3 stations

One reason for having three stations is the requirement to have three bogies. If all stations are requesting a bogie, then there needs to be a place to dock each one. Another reason for three stations is because it helps to prove the concept and ideas of the scale model. The three stations will be spread throughout the track layout. Included in the track layout is a shortcut route that allows a bogie to skip a station if it needs to hurry to the next one in line. It is also important to have two stations in a row along the same path of travel. One of the main benefits of the Spartan Superway is that a bogie does not have to stop at each station. There are two stops during a groups travel time. One stop is for them to load into the cabin and the second stop is for them to unload. Having two stations along the same loop of track demonstrates this ability for direct transportation without the need to make any additional stops.

- Computer controlled

It is absolutely necessary for this scale model to be computer controlled. The main controller can be installed on any laptop with the correct libraries and all of the bogie controllers will consist of Arduino Uno microcontrollers. The laptop will control all operations relating to the system. User input will be limited calling a bogie to a specific station. The less involvement the user has with the system the better. The more control the user has the less automated the system becomes which takes away from the idea of the track being an automated transit network.

- Emulates the full scale model

It is necessary to have the scale model emulate the full-scale model as closely as possible. Seeing is believing, and it will be hard to convince people about the importance of an automated transit network if the model does not even come close to mimicking the full scale system. The switching mechanism, drive, and track will seek to emulate the full-scale model to the highest degree.

- Implement wayside pickup 12 volts that supply up to 12 amps

In order to improve upon the progress created by last year's model, the team will work to implement wayside power pickup. There will be no need to constantly swap out battery packs. The absence of battery packs will also decrease the weight of the bogie overall, which can help improve the performance of the bogie. In order to power all three bogies wayside pickup will need to supply at least 12V and close to 12 amps. This will power all of the motors, Arduinos, actuators, and sensors.

Literature Review

- Spring 2014 Report

The 2012 - 2013 Superway Team built the current Scale Model. Last year's team improved it and the controls were demonstrated by the Computer Engineering team during the Fall semester. The original intention of the scale model was to closely represent the full-scale model and prove system-wide concepts. This proved to be a larger task that was possible in a single year. The model ended up being less representative of the full-scale model, but managed to demonstrate a basic ATN system. This was important work for the Superway project because it clearly demonstrated the fundamental concept of an automated transportation network. Last year's work to improve reliability to implement the current control system was a large step in the right direction.

The mechanical part of the model is comprised of a square guideway with a slit cut out of the bottom. This square guideway easily supports the bogie at the cost of some efficiency. Square tubing is usually very good at resisting torque, but once a slot is made it is no better than a wide, flat beam. The square guideway also caused the switching to be unreliable due to the wheels having to pass over cut outs in the guideway. This would sometimes cause the bogie to stall and always make for a bumpy transition between sections. Metal poles set into concrete in plastic buckets support the guideway. This is very stable, but does not allow for much adjustment to compensate for uneven ground.

The controls part of the model is currently set up for a central controller to wirelessly communicate with the controllers on each bogie. The bogies each have two Arduinos, one for communication with the master controller and one for processing sensor input and actuation. The master controller can be setup on any laptop and the control system is programmed using Python. The control program determines the position of each bogie and then takes user input to determine where the bogies need to go. Then it chooses the bogie that will execute the user input most efficiently and calculates a path for that bogie. This path takes into account where the other bogies are and where they will be. The bogies use hall sensors to detect where they are on the track and use an Xbee to wirelessly communicate that information to the master controller. The bogies also have ultrasonic proximity sensors to prevent collisions with other bogies.

This year the team intends to use the fundamental lessons learned by the previous teams to produce a new scale model. If applied, these lessons will make the model easier to transport, assemble and adjust. The model will be more mechanically reliable while still faithful to under-the-rail ATN concepts. The controls will remain essentially the same as they are now, but with some changes toward a more robust system. The previous teams' efforts were valuable and will go a long way to make this year's model successful and impressive.

- Patent by Bengt Gustaffson

Mr. Gustaffson's patent was created several years ago and in that time the particular configuration of the bogie, pictured in **Figure 1**, has changed. However the fundamental components are still present.

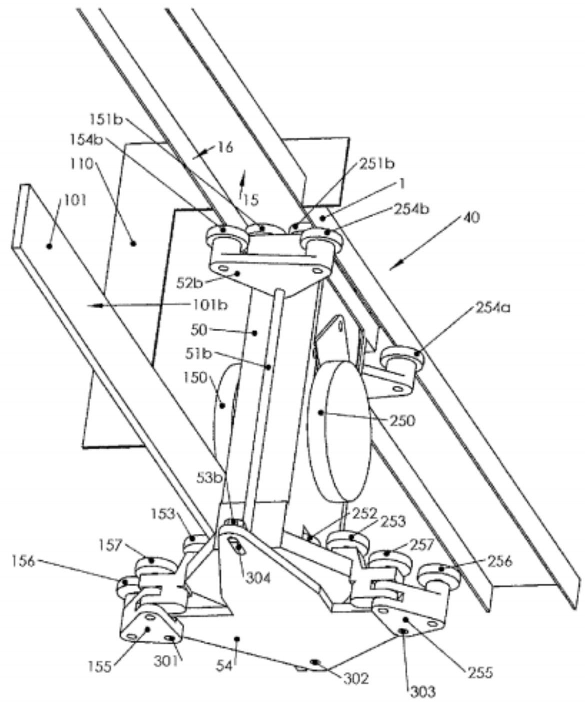


Figure 4-1: 48: Gustaffson's Bogie Design. Note the upper and lower steering mechanisms, two upper rails and one lower rail.

In his patent Mr. Gustaffson describes a device that is supported by a system of rails that are in turn supported by some grounded structure. Large wheels that roll along some rail or rails would support the bogie vertically. The bogie would be laterally constrained by several smaller wheels in a rectangular section above the previously described rails. The bogie would steer using small horizontal wheels that could catch onto another set of switching rails. This switching portion of the guideway requires many special considerations like timing and supplemental support while the bogie shifts configuration.

- Previous Specifications

The specifications for the previous model were not considered for the design of the year's scale model. The previous year's model was inaccessible at the time the current specifications were decided. This forced the new designers to be creative and decisive and was a positive outcome.

- Previous Software Programming

The Intersolar Arduino code was created by the previous year's team and sets up Serial Peripheral Interface communication protocol between the Arduino and the SJSUONE board. The code allowed the bogie to interface with two hall sensors, a motor, and two solenoids. The previous team also left the foundation for an ultrasonic sensor interface and navigational controls commented out. The software also made use of a manually built PID controller to regulate the speed of the bogie. The previous team has left sufficient debugging tools to adapt the code for future use, but changes in hardware may render large sections of the code obsolete or inapplicable.

Description of Design Work

- Convergent divergent design philosophy

The Scale model team used a convergent divergent design philosophy in order to maximize iterations in a short period of time. The philosophy begins in the divergent stage; the team was split into three teams of 3 to 4 members: Honey I Shrunk the Superway (HISTS), team Red, and team Not a Number (NaN). In the divergent phase, individual members were tasked with creating as many designs as possible. These ideas were then filtered by the first convergence; teams deliberated upon which idea was optimal. Each team was then tasked with building a physical manifestation of their best ideas. The results are shown below:

HISTS

HISTS's design maximized simplicity of the guide rails. The two guide rails minimize cost and time to build track. The bogie switch created two mutually exclusive states; this prevents a floating state in which the bogie is neither turning nor going straight.

Red

Team Red's design uses a single travel rail, with a secondary rail at the switch. The switching is initiated by the lower four bar mechanism pictured in green below. This design required a notch in order to give the four bar mechanism room to actuate.

NaN

Team Nan's design modified the previous team's scale model. The boxed cross section remains, with a notch cut in the top in switching regions. The method of actuation was changed to a lever arm that would lift the bogie when it reached the notch. This removes the catching that occurred in the previous years.

The final convergence dissolved the teams back into a full team, whose task was to decide which model had the most potential to meet the team's overall objectives.
By splitting into smaller teams, all members were able to give input, without the administrative and moderation that is necessary in large group discussions.

- Engineering Design Process

The engineering design method is the governing path that Engineers use in order to complete a design; this project is no different. The problem that the Scale team has sought to solve is the lack of a reliable and representative test course. The convergent-divergent philosophy was a means of coming up with concepts; building proof-of-concept models was a phase of research. The team is in the process of completing further research and getting ready to create prototypes.

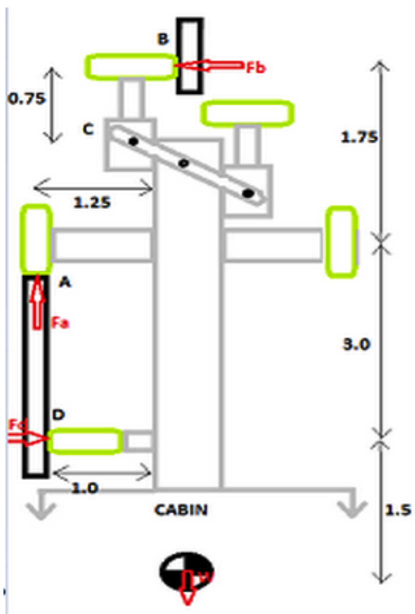
Analysis and Concept Selection

- Moment and force equation

As stated, the goal of the Scale team is to demonstrate the Superway concept with the Scale model. Prior to designing the scaled bogie and track, moment and force analysis were studied and calculated. The bogie has to maintain equilibrium any time while running on top of the track. Thus, all the initial concepts of prototypes from sub-teams were designed around balancing the moment and force acting on the bogie.

<u>HISTS</u>

HISTS's design uses the upper track for force balance and the side track to counter the moment produced by the weight of bogie and cabin.



Assume W=3lbs

$$\sum F_y = 0 = F_A - W$$
$$F_A = 3\ lbs$$

$$\sum F_x = 0 = F_D - F_B$$
$$F_D = F_B$$

$$\sum M_A = 0 = F_B * 1.75 - W * 1.25 + F_D * 0.25$$
$$\sum M_A = 0 = F_B * 1.75 - W * 1.25 + F_B * 0.25$$
$$2 * F_B = W * 1.25$$
$$F_B = 1.875\ lbs$$

$$M_{B\ due\ to\ Fa} = F_A * 1.25$$
$$M_{B\ due\ to\ Fa} = 3.75\ lb * in$$

$$M_{C\ due\ to\ Fb} = F_B * 0.75$$
$$M_{C\ due\ to\ Fb} = 3.75\ lb * in$$

Figure 4-2: 49: Force and Moment Analysis on HISTS team bogie design

<u>Red</u>

Red's team design have the moment and force balanced around the bottom bearings. The outer bearing will counter the force and the track will counter the moment produced by the weight of bogie and cabin.

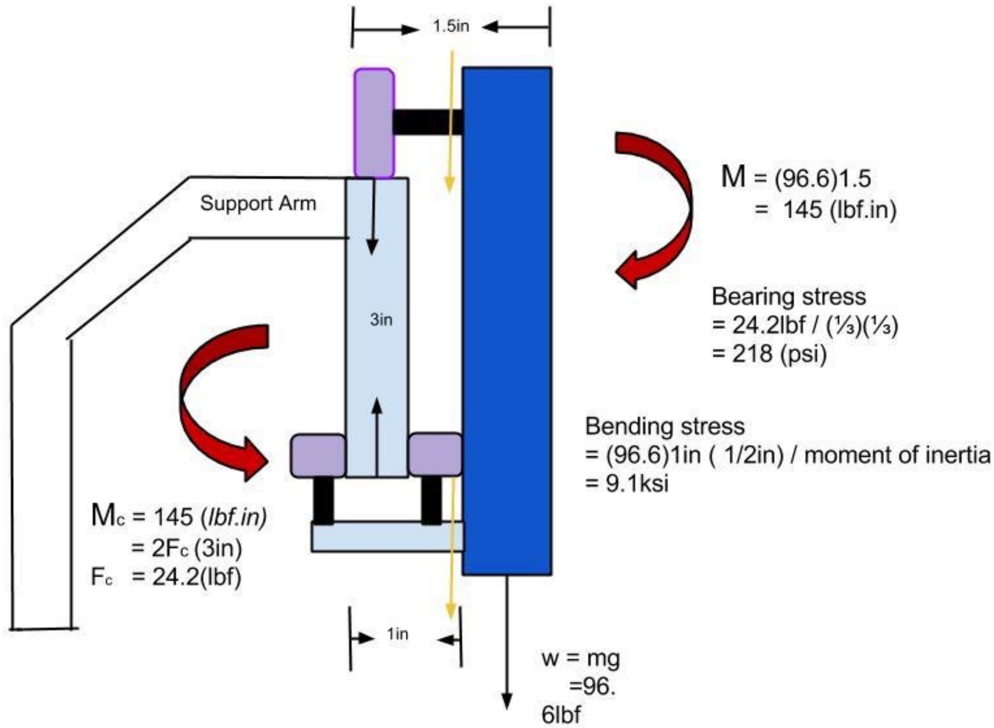


Figure 4-3: 50: Force and moment analysis on Red team bogie design

- <u>Pugh chart</u>
  With each sub-team coming out with one design, the Scale team decided to use a Pugh chart to evaluate the strength and flaw of each prototype design. The evaluation was based on the ease of construction, overall cost, safety issue and stability of bogie. The result showed that design from HISTS team was relatively desirable out of all three designs. Thus, the Scale team used the HISTS team's design concept as the base for the final design.

Results and Discussion

A bogie design was selected that absorbed the HISTS, Team Red, and Team NaN
While designing the bogie, there are two requirements that the Scale team will specifically focus on. First, after entering the switching section, the bogie has to be capable of making a smooth transition from one track to the other. Second, to address safety issues, the bogie has to have good stability when running on the guide way. To meet these two specifications, the Scale team combined the switching mechanism from team HISTS and Red to ensure smooth switching and also enhance the stability of the bogie.

In the previous year's design, the Scale team used battery packs to provide the required power for system operation. It was inefficient and required constantly replacing the batteries to ensure the system would work. To correct this problem, the Scale team will implement wayside power pickup. The concept is taken from Team NaN's design. The idea is to store and transmit the solar power into electrical power. Through powering of the track, the bogie can pick up power from an external source.

The Scale team splits then into the following teams:

- **Hardware**
  - Motor Sizing

The motor, essentially the key element of the system, has to meet certain requirements in order to drive the bogie and cabin at required speed. Thus, calculations for motor sizing were performed.

1. The goal is to have the bogie running at 0.5m/s (19.685in/s), and to be accelerated within 0.5 second
2. From bogie design, the Scale team decided to make assumption for a size of NEMA 11 motor with diameter of 0.022 m, 110 g
3. To calculate the RPM of the motor required, the motor has to reach: 0.5m/ (0.022 m x pi) = 7.24 rotations per second to get the speed of 0.5m/s
4. Convert the rotation per second to RPM: 7.24 x 60 = 435 RPM. Thus, a motor within 440~450 RPM seems to be a reasonable choice, depending on the actual size of the motor.
5. While running on the guideway, friction torque will exert resistance to the bogie. Thus, friction torque has to be part of the motor sizing concerns.
6. System inertia is needed to calculate friction torque and the total torque required.
   The motor inertia is 0.05 oz-in^2 (32mm in length) = 9.1e-7 kg-m^2
   Friction torque:
   ω (rotational speed) = 450 RPM = 47.12 rad/sec,
   a (acceleration) = 47.12/(0.5sec) = 94.24 rad/sec^2
   T_f(friction torque) = Ia = (94.24)(9.1e-7) = 0.0000857 N-m
7. Now apply the formula: $T = (J*N*\pi)/(ta) + T_f$
   $T = (9.1e-7)(450)(\pi) / (0.5) + 0.0000857 = 0.00267$ N-m

For the bogie to reach 0.5m/s with 0.5 sec, the motor requires a minimum of 0.00267N-m of torque at 450 RPM when powered.

- Selecting an switch actuation method

In the current bogie design, (see 14.2.3) a switch mechanism is designed to complete the switching when the bogie changes direction. To move the switching bar to the desired position, a linear actuator would be used to actuate the switching mechanism.

One of the concerns of using the linear actuator is that the actuator would retract back to its initial position if the control system lost power. And it will result in presenting a failed concept during any demonstration.

A latching solenoid actuator is another option. The feature of latching solenoid is that the actuator will maintain at extended position once it is actuated, and retract when energy is passed through it again. In addition, the latching solenoid operates on low duty cycle with power requirement between 3 to 6 Volts. Therefore, using latching solenoid actuator leads to steady actuation and requires low power for operation.

A servo in combination with a linkage system is also an option. While servos require continuous current, the current required is relatively low. Some servos of small form factor are capable of large torque. This torque aids in maintaining the position of the switching mechanism without additional hardware.

- Implementation of wayside pickup

As stated in section 13.1, one of the major differences that distinguish the Scale model from last year's design is the implementation of wayside pickup. The implementation of wayside pickup is important because it helps to mimic the idea of the full scale. It will also remove some of the issues that were evident with the previous year's Scale model. The previous year had battery packs attached to each bogie. During their display time at the Maker Faire they constantly had to replace the battery packs. The lack of a practical use time from the battery packs created the need to find alternative solutions. This led the team to deciding upon the use of wayside pickup.

Initial tests have been performed to test the practicality of wayside pickup. This was done at the most basic level practical. A 12V 2A power supply was used power two aluminum rails. The positive wire was wrapped around one rail and the ground wire around the other. A 12V DC motor was then used to prove whether or not power was successfully transmitted through the rails. Initially the wires coming off of the motor were placed directly on the rails. Once both wires were on the motor ran. The wires were then slid along the length of the rails to test if the motor could maintain power while moving. This also worked. The next step was to attach some kind of pickup mechanism to the motor wires and see if power could be transmitted that way. This was done to mimic a wheel or ski being used on the bogie to pick up power. This was tested the same way as the wires. The use of the metal skis actually worked better just the wires. The extra weight and larger surface area helped maintain a greater contact between the skis and the powered rails. Electrical tape was also used to see if it could isolate the rails from each other. This was another successful test. The tape successfully isolated one rail from the other allowing the motor to run. A photo of this experiment can be seen below in **Figure 4**.

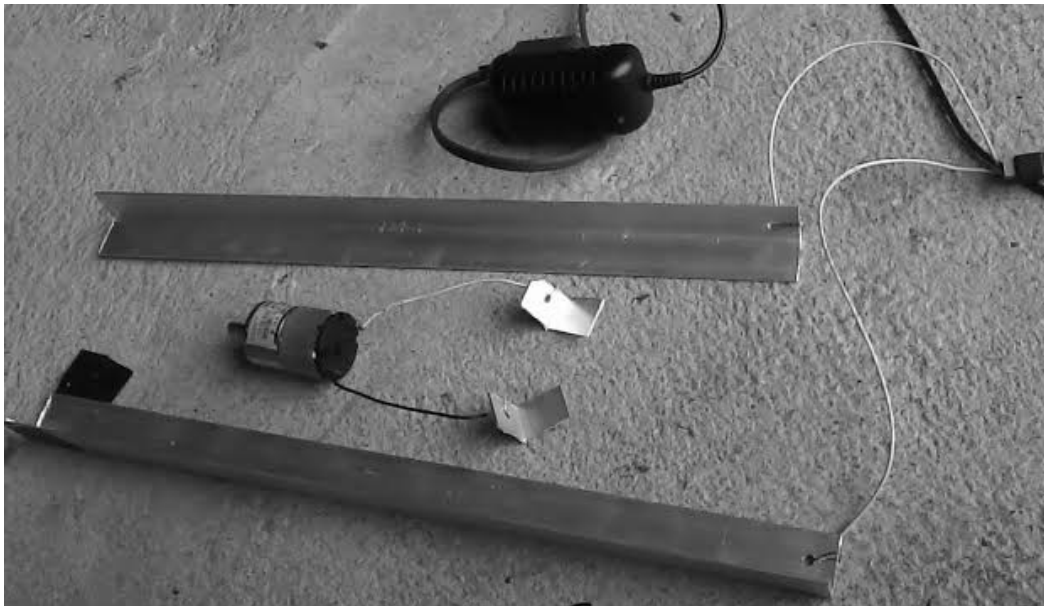


Figure 4-4: 51: Initial test of wayside power pickup using aluminum rails.

The physical implementation of wayside pickup is also a challenge and needs to be further explored. Initial thoughts were to use already proven methods of wayside pickup. Some of these ideas included the use of model train track. Model trains are able to pull power from the train tracks through their wheels. The idea would be to line the entire inside of the track with the model train track. The benefit of using train track is that it would come fully prefabricated, including connection joints. This would greatly ease the implementation of wayside pickup if it already comes fully fabricated. The only need for custom fabrication would be the device used to pick up power from the rails and transmit it to the bogie motor. It would be possible to use the wheels that the model trains have, however, that would require an extreme amount of precision especially when switching tracks. If the wheels slipped off of the track, even a little bit, the motor would lose power. Because of this, a custom pickup tool would need to fabricated to help cover for any potential errors in precision. These pickup tools could be a metal wheel or bearing, a metal ski, or even a metal brush would work. These power pickup tools would be built wider than the model train track rail. Concerns for using the model railroad track involved the precision required as well as the challenges that would arise from trying to bend the track. The way the beams are formed would make them very challenging to bend around corners. Producers do office flexible track, however, they will still not meet the required bend radius on the Scale track without additional bending.

Another idea was to use conductive tape. This would allow the team to get around the challenges that would occur from trying to bend the model railroad track. The tape would easily apply to the side of the track and could be bent to whatever dimensions are required. The conductive tape would need to be applied on top of electrical tape. This would keep the powered conductive tape from grounding itself out on the track. The same power pickup mechanisms from the previous paragraph could be used to pull power from the electrical tape. Concerns with using tape involve reliability. If three bogies are constantly circling the track it is possible the tape would get worn out or start to peel. Because this track will be functioning in front of audiences, it needs to be aesthetically pleasing to the eye. The use of tape might take away from that experience.

Fabricating the entire wayside pickup track is also an option. Aluminum or any other metal could be bent and applied to the side of the track. It would need to be applied over electrical tape, similar to the previous idea so that it would ground itself out on the track. Problems with using an aluminum power rail would involve cost and practicality. It will take a large amount of time and energy to fabricate aluminum power rails to run along the entire inside of the track. However, it would be the most visually appealing.

One last idea that was brought up during the Scale team's final presentation was to use the drive rail as the power rail. This would make use of already existing material and would require no additional parts or materials. With this method it would then have to be decided how to best isolate the drive rail from the remainder of the track. This would be the ideal method and will be further researched in the upcoming months.

After comparing all of the different options, a final decision was made to move forward with model railroad track. This was chosen because it came prefabricated and one of its main duties was to carry power to model railroad trains. It was decided to use N Scale Code 80 track. Code 80 refers to the height of the rails and N Scale refers to the overall size and scale of the track. This track will be attached to the top of the drive rail. Two aluminum "skis" will be placed on each side of the bogey. These will be able to take power from the rails and transfer it to the bogey.

However, there is still a need to put power to these rails. This will be done through the use of a computer power supply that will be wired to output 12 V to the track. Wires will travel from the computer power supply to the track. Separate pieces of track are connected together using rail joiners. The wires traveling to the track will be soldered onto these rail joiners and will allow for a successful transmission of 12 V to the track. This implementation of wayside power pickup will lead to a much more efficient design.

Now, even though 12 V is being brought to the track all of the electrical components on the bogey and cabin run off of 6 V. A LM 2596 DC to DC buck converter was used to step down the voltage for 12 to 6 V. 12V is being supplied to the track in order to give future teams the option of switching out motors and components for higher voltage ones. Another benefit to supplying a larger voltage than necessary to the rails is that loss will no longer be a concern. If there is an increased resistance in one area of the track that is fine. As long as the voltage at any point doesn't drop below 6 V the wayside power pickup system will still have enough power to supply the components.

However, in the off chance that the wayside power pickup fails, there will still need to be an onboard backup battery system that will supply power.

- Backup Power System:

To power each bogie's assortment of control and drive components, the entire system cannot depend on rail power alone. As each pod moves around the track, it is subject to a range of forces and vibrations that may cause the power pickup sleds to lose contact with the power rails. If the power system relied solely on power from the rails, any loss in connection during acceleration, turns, or switching would cause the system to stall and the controllers to reset. To improve stability, a battery backup system was required to run the system when rail power cannot be supplied.

Design requirements:

- Provide enough power to drive entire system when required
- Rechargeable backup battery that doesn't need to be replaced
- Seamlessly switch between rail and battery power without resetting the controls system.

In order to meet these design requirements a spreadsheet was created that listed the electrical components being used and the amount of current they draw at any given time. The maximum current draw was used on the spreadsheet in order to prepare for the worst-case scenario in which each component drew its max. The initial assumptions can be seen below in **Figure 33.**

Initial Assumption of System Requirements

	Current (mA)
Per Bogey & Cabin	2390
For all Three	7170

Item	Current (mA)	Quantity	Total Current (mA)	Notes
Arduino Uno	50	2	100	
Ultrasonic HC-SR04	15	1	15	
Hall Sensor OH44E	50	4	200	
Xbee S2	295	1	295	
75:1 Micro Gearmotor	1600	1	1600	Current when stalled
HS-55 Servo	180	1	180	

Total (mA)	2390

Figure 4-33: 52: Initial assumption of system power requirements

The components sourced for each bogey need to be able to withstand either sourcing or outputting 2390 mA. Actual power usage will probably be closer to about half of this number due to the motor not being consistently stalled or the other components operating at their max. The current for three bogeys was also calculated. In the off chance that the scale model is setup in an area without a wall outlet, batteries would have to be used to power the rails. The total current that all three bogeys would draw would allow the user to calculate the total number of mAh that the batteries would need to supply for the system to operate.

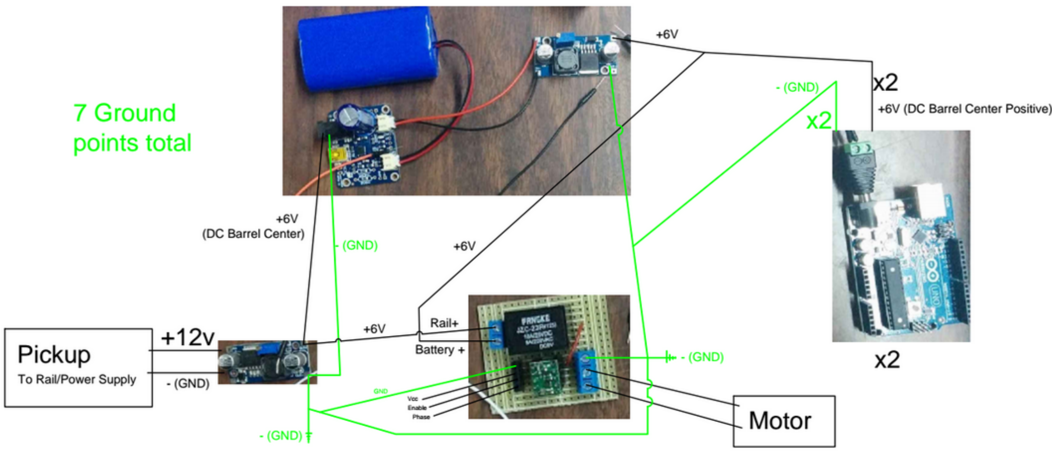


Figure 4-34: 53: General system schematic (Temp Photo)

The backup power system relies on the pickup rails, power sleds, and step-down buck converter previously discussed. While the system is receiving pickup power from the rails, the regulated 6 volt supply powers the drive motor directly and charges the battery. The 4400 mAh lithium ion battery pack was chosen for its high current draw potential of 2.6Amp continuous and 4.4Amp spike. The battery is charged using a 6 volt continuous charger that allows for uninterrupted power output that is essential in keeping the Arduinos from resetting when rail input power is temporarily lost. The output of the battery charger is immediately stepped up from the battery's nominal 3.7 volts to the standard 6 volt system voltage that the Arduinos and motor operate at.

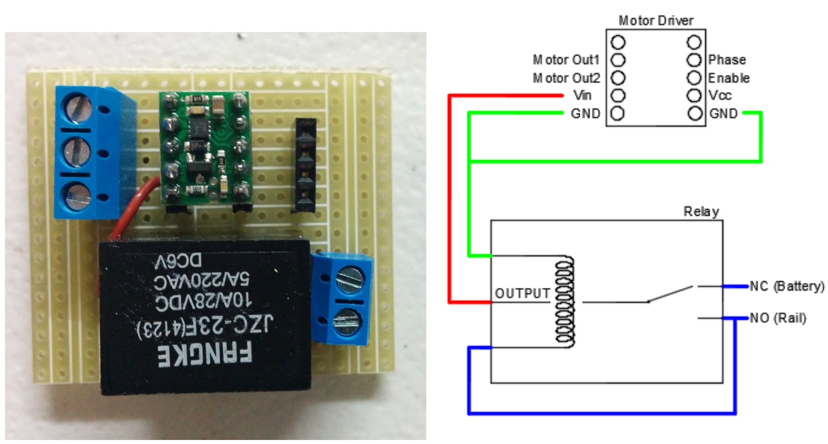


Figure 4-35: 54: Power relay and motor driver board (left) schematic (right)

To reduce the load on the battery and charger, it is ideal to run the motor directly from the rail supply. This is achieved using the relay seen in **Figure 35** the input from the rail power is connected to both the coil and the normally open pin of the relay. When rail power is available, the coil is energized and the normally open pin closes to switch the output to run off of rail power. If rail power is lost, the output switches back to the normally closed pin that draws power directly from the battery. With this system, even if the bogie stalls and loses connection to rail power, the motors can be driven from the battery until the connection is restored.

- **Controls**

  - Introduction

The Scale team is primarily designed to demonstrate the controls functionality of an ATN system. Two versions of the Systems code were created. Version 1 of the Scale model control system was delivered to the Mechanical Engineering during the early weeks of the Spring 2015 semester by a team of Computer Engineering students. This version was developed and tested for the 2013-2014 Scale Model. The Python code and programming concepts implemented by the CompE team were, at the time of delivery, beyond the scope of the Mechanical Engineering controls team. After several weeks of working with the Version 1 system and several meetings with the CompE team, the ME team came to the conclusion that the system was buggy and did not function 100% of the time, so a new controls system, named Controls System Version 2, was created from the ground up by the ME team. Several key concepts and paradigms from Version 1 were implemented but a redesign of the controls system allowed the ME team to have a thorough understanding of how the Scale model system functioned. Version 1 is a system that should be revisited by an individual/team who has a deep understanding of object-oriented programming and Python experience. With more time and effort, Version 1 would serve as a robust controls system for the scale model. It is strongly advised that previous experience with object-oriented programming is needed for Controls System Version 1 because the all aspects of the code need to be adapted to work with the 2014-2015 scale model. The 2014-2015 team strongly advises next year's mechanical engineering students to use version 2 for the scale model. This code does not use deep object oriented concepts and is designed for the 2014-2015 scale model.

2014-2015 Scale Model Controls Design Version 1

The computer engineering team established the main control system for the Scale track. This included a B+ Raspberry Pi, 6 Arduinos, 6 OH4EE hall sensors, and 3 proximity sensors. There are 3 important components to the Scale control design: a main hub, a communication Arduino, and a hardware controls Arduino. A graphical user interface, which is part of the main hub, monitors the location, the status of each pod on the track, and provides the operator to designate routing instructions for each pod. The Pi serves as the main hub, which communicates with each Arduino and gives routing instructions. Two Arduinos are designated to each pod, which serves as a communication board and a pod controls board. The communication boards are equipped with a Series 2 Xbee shield. Xbee is a wireless communication protocol that can send and receive data within a 300 ft. range. Refer to **Appendix C** for a more detailed explanation of the sender/receiver communication protocol between the Pi and a pod's communication board via Xbee wireless. The control boards primarily serve to control motor speed, hall sensors, and proximity sensors. Initially, only the controls board was supposed to be coded and designed by the Superway Mechanical Engineering team. However, due to a few hiccups in the handoff between the Computer Engineers and the Mechanical Engineers, the team decided to start from scratch and redesign the entire ATN system.

2014-2015 Scale Model Controls Design Version 2
Version 2 of the controls system was created by the Scale Model Mechanical Engineering team. The design goal was to make 3 pods move around the track autonomously. Below are some specifications of the Controls System:

Design Specifications/Intent
- Pods would move from station to station, designated by Main Hub input
- No on-the-fly destination change
- Collision prevention
- Pods would keep track of last known station location
- No pod-to-pod communication

Hardware for the entire system:
- 6 Arduinos
- 1 Xbee explorer board for Main Hub to Pod communication
- 4 Series 2 Xbees (3 per each pod + 1 for Main Hub)
- 9 proximity sensors (3 per each pod)
- 12 hall sensors (4 per each pod)
- PC/Mac capable of executing Python Scripts (using IDLE or PyCharm)
- Refer to "Power Section" for circuit diagrams and schematics which show individual pod hardware setup/powering

Version 2 can be separated into 3 major components: Main Hub, Comm Board, and Controls Board. There are a total of 3 comm boards and 3 control boards for the entire system, where each pod is equipped with 1 comm board and 1 control board. Only one Main Hub is needed for the system, which controls all of the pods individually.

What is the Main Hub?

The Main Hub used by the scale model team is the brains of the entire system; it demonstrates the concept of the automated transit network (ATN) through the use of a graphical user interface (GUI). This GUI is where the user can interact with the computer to call a pod from one station to another. In Fall 2014, the Computer Engineers used a Raspberry Pi B+ as the main hub for the system. This main hub had its own GUI made using Python. Although they were able to prove some of the concepts of the ATN system, it was not complete and did not function reliably with 3 pods. Thus, our Mechanical Engineering Controls Team had a difficult task ahead of it for the Spring Semester.

In order to understand the main hub written in Python, several members took a course during the winter break to learn the basics of the language. This would go a long way during the Spring semester. The team also met up with the Computer Engineers during Winter break to understand the messaging protocols as well as the code they had written. The team spent several weeks trying to understand the code that was handed to them, but the task seemed difficult to complete. After struggling for a few weeks, the team decided to start from scratch. An entirely new Python script was written for the GUI used in the main hub. The main hub did not require a Raspberry Pi anymore and switched to using Windows/Mac laptops to give the flexibility of using the system with any platform, as long as the pySerial library along with a Python IDE are installed on the machine.

The main hub communicates through serial with the Comm board Arduinos on the pods. It collects input from the users using buttons on the screen and translates this input to commands for the Arduino. The messages are transmitted using XBee Series 2. Several handshakes, which are message confirmations, take place before the directions are sent.

The main hub has been made intelligent enough so that it can determine which pod to talk to based on the location of the pod as well as the source location selected by the user on the GUI. If no pods are available, the system tells the user to 'Try again later'. In cases of emergencies, a separate Python script can also be run in order to re-initialize a pod and its location along with its availability. All of this can be done wirelessly without having to plug in the USB cable to reprogram the Arduino boards. This sort of a system makes things much easier and hassle-free when problems during tests. s

What is the Comm Board?

- The comm board is the communication interface between a pod and the main hub
- The comm board is an Arduino equipped with a Xbee shield and is located on a pod
- The comm board communicates to the control board (also located on a Pod) via I2C
- The comm board is a pseudo Finite State Machine where each function is considered a state
- Characters ('A', 'B','C'... etc.) are used to change a comm board state. See **Appendix C** for detailed wireless messaging protocol.

Comm Board Breakdown:

The comm board's code architecture is similar to a Finite State Machine. A finite-state machine (FSM), a finite-state automaton, or simply a state machine, is a mathematical model of computation used to design both computer programs and sequential logic circuits. In brief, a FSM remains in a state (or loop) until a new command is received. Once a unique command is received, the code jumps to a new state (or loop) and executes code. The commands used to change a comm board's state are individual characters (i.e. chars 'A', 'B', .. 'F'...etc.) and are received via an Xbee module. All commands are sent from the main hub Xbee (PC/Mac with Xbee explorer board). Refer to "Version 2 Wireless Messaging Protocol" in the **Appendix C** for the list of unique commands used to change states and to confirm wireless communication.

For the purpose of the Scale model, a FSM architecture was used to simplify wireless communication between pods and the main hub. Xbee wireless modules use "Serial Communication" to communicate with other computers or controllers. Serial communication is a standard for interfacing computers and electronics. This FSM architecture allows a comm board to always wait for main hub commands and not run any code unless the proper command, usually unique to each pod, is received. The commands were made unique for each pod so that the main hub can communicate with one pod without having other pods intercept messages and confuse themselves.

The Comm board is equipped with several states. Each function in the code can be considered a state. The next section describes these states.

<u>Comm Board States</u>:

Idle()

The idle state is the main state for the comm board since it is the only state that waits for commands from the main hub. This is the only state where Xbee communication (serial communication) between pod and main hub takes place. With the exception of when a pod is running, the comm board always returns to the Idle() state after a portion of code is executed.

CheckStatus()

This state checks the availability of each pod to see if the pod can be used by the main hub. Each pod has a unique uppercase character that sends the comm board to this state. If this code is executed, then the comm board sends back the location of the station that it currently resides in. If the pod is busy, however, a '0' is sent back to the main hub, indicating that the pod is busy and cannot be accessed at this time.

makePending()

This state simply makes a pod "pending" by simply changing the pending flag to "true". Each pod has a unique uppercase character that sends the comm board into a pending state. When a pod is pending, then any direction command sent by the main hub will only be processed by this pod. If this code is executed, then the comm board sends back a confirmation value to the main hub.

confirmRoute()
This state simply confirms that it received the correct directions form the main hub. The character sent by the main hub will be seen by each pod, but ONLY the pod that is pending (pending flag = true) will execute this code. If this code is executed, then the comm board sends back a confirmation value to the main hub.

execute()
This state confirms that a pod is pending and is ready to move to the next station, and then moves to the *sendDirections()* state. It does not send back a confirmation value.

sendDirections()
This state simply just sends directions to the control board via I2C. It does not send back a confirmation value. After this code is executed, the pod pending status goes back to “false” and will not process any direction chars sent by the main hub.

What is the Control Board?

- The control board acts as the eyes and ears of the pod.
- The control board is an Arduino powered through the barrel jack that regulates
    - 4 Hall sensors
    - 1 DC motor
    - 1 servo
    - 3 Proximity sensors
- Communicates through I^2C as a slave to the communications board
- The board contains approximate location of the pod in the form of the variable count.

<u>Control board breakdown:</u>
The control board breaks each piece of hardware into a function to be called upon usage. This allows for quick and targeted troubleshooting. Upon receiving and confirming the character from the comm board, the controls enter a switch case. Each case contains one routing number (mcount), up to two actuation and confirmation numbers: act1/2 and confirm1/2, respectively. When a new destination is set in the switch case, the motors will run in the main while loop until the number of magnets read and stored in the variable count is equal to the mcount value. Inside of the while loop, the following functions occur in this order:

hallread()
This polls all the hall sensors and increments the counts accordingly. The function uses a non-blocking delay of 250 milliseconds between reads in order to prevent consecutive reads of one magnet.

checkdistance()

Reads the left, right, and front proximity sensors. This model of ultrasonic sensors sends out a trigger pulse and records the time it takes for the echo pin to receive a response. It then multiplies the time delay between trigger and echo by the speed of sound in order to yield a distance. This function outputs the distances to the global variables Prox_L, Prox_R, and Prox_F.

motorControl(scalepwm)
motorControl outputs a PWM signal to IN1 to move the motor forward. The speed is based upon the input criteria.

The aforementioned functions will run repeatedly waiting for three exclusive if statements to trigger: if the confirmation variable matches act1 or act2, the servo will trigger, if confirmation matches confirm1 or confirm2, the servo will de-actuate. Finally when the count matches the mcount, the loop will be terminated and the pod will halt.

<u>Pseudo-Code for Version 2: After setup, move pod from a station to a station</u>

1. Start Main Hub (Run Python Script)
2. GUI input
3. Main Hub Checks pod availability
   a. Main Hub sends individual chars (N, O, or P) to all pods and waits for response
      i. Main Hub sends 'N' for pod 1 availability and location
         1. If available, Pod 1 sends back the location of station it currently resides in ('110', '111' or '112')
         2. Pod sends '0' if not available
         3. Main Hub prints and stores char received
      ii. Main Hub sends 'O' for pod 2 availability and location
         1. If available, Pod 2 sends back the location of station it currently resides in ('110', '111' or '112')
         2. Pod sends '0' if not available
         3. Main Hub prints and stores char received
      iii. Main Hub sends 'P' for pod 3 availability and location
         1. If available, Pod 3 sends back the location of station it currently resides in ('110', '111' or '112')
         2. Pod sends '0' if not available
         3. Main Hub prints and stores char received
4. Main Hub decides which pod to talk to based on the locations of the pods received in the previous step
5. Main Hub sends pending char (Q, R, or S) to desired pod and waits for confirmation
   i. Pod sends back (q, r, or s) for confirmation
   ii. Sends '0' if something went wrong
6. Main Hub sends directions (A, B, C, D, E, or F) to the pending pod from step 5
   a. Pod sends back direction char (A, B, C, D, E, or F as DECIMAL values) to Main Hub as confirmation
7. Main Hub checks whether received direction is the same as the one sent in step 6.
   a. If the check is successful:
   i. Main hub sends directions from step 6 using lowercase 'a', 'b', 'c'...'f'.

ii. Pod resets mCount to 0 and sends directions to control board using I2C.

8. Pod moves to destination

Example: Make pod 2 go from station 1 to station 2. (This is what the serial communication would look like)

Main Hub Sends	Function	Pod Sends	Function
‘O’	Checks Availability	‘n’	Pod 2 is available in station 1
‘R’	Make pod 2 pend	‘r’	Pod 2 Confirming it is pending
‘A’	Send directions to pending pod (pod #2 in this case)	65 (DEC value for ‘A’)	Confirms it got the right package
‘a’	Tells pod to execute directions	-	-

<u>Navigation System:</u>

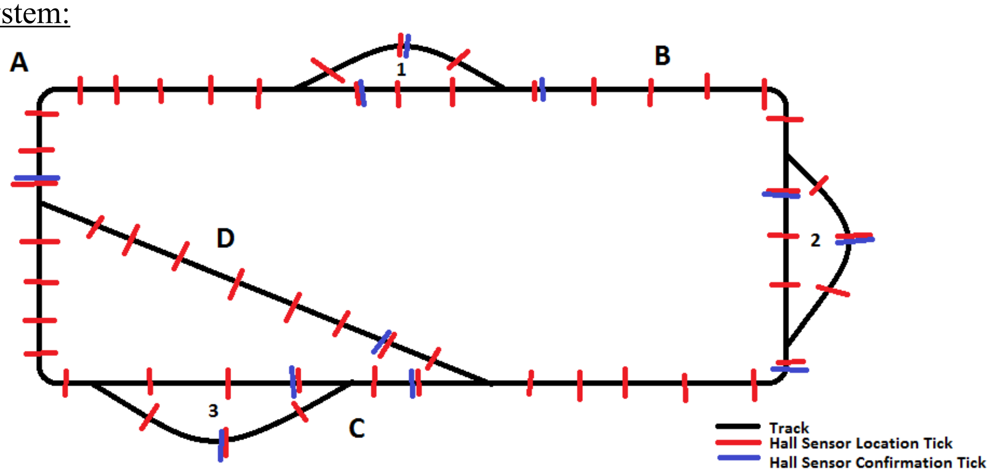


Figure 4-5: 52: Navigation protocol for the Scale track will use hall sensors.

In the figure above, there are 4 regions and 3 stations: A, B, C, and D. and 1,2 and 3 respectively. Magnets will be placed around the track, which are shown in the figure as red and blue lines. These magnets will be used with the four hall sensors equipped on each pod. A red line is the *location* tick, and the blue line is the *confirmation* tick. Or in other words, the red lines are magnets that designate location, whereas the blue line are magnets that will confirm a pod is following the correct path. The red lines (magnets) will be equally placed around the track so that both the pod and main hub will know where the bogie is at all times. The main purpose for the second magnet is to confirm a pod has followed its instructed path. When compared with the second magnet count, the pod will always know if it is on course or took a wrong turn.

<u>Navigation Example:</u>

To tidy up the terminology use, assume the red lines are red magnets and the blue lines are blue magnets. Know that when a pod reads a red or blue magnet, it is actually the hall sensor that reads the magnet. One hall sensor for the red magnets; and one hall sensor for the blue magnets.

The main hub instructs a pod in station 3, which at rest on a blue and red magnet, to station 2. Starting from rest, the pod will count 6 red magnets before entering region A. Region A is designated by *both* a blue and red magnet. When the pod passes over these two magnets, it will confirm that a blue magnet was read on the 7th red magnet count. Thus confirming that the pod is on the correct path. The pod is now aware that it is in Region A. The counter resets and the pod continues course.

The pod moves along and counts 8 more red magnets until it counts another blue magnet. The pod confirms that a blue magnet was read on the 8th red magnet count. Thus confirming that the pod is following the correct path. The counter resets and the pod moves along.

Now consider that the pod read a blue magnet on the 9th tick. The pod would then be in station 1, which is not the correct station. The pod would stop at this station and wait for instructions from the main hub.

Back to the example, with the pod on the correct path and the counter reset, the pod moves along towards its destination, station 2. The pod counts 3 more red magnets until it reads a blue magnet. This confirms that the pod is now in Region B. The counter resets and the pod continues course.

The pod moves along and counts 7 more red magnets until is counts another blue magnet. The pod confirms that a blue magnet was read on the 7th red magnet count. The pod is now at its destination, station 2. Confirming that a blue magnet was read on the 7th red magnet, also confirms that the pod followed the correct path. The counter resets and the pod waits for instructions from the main hub.

If the pod read a blue magnet on the 6th red magnet count, then the pod would know that it did not make the turn necessary and lost course. It would stop on the track and wait for further instruction from the main hub.

<u>Discussion about Navigation System:</u>

Since each region, except for region D, consists of a station, a 90-degree turn, and two straight sections. It would be wise have equal number of location magnets and confirmation magnets in each region. Furthermore, the confirmation magnets should be placed in the same place for each region, except for region D. This would establish consistency among the regions and make code easier to write.

For example, all regions will have 20 magnets location magnets. Regions A, B, C (which are all the same and consist of a station, 90 degree turn, and a 2 straight sections) will have 3 confirmation magnets and Region D (which does not have a station) will also have 2 confirmation magnets (one being a dummy magnet).

If the first of 3 confirmation magnets in a region is used to confirm that the pod has entered a region, then the number of location magnet to the next confirmation magnet will be the same for each region. If a 2nd confirmation magnet is *always* placed with the location magnet *immediately* after a junction (the first location magnet passed a turnoff), then confirmation that a pod has followed did not turn will *always* align with the number of location magnets it has previously read. If the 3rd confirmation magnet is placed in station, and each station has equal number of magnets, then the confirmation will always align with the number of location magnets it has previously read. For the special case of Region D, the first magnet will confirm pod has entered region D, the second will confirm that a pod has taken the shortcut, and the third will be used as a dummy for the purpose of keeping code constant. A special SWITCH case can be created for the dummy confirmation magnet in region D.

Note about Navigation System:
A couple of hard coded pre-designated paths that demonstrates the concept of an ATN may be sufficient. Furthermore, the Arduino processing power may need to be reserved for higher priority functions such as motor control.

<u>PID Library for Arduino:</u>
It is important to not waste any progress made by previous years' work. Last year, the Superway team created a PID library for bogie speed control rather than use the open source Arduino PID library. The primary reason for this is because it is believed that the Arduino PID library is inherently flawed and requires lots of processing power to run the functions. It will be ideal to use the library created by the previous semester's team.

Further evidence shows that the Arduino PID library is flawed because a loop of track and bogie was prototyped to test the Arduino PID library. A track was built to test a single Arduino running a PI control for bogie speed. Figures **6** and **7** show the CAD rendering as well as the fabricated track.

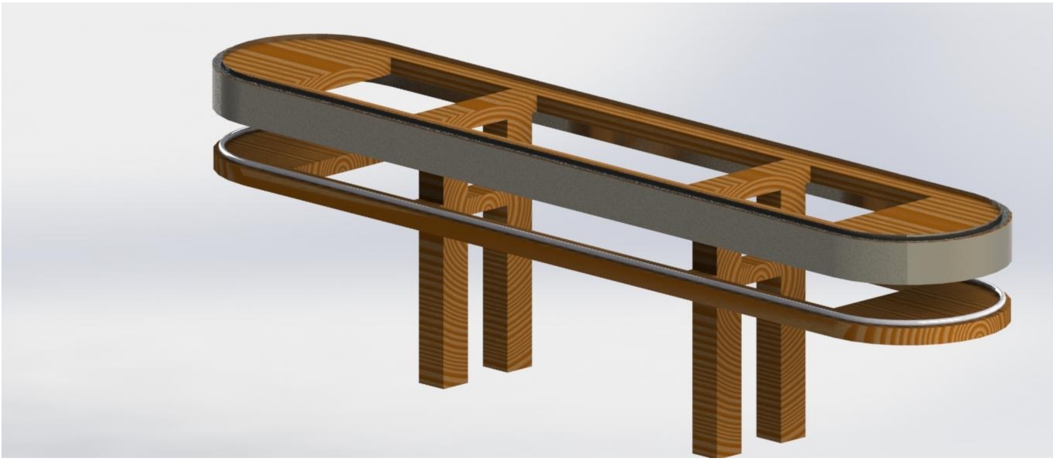


Figure 4-6: 53: CAD rendering of a Scale track loop. This was created to determine a PID controller for a speed control of a bogie.

Figure 4-7: 54: A Scale track loop was created to test PID speed control

The limited amount of processing an Arduino is capable of restricts the team to use this Library. Many teams in the ME 190 course attempted to use the Arduino PID library for control systems. General consensus was that the PID library is inherently flawed and should not be used.

In addition, wood was found to not be a good construction material for the track because of its permeability to moisture. Over time, the wood warped which, as a result, changed the tracks intended shape design. The warped shape track affected bogie's performance while moving along the track by introducing more resistance. This increase in resistance sometimes caused the bogie to get stuck or slow down dramatically.

<u>Hall Sensor functions:</u>

The previous year's team utilized hall sensors to actuate mechanisms on the bogie. These functions will most likely not be used because a more robust design will be implemented. Two hall sensors may be used on each pod to identify a pod's location on the track.

- **<u>Bogie</u>**
  - Design Chronology

As discussed earlier, there were three initial bogie and guideway combination prototypes built prior to the development of the final design. Each prototype's relative merits and weaknesses were analyzed, and the merits of each design would be implemented into one final design.

To begin designing a bogie that follows a guideway, the guideway cross section and width dimensions must first be defined. **Figure 8** below shows a figure of the guideway dimensions.

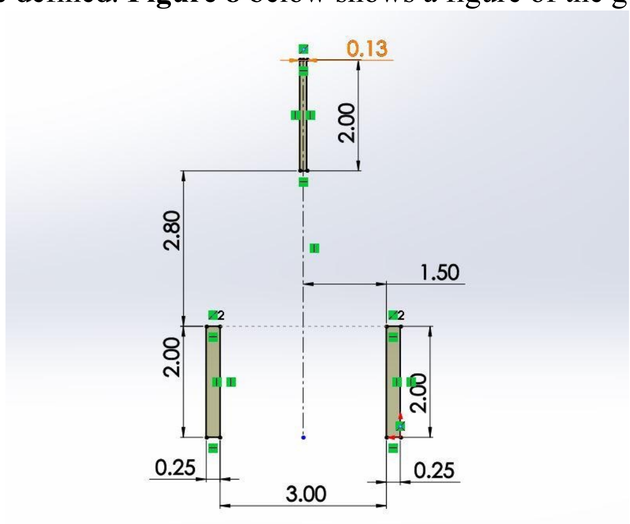


Figure 4-8: 55: Computer-aided model of the defined scale model rail cross-section.

There are three rails with the top rail being in different width than the lower two rails. The top rail is used to guide a switching mechanism utilizing a set of bearings linearly actuated to each side of the rail for direction selection. These bearings are linked in such a way that only one side (left or right) will be selected at any given time. The pair of rails at the bottom of the cross section are used for propulsion and switching. On the top surface will sit driven wheels that propel the bogie. At the bottom of those rails will be a linearly actuated switching mechanism. Similar to the upper switching mechanism, this lower switching mechanism will utilize bearings to select either the left or the right rail for direction selection. These concepts were shown in the previous prototypes, and this final design of the bogie will effectively integrate these concepts into a working model. **Figure 9** below shows the current final design of the bogie.

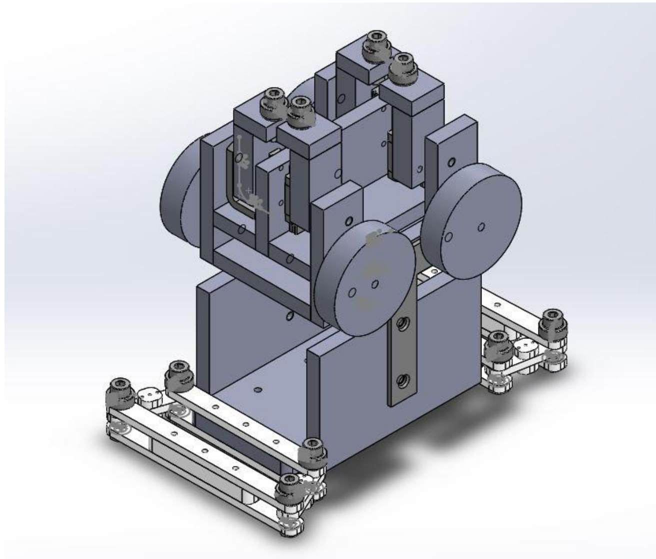


Figure 4-9: 56: Computer-aided model of the bogie final design. The model does not currently show actuation hardware, as these have not yet been decided upon.

This final design has been made to integrate the previous concepts in a manner where each concept has been separated into individual portions. This allows simultaneous development of individual concepts. Also, this design has been built for fabrication via laser-cut acrylic chemically bonded together. As such, these portions may be iterated quickly to improve the overall efficiency of production. **Figures 10, 11, and 12** below show the individual portions:

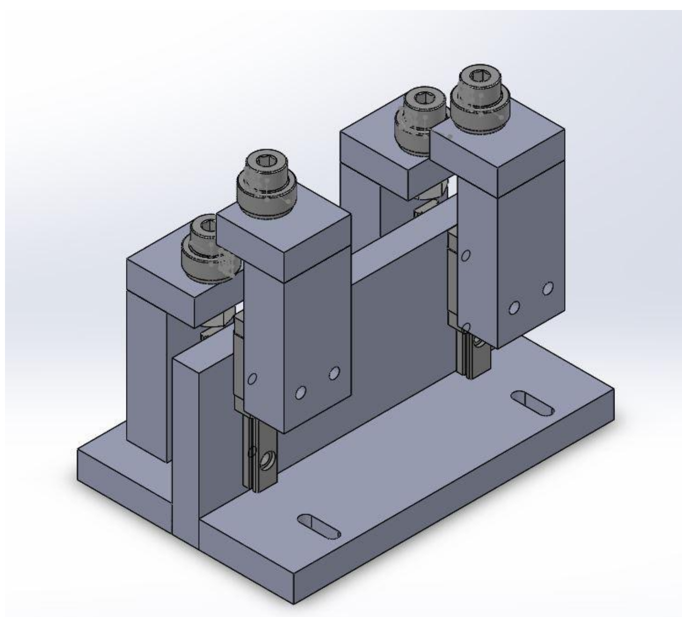


Figure 4-10: 57: Computer-aided model of the upper switch mechanism. The model currently does not show how each opposite pair of linear sliders will be linked together in an inverse configuration. The base pieces have slots for mating to the propulsion portion via L-brackets.

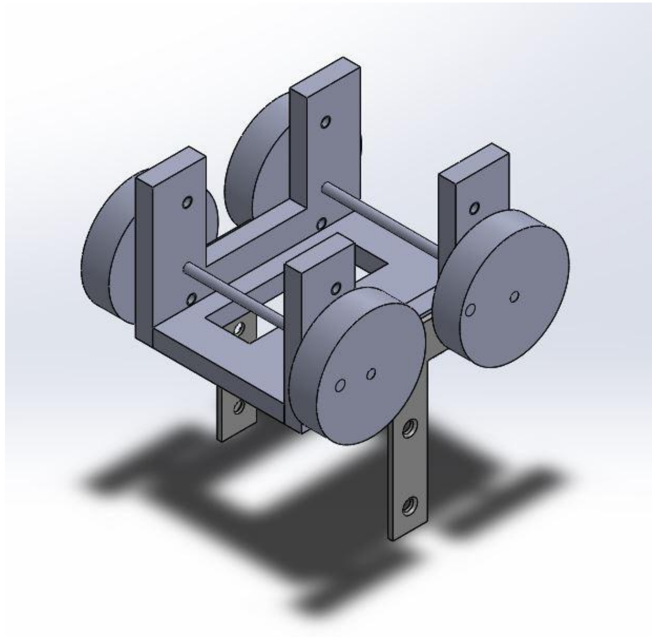


Figure 4-11: 58: Computer-aided model of the propulsion portion of the bogie. This portion connects the upper switch to the lower switch. Propulsion wheels will be motor driven. The link between the motor and the wheels has not been decided.

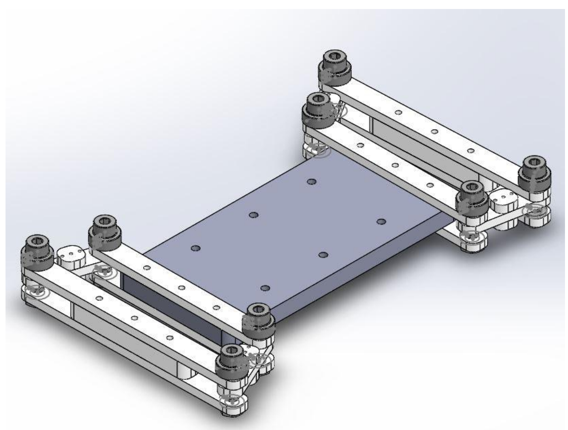


Figure 4-12: 59: Computer-aided model of the lower switching mechanism of the bogie. This switching mechanism utilizes two four-bar mechanisms to latch onto either the left or the right rail to determine movement direction. Actuation of this switching mechanism will involve linking two of the long couplers at each end of the bogie in an inverse manner.

Each of these portions will be assembled together with brackets and fasteners. These brackets and fasteners were located in such a way where an operator will be able to find them and assemble/disassemble the bogie.

Switching between left and right directions of the guideway involves actuating both upper and lower switching mechanisms before the change in guideway occurs. **Figures 13, 14, and 15** illustrate how the current bogie design switches between rails.

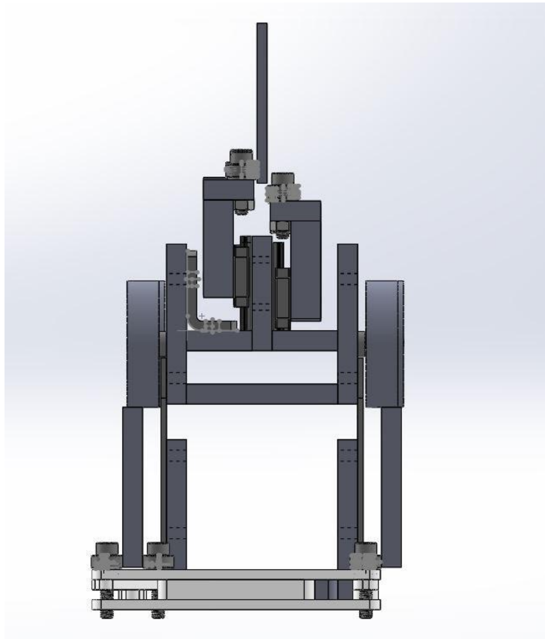


Figure 4-13: 60: Rear view of the bogie as it traverses along the guideway. The upper switch has selected the left rail by moving its bearings upward. The lower switch selected by latching onto the left rail with its four bar mechanism.

The bogie has been given a command to switch to the right rail. Since there are currently no switching sections, no action beyond traversing forward can be taken.

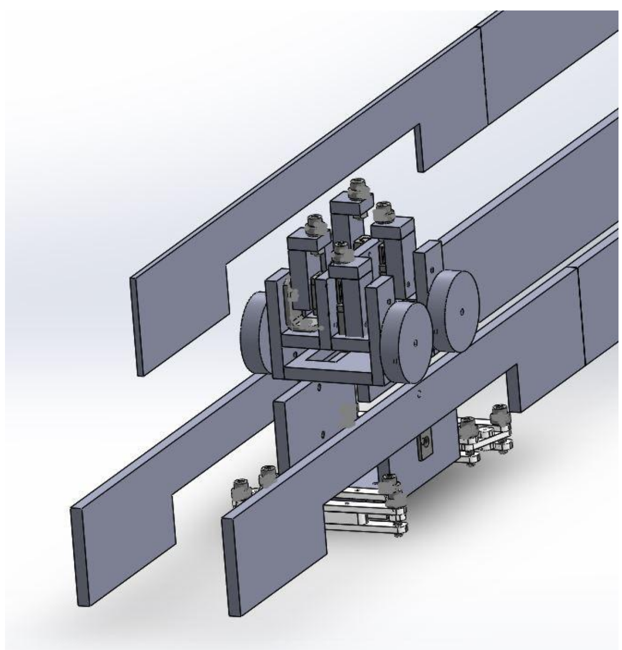


Figure 4-14: 61: Isometric view of the bogie as it arrives at a switching portion of the track. This is noted by the notches cut into the rail material. The controls of the bogie will allow it to recognize that it has arrived in a switching portion of the track. It is now allowable to switch rails.

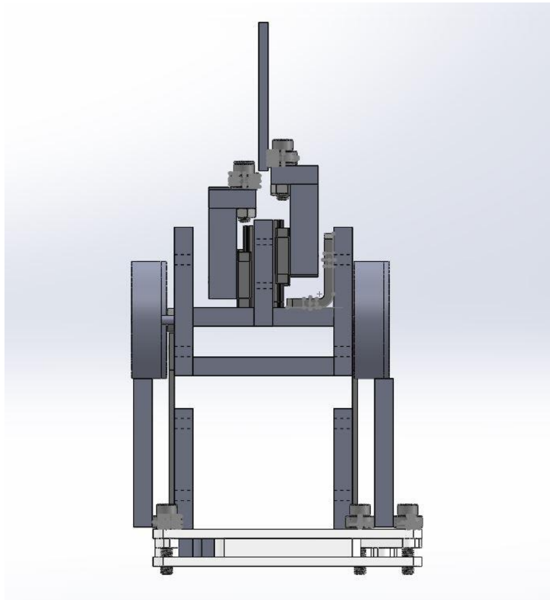


Figure 4-15: 62: Back view of the bogie with switching mechanisms selecting the right rail of the guideway. Notice the upper and lower switch have moved their bearings away from the left side of the guideway cross sections to the right.

There are a number of concerns with this current bogie design. Inherently, this design allows the upper and lower switch to operate independently. A catastrophic failure will occur if the upper and lower switches do not select the same side. Also, there are currently many components to assemble for this bogie design. The overall wheelbase may also be shortened by selecting smaller wheels, thereby decreasing the turning radius of the bogie. Further development must be made to reduce the amount of components to shave weight and mitigate unforeseeable circumstances. At the same time, the bogie must be designed to hold all other components such as microcontrollers and sensors for the controls of the bogie. The lower switching mechanism was also deemed to be too complicated and so requires significant design alterations.

One of the concerns was the complexity of the switching mechanism. To simplify the lower switch, the design was changed from two independently moving four bar mechanisms to a single sliding arm. A development effort was made to prove the functionality of this slider switch mechanism. The small scale of the bogie design required a proof-of-concept to be made for verification of capability. This effort proved another solution to a linearly actuated switching mechanism that latched onto the lower pair of rails of the guideway with a significant reduction of material. **Figure 16** below illustrates this next-generation lower switching mechanism's two states.

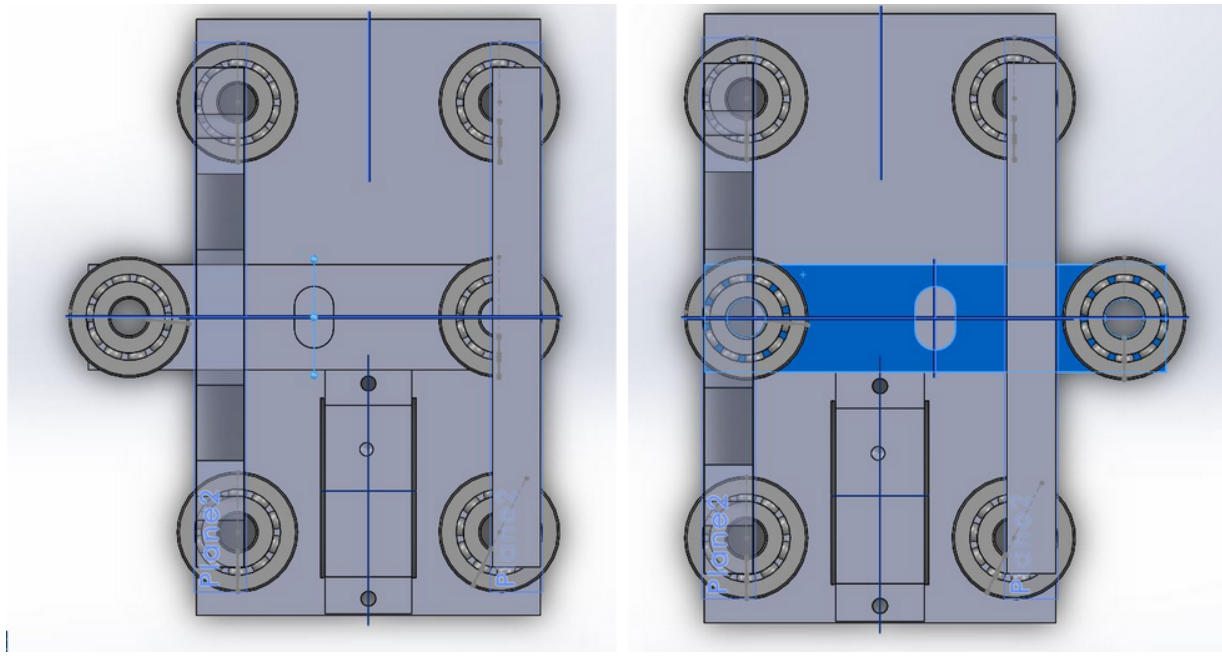


Figure 4-16: 63: Graphical representation of the new lower switching mechanism's two states. The left image corresponds to left rail selection, and the right corresponds to the right rail selection. Actuation will move the link left and right through these two states.

This new switching mechanism was designed with the dimensions of the defined guideway cross section in mind. Since this mechanism was the only concept requiring proof-of-concept, a prototype was rapidly produced. To further this development effort, actuation was also designed and implemented in the prototype. As such, this development effort was invaluable to the overall design process of the final bogie design. **Figure 17** below shows the computer-aided model of the prototype that proved this new lower switching mechanism.

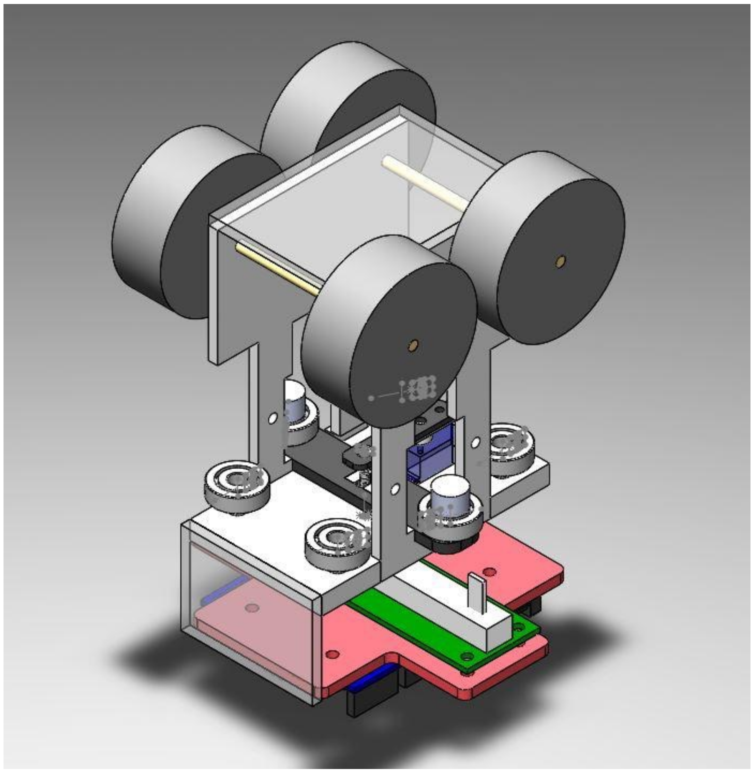


Figure 4-17: 64: Computer-aided model of the new lower switching mechanism. This prototype was physically small, and therefore was relatively light and easy to handle.

This prototype was also designed to be fabricated with laser-cut acrylic that is chemically bonded together. The hardware was purchased and implemented. A separate guideway model was also built to demonstrate effectiveness of this switching mechanism. These attributes of this development effort, therefore, proved more than just this new switching mechanism. **Figure 18** below shows the prototype stemming from this development effort.

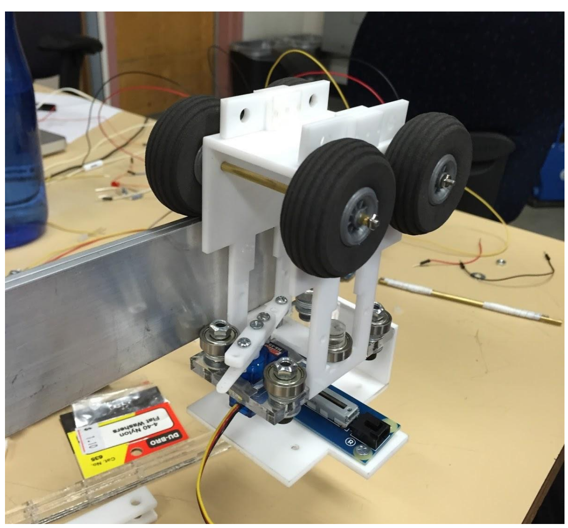


Figure 4-18: 65: Image of the prototype of this development effort. The prototype bogie is capable of hanging on the single rail by means of constant force applied by a Hitec HS-55 servo motor.

Form factor of this prototype is similar to the form factor of the final bogie. The wheels used in this prototype are too large for the final bogie design. Bearings used in this prototype can be scaled down, but factors such as cost and availability of fastening methods lead to an inclination away from scaling down further. This prototype also revealed that such a small form factor limits the amount of external components attached to the bogie within the guideway cross section. This could lead to hardware organization issues, and messiness of the overall bogie. **Figure 19** below illustrates this organization concern.

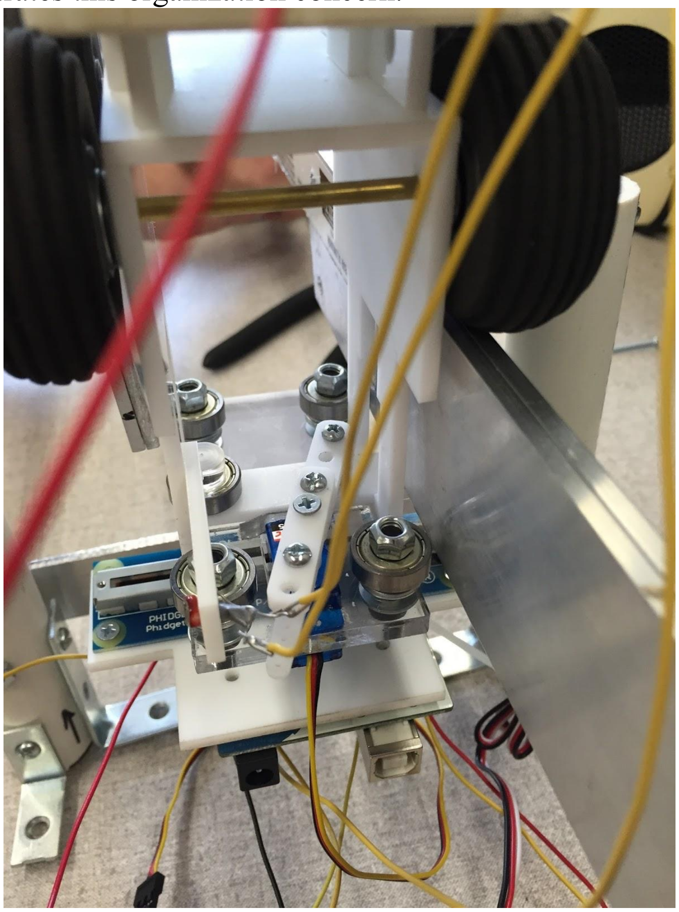


Figure 4-19: 66: Image of the prototype's state of organization. Wires and components were tightly packed onto the prototype.

This prototype had many wires hanging off of it. Also, the actuation of the linkage would occasionally misalign wires, causing certain portions of the control logic to fail in function. Also, the Arduino microcontroller used to actuate the switching mechanism was mounted upside down, as shown in **Figure 19** above. With this physical iteration, many design considerations have been proven and there is now a clearer understanding of the direction the bogie development must move towards.

The final bogie design implements design changes from the previously mentioned bogie design, as well as the improvements discovered through the development effort mentioned above. **Figure 20** below shows this final bogie design.

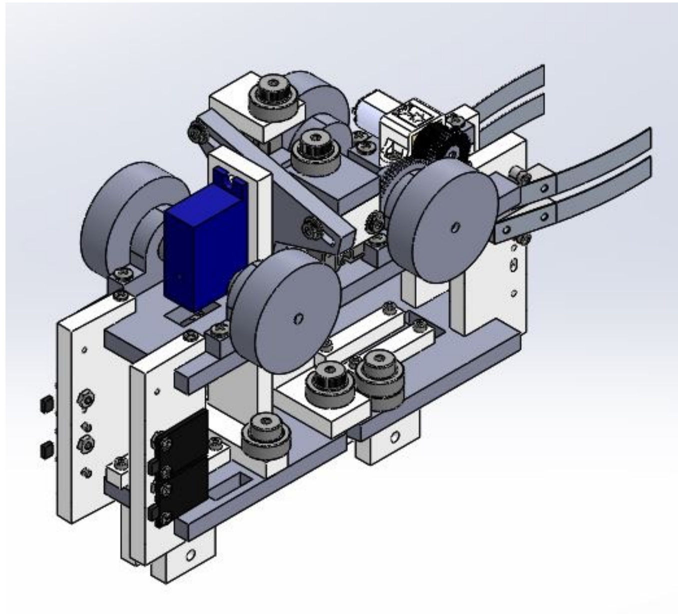


Figure 4-20: 67: Isometric view of the final bogie design for use in Maker Faire 2015. Note the simplified frame with increased switching complexity, the decreased wheel size, and increased number of small hardware.

One of the major functional concerns mentioned earlier was that the upper and lower switch mechanisms were not linked together. In the final design, they are linked together in motion via a central triangular link. A servo actuates this link as the steering system of the bogie. **Figure 21** shows the two intended states of this switching link.

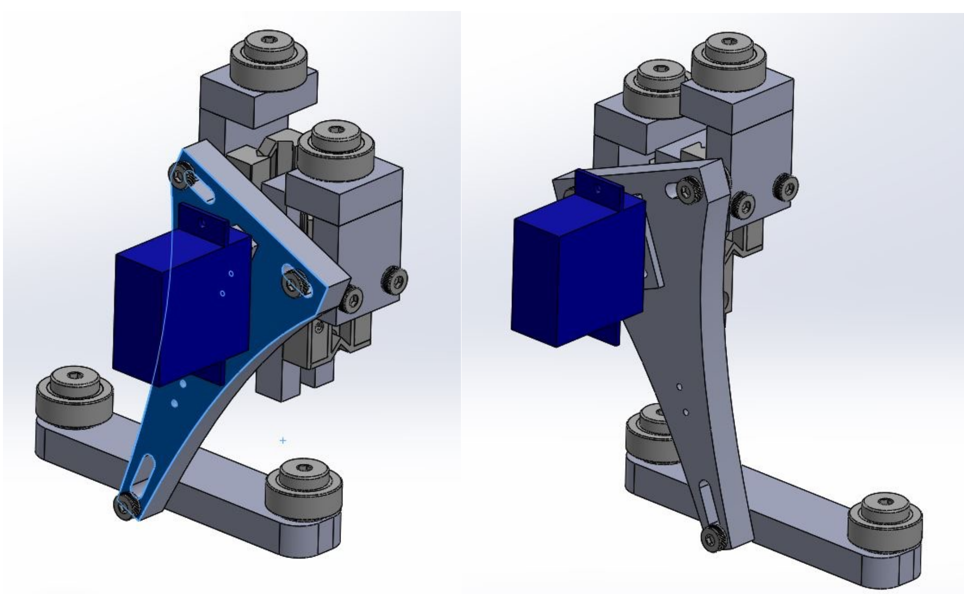


Figure 4-21: 68: Graphical representation of the final switching mechanisms two states. The left image corresponds to left rail selection, and the right corresponds to right rail selection. Actuation of the triangular link via servo will move the link left and right through these two states.

Since the design of this switching mechanism will lead to torque being applied to the servo, the Hitec HS-82MG metal gear servo was selected for use as the steering servo. The location of the pivot point, the distance between the top and the bottom switch mechanisms on the link were important parameters to the amount of translation each switch mechanism is capable of achieving. Tuning these parameters within the mechanical design of the entire bogie was achieved to ensure that the top switch was capable of switching without a notch in the upper rail, while allowing the lower switch to translate enough to pass through rail notches to select the desired location. **Figure 22** below shows the mathematical relationship between the previously mentioned parameters.

The switching linkage connects the vertical switching bearings and the horizontal switching bearings. This allows both the vertical and the horizontal switching components to be actuated by a single servo. This required the linkage to be a specific shape and have specified slot lengths. The analysis to determine those specifications resulted in the following geometric relationships:

$$L = \frac{BT}{H}$$

$$S_1 = \sqrt{\left(\frac{H}{2}\right)^2 + T^2} - T$$

$$S_2 = \sqrt{L^2 + \left(\frac{B}{4}\right)^2} - \frac{B}{2}$$

T: bearing radius + ½ switch rail thickness
H: from bearing height and rail height
B: from guiderail width and bearing diameter

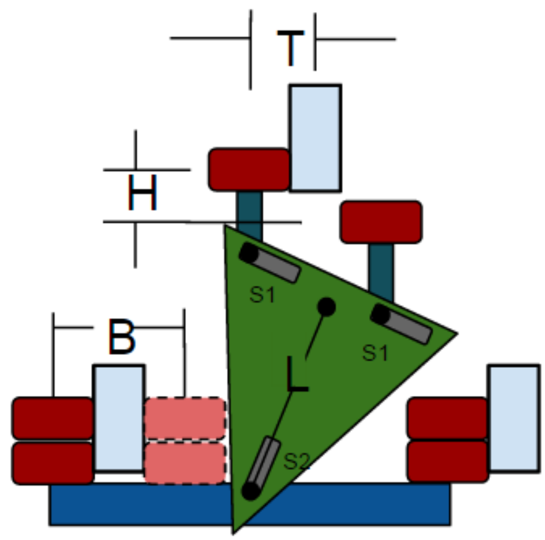


Figure 4-22: 69: Calculations showing the relationship between pivot point, switch distance, length of entire switch, and translational range in the triangular linkage.

Another functional concern was the number of parts of the bogie as well as parts on the bogie. This concern affects complexity of manufacturing and weight. The bogie uses thirteen different acrylic pieces as the frame, and all parts may be fastened together. Once a bogie has completed testing, the frame will be chemically bonded together for maximum rigidity. This allows removal of roughly half the number of fasteners, leading to a lighter bogie.

Length was also a concern. Due to the nature of the triangular link, as well as the need to maintain the switching mechanism in the center of the bogie, the wheelbase was lengthened to allow the triangular link to pass beyond the width of the wheelbase. Also, the wheel diameter was decreased to improve clearance capability, leading to a smaller over all bogies. **Figure 23** below compares the wheelbases of the old and the final bogie design.

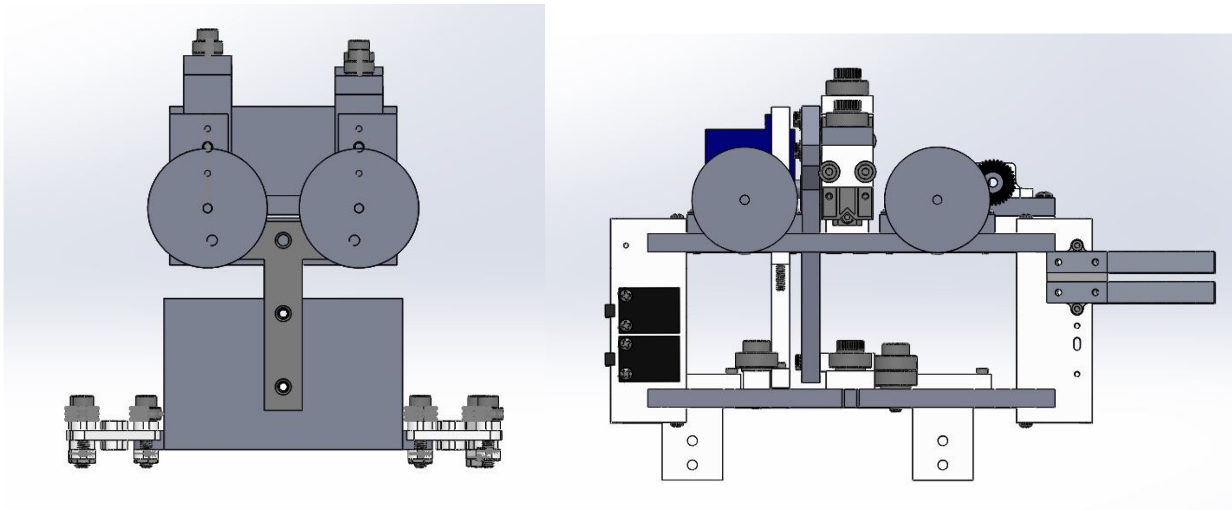


Figure 4-23: 70: A comparison of wheelbases between the old bogie design and the final design. Note the separation of the wheel axles, as well as the decreased wheel diameter from left to right. Visible changes between the switching mechanisms can also be seen in this comparison figure.

The bogie was also changed to implement wayside power pick-up from the track. To pick up power, the bogie must conduct power and connect it to the cabin, where all of the controls are done. With specifications from the wayside power team, this was achieved. The wayside power team designed a set of claw-like conductor plates mounted to an extruded plastic part. **Figure 24 below** shows these conductor plates mounted onto the bogie.

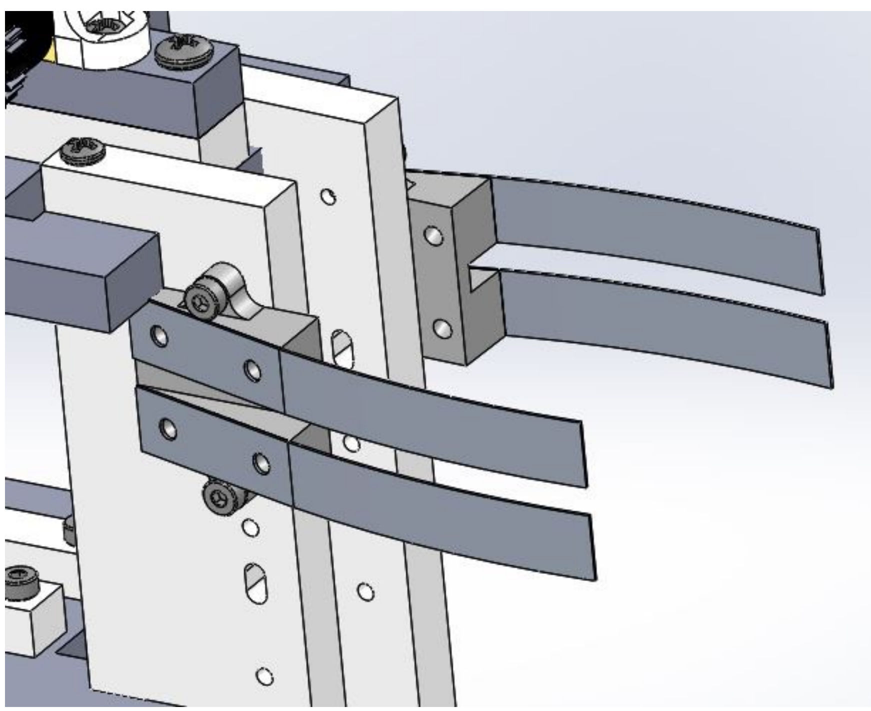


Figure 4-24: 71: Wayside power pick-up conductor plates mounted onto base connecting plates on the final bogie design.

The connecting plate of the bogie has been designed to mount those conductor plates base directly onto the bogie. They are also used on the opposite side of the bogie to mount hall sensors for feedback from the track. **Figure 25** below shows the hall sensors and their PCB's mounted to the other pair of base connecting plates.

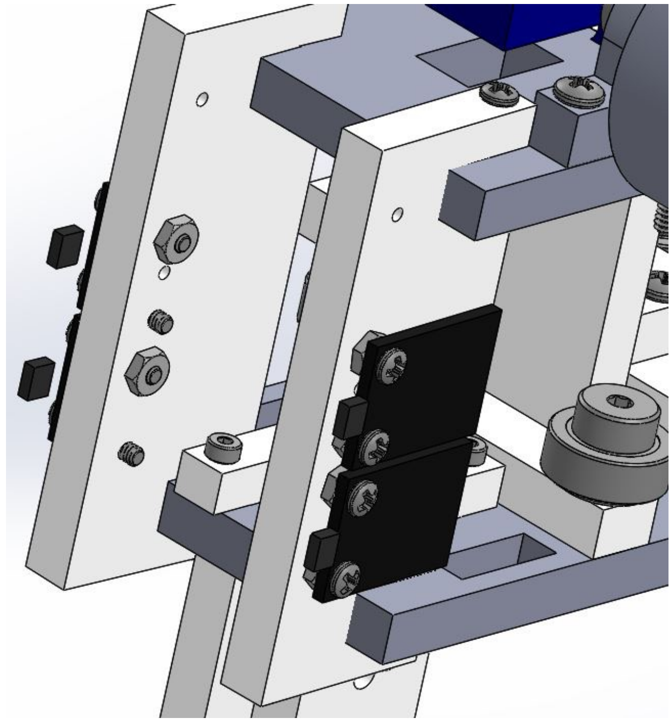


Figure 4-25: 72: Hall sensor PCB's mounted to connecting plates with a traditional screw and nut clamping method through a slot, and straight mounting by threads and a screw.

Cabin mounting is achieved via two clevis-type mounting brackets. These brackets allow for a screw and nut to be used for fastening the pieces together. **Figure 26** below shows these brackets mounted to the bogie.

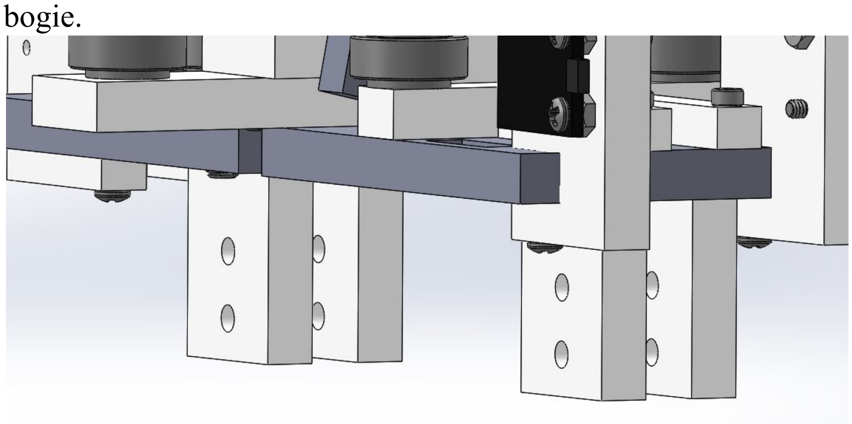


Figure 4-26: 73: Cabin mounting brackets with through holes for 4-40 threads to pass through easily. The cabin will also have the same holes for the screws to pass through.

Mechanical drawings of the bogie and constituent parts can be found in **Appendix C.**

- Prototyping

Prototypes of the final design proved the important aspects of the design. These important aspects are bogie fitment to the track, mechanical switching action, and the bogie's ability to carry itself and load from the cabin on the track. **Figures 27 and 28** below show one of the bogie prototypes in the system-testing phase.

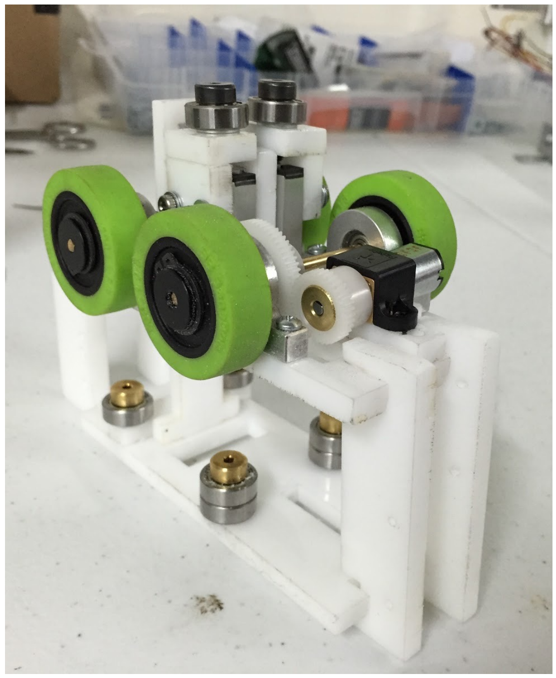


Figure 4-27: 74: One of the functional bogie prototypes without lower switching mechanisms. This prototype was used to prove motor functionality and was also used in conjunction with a prototype cabin from the Controls team for preliminary visualization of the final system.

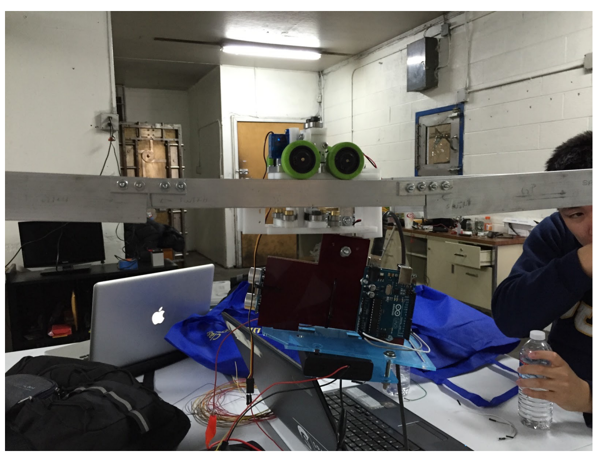


Figure 4-28: 75: The prototype bogie with switching mechanism and cabin prototype installed. The bogie ran on the test track with the cabin underneath. The propulsion motor was powered and ran by the hardware and software from the Controls team.

The prototypes were made of laser cut acrylic sheets. These sheets were bought from Tap Plastics as scrap Chemcast brand sheets. The Epilog Helix laser cutter in the San Jose State University Mechanical Engineering department mechatronics lab was used to cut these pieces. During the process of prototype iteration, the laser cutter failed due to a power supply failure. Throughout the three weeks in which the laser cutter was unavailable, an external acrylic shop was contacted in hopes of having parts cut from them instead. This shop was named Acrylonics. However, their communication was not great, and after the laser cutter was back online, the request for a quote was dropped.

- **Cabin**

As the Scale team designed an entirely new bogie and guideway to meet the specifications and requirements made this year, there was also additional hardware added in order to demonstrate the navigation and power system. Thus, the old cabin no longer serves the need to carry all necessary hardware. The scale team would also like to design a shell for the cabin for the purpose of showing an actual concept of scaled cabin operating.

Cabin Design Requirements:

1. Each station has a total length of 10 inches. For the purpose of parking 2 vehicles in each station, the goal is to keep the cabin within a desired length. (5 to 7”)
2. The main frame of Cabin has to be able to hold 3 ultrasonic sensors, 1 step up converter, 1 step down converter, a development board, breadboard and Lithium-Polymer (Li-Po) charger, a battery and 2 Arduino boards.
3. In addition, the design needs to account the easiness of wiring the electronics and leave space for wiring works.
4. The top frame of Cabin needs to leave space for wires from bogie for connections.
5. The width of the Cabin must stay within 5 inches so that Cabin will not hit the supporter during operation.
6. The frame has to be able to main stability itself as the moment and force balance is critical for single track navigation.

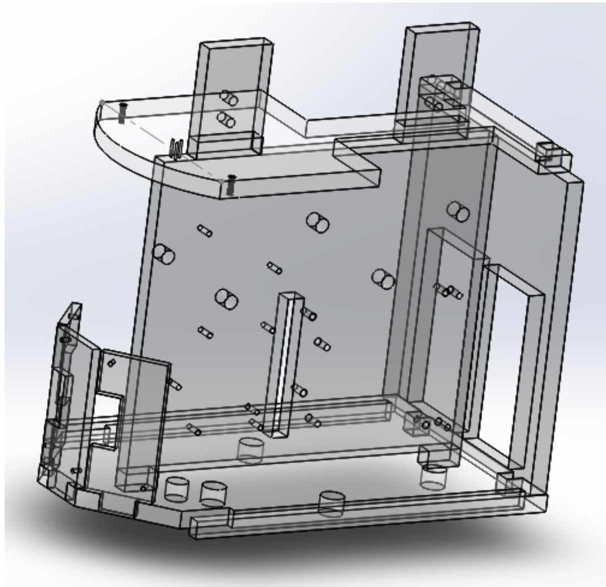


Figure 4-29: 76: The skeleton of final Cabin design for Makers Faire 2015.

The actual design:

1. The length of connecting plates are designed to fit tightly within the connecting plates of bogie (See bogie section)
2. The ultrasonic sensors are mounted in the front facing different angle to catch the signal during straight and curved sections.
3. Both Arduino have the USB ports face the back frame so the control team can easily access the Arduino for programing at any point.
4. Provided the schematic diagram from track team for power system, the step up converter and Lithium-po charger are mounted on the left part of the cabin for wiring purposes.
5. The rest of the electronics are grouped on the other side.
6. As the battery adds significant amount of weight if placed on either side, it is decided that the battery will be placed under the Cabin with a sliding tray. (See **Figure 32**)
7. The Cabin is roughly 4.1" W x 5.5"H x 6.5"L in size.
8. The whole cabin is made of Acrylic.

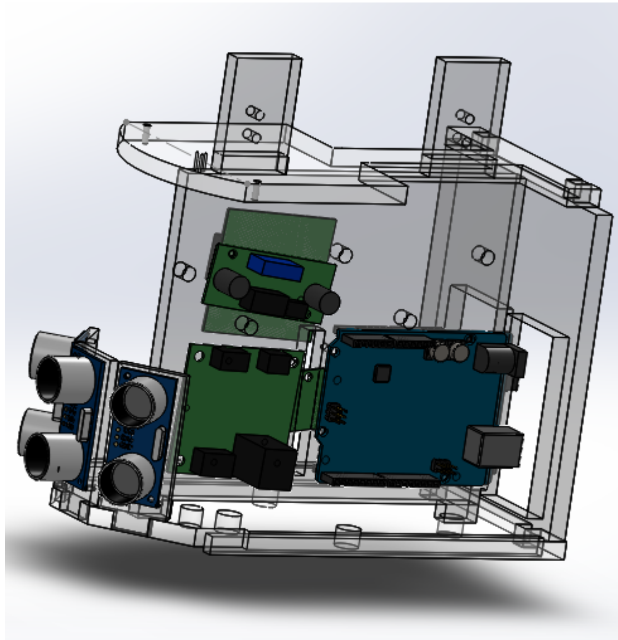


Figure 4-30: 77: The Cabin after assembling all the electronics on it. Note, the electronics are just a simple CAD drawing to simulate the actual assembly.

The Shell design:

1. The two side shells are made to cover the wires inside the Cabin and fabricated with Acrylic.
2. The front shell is designed to leave 3 square hollowed holes in front for ultrasonic sensors to go in.
3. The Shell will be connected to the Cabin frame through cap screws. The goal is to being able to remove shell easily for any replacements on electronics.

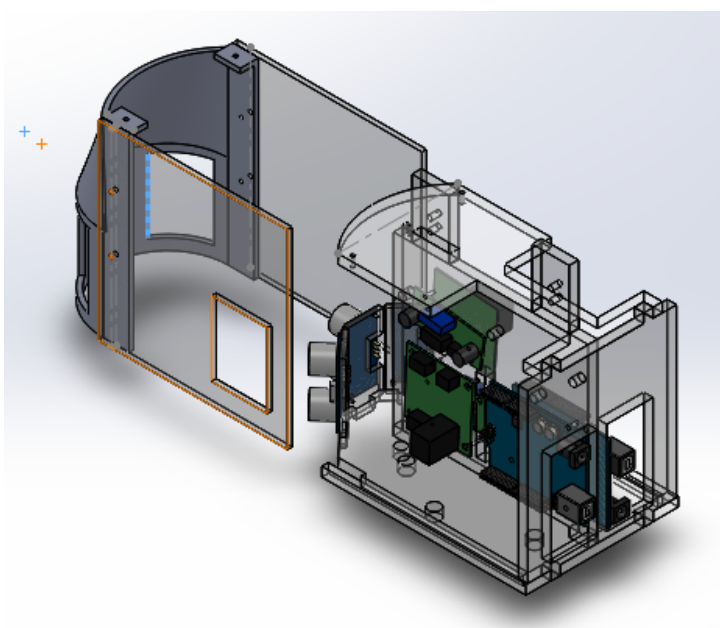


Figure 4-31: 78: The Cabin with covering shell opened.

Cabin Prototyping:

The Cabin prototype proves the design will work to meet the specifications. Yet, there was one minor change added to enhance the strength of Cabin frame. As the Cabin is assembled using Acrylic cement, chemical bonding is not perfect for holding load. To counter the weight of battery, 4-40 screws were used to bond the bottom and center frame. **Figure 32** shows the final prototype of Cabin.

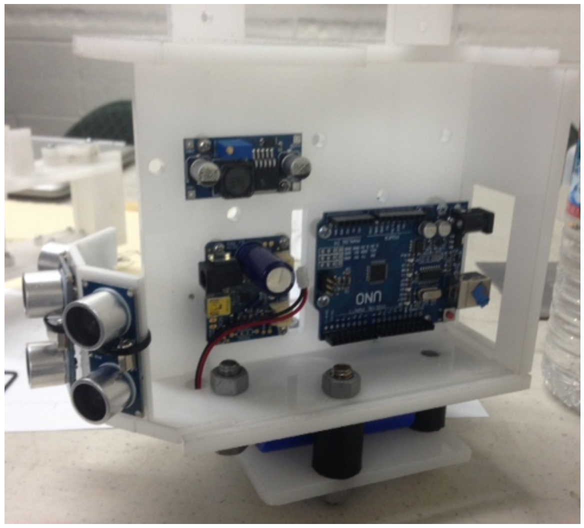


Figure 4-32: 79: The final Cabin prototype with PCBs. Noted the tray on bottom is used to hold battery. And it is designed that the front standoff can be removed easily to replace battery.

- Future Work

Below is a list of considerations for future work:

1. Further design can incorporate more tolerance-forgiving features to ensure proper fitment of parts and proper shapes
2. Replacement of switch actuation to a system that doesn't require a constant draw of current to maintain states
3. Cabin mounting design modified to ensure stability during turns and changes in rail grade.
4. Smaller overall footprint of bogie
5. Higher achievable speed from entire bogie, cabin, and track system

- **Guideway**

The new scale model track needed to be created from modular pieces, easily assembled, and adjustable.

The track can be broken down into seven modular aluminum strips shown in **Appendix C.** The pieces consist of a ½ meter straight way and curves at a ½ and 1 meter radii that are bent in 15,30, and 45 degrees. The advantage to having modular pieces is that it allows sections of the track to be replaced if they break or if future work calls for an upgrade. With this design, extra stations can be added by simply putting a 15 degree bend piece parallel to a straight way to make an additional path for the bogie to travel. Furthermore, the variety of the parts also allows the track shape to be changed into other desired configurations. This is important, because it demonstrates that the track can be customized to the path of any city streets.

Figure 4-36: 83: A SolidWorks part assembly of a three-station track and shortcut.

Assembly needed to be quick and easy. With this in mind, the track pieces were designed with both peg and screw connectors. The use of pegs ensures that the pieces line up while the screws serve to lock the pieces together. Each piece of aluminum has a set of two pegs and two screws on each side in order to line up horizontally and vertically. The pieces are short and they require many connectors to be fastened which could be time consuming. But there is a way to reduce the reassembly time. The solution is to only disassemble a fraction of the track connectors to leave sections of 3-4 pieces together. To reassemble, the segments of 3-4 pieces would only need to be reconnected later on.

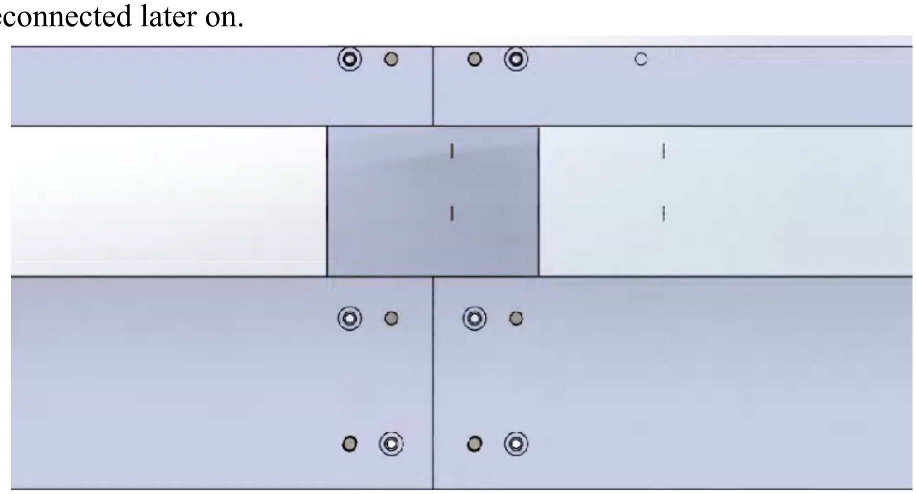


Figure 4-37: 84: This figure depicts the connection between two aluminum strips.

In the final semester it was decided to halve all of the lengths of the track. This was done because it still allowed the track to demonstrate all of the components that were present in the larger scale model. In the previous model there was a lot of empty space in the middle of the track which really wasn't necessary. Having it be smaller cut down greatly upon the amount of material and manufacturing time needed. It also takes up a smaller footprint, which is beneficial because it allows the track to more easily be set up indoors. If future track teams would like to add additional components or sections to the track they will be able to do so easily and have the room to accomplish it.

Construction of the track proved to be quite challenging. Luckily, it was fabricated out of 6061 aluminum which is relatively easy to work with. It was discovered early on that because of the modularity desired the pure number of parts that needed to be fabricated to make that happen was unreasonable. Additionally, the pieces needed to be very accurate. There is not a lot of room for error. It is because of this that it was decided as many pieces as possible needed to be created using a C&C. Originally, the central shop was commissioned to performed this task but when the returned pieces were deemed inadequate assistance from outside shops became necessary. They were able to create a majority of the pieces that the scale team was either unable to make or required a high level of accuracy that the scale team was unable to accomplish.

The scale team fabricated the straight sections, curved sections, and supports. The straight sections were first cut to a rough length using a chop saw. One side of the rough cut was then milled. The edge was found and zeroed. From there, the DRO available on the mill was used to accurately mill the section down to the correct length. Once that was completed the DRO was again used to find the locations of all of the holes that needed to be drilled. Some of the holes then needed to be threaded. Once the holes were drilled, the bit was swapped out for a tap bit. The machine was then put in neutral and manually turned in order to thread the hole. However, the DRO was still kept on in order to ensure accurate threading. After the threading was completed the part was considered finished.

Slightly more challenging to fabricate was the curved sections. Rough cuts were made to length with a chop saw. A roller bender was then used from the student machine shop to roll the pieces to length. They were considered to length when they matched curves that were drawn onto pieces of paper. Strips of paper were then cut to the desired length of the pieces. They were layed down upon the curved section of track. From this the section of track was then cut down to the desired length. The pieces were then put into a mill and was again zeroed using an edge finder. The holes were drilled and threaded before the pieces was considered finished.

The supports can be broken down into six components. The pieces consist of aluminum 6061 square plate, aluminum 6061 rod, 40 lb of cement, a cardboard cylinder, bolts, and nuts. The advantage to having this design is that both height and angle of orientation are adjustable. Any of the four corners of the plate and be raised or lowered to change the orientation of the plates surface.

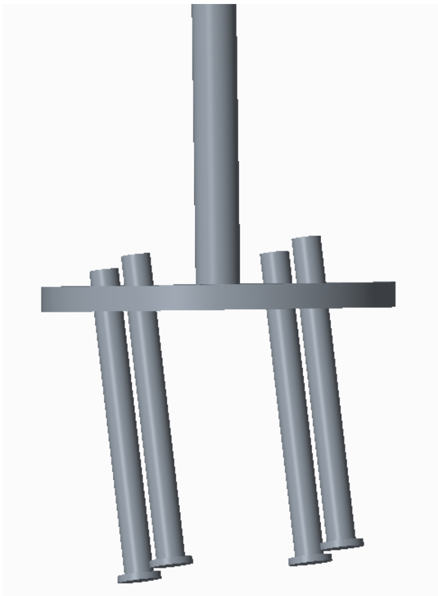
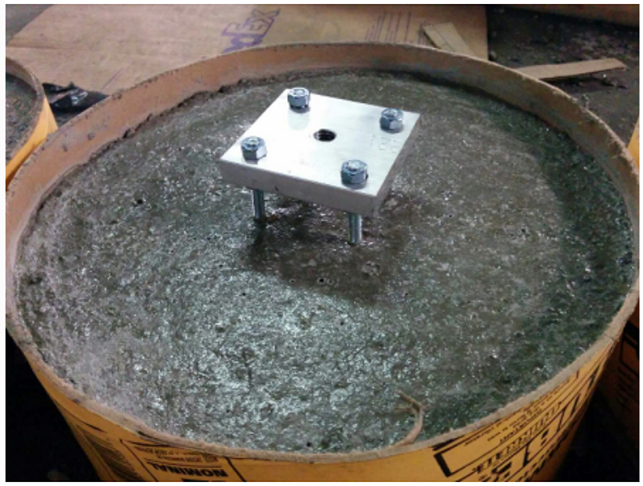



Figure 4-38: 85: The figure on the left depicts the plate oriented at an angle to keep the rod vertical.

Figure 4-39: 86: The figure on the right depicts the plate fastened on to the bolts, which are embedded into the concrete.

Figure 4-40: 87: A completed support fully assembled.

The height adjustability in this track comes from the vertical adjustment of support-guideway connectors. The support-guideway connector locks onto the support rod by tightening the clamp on the rod. To adjust the height, the bolt would be loosened and the support-guideway connector would only need to be manually slid up or down before being refastened.

Figure 4-41: 88: The part that will be used to connect the support rod to the track.

In order to prove that the supports would hold up the track and bogey while in motion, there had to be a model of the system. The bogey weighs about 4 pounds and travels around a bend with a radius of .25 m at .5m/s. This scenario depicts the case when the maximum horizontal load would be applied to one of the support beams. Using the formula for centripetal force below, we can calculate the maximum load applied to the rod. Then the data can be input into SolidWorks for finite element analysis.

Fc =(m*v2)/r = [(1.82kg)(0.5m/s) 2]/.25 m = 1.82N

In SolidWorks, the 1.82N load is applied at 5 ft on the rod to simulate the bogeys motion. The Diagram below shows that there is a deflection of about 1.4mm, which is acceptable.

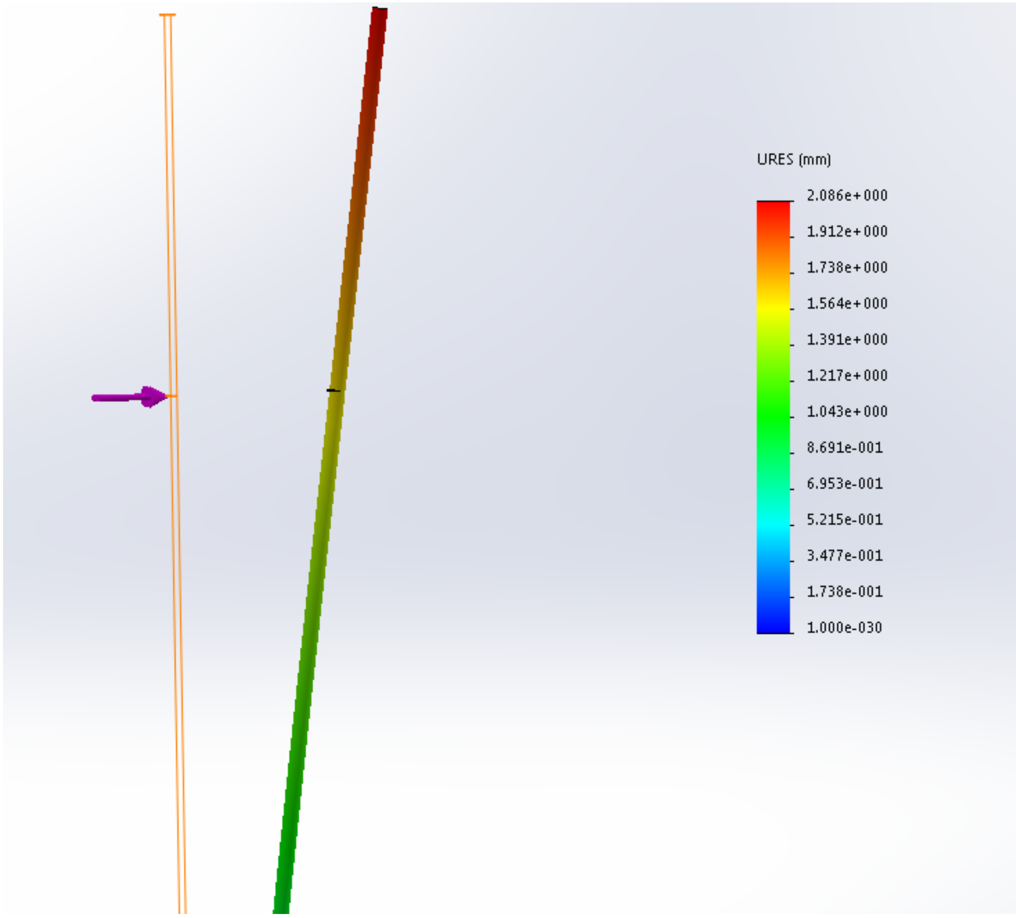


Figure 4-42: 89: Finite Element Analysis on the support rod with a 1.82 Newton load applied at 5 feet.

Conclusion and Next Steps

Preparation for next semester is underway with any final design changes scheduled for completion by the end of the year. The computer engineering team has completed their portion of the project that will be handed off to the Scale mechanical team in the first weeks of the new year. Select team members of the Scale mechanical team will be familiarizing themselves with Python over winter in preparation of receiving the computer engineers' work. Additional parts and material will be ordered over Winter break to ensure prompt arrival for fabrication and assembly in the Spring.

With Maker Faire 2015 scheduled to begin May 16th 2015, the Scale model's first public demonstration is fast approaching. To prepare for the Maker Faire deadline, a major milestone of March 31st, 2015 as be chosen as the completion date for the fabrication and assembly of both the track and bogie assemblies. Completion by the end of March allows for adjustment and tuning of final design/hardware once full testing begins in April 2015. Detailed scheduling of a completion timeline has begun in preparation for the end of the Spring ME195B Semester. The current Gantt chart can be seen in **Figure 43**.

Start	End	owner	details	Days till End date	3-Dec	4-Dec	5-Dec	6-Dec	7-Dec	8-Dec	9-Dec	10-Dec	11-Dec	12-Dec	13-Dec	14-Dec	15-Dec	16-Dec	17-Dec	18-Dec	19-Dec	20-Dec
				Sat & Sun																		
03-Dec-14	19-Dec-14	Scale Team	**1/12th Scale Report**	0																		
18-Dec-14	10-Jan-15	Controls Team	**List Necessary Controls Hardware Mounted to Bogie**	22																		
18-Dec-14	10-Jan-15	Controls Team	**Choose the Control Systems to Use in Complete Model**	22																		
01-Jan-15	16-Jan-15	Scale Team	**CompE Hand-Off**	28																		
03-Dec-14	21-Jan-15	Bogie Team	**Finalize Mech. Design of Bogie**	33																		
03-Dec-14	21-Jan-15	Track Team	**Finalize Mech Design of Track**	33																		
01-Feb-15	07-Feb-15	Track Team	**Test wayside pickup**	50																		
20-Feb-15	28-Feb-15	Controls Team	**Finalize power grid**	71																		
23-Mar-15	27-Mar-15	Superway Team	**Spring Break**	98																		
01-Jan-15	31-Mar-15	Scale Team	**Construct bogies**	102																		
01-Jan-15	31-Mar-15	Scale Team	**Construct track**	102																		
01-Apr-15	03-Apr-15	Bogie Team	**Bogie first test run on track**	105																		
31-Mar-15	10-Apr-15	Scale Team	**Testing, integrated system**	112																		
02-May-15	16-May-15	Superway Team	**Countdown to Maker Faire 2015**	148																		
16-May-15	17-May-15	Superway Team	**Maker Faire**	149																		
15-May-15	21-May-15	Superway Team	**Finals**	153																		

Figure 4-43: 90: Gantt chart for Spring ME195B Semester

Chapter 5: Solar

As part of our design, we calculated theoretical power consumption values for a system with fifty pods. This calculation can be found in Appendix D. This is an example of how the calculations can be conducted and what variables should be considered. If the theoretical power consumption of a pod is 8000 kWh per twenty hours of operation and a typical day consisted of five and a half hours of full sunlight, it would require 4849 panels at 21 percent efficiency to sustain the system of fifty pods. Theoretically, this would require about 5 miles of track to mount that many panels. This helps conceptualize the required panels and respective area needed.

Introduction

The 2014-2015 Solar Team's goal is to design and fabricate of a lightweight functional solar tracking system and stationary design which showcases thin film flexible panel donated by Miasolé. In addition, the solar team designed the models for ease of assembly and maintenance and minimal power usage.

In order to accomplish this goal, three models were built: Tracker for the Scale Model, Tracking Capable Frame Model for Full Scale, and Miasolé Model for Full Scale. The following sections will further describe the design of the models.

State-of-the-Art Literature Review

Types of Solar Panel

There are three main different types of solar panels out on the market. There are monocrystalline silicon solar panels, polycrystalline silicon solar panels, and thin-film solar cells. Each one of these has advantages and disadvantages depending on the specific use. Attributes that are looked at when selecting the correct solar panel are cost, efficiency, life span, simplicity for manufacturing, and how much space there is for the solar panels. These were all taken into consideration for the Spartan Superway solar panels.

Monocrystalline silicon solar panels are made of high-purity silicon. High purity means the silicon molecules are aligned really well. This alignment helps the solar cell to convert solar energy into electricity better. The monocrystalline solar panels have the highest efficiency rate of about 15 to 20%. Since they yield the highest efficiency output, they are the most space efficient. They also have long life spans and perform well in low light conditions. The downfall of the monocrystalline solar panel is the price. It is the most expensive of the three solar panels because of its high-purity silicon. The monocrystalline silicon solar panel is shown in Figure 5-1.

Figure 5-1: 48: Monocrystalline Silicon Solar Panel

Polycrystalline silicon solar panels use raw silicon that is melted and poured into a square mold. These panels are simpler to make and cost less than monocrystalline panels. Unfortunately, the efficiency is typically 13-16%, which is less than the monocrystalline panel. This means that more panels would need to implement in order to give the same power output. For the Spartan Superway, the panels will be on top of the guide way. This limitation of space does not allow the team to use these lower efficiency panels. The polycrystalline silicon solar panel is shown in Figure 5-2.

Figure 5-2:49: Polycrystalline Silicon Solar Panel

Thin-film solar cells are made from depositing one or several layers of photovoltaic material onto a substrate. This is the least expensive option as the panels are mass-produced. They can also have a very appealing look because they are able to bend. These solar cells do need a lot of space in order to generate power. The efficiency rate is only 7-13%. They also tend to degrade faster than monocrystalline and polycrystalline solar panels. The Spartan Superway needs to power all of its components with solar panels in a small area. The thin-film solar cells would not be able to accommodate these necessities. The thin-film solar cell is shown in Figure 5-3.

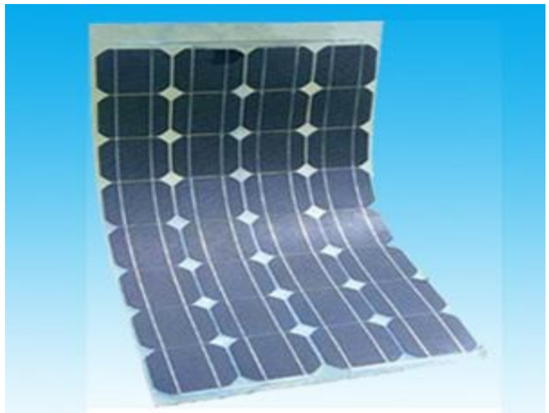


Figure 5-3: 50: Thin-film Solar Cell

After looking at all of the advantages and disadvantages of the solar panels on the market, Thin Film solar panels fit the Spartan Superway the best. They will generate enough electricity to power the whole system and they do not need a lot of area to provide this power. It does cost the most but it will be better for the whole system in the long run. In addition, Thin Film Solar Panel are widely available in the San Francisco Bay Area. The 2014-2015 Spartan Superway team worked with Santa Clara and San Jose companies Miasole and Stion in order to acquire donations of thin film modules.

Solar Trackers on the Market

Currently on the market, there exists most commonly, two major types of solar trackers. There are single and dual axis trackers. Generally, single axis trackers track the Sun from East to West throughout the day. Dual axis trackers allow for North and South directional tracking. Studies have shown that dual axis trackers provide a minimal increase in efficiency compared to a single axis tracker in most areas around the globe. In equatorial areas, the benefit is greater due to longer and more direct exposure to the Sun year round. Thus, direct exposure increases power generation considerably.

Since the system is being implemented in the Northern hemisphere, it is safe to say that a single axis tracking system is sufficient to optimize the power generation of our solar panel system. There are two major types of single axis trackers: pole top mounted systems and long arrays driven via a drive shaft. Pole top mounted systems move via an actuator that changes the tilt of the panels as shown in Figure 5-4.

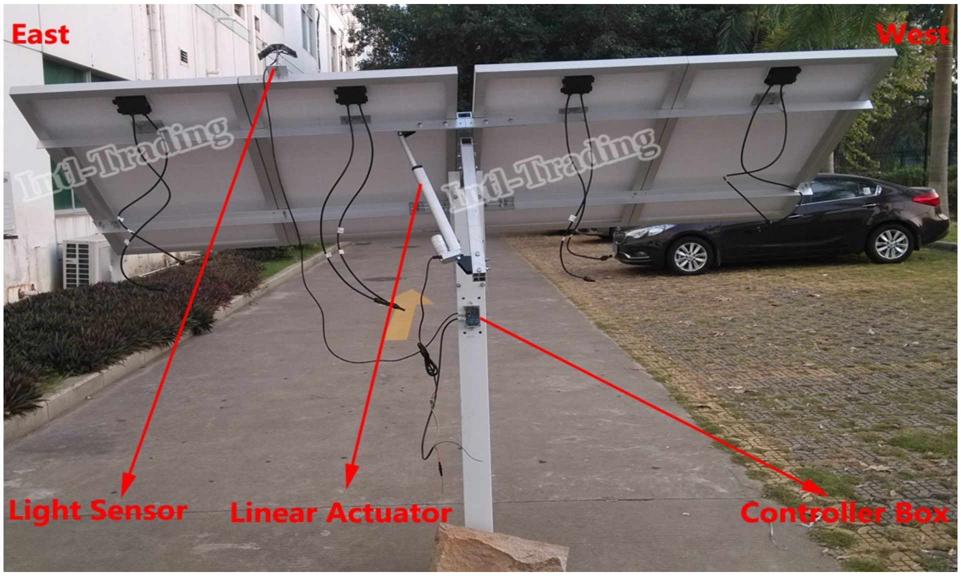


Figure 5-4: 51: Simple Pole Top Mounted Solar Tracking System

A more robust design more applicable to commercial systems includes a drive shaft to turn long arrays of panels. This is shown in Figure 5-5.

Figure 5-5: 52: Duratrack HZ single axis tracking system for long arrays of panels

It is based off the Duratrack HZ single axis tracking design that the team chose to design the system after. The Superway's design will allow for long arrays of panels to sit atop the track. Thus, the arrays would be rotated via a single axis and a motor turning the shaft that connects the panels.

After looking at all of the advantages and disadvantages of the solar trackers on the market, the 2014-2015 Spartan Superway team decided to design a solar tracker that would be implemented above the Guideway. With the acquired donations of thin film modules, the team was able to design two solar trackers; one utilized an actuator and the other utilized a servo. The following section will provide more information concerning the 2014-2015's one stationary and two solar tracker designs.

Scale Model: The Solar Tracker

Design Requirements

The Scale Solar Tracker design requirements are the following:

- Easy to assemble
- Support and display real time readings from a custom functional Miasolé flexible thin film solar panels
- Span between two supports; approximately 1 meter apart
- Design a program, which tracks the sun utilizing an Arduino, actuator, and sensors.

The Scale Solar Tracker has software and hardware requirements. The software specifications include: an Arduino Uno, servo, and two voltage divider circuits. In addition, the hardware specifications include: solar panel frames and supports, bearings, and of course, hardware (i.e. various screws, fasteners, bolts, etc.).

The Final Design and Fabrication

The Solar Tracker for the scale model was first designed with SolidWorks. After the 3d rendering was completed, hardware, raw materials, and the solar panels were acquired. The Solar tracker uses an Arduino, open source electronic prototyping platform, which is powered with a Voltaic Systems Solar Panel and Charger kit; see more on www.voltaicsystem.com. The Solar Tracker's 3d rendering on SolidWorks and prototype is depicted in Figure 5-6. In addition, Figure 5-7 conveys the Solar Tracker's range of motion.

Figure 5-6: 53: Tracker Model For the Scale Model holds a custom Miasolé Thin film Flexible Panel and is powered with a Voltaic Portable Solar Panel+ Charging System.

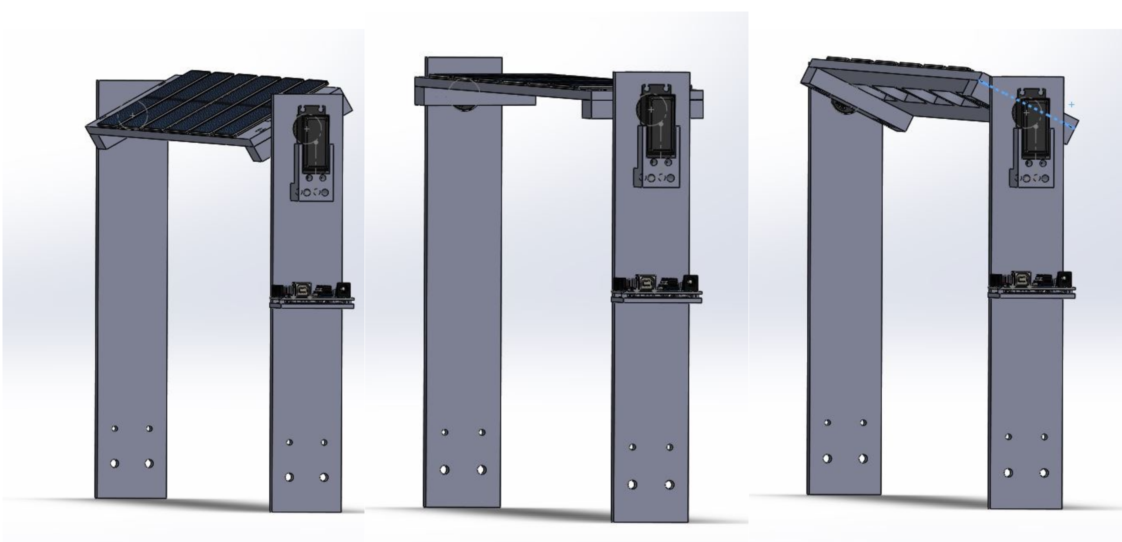


Figure 5-7:54: Scale Solar Tracker Mobility

To drive the rotation of the drive shaft, a HI-Tec HS0755 a Standard Servo will be utilized Figure 5-8) to supply the necessary torque rating for our design (as shown in the calculations portion within Appendix D). In addition, please see Appendix D for the servo's specifications.

Figure 5-8: 55: Standard Servo Being Used To Drive The Rotation of the Shaft-Housing-Panel Interface

To track the sun, two Ltd. photoresistors will be attached to the center frame housing (one on either side along the length portion of the housing, directly in the middle of the length sides of each frame housing). They will also be either press-fitted into designated slots within the housing or attached with a heavy adhesive to ensure optimum security during panel rotation see Figure 5-9

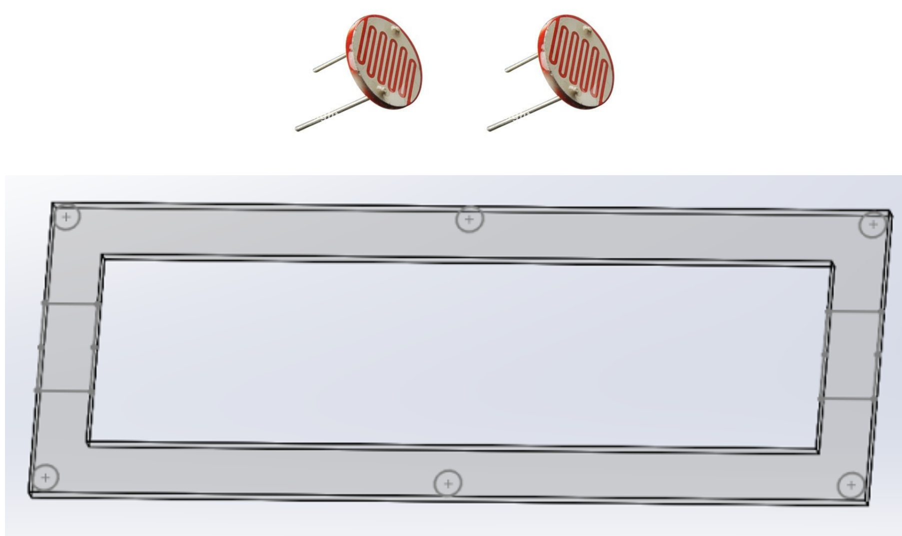


Figure 5- 9:56: Ltd. Photo resistors That Will Be Used For Solar Tracking Shown Above With the Middle Bottom Housing Frame, Where They Will Be Attached

The frame housing, panel, and shaft assembly will then be attached to two columns (each at approximately 1.5 ft high) by way of inserting each end into a circular bearing (likely a household skate bearing that contains the equivalent OD) within the top portion of each respective column (one on each side of the frame, panel, and shaft assembly). This is shown below in Figure 5-10.

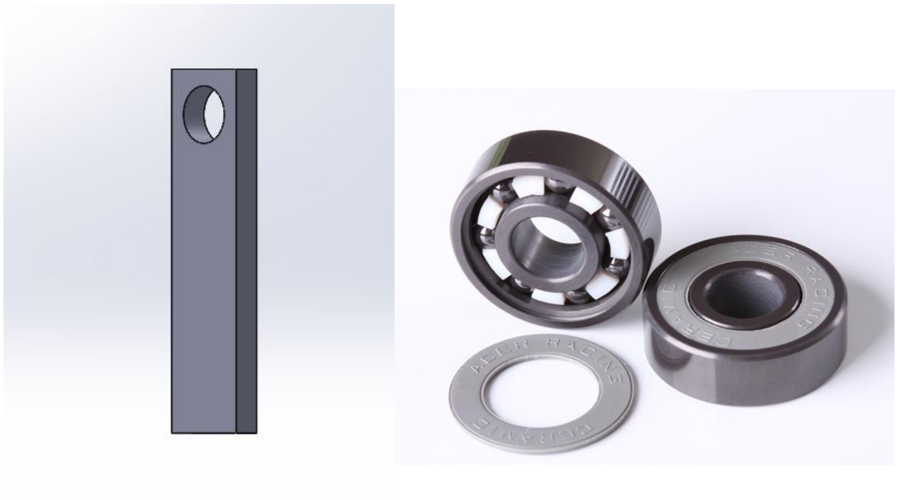


Figure 5-10: 57: Column Supports For the Scale Model With Associated Skate Bearings That Will Be Placed Within Each Slot Of The Two Column Supports

To secure the servo in place, an additional flat and rectangular column support will likely be utilized and put in place so that the servo can lie stationary on the driving end of the drive shaft while sitting horizontally flat on the top surface of the support column. Furthermore, an Arduino will be mounted in line and behind the servo on the same supported surface previously mentioned. This arrangement will be sufficient for controlling the solar tracking feature of this year’s prime design. Lastly, the entire assembly will be mounted to the 2x2 inch square metal tubing support interface set aside by the Guideway team. It is also desirable to hide all exposed wires and cables coming from the Arduino interface. The figure below shows the intended design for the interface along with the prime design assembly.

To secure the stepper motor in place, an additional flat, rectangular column support will likely be used and placed next to one side of the drive axle support column so that the servo is able to sit horizontally flat and in line with the drive axle.

The team created a LabVIEW and Arduino program which measures the solar panel’s efficiency and moves a motor to optimize solar panel collection. An Arduino will also be utilized (and likely mounted in line and behind the servo motor on the support column previously mentioned) to control the solar tracking feature of our assembly. The team also hopes to hide all wires coming from the Arduino in order to create an aesthetically pleasing design.

Analysis

Due to no initial conditions or specifications except a given mass and length of the solar panel frame, panels and hardware, the solar team was not able to properly motor size. To determine a proper servo, the team fabricated the solar panel frame, brackets, and shaft then acquired numerous servos to tests for proper rotation. Upon testing of the Parallax Standard servo and Hi-Tec HS-485HV servo, it was determined that neither was powerful enough to rotate the panel and components. The team looked into alternative motors and decided that the Hi-Tec HS-755 HB was best suited for the application. This specific servo has a maximum torque of 183 oz-in which is more than the 83.3 oz-in of torque the Hi-Tec HS-485HV has. Because the shafts of the solar panel frame are being rotated on standard household skateboard bearings, there is relatively low friction. Once the scale model was finalized and testing was completed, the results were deemed successful

<u>Full Scale: Tracking Capable Frame with Stion Modules</u>

Design Requirements

The Full Scale Tracking Capable Frame design requirements are the following:

- Easy to assemble
- Utilize an Arduino, actuator, and sensor and design a program which demonstrates a single axis solar tracker
- Support two full size functional Stion Solar Modules (37 lbs each); visit their site at www.stion.com
- Span between two supports; approximately 10 feet apart

The Full Scale Tracking Capable Frame has software and hardware requirements. The software specifications include: an Arduino Uno, linear actuator, and Wii Nunchuck controller. In addition, the hardware specifications include: solar panel frames and supports, mounted sleeve bearings, and of course, hardware (i.e. various screws, fasteners, bolts, etc.).

The Final Design and Fabrication

The Full Scale Tracking Capable Frame with Stion Modules, depicted in Figure 5-11, utilizes an actuator and Wii Nunchuck controller in order to change positions to optimize solar collection. The final design, fabrication, and assembly at Maker Fair was as smooth as it can be because the team really designed for assembly.

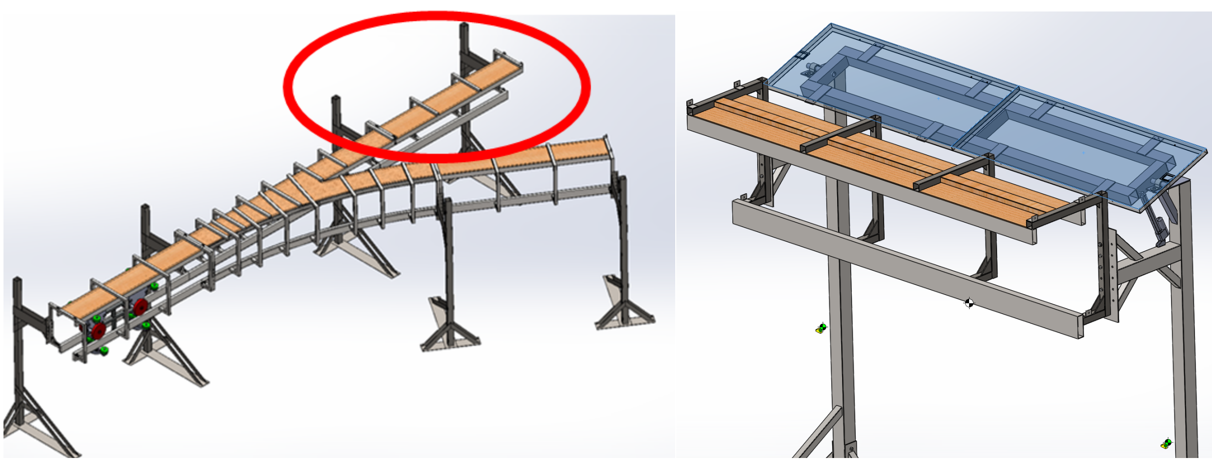


Figure 5-11: 58: For the Full Scale Model, the Tracking Capable Frame with Stion Solar Modules utilizes a programmable microcontroller and is driven and controlled by an actuator and Wii Nunchuck controller, respectively.

Using last year's 3" x 3" square aluminum tube frame was extremely beneficial in constructing the new Stion solar panel frame used in this year's design. To construct the new frame, it was first necessary to cut three 11.25" pieces from the previous year's welded frame using a standard miter saw specific for cutting aluminum (Figure 5-12 below).

Figure 5-12: 59: A miter saw was used to cut through last year's welded solar frame

After the three 11.25" pieces were cut, two long 9' segments were cut using the same saw. The last step in the initial cutting stage of the solar support frame was to mill out a couple through holes in two of the three 11.25" pieces (which would be used as the outer segments in the finshed Stion frame). One large 1.25" through hole was milled out dead center of the 11.25" tubing and a separate smaller hole with a diameter of about 0.3" was milled out at a location of 0.62" from the centerline edge so that it was aligned with the other larger hole. The larger hole was to house a 9" round aluminum tube, with an outer diameter of 1.24," and the smaller hole was to house the linear actuator extended rod. These holes are shown in Figure 5-13 below.

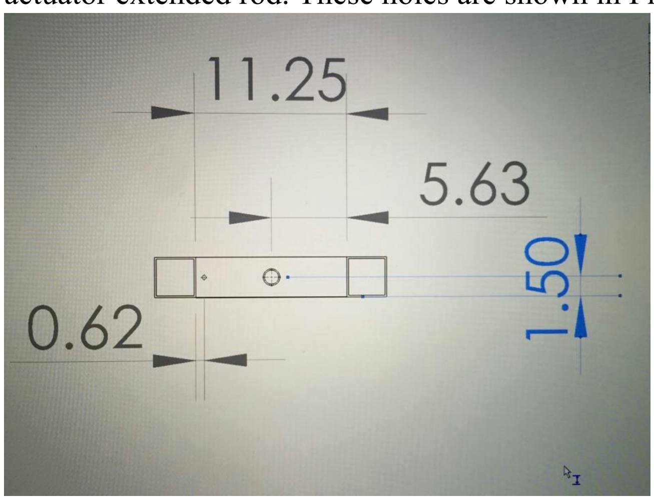
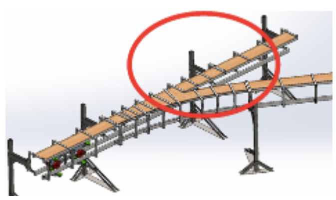


Figure 5-13: 60: Blue Print of the short 11.25" AL tube segment along with its accompanying through holes for the linear actuator and the 1.25" AL tube shaft.

After all the pieces were cut to spec, the components were to be welded according to the configuration shown below in Figure 5-14.

Figure 5-14: 61: Pre-welded Stion solar support frame showing the proper orientation of all the pre-cut AL tube pieces

The next step in the fabrication of the Stion support frame was to weld the components according to the configuration shown above in addition to welding the two 9” aluminum tube segments to each of the outer 1.25” through holes. To do this step, it was necessary to leave about a half of an inch of tubing on the inside of the frame so that the tube shafts had enough surface to hold a secure connection when welded to the through holes. Lastly, a total of eight aluminum plates were welded on the top surface of the support frame, which would be used to mount the two desired Stion solar panels with accompanying ¼” screw and nut fasteners, two per welded plate; please see attached drive for part drawings. The finished product with all the welded plates and aluminum tubing is shown below in Figure 5-15.



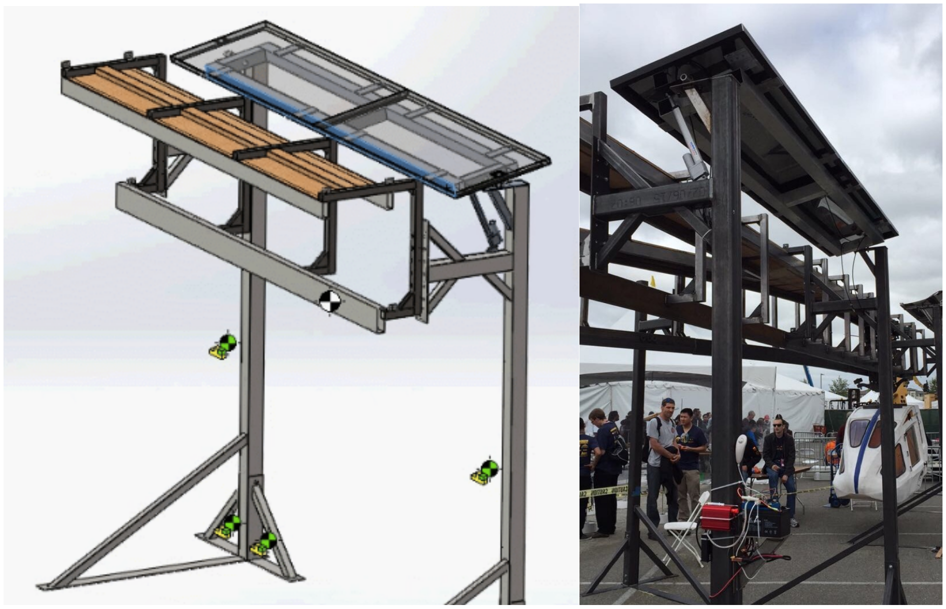


Figure 5-15: 62: Computer Rendering of the Solar Tracker with Stion Modules and an Actuator

Outputting Power from Panel

To extract power from the panel, a charge controller was installed to interface the panel and a 12 volt battery. The panel voltage is stepped down to 12 volts and is used to charge the battery. The status of the battery is read and displayed on the controller. Charging is only active when the battery is below full charge. The controller also has a third set of connections to interface a device requiring 12 volt DC. To transform the voltage to AC, an inverter is connected, which provides an outlet for a three prong plug. The exact circuit set up is shown in Figure 5-16.

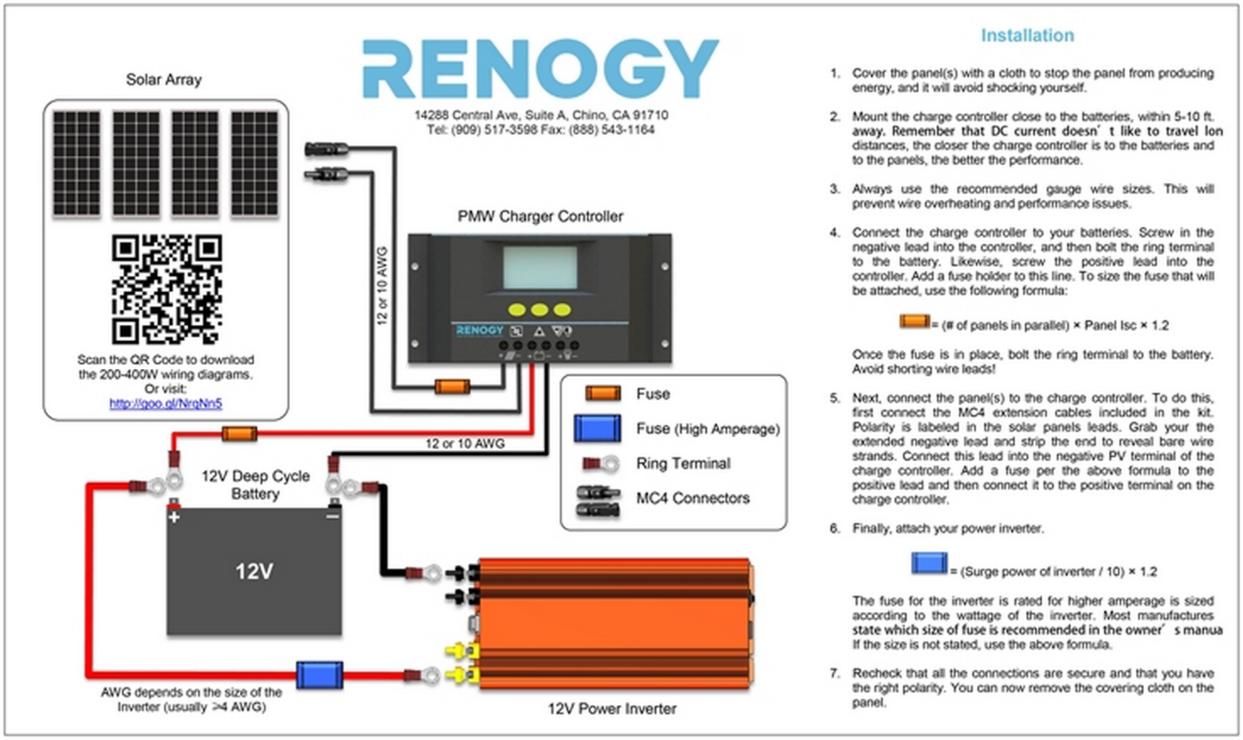


Figure 5-16:63 Circuit interfacing a charge controller, 12 V battery, and an inverter taken from Renogy Website

Our exact setup uses a Renogy 30 AMP PWM charge controller (shown in Figure 5:17) and Bestek Dual 110V AC Outlet 300W Power Inverter (shown in Figure 5-18).

Figure 5-17: 64: Renogy 30 Amp Charge Controller

Figure 5-18:65: BESTEK 300W Dual 110V AC Power Inverter

Analysis

A study was conducted utilizing SolidWorks Finite Element Analysis Application where it was determined that there would only be a 0.04 mm deflection with 800 N =200lbs load applied to the bracket. Due to the fact that each bracket would only experience less than 200 lbs during standard operations, it was determined that the design would be sufficient for the operational need

Full Scale: Stationary 8020 Frame with Miasolé Modules

Design Requirements

The Stationary 8020 Frame's design requirements are the following:

- Easy to assemble
- Support two full size functional Miasolé flexible thin film solar panels; visit their site at www.miasole.com
- Span between two supports; approximately 10 feet apart

The Stationary 8020 Frame does not have any software requirements. The hardware specifications include: 8020 extruded Aluminum, 8020 accessory plates, and various screws and bolts.

The Final Design and Fabrication

The Stationary 8020 Frame is located on the straight segment of the 2014-2015 Full Scale Switch Segment, see Figure 5-19. The frame is composed of 13 cross-members and four subassemblies. The subassemblies are made up of two 23 inch long extrusions with a 1.5" x 1.5" profile. They are attached via a pivot which can be adjusted to different configurations. The cross-members are nine 37 inch long members in rows of three. The additional four 1 foot long on the ends secure the corners of the miasole panels.

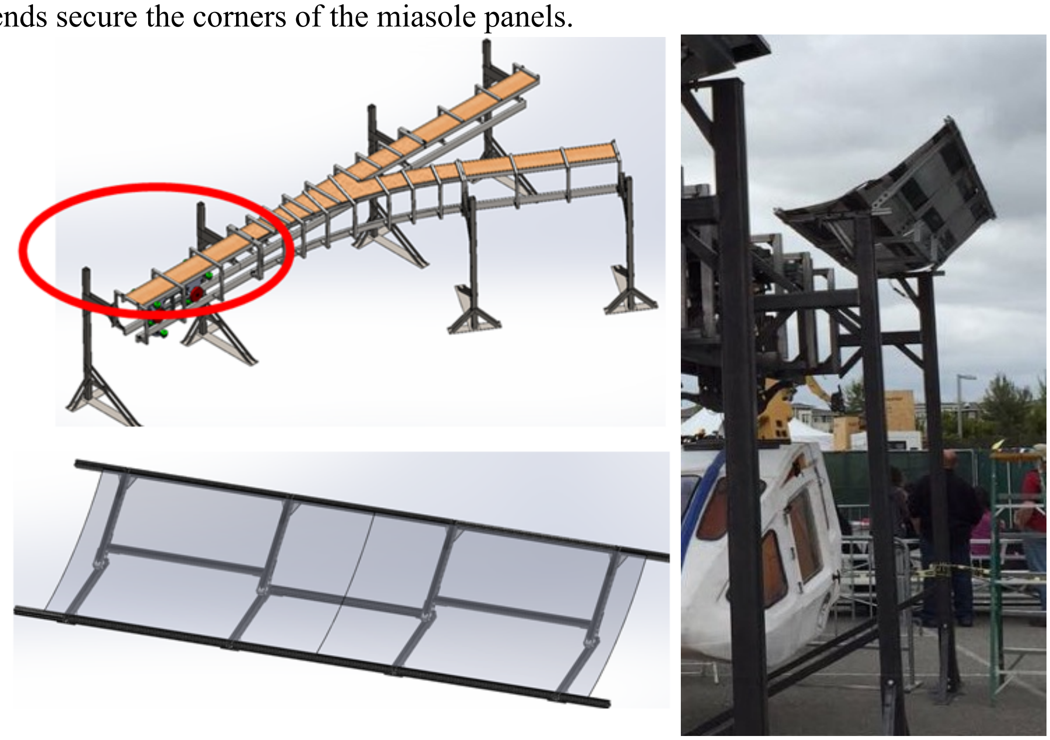


Figure 5-19: 66: For the Full Scale Model, The 8020 AL Frame showcases the Flexible Think Film Solar Modules

Analysis
A study was conducted utilizing SolidWorks Finite Element Analysis Application where it was determined that there would only be a 0.04 mm deflection with 800 N =200lbs load applied to the bracket. Due to the fact that each bracket would only experience less than 200 lbs (about 100lbs) during standard operations, it was determined that the design would be sufficient for the operational need.

Conclusions and Next Steps

A single-axis tracking frame assembly was accomplished by this year's solar design team. However, if next year's solar team is to take this assembly to the next level, there are several considerations to account for. As we are all aware, solar trackers generate more electricity than stationary assemblies due to the fact that light exposure to the sun is directly correlated to such a design. With this in mind, this year's team increased power output to the Stion solar panel frame assembly by utilizing a linear actuator to control the rotation of the frame for tracking capabilities in an intended East-West tracking orientation with respect to the sun. However, dual-axis trackers are generally more accurate when finding the brightest areas in the sky (i.e. the areas containing the most amount of light exposure). Although more accurate than single-axis trackers, dual-axis trackers are both more costly to implement due to the nature of a higher complexity system as well as a reduction in liability of the system (i.e. more maintenance will be required). Thus, this year's team chose to incorporate a single-axis tracker due to its lower cost and higher reliability. In other words, there will be a lot fewer problems that will be experienced with this type of system over longer periods of time.

One important detail that this year's team did not look at due to both time and resources is powering the Full Scale model. With that said, next year's team may take it upon themselves to provide this necessary power by implementing a grid-connected solar system, which is simply the same solar system assembly that was done by this year's team but with an added utility grid that demonstrates unused electricity from the solar modules being put back into the grid. This would be beneficial because unused electricity generated throughout the day will not be wasted.

To provide the necessary power for the single-axis system, the grid would conduct feedback through a meter that would then monitor the power that is transferred. However, it is important to note that PV solar panels that are intended for power delivery to a grid have to be pre-conditioned as well as processed before being used. This can be done by incorporating a grid-connected inverter that can sit between the solar module array and the grid; as we did for the Stion Model. Drawing power from both the solar array and the grid, the inverter may be representative of a large stand-alone unit or a collection of many smaller inverters (i.e. a setup where each smaller inverter is attracted to solar panels on an individual basis).

As a starting point for next year's research, consider the following grid-tie inverters: Enphase Energy, Fronius, Outback Power, Power One, SolarEdge, SMA, and Schneider Electric (which was formerly Xantrex). Thus, as you can see, there are many possibilities to consider and much more research about grid-tied solar assemblies must be done before one can adequately enhance the single-axis assembly built by this year's team. Lastly, the 2014-2015 Spartan Superway Solar team was able to request custom thin film panels from Miasole. Next Year's team can design custom Solar Panels with a desired current and voltage in order to provide power to both the Full and Scale models.

Chapter 6: Next Steps and Conclusion

The primary goal of this year's Superway Project was to prove the physical concepts of an Automated Transportation Network with a suspended cabin. This goal was achieved. The full scale and small scale models function to specification and prove that the mechanical, electronic and control designs are realizable for implementation. The solar analysis and models prove that the system can be entirely powered by solar energy. The cabin model and analysis conveys the internal space for riders and estimates the cost to operate the cabin in order to keep the occupants comfortable. In our project we have successfully proved fundamental ATN concepts from a system wide perspective, a full scale mechanical perspective, an energy management perspective and from the perspective of an ATN rider.

The Superway team divided 25 mechanical engineering seniors into 4 teams. Each team had multiple objectives and sub-teams to carry them out (with the exception of cabin team, which had no sub-teams). Each team was led by a team leader and the entire Superway group was led by the management team. The management team members were also part of the engineering teams so that they would also get some hands on experience with design and fabrication. Communication was important since the project had so many moving parts. Regular meetings were held for all levels from management to team leaders to teams and sub teams. This kept everyone on the same page and helped to facilitate creativity by increasing access to each other's ideas.

Communication and management started out rough, but by the second semester most of the wrinkles had been ironed out. Some specific problems were unexpected extra-curriculars and miscommunications about expectations. These problems were solved by increasing the lead time that was given to the team by management. Two weeks turned out to be the minimum time to be able to get a reasonable result.

Each of the four teams worked differently. Each member of the Superway team worked hard and is talented. The most effective methods of leading the teams were having a presence and a sense of direction. Each member of the team is a graduating senior in mechanical engineering. Everyone is smart and everyone is able to work hard. So the most effective means of leadership was to get everyone working in the same direction and being accessible if a difficult problem arises. The student could very quickly solve problems on their own, but would need help to implement those solutions. So as long as everyone was on the same page, their solutions would work together well and as long as a leader with purchasing authority approved it, the parts could be purchased or fabricated and the team could move on. In the future this process might be streamlined to allow for more efficient problem solving. Ultimately the Superway team worked well together and accomplished a good deal of great work.

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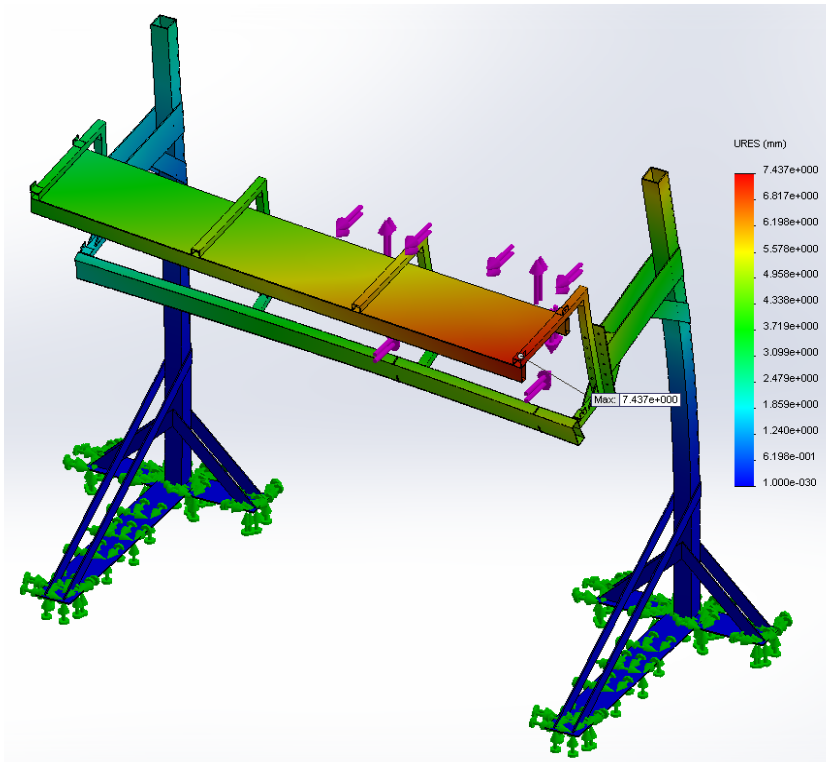
Appendix A-Full Scale



Total deformation of guideway

Guideway Condensed Bill of Materials

Final Assembly						
Part Number	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**	**Notes**
NA	Support Column	6	each	$241.85	$1,451.09	
NA	Single Sided Straight	1	each	$183.09	$183.09	
P02	Double Sided Straigh	1	each	$254.24	$254.24	
P03	Switch Section	1	each	$495.90	$495.90	
NA	Miscellaneous				$1,000.00	Consumables, material drop ect...
				Total	$3,384.32	

Estimate of Prototype Traction Requirements

Author: Natalie Granados

The purpose of this file is to calculate the requirements of the spartan Superway prototype propulsion system. A force analysis is done to determine the torque and necessary to accelerate the bogie. This is used to find the minimum torque and power necessary for the motor.

The traction system is analyzed to determine if the material used in its construction can accomodate the stresses produced by the system. The equations derived and corresponding diagrams are appended to the report.


```
clear workspace
```

Variables and Constants

```
r_drive_wheel = 4/12;            % Radius of drive wheel prototype in inches
Weight_vehicle = 550;                     % weight of prototype system in lb
g=32.2
mass_vehicle = Weight_vehicle/g;          % mass of prototype (slugs)
acceleration = 1;                % Acceleration of prototype (ft/s^2)
Grande_angle = 0;                % grade angle of prototype (rad)
Cd = .2;                        % prototype drag coefficient
v = 1;                          % speed of prototype (ft/s)
fr_drive = .001*r_drive_wheel;   % coefficient rolling resistance bike tire on wood
(dimensionless version, so multiply by rd for consistency)
fr_support = 0.019;              % coefficient rolling resistance steel on steel (in) [1]
mu_static = 0.7;                 % friction coefficient prototype (rubber on wood) [2]
fp_guide_wheels=.057;            % coefficient friction of polyurethane on steel [1]
A_vehicle_frontal = 43.06;       % frontal area (left same as full for simplicity. Contribution
of drag minimal at slow speed
Airdens = .002329;               % density of air (slug/ft^3)
W_wheel = 8;                     % weight of motor in lbs
ro=6.75/2;                       % radius of top orange wheel in inches (to match rolling
resistance coefficient)
rg=5.25/2;                       % radius of bottom green wheels in inches
rs=12/2;                         % radius of support wheel in inches
```

```
% From force model excel file. x1 Traction
Nr1=0;                          % normal forces on top orange wheels
Nr2=156;                        % normal force on top orange wheels (other side)
Ng=156;                         % normal force on green wheels
rpm = (v/r_drive_wheel)*(60/(2*pi));     % rpm of drive wheel for prototype
Nd = Weight_vehicle/2;                      % preliminary normal force. Well above expected
% Traction System
ls = 9.5;                        % verticsl length from spring to hinge
ln = 0;                          % vertical length from wheel to hinge
lw = 5.255;                        % horizontal length from wheel to hinge
E = 29000000;                   % Modulus of elasticity of lever material in psi (low carbon
steel) [3]
syc = 22000;                    % compression strength lever material in psi (low carbon steel)
[3]
bw = 0.25;                      % width of link of lw link (in)
hw = 1.5;                         % height of link of lw linkin)
t = 1.5;                        % length of side of square tube (ls)
ti = t-2*(.094);                 % length of inner, hollow side of square tube (ls)
lt=2+(.25/2);                   % offset acomodating wheel thickness
r_bolt = 1/8;                   % radius of bolts in inches
r_motor_bolt=1/4                     % radius of motor bolt/bearing

FTLB_TO_NM = 1.35581795;
LB_TO_N = 4.44822162;
HP_TO_KW = 0.745699872;
PSI_TO_PA = 6894.75729;
```

```
g =

   32.2000


r_motor_bolt =

    0.2500
```

Force Analysis

```
Fd = 0.5*Cd*Airdens*A_vehicle_frontal*(v)^2;
Ns= Nd + Weight_vehicle*cos(Grande_angle);
Rd = Nd*fr_drive/(r_drive_wheel*12);
Rs = Ns*fr_support/rs;
Rg = (fp_guide_wheels*(Nr1+Nr2)/ro)+(fp_guide_wheels*Ng/rg);
Ft=Fd + Rs + Rd + Weight_vehicle*sin(Grande_angle) +mass_vehicle*acceleration + Rg
Ft_continuous = Ft-mass_vehicle*acceleration
Nd_req=Ft/mu_static
```

```
Ft =

   25.7483
```

```
Ft_continuous =

    8.6675


Nd_req =

   36.7833
```

Motor torque requirement of prototype

Peak Torque at maximum acceleration

```
T_peak = Ft*r_drive_wheel

T_peak_SI=T_peak*FTLB_TO_NM
```

```
T_peak =

    8.5828


T_peak_SI =

   11.6367
```

Continuous torque

```
T_continuous = (Ft-mass_vehicle*acceleration)*r_drive_wheel

T_continuous_SI=T_continuous*FTLB_TO_NM
```

```
T_continuous =

    2.8892


T_continuous_SI =

    3.9172
```

Power requirements of prototype

Peak output power

```
P_peak= T_peak*rpm/(5252)

P_peak_SI = P_peak*HP_TO_KW
```

```
P_peak =

    0.0468


P_peak_SI =

    0.0349
```

Contiuous output power

```
P_continuous = T_continuous*rpm/5252

P_continuous_SI=P_continuous*HP_TO_KW
```

```
P_continuous =

    0.0158


P_continuous_SI =

    0.0118
```

Prototype Traction Analysis

Force Reactions

Force divided between two wheels. A total safety factor of 1.5 signifies a safety factor of 3 for each lever.

```
Nd = Nd_req;                % Divided between two motors. Allow up to twice normal force required
Rwx = Ft;                                     % Horizontal reaction at wheel bearing
Rwy = Nd + W_wheel;                           % vertical reaction at wheel bearing
F_spring = (Rwy)*(lw/ls)+Rwx*(ln/ls);          % Force of spring to apply normal force
F_hinge_y = Rwy;                               % Vertical force at the hinge
F_hinge_x = F_spring+Rwx;                            % Horizontal force at the hinge
```

Stress Calculations

```
Aw=hw*bw;                          % area of lw link cross section (in^2)
Iw_x = bw*(hw^3)/12;               % moment of inertia of lw link cross section (in^4)
```

```
Iw_y = hw*(bw^3)/12;
Jw=Iw_x+Iw_y;
k=Iw_x/Aw;
cw=hw/2;
leff=0.8*lw;
Sr=leff/k;
srd=pi*((2*E/syc)^.5);
```

Critical Buckling Load on lw

```
if(Sr>srd)
    Pcr=(pi*pi*E*Iw_x/(leff^2))
else
    Pcr=Aw*(syc-((1/E)*((syc*Sr/(2*pi))^2)))
end
```

```
Pcr =

   8.1703e+03
```

Stress on lw

A monoshaft motor is assumed

At point B (offset accomodating wheel thickness)

```
Shear_max_B = (3)*((Rwy/2)/Aw)        % Transverse shear stress
Stress_max_B = (Rwy/2)*lw*cw/(Iw_x)       % bending stress
% deflection at wheel
ymax_w=((Rwy/2)*lw^2)*(lw-3*lw)/(6*E*Iw_x)
% At A1 (near weld)
Stress_A1 = (Rwy/2)*lt/Iw_x
Torsion_A1 = (Rwy/2)*lw/Jw
Shear_max_A1 = ((0.5*Stress_A1)^2 + Torsion_A1^2)^(1/2)
Princ_stress_1_A1 = 0.5*Stress_A1 + Shear_max_A1
Princ_stress_2_A1 = 0;
Princ_stress_3_A1 = 0.5*Stress_A1 - Shear_max_A1
% At A2
Shear_trans_A2 = (3/2)*((Rwy/2)/Aw);
Shear_max_A2 = Shear_trans_A2 + Torsion_A1
% Deflection at point B
ymax_B=((Rwy/2)*lt^2)*(lt-3*lt)/(6*E*Iw_x)
y_max_short_link = ymax_B+ymax_w
```

```
Shear_max_B =

  179.1331
```

```
Stress_max_B =

   1.2551e+03


ymax_w =

  -5.3119e-04


Stress_A1 =

  676.7249


Torsion_A1 =

   1.6283e+03


Shear_max_A1 =

   1.6631e+03


Princ_stress_1_A1 =

   2.0014e+03


Princ_stress_3_A1 =

  -1.3247e+03


Shear_max_A2 =

   1.7178e+03


ymax_B =

  -3.5125e-05


y_max_short_link =

  -5.6632e-04
```

stress on ls

```
Is=(t^4 - ti^4)/12;
cs=t/2;
As= t*t-ti*ti;
% bending and shear
Shear_max_ls = (3/2)*(F_spring/As)
Stress_max_ls = F_spring*ls*cs/Is
% deflection
y_max_long_link=(F_spring*ls^2)*(ls-3*ls)/(6*E*Is)
```

```
Shear_max_ls =

   70.2883


Stress_max_ls =

   1.0088e+03


y_max_long_link =

   -0.0014
```

Stress on bolts

```
A_bolt = pi*r_bolt^2;
% At hinge
F_hinge = (F_hinge_y^2 + F_hinge_x^2)^(1/2);
Shear_hinge_bolt = F_hinge/(2*A_bolt)                % double shear
Bearing_stress_hinge_bolt = F_hinge/(2*r_bolt*0.25/2)  % bearing stress at hinge bolt
Tearout_stress_hinge = F_hinge_x/(2*0.25*0.25)          % approximate area of tearout for
simplicity
% at wheel
A_bearing = pi*r_motor_bolt^2;                                % currently an assumption, will
change when actual bearings are known
Rw=(Rwx^2 + Rwy^2)^(1/2);                            % reaction at bearing
Shear_wheel_bearing = Rw/A_bearing;                  % Shear at bearing, assuming single shaft
Bearing_stress_wheel_bearing = Rw/(r_bolt*bw)       % bearing stress at wheel bolt
Tearout_stress_wheel_bearing = Rw/((0.25*0.25))     % approximated area only
Tearout_stress_spring_attachment = F_spring/((t*0.065+2*0.65*0.25))

shear_on_link_short = [Shear_max_B, Shear_max_A1, Shear_max_A2, ];
max_shear_on_link_short=max(shear_on_link_short)
stress_on_link_short = [Stress_max_B,Princ_stress_1_A1,Princ_stress_3_A1];
max_stress_on_link_short=max(stress_on_link_short)
shear_on_bolt=[Shear_hinge_bolt,Shear_wheel_bearing];
max_shear_on_bolt=max(shear_on_bolt)
tearout_stress=[Tearout_stress_wheel_bearing,Tearout_stress_hinge,Tearout_stress_spring_attachmen
t];
```

```
max_tearout_stress=max(tearout_stress)
bearing_stress=[Bearing_stress_hinge_bolt, Bearing_stress_wheel_bearing];
max_bearing_stress=max(bearing_stress)
deflection_lever=[y_max_short_link,y_max_long_link];
max_deflection=max(deflection_lever)
```

```
Shear_hinge_bolt =

  687.6710


Bearing_stress_hinge_bolt =

   2.1604e+03


Tearout_stress_hinge =

  404.1640


Bearing_stress_wheel_bearing =

   1.6530e+03


Tearout_stress_wheel_bearing =

  826.5228


Tearout_stress_spring_attachment =

   58.6325


max_shear_on_link_short =

   1.7178e+03


max_stress_on_link_short =

   2.0014e+03


max_shear_on_bolt =

  687.6710


max_tearout_stress =
```

```
  826.5228


max_bearing_stress =

   2.1604e+03


max_deflection =

  -5.6632e-04
```

Results

```
material_stresses=[max_shear_on_link_short,max_stress_on_link_short,Shear_max_ls,Stress_max_ls,ma
x_shear_on_bolt,max_tearout_stress,max_bearing_stress,Pcr,max_deflection];
specs_motor=[Ft,T_peak*FTLB_TO_NM,T_continuous*FTLB_TO_NM,rpm,P_peak*HP_TO_KW*1000,P_continuous*H
P_TO_KW*1000,Nd_req,0,0];
specs=[material_stresses;specs_motor];
xlswrite('Prototype Specifications.xls',specs)
```

Spring Requirements

```
Mechanical_advantage=ls/lw
F_spring
```

```
Mechanical_advantage =

    1.8078


F_spring =

   24.7722
```

References

[1] http://www.plantengineering.com/single-article/calculating-proper-rolling-resistance-a-safer-move-for-material-handling/82fa156f91ea516c6b08be3bc595db65.html
[2] http://books.google.com/books?id=U-U-WdU53ywC&pg=PA26&lpg=PA26&dq=rubber+wood+static+friction&source=bl&ots=KLBS1kZN3D&sig=z1_-gZIFWMPfkPnx1VEqxJtJaRY&hl=en&sa=X&ei=cMZNVKGOE4m2yQTY2oDQDg&ved=0CFcQ6AEwBw#v=onepage&q=rubber%20wood%20static%20friction&f=false
[3] http://www.matweb.com/search/DataSheet.aspx?MatGUID=034970339dd14349a8297d2c83134649&ckck=1
[4] http://www.engineeringtoolbox.com/rolling-friction-resistance-d_1303.html

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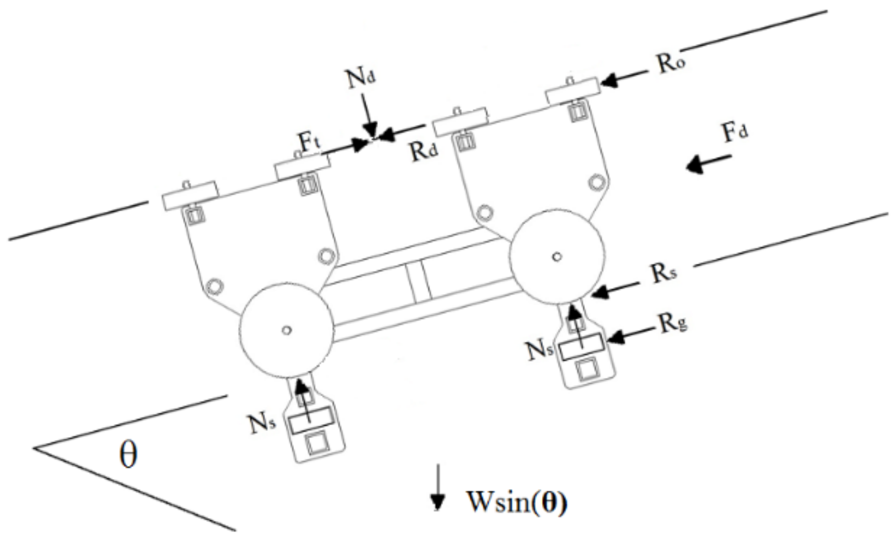


$$\sum F_x = m \times a = F_T - R_D - R_o - F_D - R_S - R_G - W\sin(\theta)$$

$$F_T = m \times a\, R_D + R_o + F_D + R_S + R_G + W\sin(\theta)$$

$$\sum F_y = 0 = -N_D + N_S - W\cos(\theta)$$

$$N_S = N_D + W\cos(\theta)$$

Traction Force

$$F_T = F_D + W\sin\theta + m \times a + R_o + R_G + R_S + R_D$$

Rolling Resistance $\quad R = \frac{f \times N}{r}$

$f = Rolling\ Resistance\ Coefficient$

$N = Normal\ Force\ on\ Wheel$

Wind Resisance $\quad F_D = \frac{1}{2} C_D \rho A v^2$

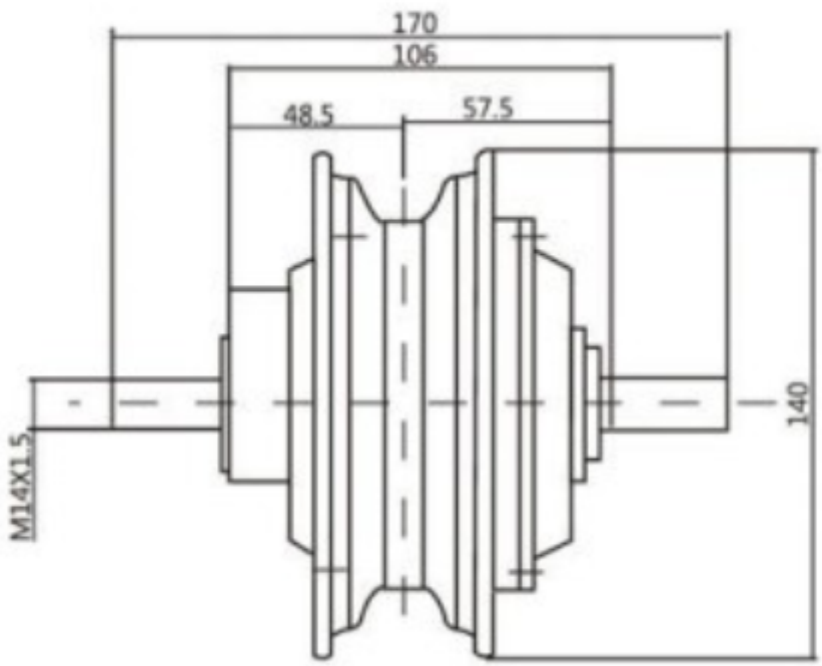
Traction Requirements

$$N_D = \frac{F_T}{\mu}$$

$\mu = Coefficient\ of\ Static\ Friction$

Propulsion Bill of Materials

Propulsion					
8 inch brushless hub motor kit	Ali Express		2	$228.72	$445.05
3 pack 12V 12Ah, 500 WT 36V Electric Scooter Battery	ebay	ML12-12F2MP3	1	$69.99	$69.99
12V 12AH battery	ebay		1	$24.25	$24.25
36V Scooter Battery Charger	ebay		1	$15.99	$15.99
1/8" x 50' Shock Cord	ebay		1	$6.95	$6.95
3/8 in. x 10-1/2 in. Zinc-Plated Turnbuckle Hook/Eye	home depot		2	$3.27	$6.54
1x1x.060 wall square tube	McMaster		3ft	$10.66	$10.66
1x.25 rectangular steel tube	McMaster		3ft	$11.08	$11.08
miscellaneous				$50	$50
Propulsion Subtotal					**$640.51**

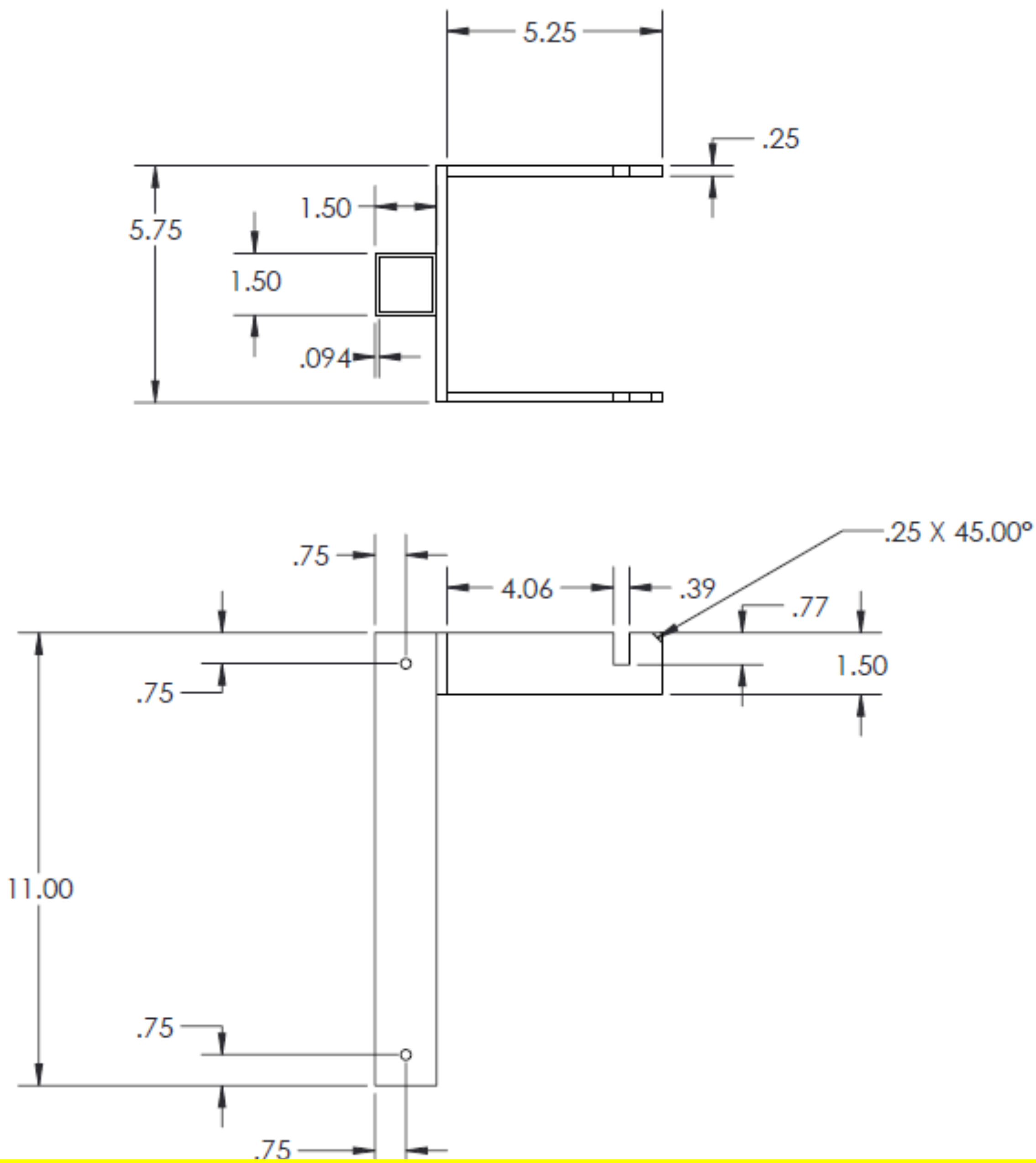


Gearless hub motor
Reted voltage: DC 24/36V
Reted power:150-350W
Speed: 400-1200rpm
Tyre: 200x50-5, vacuum tyre
Rim size: 8 inch
Diameter with tyre: 200MM
Efficiency: >83%
Packing: 2 pcs/carton
Carton size: 41x23x26cm
Net Weight.: 3.3kg/2pcs(with tyre)
Gross Weight: 6.9kg/2pcs

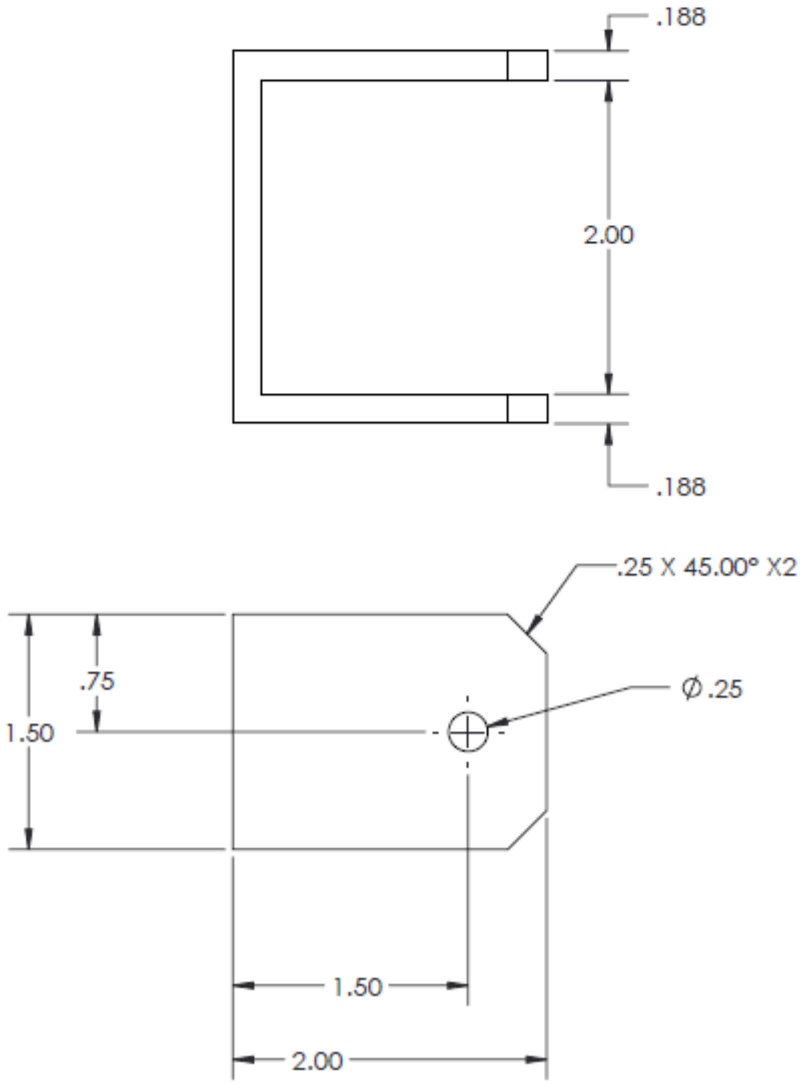
Link: http://www.aliexpress.com/item/8-inch-brushless-hub-motor-for-two-wheel-electric-escooter/32238304871.html

Traction System Drawings

L-Lever


5.25
.25
5.75
1.50
1.50
.094
.25 X 45.00°
.75
4.06
.39
.77
1.50
.75
11.00
.75
.75

Hinge



Bogie Steering Force Hand Calculations

$\Sigma M_{pivot} = 0$

$\Sigma F_x = 0$

$\mu = Coefficient\ of\ Friction = 0.8$

$F1 = Upper\ Steering\ Force = 41.02\,lb = 182.47\,N$

$F2 = Frictional\ Force = \mu F3 = 300\,lb = 1334.47\,N$

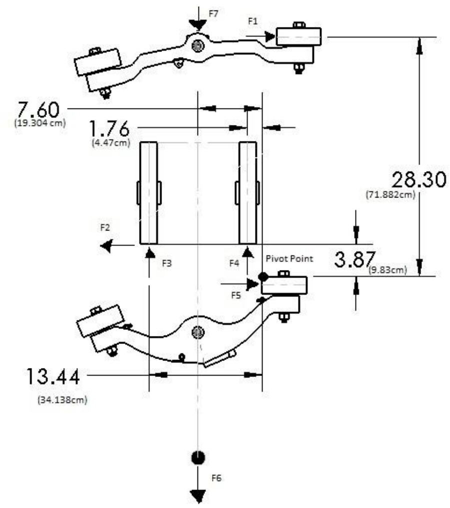
$F3 = Support\ Normal\ Force1 = 375\,lb = 1668.08\,N$

$F4 = Support\ Normal\ Force2 = 375\,lb = 1668.08\,N$

$F5 = Lower\ Steering\ Force = 258.97\,lb = 1151.96\,N$

$F6 = Weight\ of\ Bogie + Cabin = 700\,lb = 3113.76\,N$

$F7 = Drive\ Wheel\ Force = 50\,lb = 222.41\,N$



Force analysis for track separation

$\Sigma M_{pivot} = 0$

$\Sigma F_x = 0$

$Velocity = 1\,ft/s = 0.3048\,m/s$

$F1 = Drive\ Wheel\ Force = 50\,lb = 222.41\,N$

$F2 = Upper\ Steering\ Force = 56.1\,lb = 249.54\,N$

$F3 = Frictional\ Force = \mu F4 = 375\,lb = 1668.08\,N$

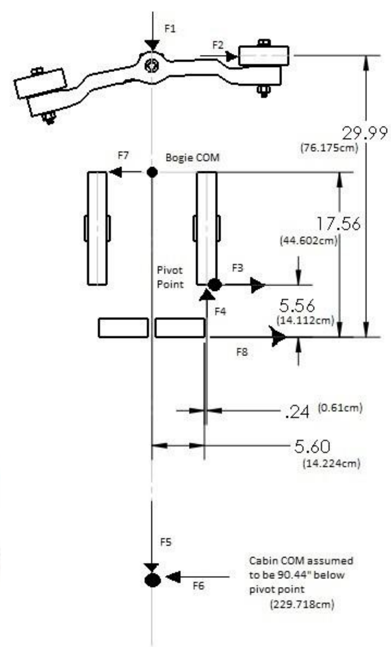
$F4 = Support\ Wheel\ Normal\ Force = 750\,lb = 3336.17\,N$

$F5 = Weight\ of\ Bogie + Cabin = 700\,lb = 3113.76\,N$

$F6 = Centripedal\ Force\ of\ Cabin = \frac{m \cdot v^2}{r} = \frac{400}{32.2} \cdot \left(\frac{1^2}{26.25}\right) = 0.473\,lb = 2.1\,N$

$F7 = Centripedal\ Force\ of\ Bogie = \frac{m \cdot v^2}{r} = \frac{300}{32.2} \cdot \left(\frac{1^2}{26.25}\right) = 0.355\,lb = 1.58\,N$

$F8 = Lower\ Steering\ Force = -\ 430.27\,lb = -\ 1913.94\,N$



Force analysis for switching section

$$\Sigma M_{pivot} = 0$$

$$\mu = Coefficient\ of\ Friction = 0.5$$

$$Velocity = 1\ ft/s = 0.3048\ m/s$$

$$F1 = Frictional\ Force = \mu F2 = 375\ lb = 1668.08\ N$$

$$F2 = Support\ Wheel\ Normal\ Force = 750\ lb = 3336.17\ N$$

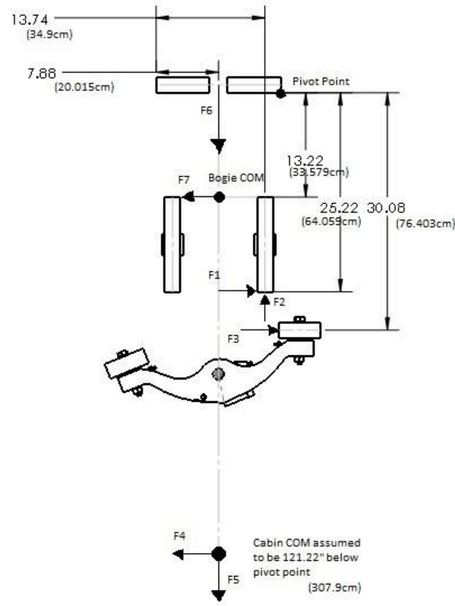
$$F3 = Lower\ Steering\ Force = -\ 459.39\ lb = -\ 2043.47\ N$$

$$F4 = Centripedal\ Force\ of\ Cabin = \frac{m * v^2}{r} = \frac{400}{32.2} * \left(\frac{1^2}{26.25}\right) = 0.473\ lb = 2.1\ N$$

$$F5 = Weight\ of\ Bogie + Cabin = 700\ lb = 3113.76\ N$$

$$F6 = Drive\ Wheel\ Force = 50\ lb = 222.41\ N$$

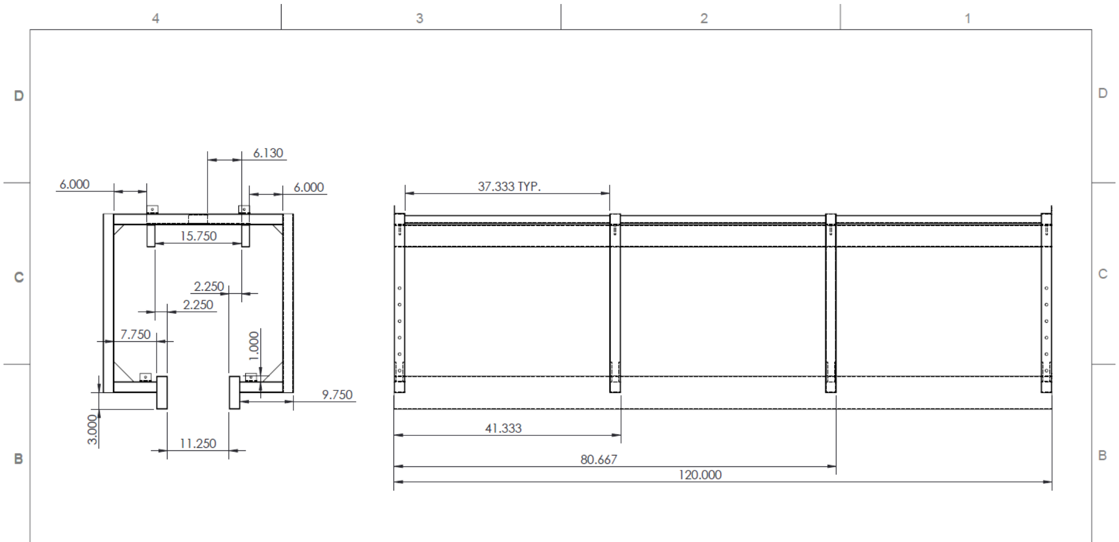
$$F7 = Centripedal\ Force\ of\ Bogie = \frac{m * v^2}{r} = \frac{300}{32.2} * \left(\frac{1^2}{26.25}\right) = 0.355\ lb = 1.58\ N$$



Force analysis for cornering section

Bogie Steering Bill of Materials

Vendor	Vendor Part Number	Description	Quantity Per Bogie	Price	Total Quantity needed	Quantity to Order	Total Cost
McMaster	90917A927	Shaft Bushing(1/2") x 10	4	$12.64	8	1	$12.64
McMaster	6384k61	1/2"Bearing (per)	4	$8.69	8	8	$69.52
McMaster	3016t32	3/8"-16threaded eyebolt(per)	4	$5.26	8	8	$42.08
McMaster	91236a857	3/4"-10 steel cap screw (5)	4	$12.09	8	2	$24.18
McMaster	90126a036	3/4" Zinc Plated Washer (21)	12	$4.20	24	2	$8.40
McMaster	95606a561	Nylon wASHER (50)	12	$10.85	24	1	$10.85
McMaster	95462a538	3/4"-10 Zinc Hex nut (25)	4	$13.19	8	1	$13.19
McMaster	91247a730	1/2"-13 Steel Cap Screw (10)	2	$12.26	4	1	$12.26
McMaster	90108a033	1/2" Zinc Plated Washer (50)	4	$6.67	8	1	$6.67
McMaster	94804a340	1/2"-13 Nut (10)	2	$4.67	4	1	$4.67
McMaster	91247a112	5/16-24 steel cap screw (50)	4	$12.83	8	1	$12.83
McMaster	90499a810	5/16-24 hex nut (100)	4	$4.93	8		$4.93
McMaster	90126a030	5/16 Zinc Plated Washer (192)	8	$4.41	16		$4.41
WindyNation	LIN-Act1-02	2" Electric Linear Actuator	2	$36.99	4	4	$147.96
							$0.00
Ebay		Linear Solenoid	2	$12.00	4	4	$48.00
Sparkfun		Arduino Uno-R3	1	$25.00	1		$25.00
Misc Electronics							$100.00
metalsdepot		6'x4' 11 Gauge Cold Rolled Steel	0.5	$154.80	1	1	$154.80
metalsdepot		1'x2' 1/4" A36 Steel Plate	0.5	$31.02	1	1	$31.02
metalsdepot		1"x1"x0.03" A513 Steel Tube	0.5	$8.00	1	1	$8.00
						Total Cost	$741.41



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	15FUL10009	10 ft Upper Track Section	2
2	15FUL10010	10 ft Lower Track Section	2
3	15FUL11002	.083 Double Sided Rib	2
4	15FUL10012	Plywood Track Ceiling for Propulsion	3
5	15FUL11004	.120 Double Sided Rib	2
6	15FUL10013	Ceiling Reinforcement	3
7	15FUL10011	Track Coupling Tab	8

TOLERANCES UNLESS OTHERWISE NOTED: 2 PLC ±.01; 3 PLC ±.005; ANGLE ±.5°. INTERPRET DIM AND TOL PER ANSI Y14.5M - 2009. REMOVE BURRS & SHARP EDGES. SURFACE FINISH 32. DO NOT SCALE THIS DRAWING. THIRD ANGLE PROJECTION.

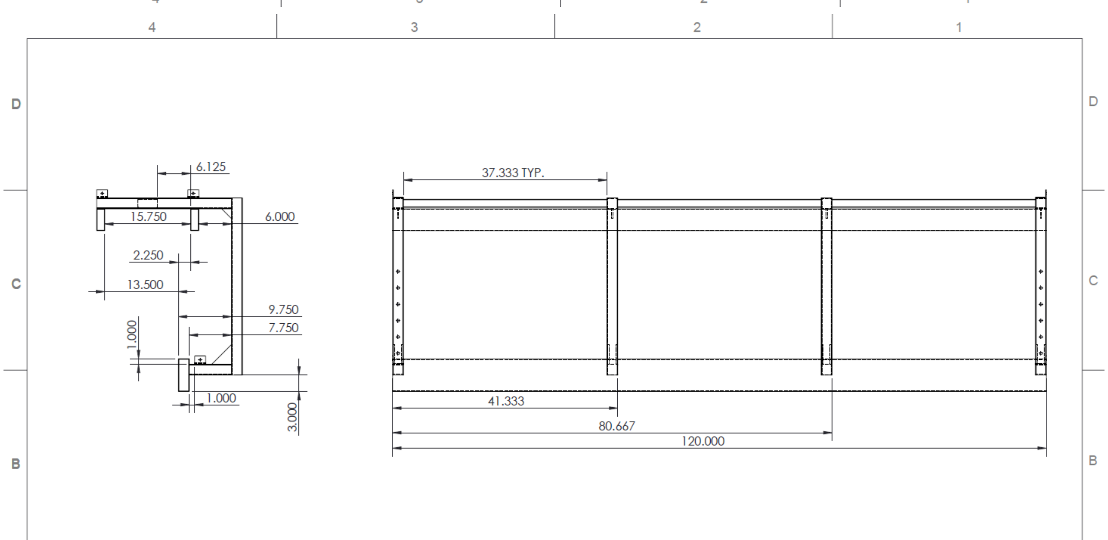
DETAIL: D. ORNELLAS 03/04/2015; CHK'D: –; APP'D: –

SPARTAN SUPERWAY

Description: Double Sided Guideway Section

MATERIAL: N/A — FINISH: --- — DIMENSIONS ARE IN INCHES

SIZE: B — DRAWING NUMBER: 15FUL11006 — REV: AA — SCALE 1:12 — SHEET 1 OF 2



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	15FUL10009	10 ft Upper Track Section	2
2	15FUL10010	10 ft Lower Track Section	1
3	15FUL11001	.083 Single Sided Rib	2
4	15FUL11003	.120 Single Sided Rib	2
5	15FUL10012	Plywood Track Ceiling for Propulsion	3
6	15FUL10013	Ceiling Reinforcement	3
7	15FUL10011	Track Coupling Tab	6

TOLERANCES UNLESS OTHERWISE NOTED: 2 PLC ±.01; 3 PLC ±.005; ANGLE ±.5°. INTERPRET DIM AND TOL PER ANSI Y14.5M - 2009. REMOVE BURRS & SHARP EDGES. SURFACE FINISH 32. DO NOT SCALE THIS DRAWING. THIRD ANGLE PROJECTION.

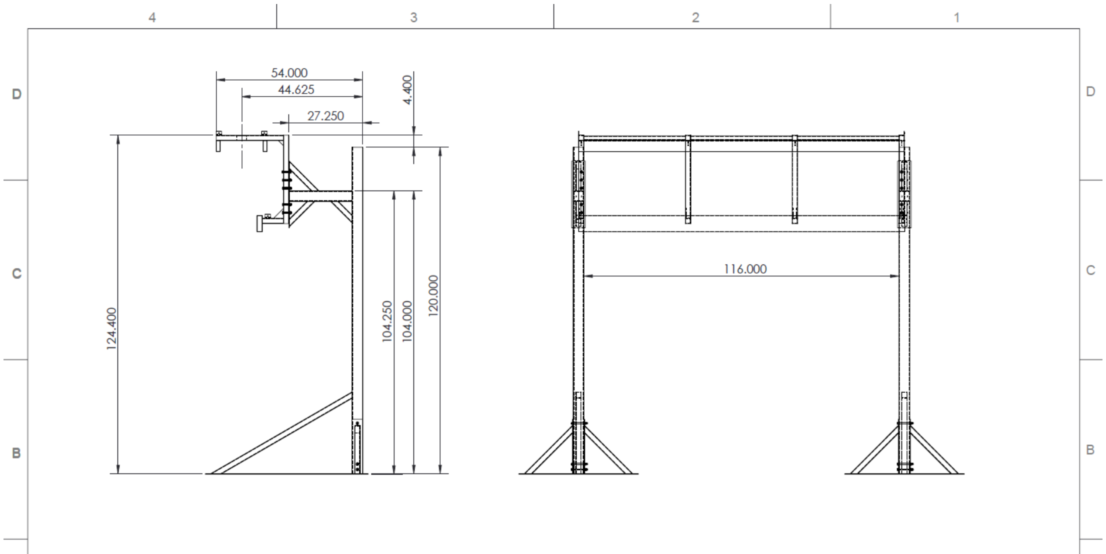
DETAIL: D. ORNELLAS 03/04/2015; CHK'D: –; APP'D: –

SPARTAN SUPERWAY

Description: Single Sided Straight Section

MATERIAL: N/A — FINISH: --- — DIMENSIONS ARE IN INCHES

SIZE: B — DRAWING NUMBER: 15FUL11005 — REV: AA — SCALE 1:12 — SHEET 1 OF 2



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	15FUL11005	Single Sided Straight Section	1
2	15FUL51002	Support Column Assembly	2
3	92865A724	Bolt: 1/2"-13 3" Long, McMaster No. 92865A724	10
4	91083A033	Washer: 1/2" McMaster No. 91083A033	12
5	90490A033	Nut: 1/2"-13 McMaster No. 90490A033	10

DO NOT SCALE THIS DRAWING

TOLERANCES UNLESS OTHERWISE NOTED: 2 PLC ± .01 | 3 PLC ± .005 | ANGLE ± .5°
INTERPRET DIM AND TOL PER ANSI Y14.5M - 2009
REMOVE BURRS & SHARP EDGES
SURFACE FINISH 32

	SIGNATURE	DATE
DETAIL	D. ORNELLAS	03/04/2015
CHK'D	–	MM/DD/YYYY
APP'D	–	MM/DD/YYYY

THIRD ANGLE PROJECTION
SPARTAN SUPERWAY
Description: Complete Single Sided Assembly
MATERIAL
DIMENSIONS ARE IN INCHES
FINISH ---
SIZE B | DRAWING NUMBER 15FUL11007 | REV AB
SCALE 1:24 | PDF Template: 2/25/13 | SHEET 2 OF 2

Appendix B: Cabin

Appendix B-1: Projected Cost for Cabin Team

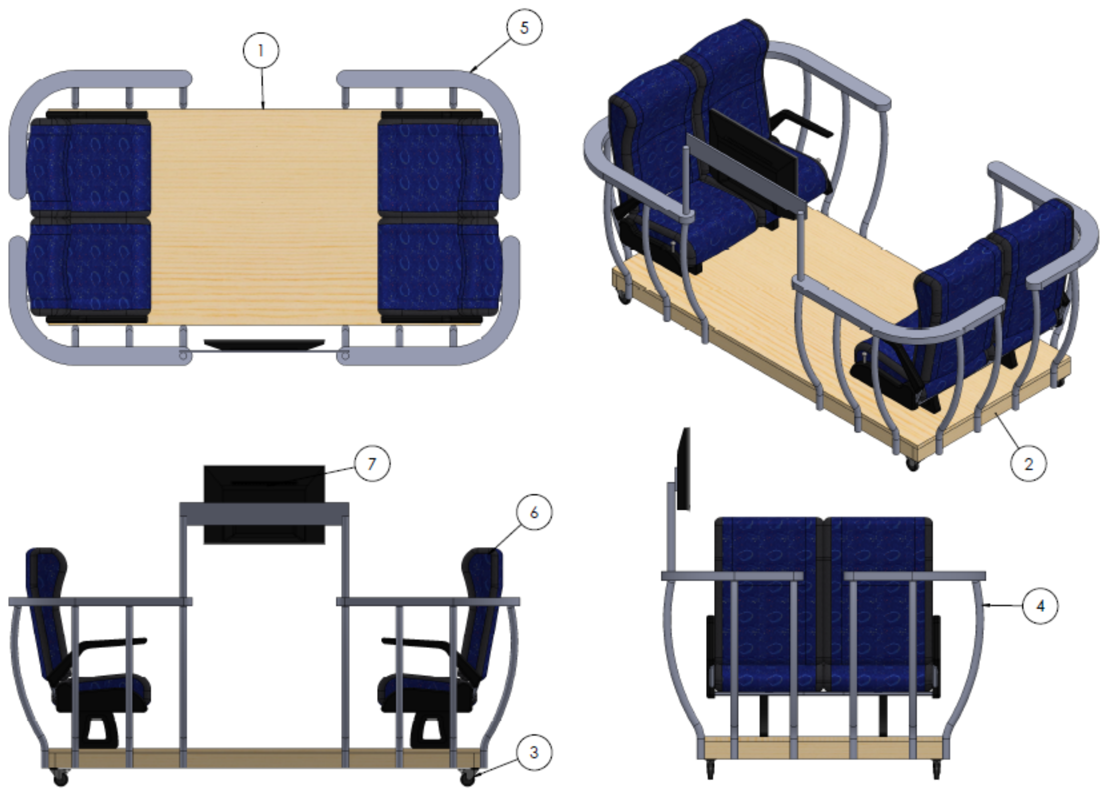
The Cabin Team requires $1250.00 in order to purchase materials and complete the fabrication of the parts listed in Appendix B. The following tables include the cost breakdown and bill of materials.

BOM for Fabrication

Item #	Component	Unit Cost	Qty	Total Cost
1	Plywood Platform (4' x 8' x .75")	$25.00	1	$25.00
2	2x4 (8' length)	$3.00	5	$15.00
3	Lockable Caster Wheels	$5.00	4	$20.00
4	Metal Frame Tubing (10' tube)	$5.00	6	$30.00
5	Frame Lock	$25.00	4	$100.00
6	Bench Seats	$100.00	2	$200.00
7	LCD	$100.00	1	$100.00
8	Frame Covering	$250.00	1	$250.00
9	Floor Covering	$100.00	1	$100.00
10	Miscellaneous Fasteners	$100.00	1	$100.00
11	Cosmetic Components	$100.00	1	$100.00
12	Additional Components	$210.00	1	$210.00
	Total Cost:			$1,250.00

Appendix B-2: Parts Drawings

Assembly A Drawing:



List of Parts in Assembly A

The following table includes all the parts in Assembly A

Part No.	Part Description	Page No.
1	Plywood Platform (4' x 8' x .75")	-
2	2x4 (8' length)	-
3	Lockable Caster Wheels	-
4	Metal Frame Tubing (10' tube)	-
5	Frame Lock	-
6	Bench Seats	-
7	LCD	-

Appendix B-3: Trace 700 Checksum

System - 001 | Double Duct

COOLING COIL PEAK — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 81 / 67 / 77

CLG SPACE PEAK — Mo/Hr: 7 / 15; OADB: 81

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	145	0	145	4	145	6
Glass Solar	629	0	629	19	629	28
Glass/Door Cond	77	0	77	2	77	3
Wall Cond	161	0	161	5	161	7
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	0		0	0	0	0
Sub Total ==>	1,011	0	1,011	30	1,011	45
Internal Loads						
Lights	98	25	123	4	98	4
People	2,200	0	2,200	65	1,100	48
Misc	61	0	61	2	61	3
Sub Total ==>	2,360	25	2,384	70	1,260	55
Ceiling Load	0	0	0	0	0	0
Ventilation Load	0	0	0	0	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		0	0	0		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	3,371	25	3,396	100.00	2,271	100.00

HEATING COIL PEAK — Mo/Hr: Heating Design; OADB: 36

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	-57	-57	6.62
Glass Solar	0	0	0.00
Glass/Door Cond	-512	-512	59.17
Wall Cond	-296	-296	34.21
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	0	0	0.00
Sub Total ==>	-866	-866	100.00
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	0	0	0.00
Ventilation Load	0	0	0.00
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		0	0.00
OA Preheat Diff.		0	0.00
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-866	-866	100.00

TEMPERATURES

	Cooling	Heating
SADB	43.8	81.9
Ra Plenum	75.0	70.0
Return	75.3	70.0
Ret/OA	75.3	70.0
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	65	65
Terminal	65	65
Main Fan	65	65
Sec Fan	0	0
Nom Vent	0	0
AHU Vent	0	0
Infil	0	0
Min Stop/Rh	0	0
Return	65	65
Exhaust	0	0
Rm Exh	0	0
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	0.0	0.0
cfm/ft²	1.81	1.81
cfm/ton	230.91	
ft²/ton	127.23	
Btu/hr-ft²	94.32	-24.05
No. People	4	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	0.3	3.4	2.3	65	75.3	62.7	65.2	43.8	43.4	41.1
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.3	3.4								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	36		
Part	0		
Int Door	0		
ExFlr	0		
Roof	36	0	0
Wall	126	30	24

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-0.9	65	70.0	81.9
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0

Appendix B-4:4130 Steel Material Properties

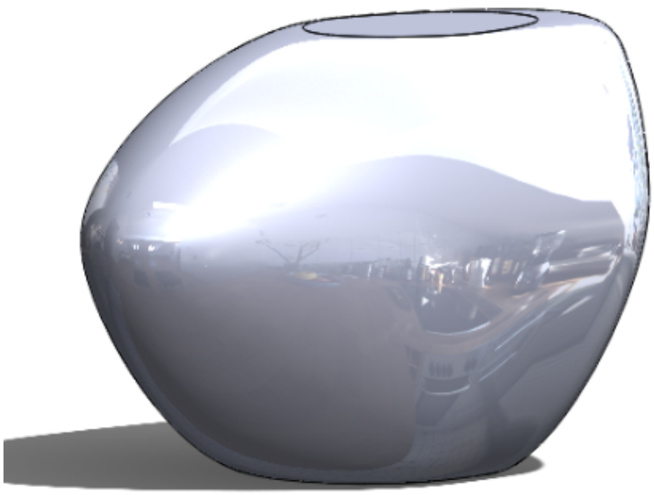
Property	Value	Units
Elastic Modulus	2.05e+011	N/m^2
Poisson's Ratio	0.32	N/A
Shear Modulus	8e+010	N/m^2
Mass Density	7850	kg/m^3
Tensile Strength	1110000000	N/m^2
Compressive Strength		N/m^2
Yield Strength	710000000	N/m^2
Thermal Expansion Coefficient	1.23e-005	/K
Thermal Conductivity	44.5	W/(m·K)
Specific Heat	475	J/(kg·K)
Material Damping Ratio		N/A

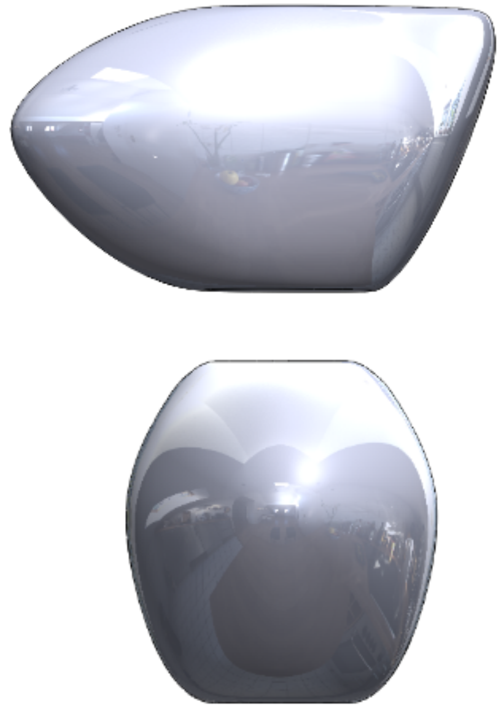
Chemistry Data : [top]

Carbon	0.28 - 0.33
Chromium	0.8 - 1.1
Manganese	0.7 - 0.9
Molybdenum	0.15 - 0.25
Phosphorus	0.035 max
Silicon	0.15 - 0.35
Sulphur	0.04 max

Principal Design Features	AISI 4130 is a low alloy steel containing molybdenum and chromium as strengthening agents. The carbon content is nominally 0.30% and with this relatively low carbon content the alloy is excellent from the fusion weldability standpoint. The alloy can be hardened by heat treatment.
Applications	Typical applications for 4130 low alloy steel include. structural use such as aircraft engine mounts and welded tubing applications.
Welding	4130 alloy is noted for its weldability by all of the commercial methods.
Heat Treatment	Heating at 1600 F followed by an oil quench will harden the 4130 alloy. For best results a normalizing pre-hardening heat treatment may be used at 1650 to 1700 F followed by the 1600 F soak and oil quench.

Appendix B-5:Cabin shape drawings





Appendix C: Scale Model

Wireless Messaging Protocol, Version 2 (Controls Team, Spring 2015)

Char	Action	Dec Value
A	Directions- Station 1 to 2	65
B	Directions- Station 1 to 3	66
C	Directions- Station 2 to 3	67
D	Directions- Station 2 to 1	68
E	Directions- Station 3 to 1	69
F	Directions- Station 3 to 2	70
G		71
H	Stop pod 1 motors	72
I	Stop pod 2 motors	73
J	Stop pod 3 motors	74
K	Access Pod 1 settings	75
L	Access Pod 2 settings	76
M	Access Pod 3 settings	77
N	check availability - Pod 1	1
O	check availability - Pod 2	2
P	check availability - Pod 3	3
Q	make pod 1 pend	4
R	make pod 2 pend	5
S	make pod 3 pend	6
T	make pod 1 not pend	7
U	make pod 2 not pend	8
V	make pod 3 not pend	9
W		10
X	Pod 1 - make available	11
Y	Pod 2 - make available	12
Z	Pod 3 - make available	13

a	Execute A	97
b	Execute B	98
c	Execute C	99
d	Execute D	100
e	Execute E	101
f	Execute F	102
g		103
h		104
i		105
j	move pending servo left	106
k	move pending servo right	107
l	if pod pending, move 1 second	108
m	move pending pod 1 magnet & stop	109
n	station 1 location	110
o	station 2 location	111
p	station 3 location	112
q	confirms pod 1 is pending	113
r	confirms pod 2 is pending	114
s	confirms pod 3 is pending	115
t		116
u		117
v		118
w		119
x		120
y		121
z		122

Wireless Messaging Protocol, Version 1 (CMPE Team, Fall 2014)

Wireless Message Format

The following discusses the format of the messages which will be sent between the main hub and pods throughout the duration of the systems runtime. Each message will be 32-bit long, which is sufficient for the current design of the system's hardware. There are four sections that make up the wireless message. The first two bits indicate the ID of the receiver, the next two bits indicate the sending device. Following the two sections is the Message Type, which is four bits and can represent sixteen different types. The payload that takes the next three bytes represent the data relative to the message type.

The 32-bit wireless message format is as follows:

Receiver

Payload information:

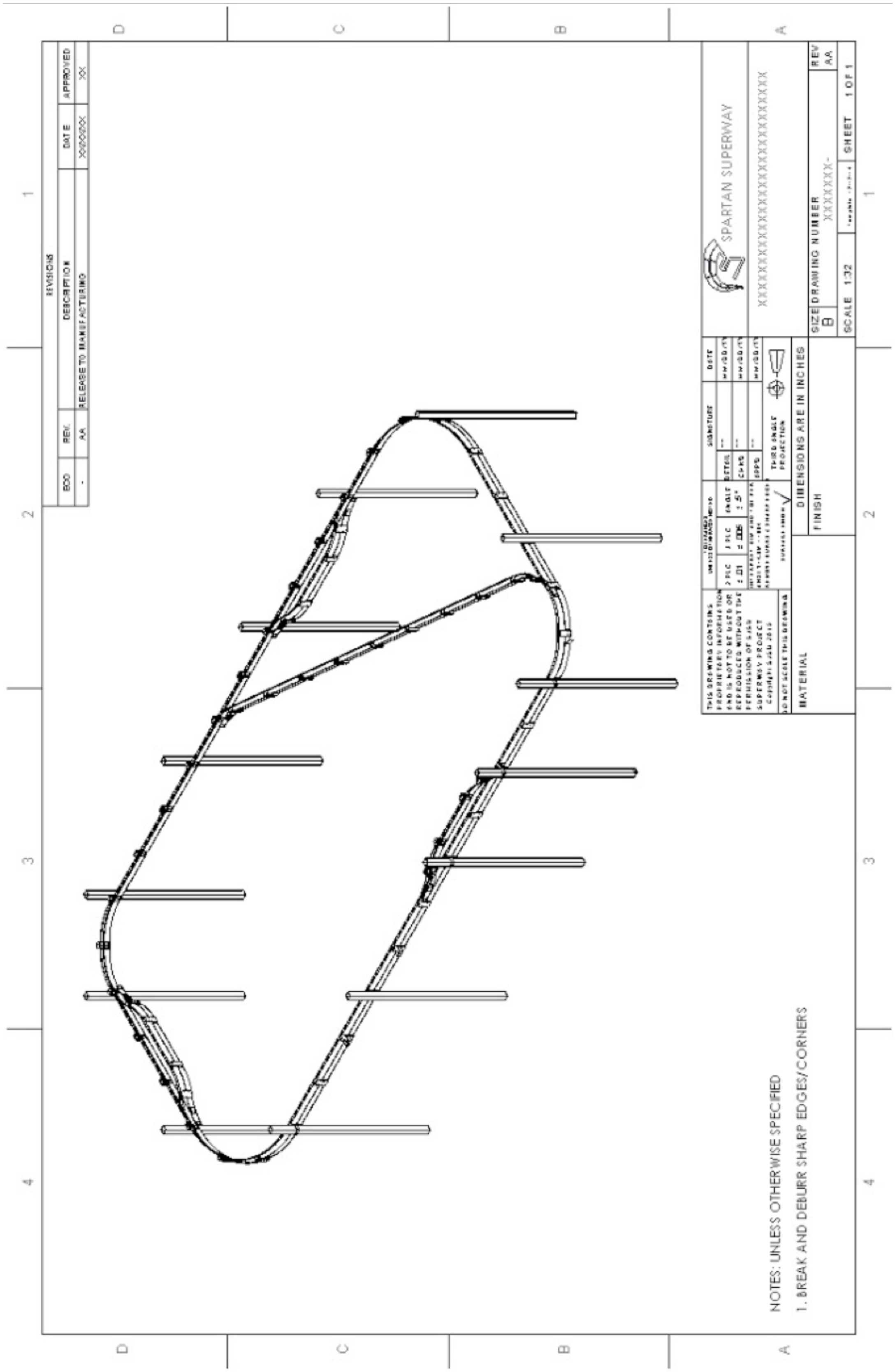
Message Type	Payload Description
Path	Every two bits, from left to right, represents an instruction: forward, left, right, stop.
Status	(See Next Table)

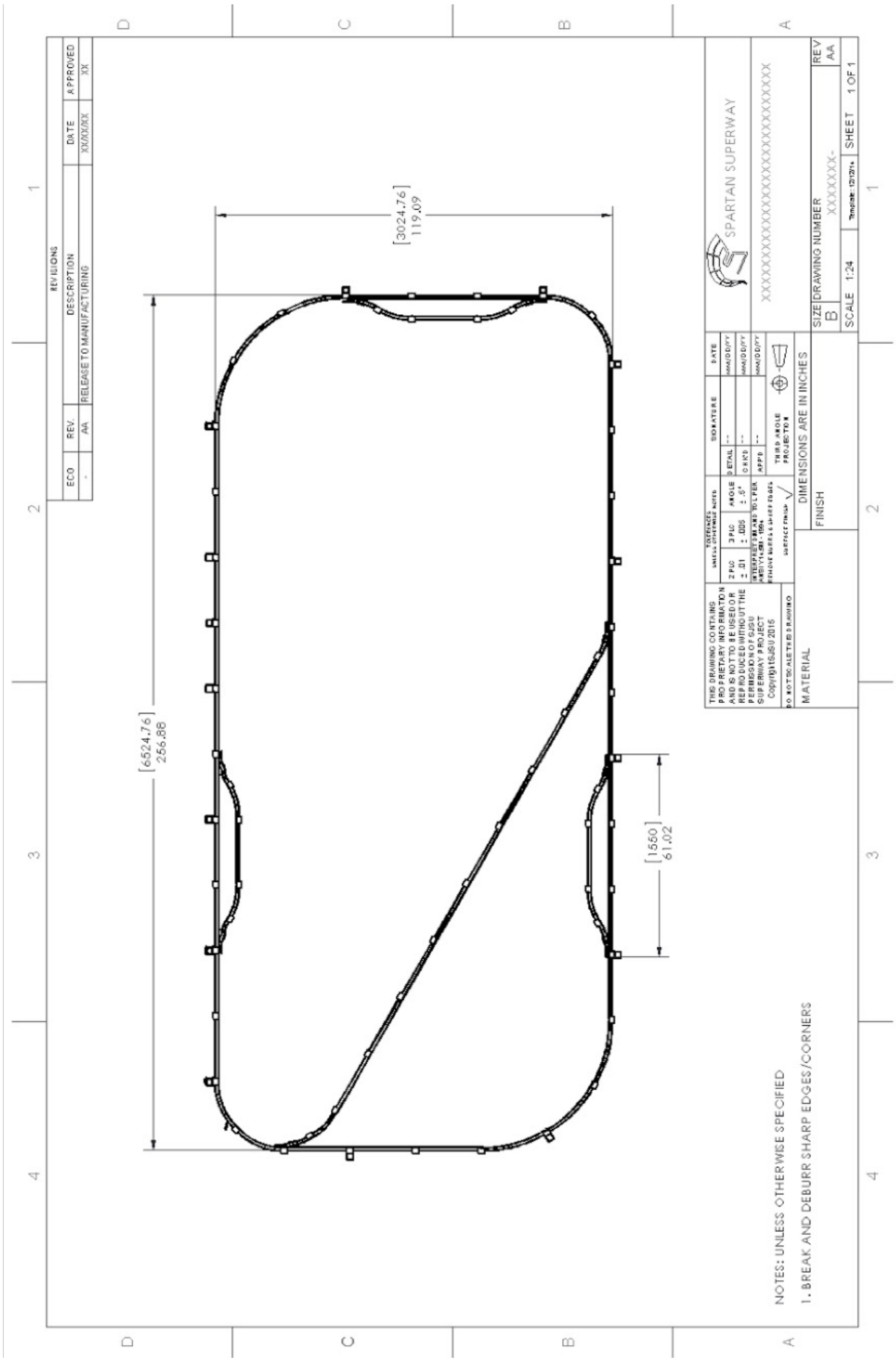
Status Message format

Speed	Proximity Sensor Readings						Location			State
23 - 10	9	8	7	6	5	4	3	2	1	0

Bit	Description
0	Indicates if the board is running or not running. 0 for running, 1 for standby.
1-3	Represents location on track. Can represent up to eight different locations on the map.
4-9	Bits 4-5 represents the right sensor readings. Bits 6-7 represents the front center sensor readings Bits 8-9 represents the left sensor readings. Note: Sensor readings have three different enumerations. 0 for extremely close – stop. 1 for relatively close – slow. 2 for far – move at regular speed.
10-23	(Reserved for speed)

Track Part Drawings


REVISIONS
RELEASE TO MANUFACTURING
SPARTAN SUPERWAY
DIMENSIONS ARE IN INCHES
MATERIAL
FINISH
DRAWING NUMBER
SCALE 1:32
SHEET 1 OF 1
NOTES: UNLESS OTHERWISE SPECIFIED
1. BREAK AND DEBURR SHARP EDGES/CORNERS


REVISIONS
ECO
REV.
DESCRIPTION
DATE
APPROVED
-
AA
RELEASE TO MANUFACTURING
XX/XX/XX
XX
[3024.76]
119.09
[6524.76]
256.88
[1550]
61.02
THIS DRAWING CONTAINS PROPRIETARY INFORMATION AND IS NOT TO BE USED OR REPRODUCED WITHOUT THE PERMISSION OF SJSU SUPERWAY PROJECT
Copyright SJSU 2015
DO NOT SCALE THE DRAWING
MATERIAL
FINISH
DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION
SPARTAN SUPERWAY
SIZE
B
DRAWING NUMBER
REV
AA
SCALE 1:24
SHEET 1 OF 1
NOTES: UNLESS OTHERWISE SPECIFIED
1. BREAK AND DEBURR SHARP EDGES/CORNERS

Datasheets

Product Folder | Sample & Buy | Technical Documents | Tools & Software | Support & Community

TEXAS INSTRUMENTS

DRV8837, DRV8838

SLVSBA4C – JUNE 2012 – REVISED FEBRUARY 2014

DRV883x Low-Voltage H-Bridge Driver

1 Features

- H-Bridge Motor Driver
  - Drives a DC Motor or Other Loads
  - Low MOSFET On-resistance: HS + LS 280 mΩ
- 1.8-A Maximum Drive Current
- Separate Motor and Logic Supply Pins:
  - Motor VM: 0 to 11 V
  - Logic VCC: 1.8 to 7 V
- PWM or PH/EN Interface
  - DRV8837: PWM, IN1/IN2
  - DRV8838: PH/EN
- Low-power Sleep Mode With 120-nA Maximum Sleep Current
  - nSLEEP pin
- Small Package and Footprint
  - 8 WSON (PowerPAD™)
  - 2.0 × 2.0 mm
- Protection Features
  - VCC Undervoltage Lockout (UVLO)
  - Overcurrent Protection (OCP)
  - Thermal Shutdown (TSD)

2 Applications

- Cameras
- DSLR Lenses
- Consumer Products
- Toys
- Robotics
- Medical Devices

3 Description

The DRV883x provides an integrated motor driver solution for cameras, consumer products, toys, and other low-voltage or battery-powered motion control applications. The device can drive one DC motor or other devices like solenoids. The output driver block consists of N-channel power MOSFET's configured as an H-bridge to drive the motor winding. An internal charge pump generates needed gate drive voltages.

The DRV883x can supply up to 1.8 A of output current. It operates on a motor power supply voltage from 0 to 11 V, and a device power supply voltage of 1.8 V to 7.0 V.

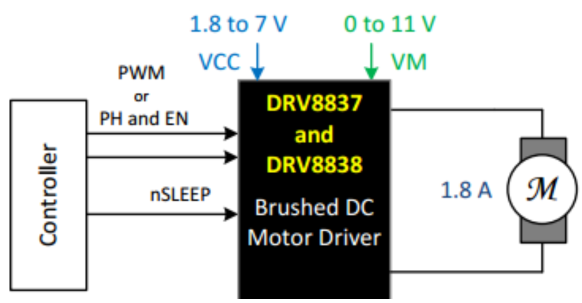
The DRV8837 has a PWM (IN/IN) input interface; the DRV8837 has a PH/EN input interface. Both interfaces are compatible with industry-standard devices.

Internal shutdown functions are provided for overcurrent protection, short circuit protection, undervoltage lockout, and overtemperature.

Device Information

ORDER NUMBER	PACKAGE	BODY SIZE
DRV8837DSGR	WSON (8)	2.0 × 2.0 mm
DRV8838DSGR	WSON (8)	2.0 × 2.0 mm

DRV883x



TEXAS INSTRUMENTS

LM1577, LM2577

www.ti.com SNOS658D – JUNE 1999 – REVISED APRIL 2013

LM1577/LM2577 SIMPLE SWITCHER® Step-Up Voltage Regulator

Check for Samples: LM1577, LM2577

FEATURES

- Requires Few External Components
- NPN Output Switches 3.0A, can Stand off 65V
- Wide Input Voltage Range: 3.5V to 40V
- Current-mode Operation for Improved Transient Response, Line Regulation, and Current Limit
- 52 kHz Internal Oscillator
- Soft-start Function Reduces In-rush Current During Start-up
- Output Switch Protected by Current Limit, Under-voltage Lockout, and Thermal Shutdown

TYPICAL APPLICATIONS

- Simple Boost Regulator
- Flyback and Forward Regulators
- Multiple-output Regulator

DESCRIPTION

The LM1577/LM2577 are monolithic integrated circuits that provide all of the power and control functions for step-up (boost), flyback, and forward converter switching regulators. The device is available in three different output voltage versions: 12V, 15V, and adjustable.

Requiring a minimum number of external components, these regulators are cost effective, and simple to use. Listed in this data sheet are a family of standard inductors and flyback transformers designed to work with these switching regulators.

Included on the chip is a 3.0A NPN switch and its associated protection circuitry, consisting of current and thermal limiting, and undervoltage lockout. Other features include a 52 kHz fixed-frequency oscillator that requires no external components, a soft start mode to reduce in-rush current during start-up, and current mode control for improved rejection of input voltage and output load transients.

Connection Diagrams

Figure 1. 5-Lead (Straight Leads) TO-220 (T) – Top View
See Package Number KC

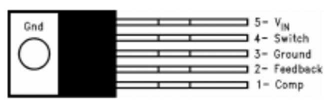


Figure 2. 5-Lead (Bent, Staggered Leads) TO-220 (T) – Top View
See Package Number NDH0005D

TEXAS INSTRUMENTS

LM2596

www.ti.com

SNVS124C – NOVEMBER 1999 – REVISED APRIL 2013

LM2596 SIMPLE SWITCHER® Power Converter 150 kHz 3A Step-Down Voltage Regulator

Check for Samples: LM2596

FEATURES

- 3.3V, 5V, 12V, and Adjustable Output Versions
- Adjustable Version Output Voltage Range, 1.2V to 37V ±4% Max Over Line and Load Conditions
- Available in TO-220 and TO-263 Packages
- Ensured 3A Output Load Current
- Input Voltage Range Up to 40V
- Requires Only 4 External Components
- Excellent Line and Load Regulation Specifications
- 150 kHz Fixed Frequency Internal Oscillator
- TTL Shutdown Capability
- Low Power Standby Mode, I_Q Typically 80 μA
- High Efficiency
- Uses Readily Available Standard Inductors
- Thermal Shutdown and Current Limit Protection

APPLICATIONS

- Simple High-Efficiency Step-Down (Buck) Regulator
- On-Card Switching Regulators
- Positive to Negative Converter

DESCRIPTION

The LM2596 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving a 3A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, 12V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation , and a fixed-frequency oscillator.

The LM2596 series operates at a switching frequency of 150 kHz thus allowing smaller sized filter components than what would be needed with lower frequency switching regulators. Available in a standard 5-lead TO-220 package with several different lead bend options, and a 5-lead TO-263 surface mount package.

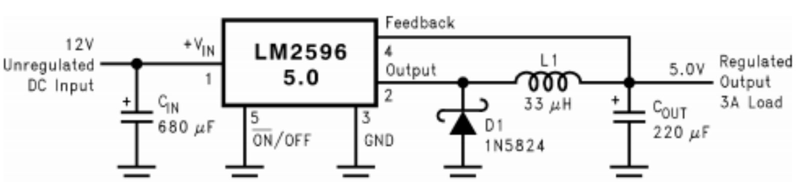
A standard series of inductors are available from several different manufacturers optimized for use with the LM2596 series. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a ensured ±4% tolerance on output voltage under specified input voltage and output load conditions, and ±15% on the oscillator frequency. External shutdown is included, featuring typically 80 μA standby current. Self protection features include a two stage frequency reducing current limit for the output switch and an over temperature shutdown for complete protection under fault conditions. (1)

(1) † Patent Number 5,382,918.

Typical Application

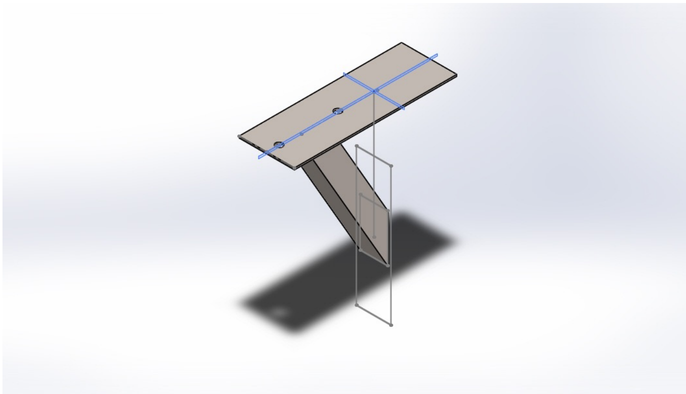
(Fixed Output Voltage Versions)



-

Appendix D: Solar

D-1: FEA on Mounting Brackets for the Full Scale Models



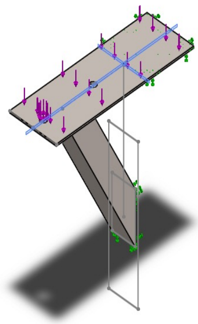
Simulation of 042215_mountbracket

Date: Thursday, April 23, 2015
Designer: Solidworks
Study name: SimulationXpress Study
Analysis type: Static
s

Description
Static Study on Stion Brackets with Max Force of 200 lbs=800 N applied to a single bracket.

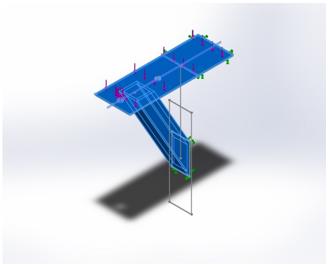
Assumptions

Model Information

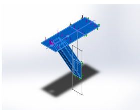


Model name: 042215_mountbracket
Current Configuration: Default

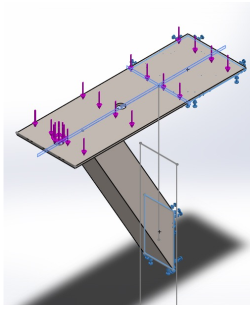
Solid Bodies

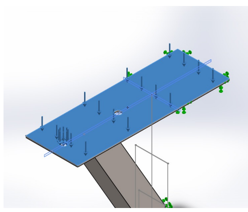
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date
Modified Boss-Extrude3 	Solid Body	Mass:2.69461 kg Volume:0.00034995 m^3 Density:7700 kg/m^3 Weight:26.4072 N	C:\Users\James and Africa\Downloads\042215_mountbracket.SLDPRT Apr 23 09:40:05 2015

Material Properties

Model Reference	Properties	Components
	Name: Alloy Steel Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength: 6.20422e+008 N/m^2	

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1 Type: **Fixed Geometry**		Entities:**2 face(s)**

Load name	Load Image	Load Details
Force-1 Type: **Apply normal force** Value: **890 N**		Entities:**1 face(s)**

Mesh Information

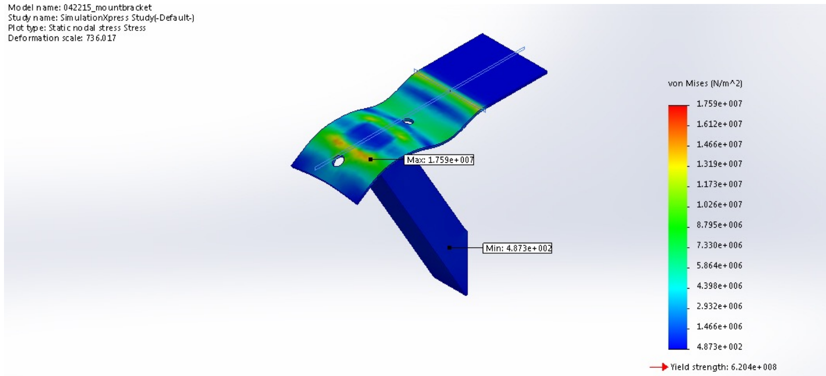
Mesh type Solid Mesh
Mesher Used: Standard mesh
Automatic Transition: Off
Include Mesh Auto Loops: Off
Jacobian points 4 Points
Element Size 0.308478 in
Tolerance 0.0154239 in
Mesh Quality High

<u>Mesh Information - Details</u>

Total Nodes 15159
Total Elements 7442
Maximum Aspect Ratio 8.6066
% of elements with Aspect Ratio < 3 89.8
% of elements with Aspect Ratio > 10 0
% of distorted elements(Jacobian) 0
Time to complete mesh(hh;mm;ss): 00:00:03
Computer name: CORDERO

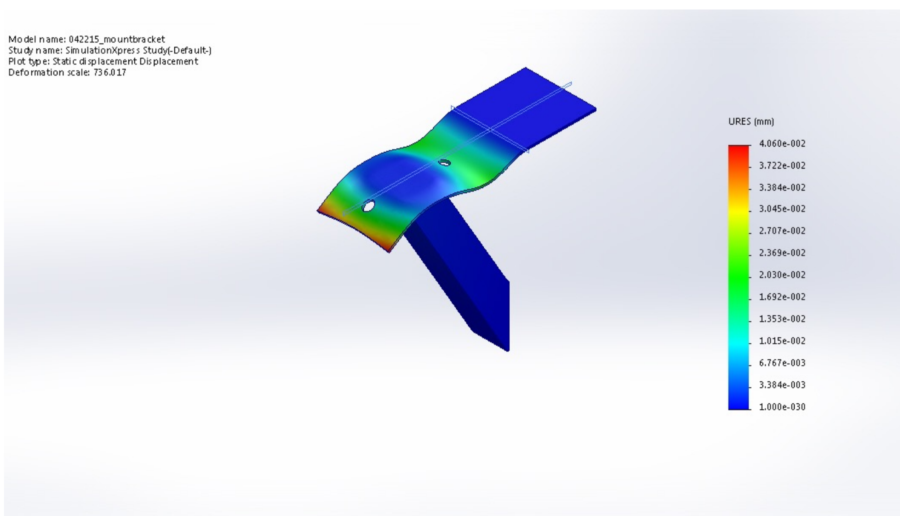
Study Results

Name Type Min Max
Stress VON: von Mises Stress 487.332 N/m^2
Node: 5251 1.75901e+007 N/m^2
Node: 14849



042215_mountbracket-SimulationXpress Study-Stress-Stress

Name Type Min Max
Displacement URES: Resultant Displacement 0 mm
Node: 87 0.0406047 mm
Node: 442



042215_mountbracket-SimulationXpress Study-Displacement-Displacement

Name Type
Deformation Deformed Shape

Conclusion

The Stion and MiaSole Assembly will be simply supported with two brackets. With the force distributed over the two brackets, the brackets will not have significant deformation because one mount bracket deforms less than 0.04 mm with 200lbs=800N of force applied to it

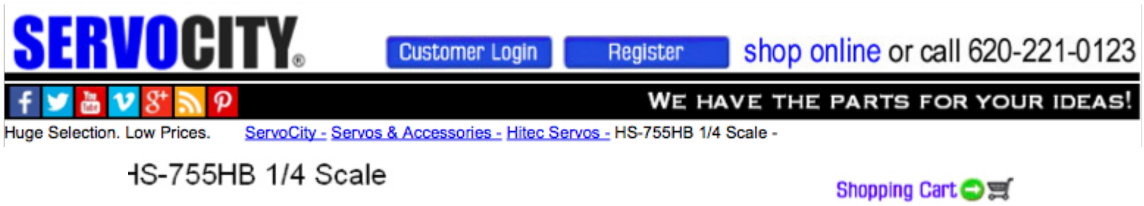
D-2: Initial Power Calculation

Pod Car Energy Consumption																	
Per Pod	**Propulsion**	5000	watts	=	5	kW	**A/C**	3000	watts	=	3	kW			**Total Length of Track Required for Panels**		
	# of Pod Cars	70	pod(s)												29773.88	ft	
	Consumption														5.64	mi	
	Propulsion	350000	W	=	350	kW	**A/C**	210000	W	=	210	kW					
	Subtotal	560000	W	=	560	kW											
	Hours of Operation	20	h														
	Total(no A/C)	7000000	Wh	=	7000	kWh											
	Total	11200000	Wh	=	11200	kWh											
	Hours of Sun	5.5	h														
Panel	**Power of Panel**		**Energy Produced**					**Panels Needed**			**Price/Panel**			**Total Price**	**Length (in.)**	**Width (in.)**	
SunPower X21 345	350	W	1925	Wh	=	1.925	kWh	5819		$	1918		$	11160842	61.4	41.2	
MicroInverter								**Inverters Needed**			**Price/Inverter**						
ABB								5819		$	200		$	1163800			
Batteries	**Voltage**	**Ah**	**Wh Stored**					**Batteries Needed**			**Price/Battery**						
Industrial Battery	4	1233	4932	Wh				2271		$	1417		$	3217843			

D-3: Initial Torque Calculation with out bearing

1 Shaft @	3.5	ft			
					using :
					6061-T6 Al
					ID= 0.245 in
6 panels @ roughly	0.6	lbs.	(0.1 lb per panel)		OD= 0.375 in
					3.5 ft long
Panel Housing (x3) :	1.21 lbs				
brackets & panel frame will be 3-D printed.					
Screws / Hardware :					
Torque on our servo:	38 oz.-in.	convert to ft.-lb		0.0625 lb / 1 oz.	1ft/12 in
		0.1979			
		roughly 0.2 ft -lb			
T=F*r					
r=	3.5	ft			
			Need:	8.1214/2 ft-lb	:Torque
T=(mg)*(r) = Wr				4.0607 ft-lb	
			with hardware		

D-4: Servo (HS-755HB Specifications)



D-5: Scale Model Bill of Materials

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	15SLR01002	Support Column With Servo Mount	1
2	15SLR01003	8mm Bearing	2
3	15SLR01002	Support Column Without Servo Mount	1
4	15SLR01004	24T Coupler	1
5	15SLR01005	Machined Solar Panel Frame	1
6	15SLR01016 (Assembly)	Solar Panel Bracket Assembly Servo Side	1
	15SLR01013	Solar Panel Pracket	1
	15SLR01014	Shaft .25in to 8mm	1
7	15SLR01017 (Assembly)	Solar Panel Bracket Non Servo Side Assembly	1
	15SLR01013	Solar Panel Pracket	1
	15SLR01015	Shaft 8mm	1
8	15SLR01007	Arduino Interface for Suppor t Column	1
9	15SLR01006	Bracket for Arduino	1
10	15SLR01008	Voltaic Solar Panel	1
11	15SLR01009	Miasole Custom Panel	1
12	91290A318	Hex Bolts M6	8
13	92313A826	Set screw for brackets	2
14	15SLR01018 (Assembly)	Servo Assembly	1
	Carcasa Servo Hitec HB-755HB	HB-755 Servo	1
	Pinon	Gear on Servo	1
15	15SLR01012	Servo Mount	1
16	91772A254	Screw for Servo Mount	2