The Spartan Superway - A Solar Powered Automated Transportation Network:
Spring 2019 Full-Scale Solar Team

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Abstract

The Full-Scale Solar team focuses on making a Solar PV Rack that can fit the design specifications set forth by the team. These specifications include serviceability from underneath the solar panel rack, light enough to be supported on the guideway with easy, provides enough solar power to power the entire Spartan Superway project's power needs, interface with the Wayside power system easily, be relatively inexpensive, and finally, minimize the need for custom parts so that sourcing all the parts and constructing will be simple.

To carry out these design specifications, the team went through several rack ideas until settling on a design that incorporates elements of a solar carport and similar projects. Creating a full CAD with all of the actual parts were necessary for the next step, making sure that all the parts, fasteners, and other items that were planned to be used could be found on the final model of the CAD. Testing each individual piece was needed to make sure that the model would work to spec, and the team worked with ANSYS to gather proper results for all components. Finally, acquiring the parts from various distributors and stores and putting the pieces together came with a learning curve, because we needed to do some work of our own to make sure everything could interface with each other.

The outcome of this project were greater than expected, seeing that the project came together relatively quickly to great results. The rack holds up impressively, the clamps have enough durability and grip to be a viable option for quick solar panel racking applications. Cable management effectively keeps the cables in an orderly fashion, and the electronic components are sturdy. Future work for this project can include improvements to the electronic system and the size of the solar panel array.

Acknowledgments

Dr. Burford Furman has been an asset to the Full-Scale Solar Team in many ways. A professor at San Jose State University and main adviser, he has provided important feedback and guidance throughout the duration of the year to ensure that the Full-Scale Solar Team met goals and reached full potential.

Ron Swenson played a key part in supporting the Full-Scale Solar Team, especially during the assembly phase of the project. He saved the solar team a large sum of money by providing material that would otherwise increase the cost of the project.

Jack Fogelquist is a graduate student at San Jose State University who is working exclusively on the solar portion of the SPARTAN Superway. He has provided the Full-Scale Solar Team with helpful and useful research information that has played huge role in the progress throughout the year.

Ralion Herzog is an undergraduate mechanical engineering student at San Jose State University who works at a solar company. Ralion provided the Full-Scale Solar Team with solar panels that were used in the assembly of the final project. Because of his contribution, the Full-Scale Solar Team was able to save a large amount of money by reducing the cost of the project.

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Executive Summary

Introduction

Traffic congestion has been the worst it has possibly ever been. The bay area is no stranger to this congestion, turning 15 or 20 minute drives into an hour and a half of slow stop and go traffic. A new, clean method of transportation is a possibility to help alleviate some of this congestion. The Spartan Superway is that new method of transportation, one that would provide a fast, convenient, and clean way for people to traverse cities. Students at San José State University have begun to work on this new method of autonomous transportation that would not only address the congestion issue in cities but also the pollution issue as well. The full scale solar team's role in this endeavor is to help create a solar rack that improves on last years design. The new design will implement an easier method of servicing of servicing the solar panels from below and a better cable management system.

Objectives

- Create and implement a serviceable method for solar panels from underneath
- Implement a clamping mechanism that can hold panels against wind force

Procedure

The team used Solidworks to put together a Solar Panel Frame using manufacturer specified dimensions to make sure that the drawing was properly scaled and will look like the finished product. The used ANSYS to test design wind loading stresses and solar panel weight stresses so that the frame has proof that it will be rigid enough to handle this application. Finally, the team used various machine equipment and tools to put together the frame exactly like the CAD drawing

Results

The final model has a ground area of 63.79" x 71.88" and a height of 76.67". The cost of the entire frame was $494.45. The design allows for panel servicing from below the panels rather than from above via a Gator Clamp. The Solar PV Rack is shown below in the figure.

Figure 1. CAD drawing of final design

Conclusions

The final design achieves the goals the team set forth and does it without complication, making this design simple yet robust. Future work on this design should focus on making the solar panel angle adjustable and fixing the electrical limits of the electronic hardware for more efficiency.

Introduction

Public transportation is an excellent way for those who do not have the resource of a personal vehicle to travel. Unfortunately, the current selection of public transportation systems are what is called an, “online network”, or a transportation network that keeps track of where all the other cars/bogies are in the system. Now this does not sounds like a particularly bad thing, but it does cause problems when there are multiple cars on one track and one stops to deliver passengers to a destination, because this in turn stops all the cars behind it to allow the passengers to leave, thus causing a delay for those who are in the cars that have had to stop and accommodate for the other passengers to leave. This is exactly how the current B.A.R.T. (Bay Area Rapid Transit) system works, and many other transit system like it.

ATN (Automated Transit Network) systems, however, do not encounter this issue, because by nature, they are an “offline network”, which means that the transportation network does not keep track of where each individual car/bogie is at (Furman et al, 2014). Passengers will not have to worry about potential stops their trip due to other passengers getting off at other stations because the stations will be off-the-network, allowing for easy travel to a destination without hasty stops. ATN systems can also alleviate the delay in a commuter’s schedule because of their offline nature. Since the transportation network is offline, passengers only have to worry about their specific destination, and do not have to make intermittent stops along the way to that destination, which is a large advantage that ATN systems have over standard online systems.

The SPARTAN (Solar Powered, Automated Rapid Transit Ascendent Network) Superway seeks to take these elements from general ATN systems as well as tackle issues with public transportation in general. One concern for public transportation systems is finding a sustainable option for commuters, because automobiles run on gasoline, a non-renewable resource, and electrical powered transportations, while good in theory, needs natural gas, another non-renewable resource, to generate electrical energy. To solve this problem, the Spartan Superway system will use solar power to generate the necessary electrical power needs for this system, because solar power can be generated with solar panels in an environmentally clean way. Solar power is also easily obtainable in metropolitan settings, unlike hydro-electrical, wind turbine, and steam generated systems, which need either a more appropriate location, or equipment that would be too large for practical applications in a city.

Social implications of this project cannot be understated, especially in the modern era, because energy renewability is a serious issue not only in the United States, but around the globe. Many countries have created several solutions to combat the waning resources, and this project is one of America’s answers to this problem. Without the need for oil-based energy sources to create energy, besides the ones needed to produce the equipment, the SPARTAN Superway will show that it is possible to travel far without the need of non-renewable resources, and encourage people to ride the transit system instead. This will reduce the amount of emissions created by vehicles because there will be less vehicles on the road, and potentially, encourage other cities and countries to adopt a system similar to reduce their local emissions as well. Being accessible for those who are poor, elderly, or disabled will also be a big social tool to this project. It will allow for mobility without too much assistance, as well as self-servicing, so not as expensive as a human controlled system. This type of transportation has the potential to drastically change the way we travel.

Background and Context

Currently in the solar racking industry, many solar racks, from commercial to consumer applications, need to have the solar panels installed from above their respective racking hardware. This creates an unsafe working hazard to whoever is installing it because they have to always be above the solar panels in all cases, and although most applications are either house roofs or solar carports, if a solar application needed to be dealt with at about 20-30 feet in the air, being above the solar panels would be a difficult and unsafe task. Having a way to install solar panels from the underside the solar panel rack, therefore, would be a more practical, and most of all, safer alternative, and would be easier to coordinate between installers of these systems.

Objectives

The Full-Scale Solar team's re-scoped objectives are as follows

- Create and implement a serviceable method for solar panels from underneath
- Implement a clamping mechanism that can hold panels against wind force
- Create cable management system to protect and clean up wires

Design Requirements and Specifications

The Full Scale Solar Team has to adhere to certain design requirements and specifications that helped get the team back on track with the re-scope. The team had to design a clamp that is able to clamp onto a wide range of solar panel frame lips. For the purpose of our prototype we used a .797 in lip as a reference.

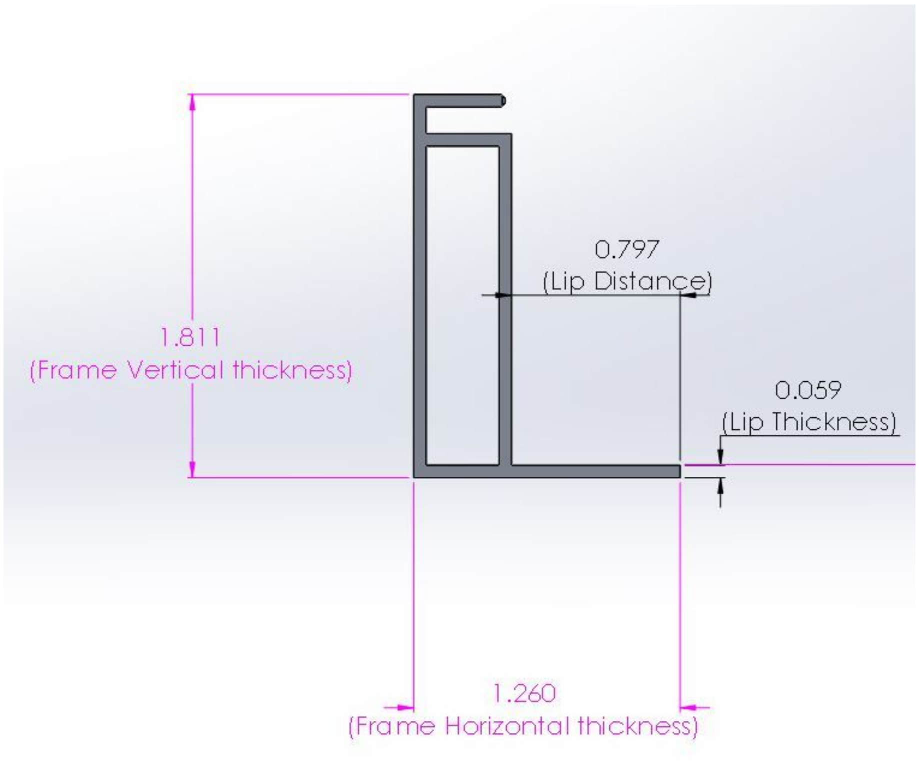


Figure 2. Cross section of a solar panel frame.

The second design requirement was for the clamping mechanism to be able to clamp on from underneath the canopy structure. The system needs to be fully serviceable from underneath, a lot of current clamping mechanisms serve to clamp the panels from up top. Another important design specification was for the clamping mechanism to be able to withstand wind forces as strong as 2537 N and weight force as strong at 471 N.

The Solar Team also needed to sort out a cable management system. The main influence to have a cable management system is to neatly arrange the wires and terminals for the wire pathways so that it would be easier to integrate with other canopies later down the line in production with the solar panel racking system, as well as protect the wires from crimping and avoiding anything that could potentially damage the cables. This would help also lead into the necessary electrical configuration of the solar panels to deliver the High Density Power Motor Team the 48 Volts that they would need to power their equipment.

State-of-the-art Literature Review

The defining components of an ATN system is the software, the electronic hardware, a guideway, the vehicles on the system, passenger stations, and the power sources (Furman et al, 2014). For this team specifically, the key features that the team needed to be aware of is the electronic components to the system, the power sources that will be driving the vehicles on the system, and the guideway itself. How the Solar Panel PV Rack would integrate into the electrical ecosystem being created by the Wayside Power Team, if the solar panels are generating enough power for the High Density Motor Team, and how it would fit onto the Guideway Team's Guideway without causing problems are all key questions that have influenced our design to make sure that the ideals of the ATN system the entire SPARTAN Superway team is trying to build is being upheld.

Similar technology that influenced the design and implementation of the team's solar frame stems from solar carports. The sleek design, the amount of room underneath the solar panels, and the simple cable management system found on standard carports guided the direction of this team to build something that could achieve the simplicity of these structures (Baja Carports, 2019). Additionally, another solar panel pv rack that influenced this team's work is the frame found at De Anza College. The design gave the team a good idea of what types of fasteners and building materials are needed to put together a rigid structure. A figure of the De Anza Solar Panel Pv Rack is shown below.

Figure 3. De Anza Solar Panel PV Rack.

Description of Your Design

The design process for the clamp was one that required a lot of research beforehand. The team set out to do some research and found various clamps from current manufacturers as well as inspiration from google patents. The team came up with 2 custom clamping designs shown below that would integrate with solar railing that is out in the market.

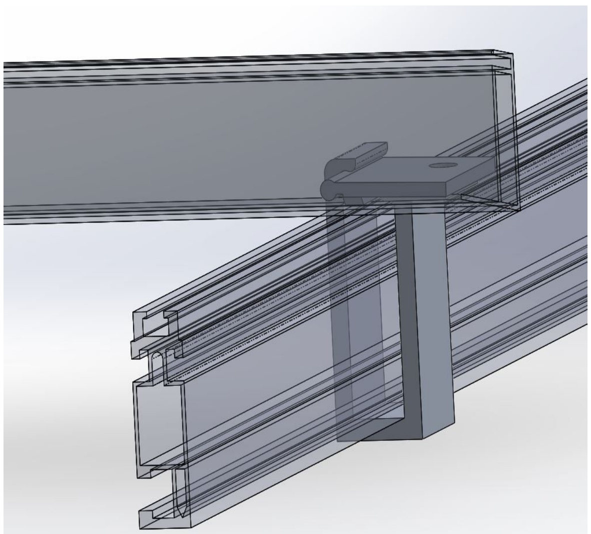


Figure 4. Custom clamp, swivel method.

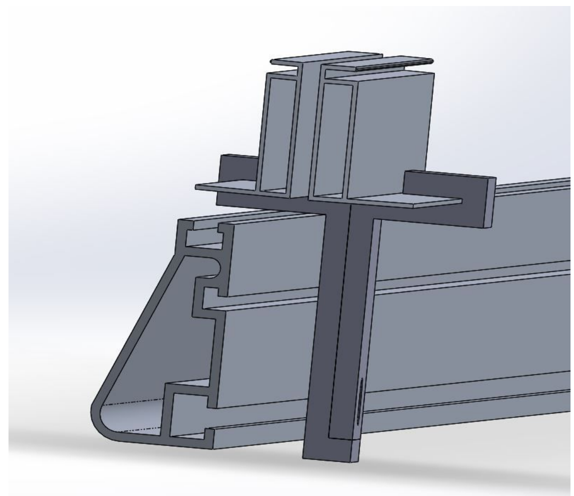
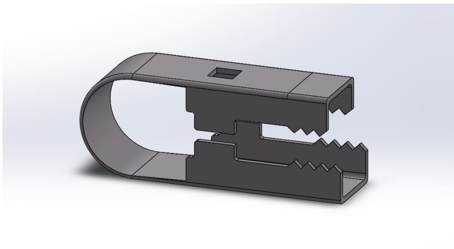


Figure 5. Custom clamp, 2 piece T method.

These clamps served the purpose of underneath servicing but with the time the team had left before the semester there would not be enough time to test and manufacture. An off the shelf solution was the next solution to our problem. Thankfully with Professor Furman's help we managed to find Powers Solar Frames and their gator clamps (Powers Solar Frames, LLC, 2019). The gator clamps were unique in that they were able to bite down onto the solar panel and C channel by tightening the bolt and nut that came with the gator clamps. This clamping mechanism can attach to the lip of the solar frame and the lip of a C channel strut effectively clamping them together quickly and securely.



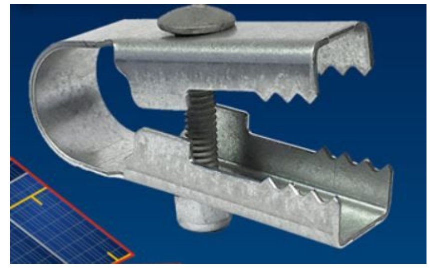


Figure 6. Gator Clamp CAD model and actual product.

The team ran FEA analysis to confirm that these clamps would be able to deal with the forces that it would be subjected to. As instructed by the manufacturer we used 4 clamps for each panel and secured it on its corners. The figure below shows the placement of the gator clamps on the solar panels and C channels.

Figure 7. Back of array showing gator clamp positioning.

The 3 panel solar array design came from taking inspiration from a variety of carports and roof installations, specifically a solar installation in De Anza college served as the benchmark for this design. The solar array base is 63.92” x 72.01” and the height of the array is about 77.20”. The base of the solar array as well as the “U” base supporting the panels were made from galvanized steel C channels which were acquired from a manufacturer at stock size and then cut down to length. The width of the “U” base is the same width of the bottom base and the supporting rails that held the solar panels are both 99”. Supporting square tubing, 63” long, were also placed attached to L brackets to better ensure rigidity. Shown below are also a set of brackets that had to be adjusted to the 45° angle. The longer brackets go at the bottom of the “U” base and the smaller 45° and 135° brackets support the square tubing. The final product was a 3 panel array at a 43.6° angle, the gator clamps were able to support the solar panels and the overall structure stood rigidly.

Figure 8. Constructed 3 panel solar array.

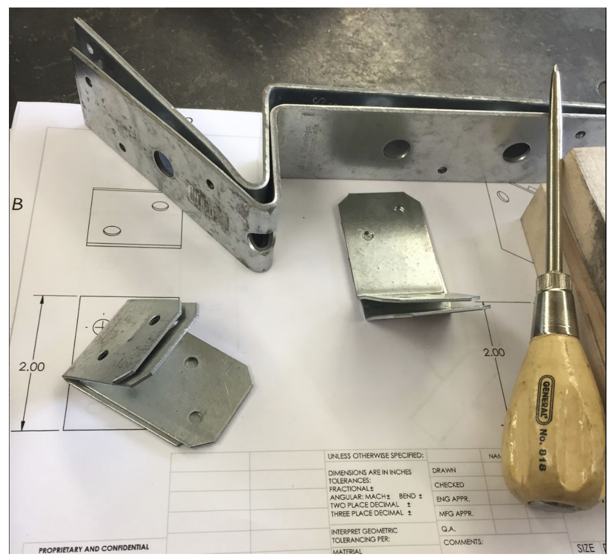
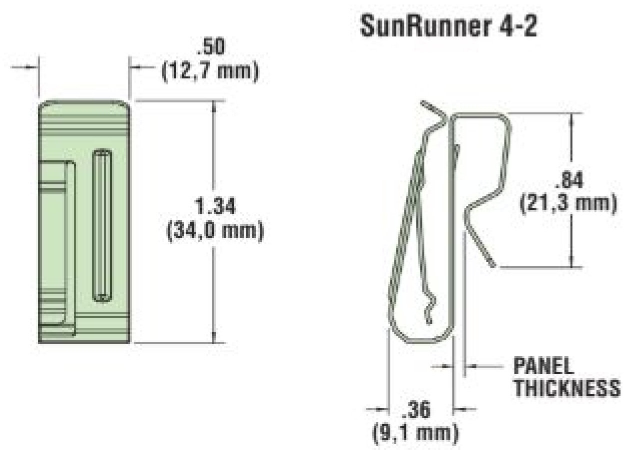


Figure 9. L brackets that had to be adjusted for the array.

An exploded CAD view is shown at the bottom to help visualize all the components necessary for the making of the 3 panel solar array.

Figure 10. Exploded CAD view of the 3 panel solar array.

For the design criteria, the team also took into consideration a cable management system to implement on the frame, as well as which electrical arrangement for the solar panels would be the most efficient given our equipment. The cable management system that the team settled on was the HEYClip Stainless Steel SunRunner 4-2 Cable Clips from Heyco, which is shown in the figure below.



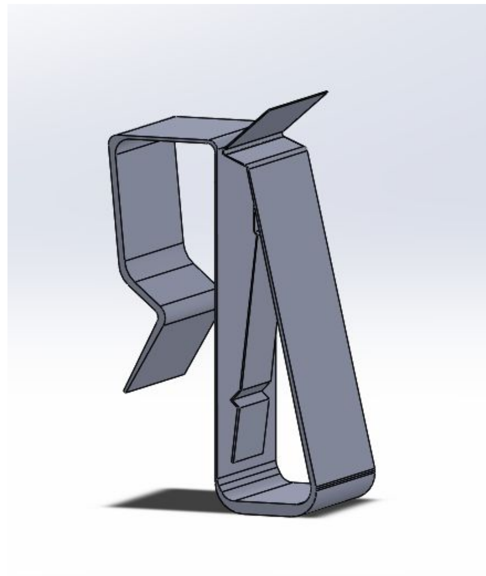


Figure 11. Heyco SunRunner 4-2 Technical Drawing. **Figure 12.** CAD Model of Heyco Clip.

These clips, while they were originally designed to focus on cable management for micro-inverters, would effectively hold onto the 0.15 inch thick purlin edges because they have a clamping range of about 0.08 inches to 0.25 inches (Heyco, 2019). They are also made out of heat treated 410 stainless steel alloy (Heyco, 2019), which allows the clips to be strong enough to deal with the wire management, while also being corrosion resistant to withstand harsh weather conditions. The clearance for the wires are also perfect for this application because it can hold up to two wires at once, and when arranging the wires for the panels, this quality makes it easier to handle the various wires.

For the overall electrical circuit for the current project, the figure below will show a flowchart of how each part interacts with each other.

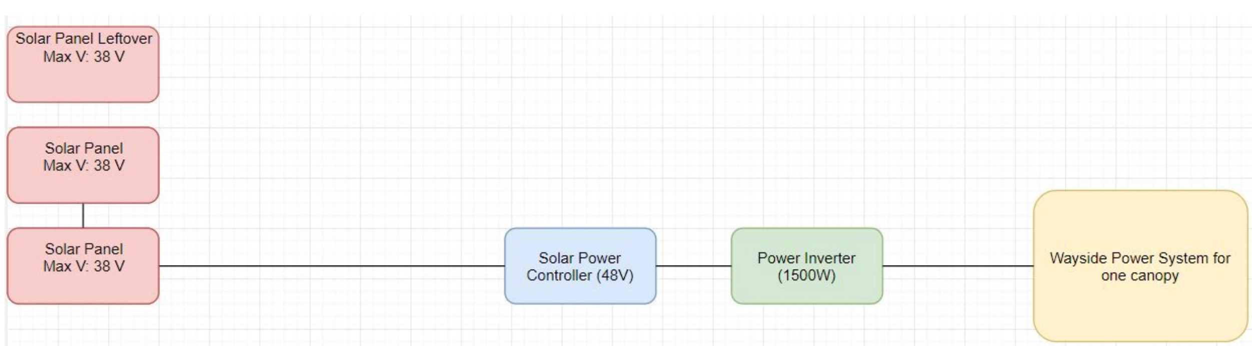


Figure 13. Solar Panel Electrical Circuit.

This current configuration will allow the maximum amount of voltage to be generated for the Wayside Power Team's system without blowing out any of this team's electronic components, especially the Solar Power Charge Controller. The Wayside Power Team needs approximately 48 Volts for the High Density Power Motor Team, and the Solar Power Charge Controller has a maximum voltage of 100 Volts (Morningstar Corporation, 2019), and each solar panel produces about 38 Volts, so the team needed to arrange the solar panels in a way that would allow for the 48 Volts to be generated while not exceeding the 100 Volts of the Charge Controller. The solution is to run two panels in series into the Solar Power Charge Controller, and to leave one lone panel to be integrated into another canopy's lone solar panel. This would allow for a voltage of 76 Volts, well in the working range of this project. The team also added 2 in-line fuses rated up to 15 Amperes to protect Solar Power Charge Controller, because its maximum rated current is 15 Amperes (Morningstar Corporation, 2019).

Analysis/Validation/Testing

For preparation on testing our parts, the team wanted to make sure that the wind loading that would be used for testing would be as accurate as possible while providing a big enough safety factor to ensure safety. To acquire a proper testing value, the team decided to follow ASCE (American Society of Civil Engineers) Standard 7-05 for the wind loading. The figure below shows the suggested design wind speed for San José, California, 85 miles per hour (Applied Technology Council, 2019).

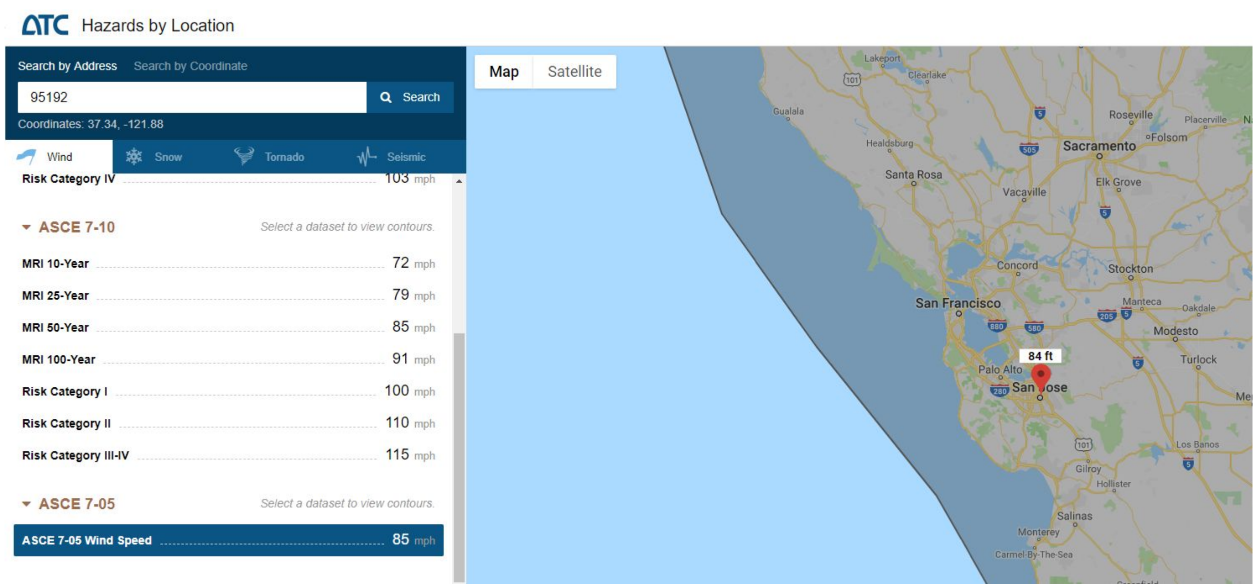


Figure 14. ATC Hazard for San José, California.

To find the wind force for this project, the team used the force equation (National Energy Foundation, 2019) shown below:

$$F = (qs) * Cpnet * Ca * A \quad (1.)$$

where the term "F" equals the force produced by the wind. The term "qs" equals dynamic wind pressure and is determined below because of the multiple steps required to find this value. The term "Cpnet" equals net pressure coefficient, and from ASCE 7-05 Standard, is equal to an upwards pressure of 11.9 psf and a downwards pressure of 13.0 psf. The term "Ca" equals the size factor, which would reduce to a value of 1 if the diagonal length of the solar panel array was less than 5 meters, but since the value is larger, the value of 2 was selected for added safety. Finally, the term "A" equals the area of the solar panel, which is 32.5" x 62.0".

The value of qs can be determined using the equation (Barkaszi & O'Brien):

$$qs = (0.00256) * Kz * Kzt * Kd * V^2 * I \quad (2.)$$

where the term "Kz" equals the velocity pressure exposure coefficient and has a value of 0.98 at 30 feet in the air (ASCE/CEI, 2006), chosen as a high value for added safety. The term "Kzt" is the topographic factor which comes out to being 1 (ASCE/CEI, 2006). The term "Kd" is the Wind Directionality Factor, and since the solar panel is being hit directly, the value of this variable is 1 (ASCE/CEI, 2006). The term "V" equals the design wind velocity, which comes out to 85 miles per hour (ASCE/CEI, 2006). Finally, the term "I" equals the importance value, which can be determined by the occupancy of the structure, and since this is a solar panel frame, it does not have any occupancy and therefore has a value of 1 (ASCE/CEI, 2006). Plug all of these values into the equation and it comes out to be approximately 16.87 psf.

Before continuing with the suggested wind speed, the breaking force of the solar panels needed to be established. The solar panels that the team has decided on are the Sharp NE-170U1, which have a surface area of 32.5" x 62.0" (826 x 1575 mm) and a maximum load of 50 psf (2400 Pascals) (Sharp Corporation, 2019). The maximum force on the panels therefore come out to approximately 415.03 lbf (1846.16 N). Since the actual angle of the solar panel is at 43.6 degrees and the breaking force of that would be at 1846.16 N, the speed that corresponds to this value would actually be at 82 miles per hour, so that will be the new value for term "V".

Heading back to equation one and plugging in all the values for each variable, the final value for the upward force on the panel comes out to be 521.93 lbf (2321.66 N) and a downward force of 570.18 lbf (2536.27 N). Since the team needs to be working with the maximum value, the design value chosen for the wind force would be 2537 N. The figures below show the angle of where the solar panel is measured and the graph below shows the corresponding values of wind force of 2537 N at each of the angles.

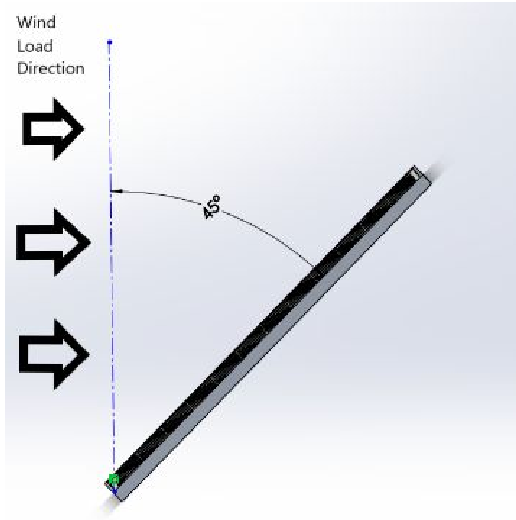


Figure 15. Solar Panel Angle Measurement.

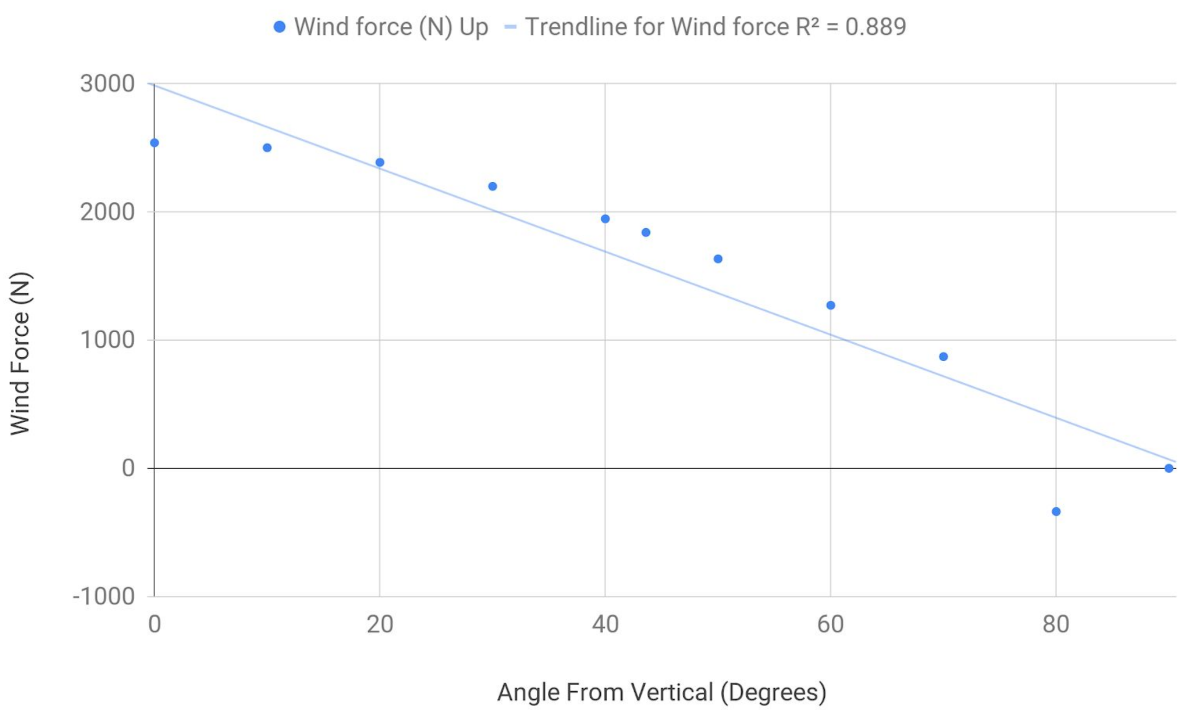


Figure 16. Solar Panel Force v.s. Angle Graph.

Having established that the solar panels would break at 82 miles an hour at 43.6 degrees, the team has a basis of where to go to test the different parts of the frame. Since the team wants to ensure that the parts will be strong enough to handle the wind loading, the wind force that will be subject to them will be 2537 N, equivalent to 96 miles per hour of wind.

Before any FEA testing can be performed, however, the team also needed to make sure that the loading from the solar panels weight was accounted for. The weight per panel given by the data sheet for the solar panels are 35.3 lbf (157 N), and since there are 3 panels, the loading would be 471 N. With this value and the wind loading, the parts can be tested properly. The parts are all tested separately due to difficulties with ANSYS, so to ensure that all the parts will be more than capable of handling minor stresses, they will be subjected to maximum loading individually.

For the Gator Clamps, since they are at 43.6 degrees along with the panel, the force will be 2879 N. Shown below are the figures for the Von-Mises stresses and the total deformation for the Gator Clamps when forces are in compression, as well as a figure of a Gator Clamp before testing.

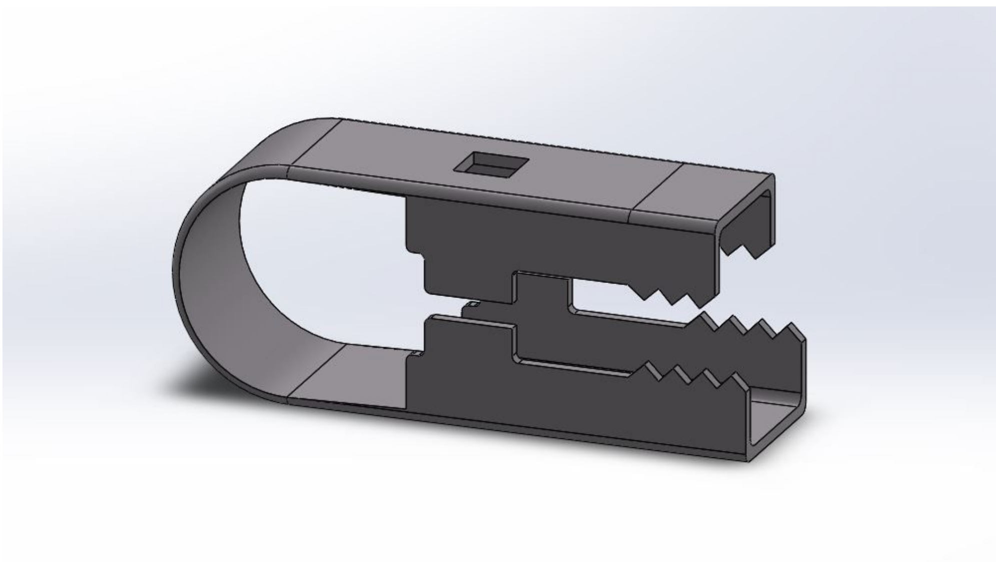


Figure 17. Gator Clamp before testing.

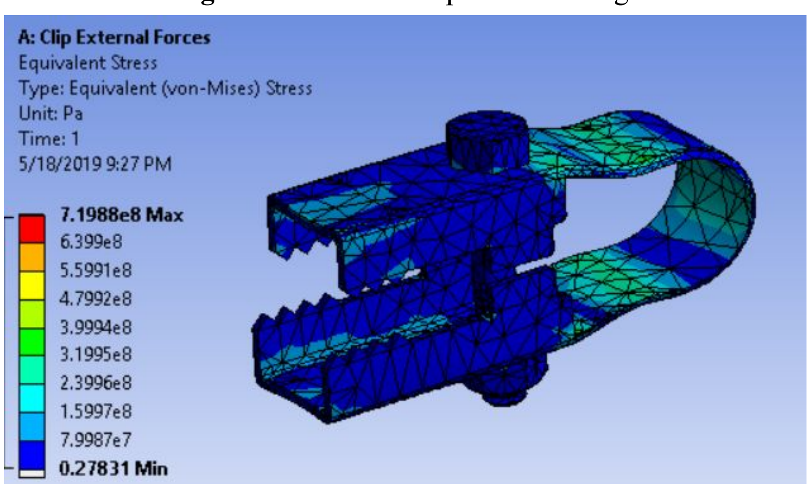


Figure 18. Gator Clamp Von-Mises Results.

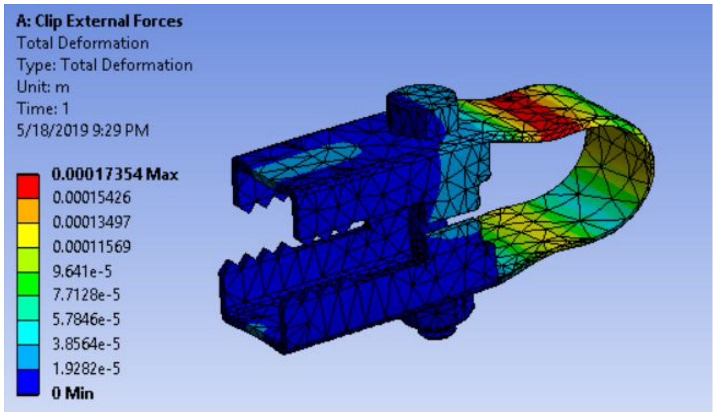


Figure 19. Gator Clamp Deformation Results.

As shown from the figures 18 and 19, the clamps experience a maximum Von-Mises stress of about 2.39e8 and a total deformation of about 0.173 mm, showing that they can easily handle well beyond the force needed to break the solar panels. Since the Von-Mises stresses and the total deformations are similar for a tensile orientation, the compression results will only be considered.

For the structural purlins, 3008 N of force from the panel weights will be used for the frame base purlins, and 2879 N for the other purlins in the frame. The figures of a purlin before testing, the Von-Mises stresses, and the total deformation are shown below for all the base purlins and remaining purlins

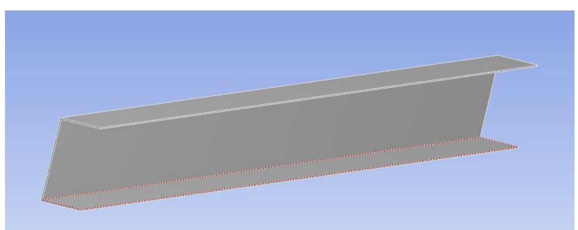


Figure 20. Purlin before testing.

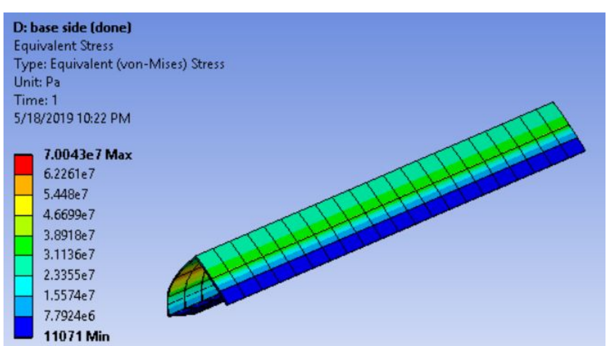


Figure 21. Base (side) Purlin Von-Mises Results.

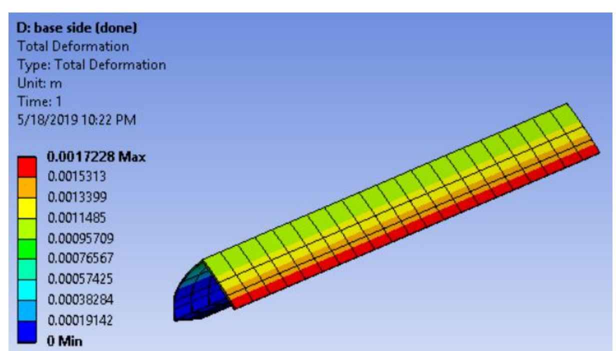


Figure 22. Base (side) Purlin Deformation Results.

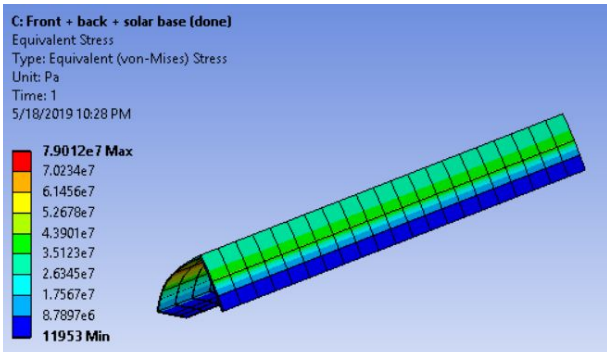


Figure 23. F/B/S side Purlin Von-Mises Results.

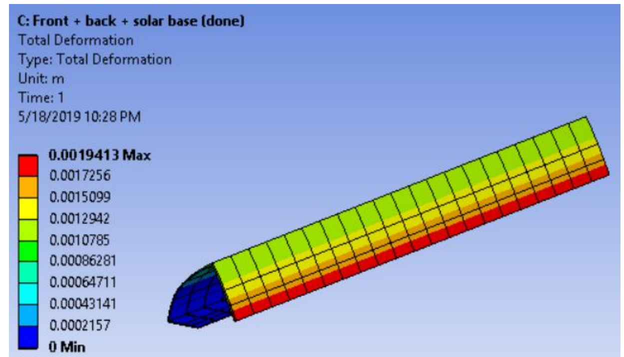


Figure 24. F/B/S side Purlin Deformation Results.

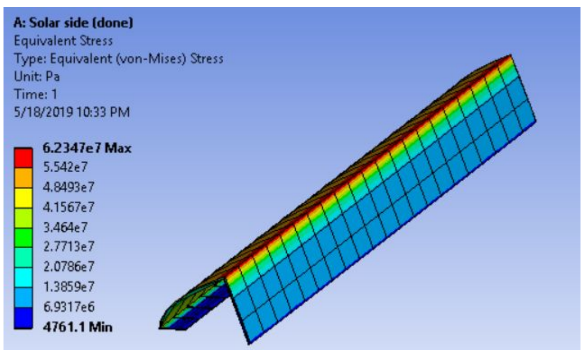


Figure 25. Solar(side) Purlin Von-Mises Results.

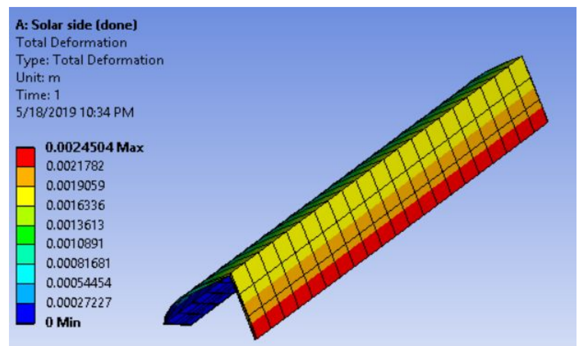


Figure 26. Solar(side) Purlin Deformation Results.

From the figures 21-26, the purlins hold up fairly well, only encountering a maximum deformation of about 1.7 mm to 2.5 mm, which in the scale of the frame, is insignificant.

Moving onto the square bar that runs vertical and will help support the solar panels, they will be analyzed using 2879 N . Shown in the figures below is the square bar before testing, the Von-Mises stresses from testing, and the resulting total deformation.

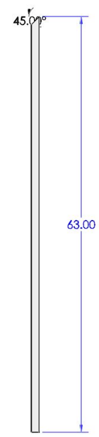


Figure 27. Squarebar before testing.

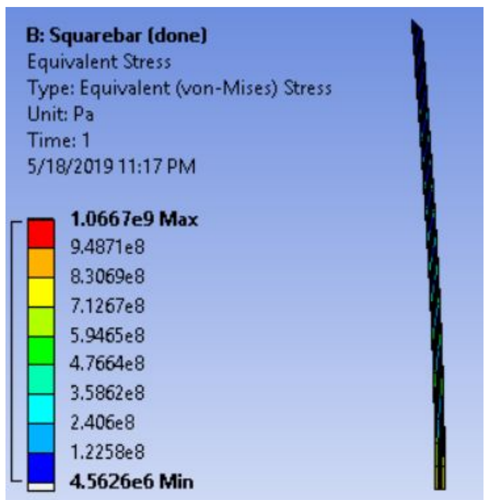


Figure 28. Squarebar Von-Mises Results.

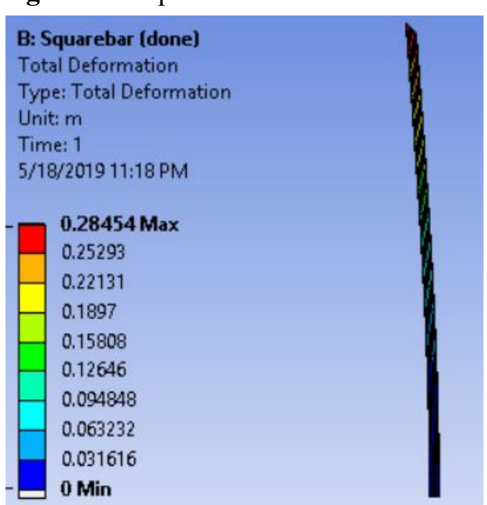


Figure 29. Squarebar deformation Results.

From the figures, the square bar is concerning when it comes to the total deformation of the bar, especially when the deformation is close to 3 cm, so making sure that this part was secured with brackets on both the top and bottom portions was crucial.

Finally, analysis on the brackets were necessary to see if they will deflect too much and cause potential problems in the frame. For the strong tie brackets and the bottom bracket securing the squarebar, they will be tested with 3008 N of force, while the other brackets securing the squarebar will be tested with 2879 N of force. Below are the figures of each bracket before testing, with their respective Von-Mises stresses and their total deformations.

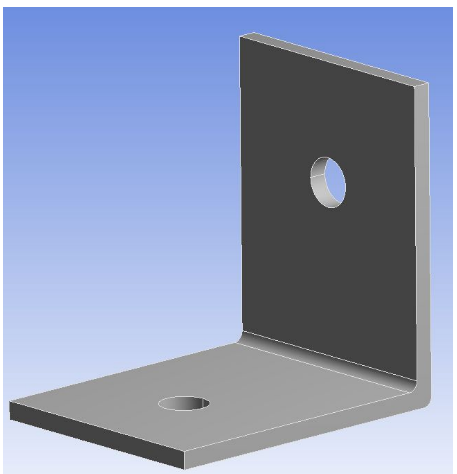


Figure 30. Strong-tie Corner before testing.

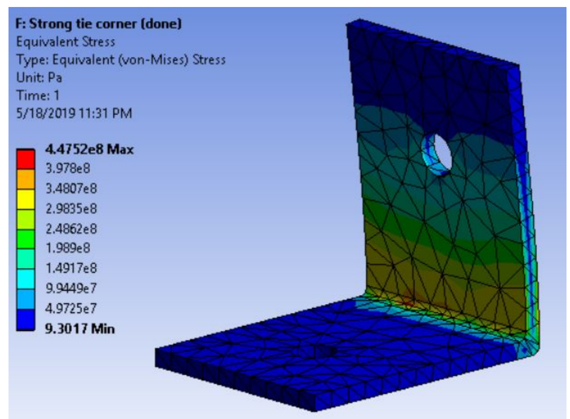
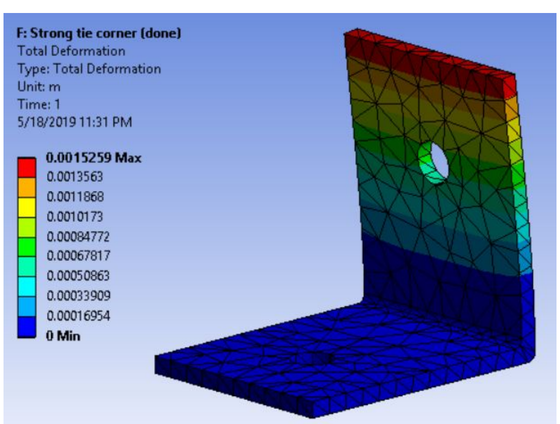


Figure 31. Strong-tie corner Von-Mises Results.



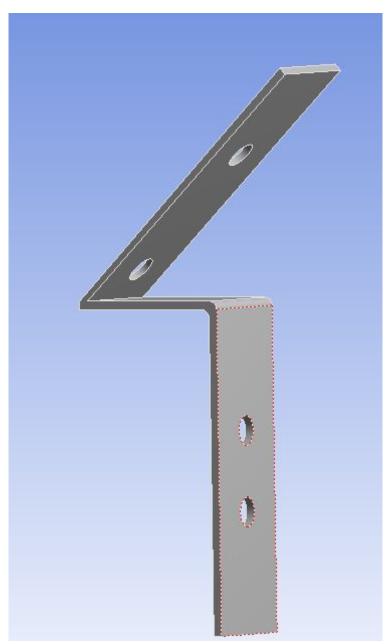
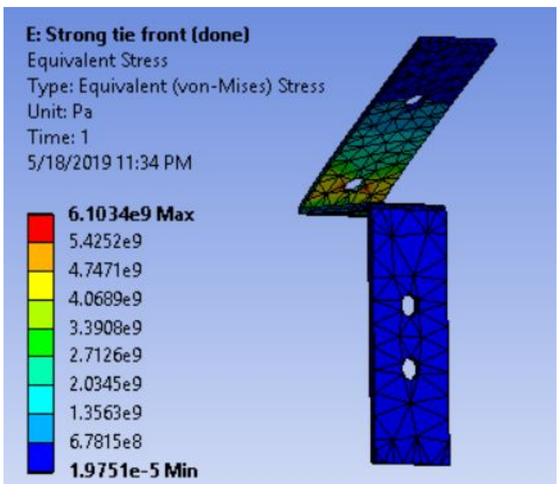


Figure 32. Strong-tie corner deformation Results.

Figure 33. Strong-tie front before testing.



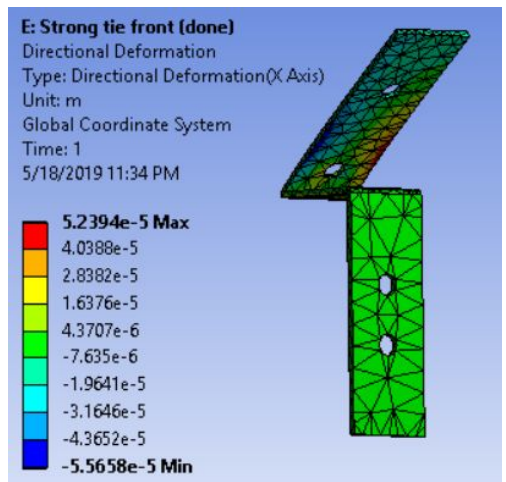
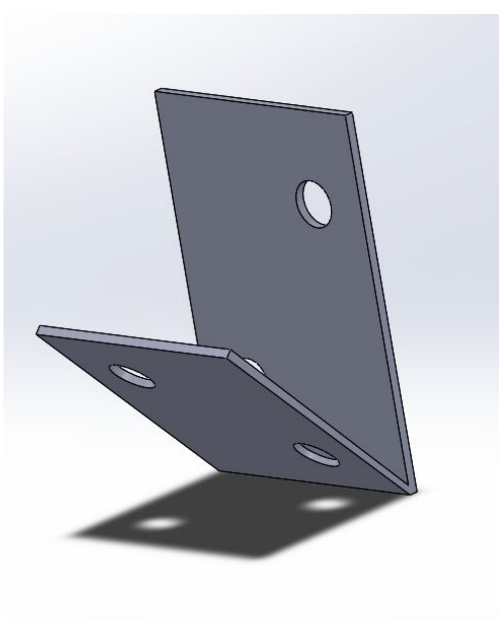


Figure 34. Strong-tie front Von-Mises Results.

Figure 35. Strong-tie front deformation Results.



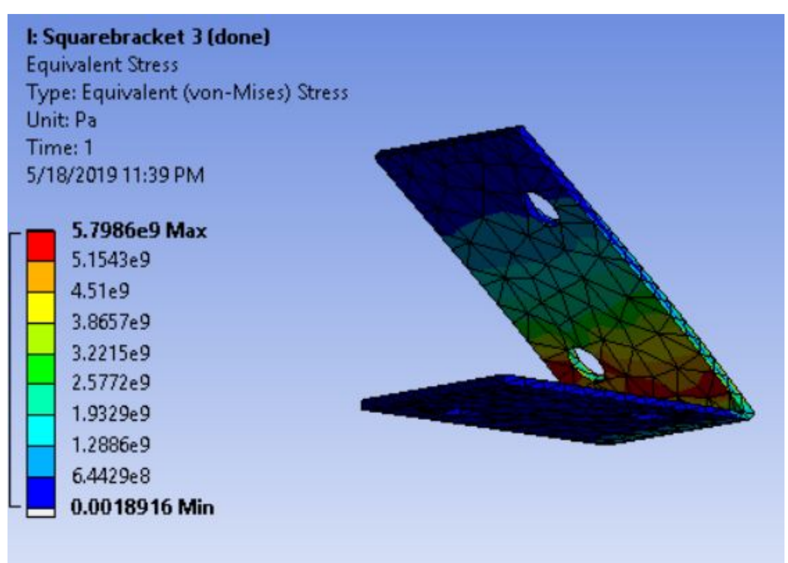
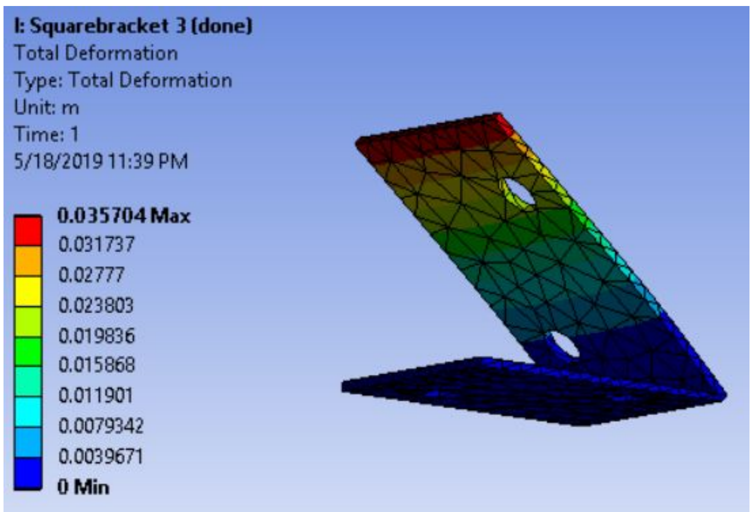


Figure 37. Squarebracket 3 Von-Mises Results.

Figure 36. Squarebracket 3 before testing.



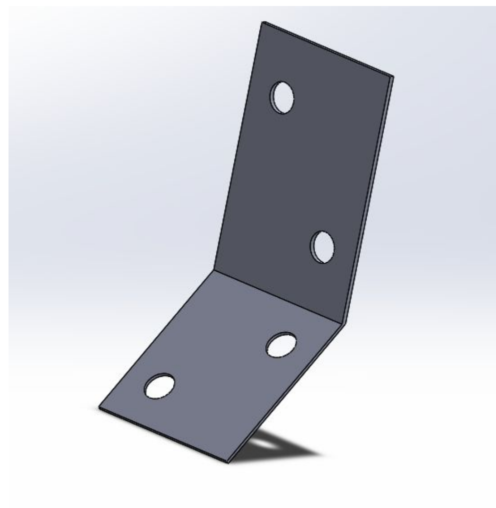
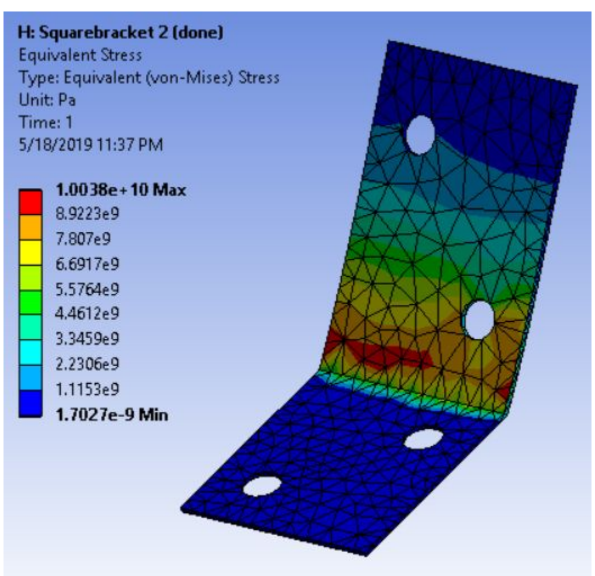


Figure 38. Squarebracket 3 deformation Results. **Figure 39.** Squarebracket 2 before testing.



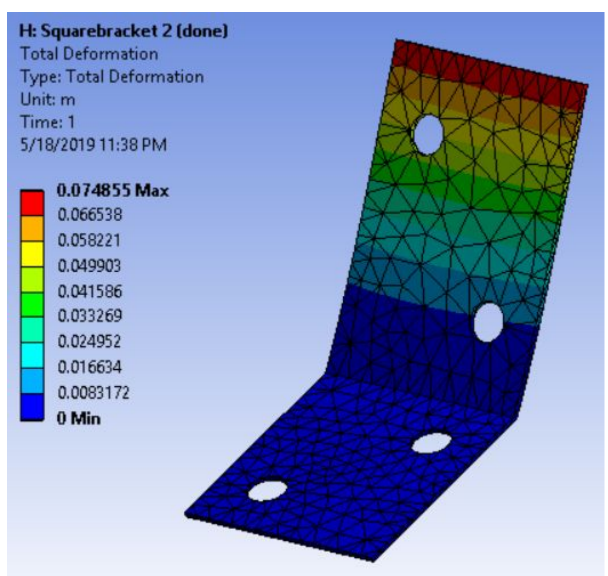


Figure 40. Squarebracket 2 Von-Mises Results.

Figure 41. Squarebracket 2 deformation Results.

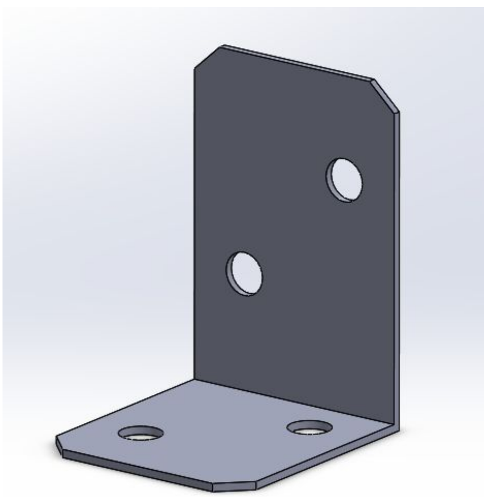


Figure 42. Squarebracket 1 before testing.

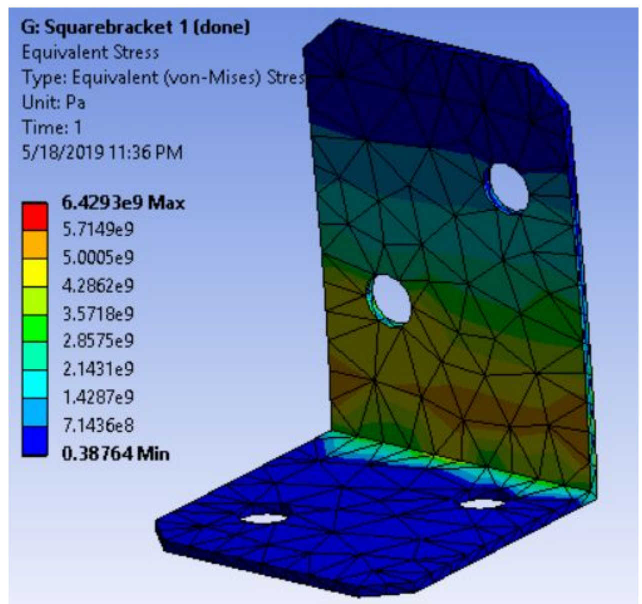


Figure 43. Squarebracket 1 Von-Mises Results.

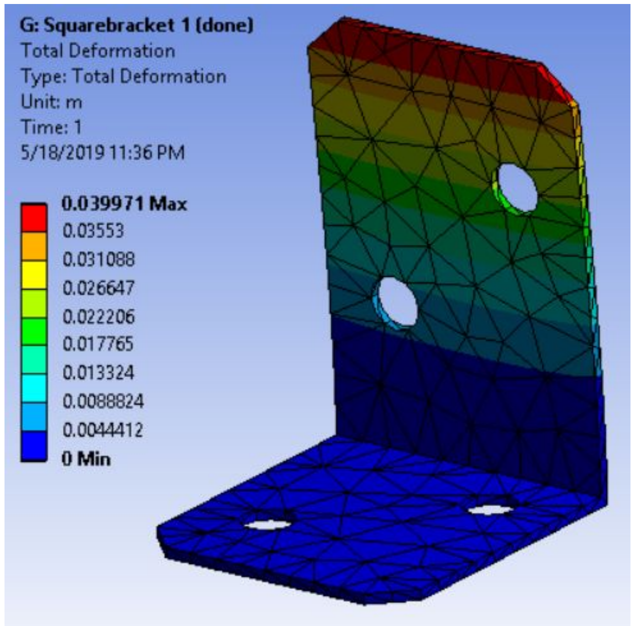


Figure 44. Squarebracket 1 Deformation Results.

Overall the brackets held up well, showing the values of each bracket's deformation, and most of them held up well. This goes especially for the strong-tie front bracket, because the circular area is a cause for concern when evaluating stresses in an object, but even with that, it deflected such a minor value that it is negligible. The only bracket that is cause for concern is bracket, "squarebracket 2", but luckily this bracket's purpose is to only keep the square bar centered, and will not be relied on for structural integrity.

For all the parts tested, they held up better than expected and they fulfill the teams requirements of being able to handle wind loading better than the solar panels can, so that if the solar panels do break on a particularly gusty day, the rest of the components will not.

Budgeting

The final cost of the project totaled at $494.45, which was much lower than what the budget intended to be. The budget intended to be $2,348.72. The larger sum was heavily weighted by solar panel and inverter costs. Luckily, those materials were given to the Solar Team and helping to reduce the total cost drastically. Below is the Bill of Materials (BOM), showing what the final project consisted of, the final total, and the intended total before the rescope. This final total includes any shipping and taxes for the items purchased.

Item Number	Part Name	Description	Quantity	Cost Per Unit	Total
1	Dek-ing Purlins (ft)	Framing	60	$4.27	$256.20
2	Gator Clamps	Clamp	50	$1.50	$75.00
3	Gator Clamps, shipping	shipping	1	$33.14	$33.14
4	Plain Square Tube	Support	2	$26.22	$52.44
5	Everbilt Create-a-bolt	Hardware	4	$5.24	$20.96
6	Everbilt Bolts	Hardware	26	$0.53	$13.78
7	#8 x 1/2 in self drilling screws	Hardware	1	$6.78	$6.78
8	Simpson Strong-Tie	Corner Braces	8	$0.61	$4.88
9	Heyco S544	Wire clips	50	$0.52	$25.82
10	Fuse Holders	Fuse Holder	1	$5.45	$5.45
				Final Bill of Materials Total	$494.45
				Expected Bill of Materials Total	$2,348.72

Table 1. Bill of Materials.

Results and Discussion

The project came out as a success, meeting all the design requirements set out in the team's re-scope. The clamping mechanism from underneath the solar panels grab onto the frames of the solar panels and dig in so that they will not become loose and they hold as predicted. The cable management effectively cleans up the clutter from underneath the solar panels and directs the cables in a neat fashion to the electrical components they need to in order to integrate with the Wayside Team's Power System.

This is good news all around for the team because with the current frame design in place, scaling it will be fairly simple, allowing for future teams to resize the frame to whatever size they might need to accommodate the solar panels they desire. The cable management will also make the job of integration a more simple process than before, which can help future teams later on when different aspects of the SPARTAN Superway project need to be combined together. The simplicity of the design also aids how the team was able to construct it. Since the majority of the pieces for the frame are off-the-shelf, minimal manufacturing needs to be done, and producing more frames could be as easy as setting up an assembly line, making it easier for future installers of this solar panel frame to put together multiple frames and implementing them on the Guideway.

Manufacturing Process

It is important to know and understand how to manufacture and assemble this fixture in a timely manner because saving time on manufacturing and assembly will save money. This section of the report explains the method of manufacturing in detail, manufacturing and assembly steps of the small-scale prototype the first time around, what was learned the first time to improve the assembly process, and step-by-step instructions on how to assemble a full-sized unit for real life application.

First time of assembly

The small-scale that was built by the Full-Scale Solar team consisted of a base frame, solar panel frame, three (3) solar panels, twelve (12) Gator Clamps that help the solar panels in place on the solar panel frame, various hardware, and two (2) square tubings that supported the solar panel frame 45 degrees onto the base frame. The full-scale version of this project is to be built with 60 solar panels, six (6) by ten (10).

The manufacturing of the small-scale started with gathering all the components and materials together. With drawings at hand, I had an itemized count for everything that was needed to make sure that there was nothing missing. The purlins used for the base frame and solar panel frame, and the square tubing were made of galvanized steel. These were measured to size and and cut using a power saw, shown in Figure 1. After the purlins and square tubing were cut to size, the edges were deburred to avoid possible injury during assembly and to ensure tighter tolerances in the assembly phase.

Figure 45. Measurement and cutting phase.

After deburring the edges of the purlins, the purlins were placed in an “outline form”, shown in Figure 2. The purpose of this was to lay out the the pieces before it was to be bolted together. During this step, I marked the pieces to keep track of the exact orientation they were placed in. Here I took the 90 degree L-bracket and placed them on the interior corners of the purlin connection points. I marked them with a permanent marker to mark where drilling needed to be for the bolt to go through. At this time, this not only applied to the base frame but the solar frame as well.

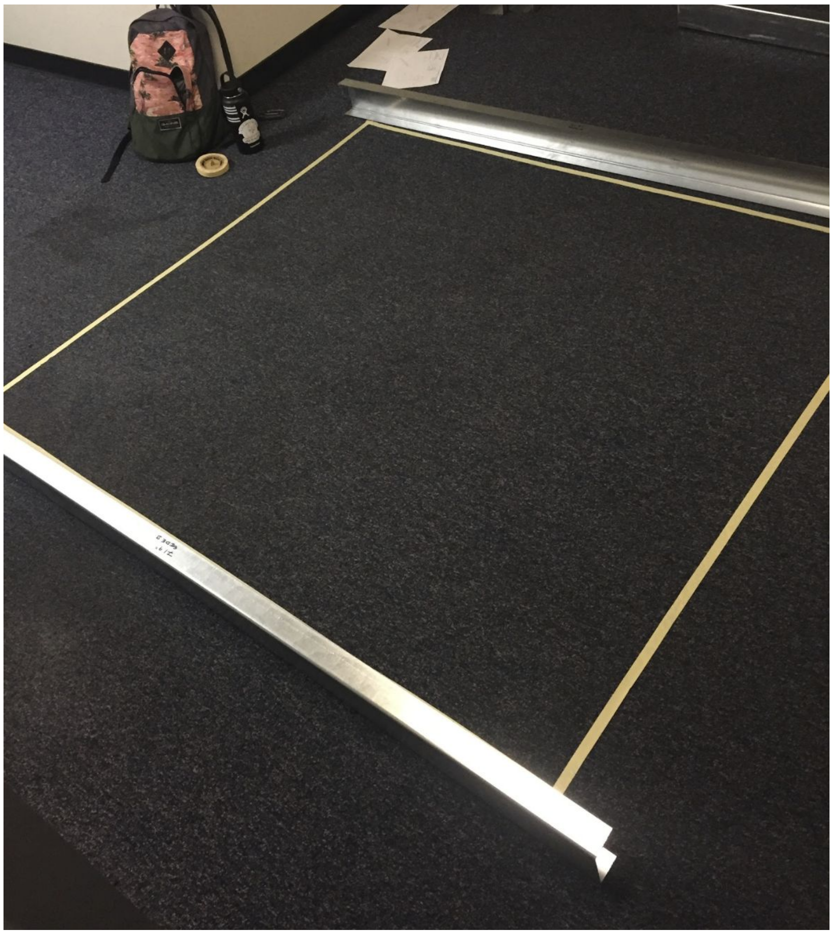


Figure 46. Process of laying out purlins for base frame.

The base frame consists of four (4) pieces of purlin and the four (4) L-brackets, making this consist of eight (8) holes to drill. The solar frame consists of three (3) pieces of purlin and two (2) L-brackets, making this consist of four (4) holes to drill. In the next step of drilling, twelve (12) total holes were drilled. Because a hand drill was used on galvanized steel, the drilling process was slow to ensure safety. When all twelve (12) holes were drilled the purlins were laid out in their assigned placement. With the L-brackets lined up to their respective holes, hardware was added to connect the purlins to the L-brackets. The hardware used here consisted of bolts, nuts, washers, and lock washers. Figure 3 and Figure 4 show the assembled base frame and solar frame, respectively.

Figure 47. Assembled base frame.

Figure 48. Assembled solar frame.

The next step in the small-scale assembly was mounting the solar panels to the solar frame. The first time mounting the solar panels to the solar frame is different than what would happen normally because this was the first time doing this. The first time consisted of placing the solar panels in a row faced down. After lining the solar panels up as squarely as possible, the solar frame was placed on top of the bottom of the solar panels. Next, the Gator Clamps were used to hold the solar panels onto the solar frame. When installing the Gator Clamps an issue occurred of not enough contact on the side that bit into the solar panels. In order to resolve this the Gator Clamps were flipped upside down to have the one side bite more. Something to note about the Gator Clamp is that one side is actually longer than the other. This is the side that bit into the solar panel. Another thing to note is that when the fixture was assembled the second time, the team realized that the orientation of the Gator Clamps actually did not matter. Due to more helping hands, the structure was more squared and aligned and, therefore, can be assembled as they were intended to be. Figure 5 shows the assembly process of the solar panel to solar frame done by one person.

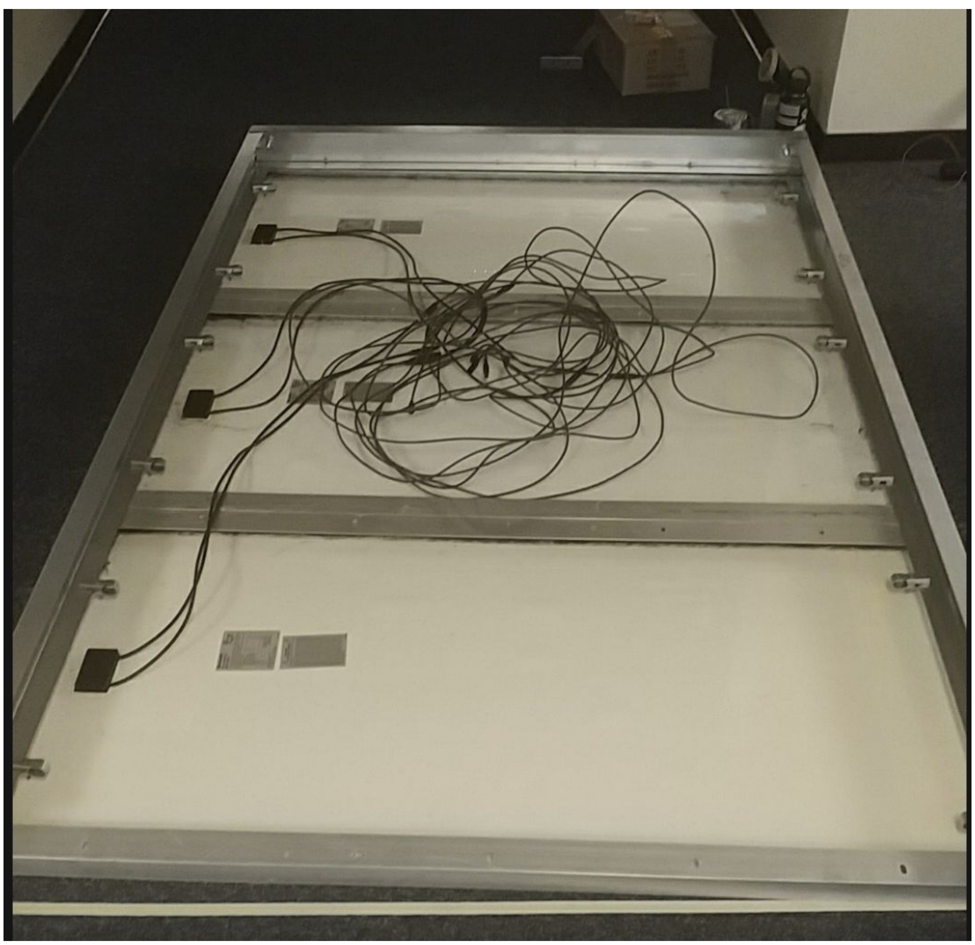


Figure 49. Solo assembly process of solar panel to solar frame using Gator Clamps.

The next portion of this manufacturing and assembly process was customizing the brackets used to connect and support the bottom of the solar frame, and the brackets that would support the square tubing in place. In addition, cutting the square tubing at a 45 degree angle occurred. The previous manufacturing steps were able to happen at the Superway facility. Because these brackets needed to be bent using the proper equipment, and the square tubing needed to be braced, these pieces were brought to the shop located in the Industrial Studies Building at San Jose State University. Figure 6 and Figure 7 show the brackets used for the bottom of the solar frame and the brackets used for the square tubing before modification, respectively.

Figure 50. Brackets used for the bottom of the solar frame before modification.

Figure 51. Bracket connecting square tubing to solar frame and base frame before modification.

The square tubing was cut at a 45 degree angle using a combination square to measure the angle, then braced and held using a bench vise. With this secured, a hack saw was used to cut the 45 degree angle, shown in Figure 8.

Figure 52. Square tubing cut at 45 degrees.

Next, the brackets were bent using blocks of wood. One block was cut at a 45 degree angle, and the other was kept at a 90 degree angle. The first set of brackets made were the two (2) larger brackets used to support the bottom of the solar frame. These were made by placing the 45 degree angle cut piece of wood on the side that would be formed at a 45 degree angle on the bracket. The other piece of wood was placed on the other side so the C-clamps used had a place t to grip on. These brackets were thick and were bent into shape using a hammer. The second set of brackets made were four (4) of the eight (8) smaller brackets. Two (2) of these were bent to a 45 degree angle, and two (2) were bent to a 135 degree angle. When forming the two (2) 45 degree brackets, a side of the bracket is clamped in between the two blocks of wood. Using a hammer, the open side of the bracket would be pounded towards the 45 degree cut block. When forming two (2) 135 degree brackets, the 90 degree bent bracket would be carefully pounded into the shape of the 90 degree and 45 degree block applied side by side. All of these bent brackets can be seen in Figure 9.

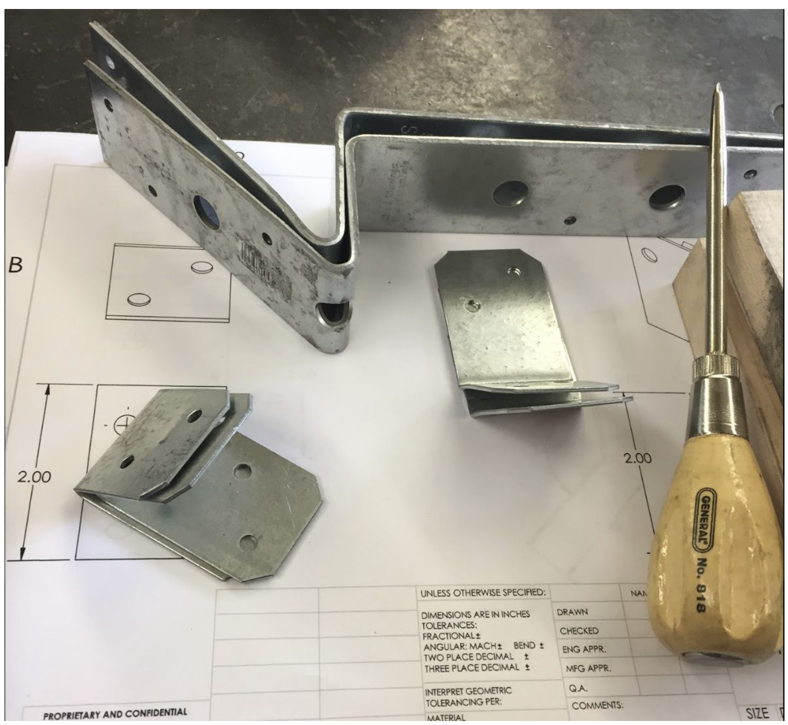


Figure 53. Bent brackets manufactured in the Industrial Studies building.

After the square tubing and brackets were modified, they were brought back to the facility with the rest of the materials. The next steps involved drilling and tapping holes to attach the brackets to the purlins and square tubing. Four (4) of the eight (8) brackets were kept at their original 90 degree bend. These were placed and drilled into the top of the side base frame, two (2) each side. Here is where the base of the square tubing was attached. The top of the square tubing is where the bottom of the solar frame rests on. Here is where the two (2) 45 degree and two (2) 135 degree brackets are placed and drilled into. Each bracket consisted of four (4) #8 x 1/2 inch self drilling screws. The final product is shown below in Figure 10.

Figure 54. Fully assembled small-scale solar canopy.

Improvements on how to assemble the small-scale

Although this described the process of how the small-scale was manufactured and assembled, it was realized throughout the assembly process that there are better ways to go about it. The next section discusses the recommendations instead of the steps taken along the way.

When assembling the solar frame at a 45 degree onto the base frame, it is recommended that the solar frame not have the solar panels clamped on. Instead, the solar panels should be clamped last. This will ensure safety during assembly because the solar panels consist of the majority of the weight of the structure itself. Additionally, the order of assembly should be as follows:

1. Base frame
2. 90 degree brackets
3. Square tubing

4. Solar frame (empty)
5. Connect square tubing to solar frame
6. Solar panels

Assembling the solar canopy in this order can be easily done with three (3) people. The first time around when the solar frame had the solar panels attached, six (6) people were required to move the solar frame and panels at a time. This new way of assembly is time efficient and keeps the safety of the installers in mind by moving around less weight at a time. As stated before, it can also be noted that assembling the solar panels in this fashion fit more squarely with the purlins. Therefore the Gator Clamps can be used as they are intended to be.

Large-scale manufacturing and assembly

Another topic to discuss is the manufacturing and assembly process of a large scale version that would be implemented in real-life applications. This next section discusses the method of manufacturing and assembling a larger version of what was built for the small-scale project for real-life applications in the future.

Assuming the large scale solar panel array is to be six (6) panels tall by ten (10) solar panels wide, a large space will be needed. To give an idea of space this would need, the longest part of the large-scale application can be measured at about fifty eight (58) feet, the width of the structure would measure at about twelve (12) feet, and the tallest point is at about twelve (12) feet high. A large warehouse space would be ideal because of its protection from the elements, like rain and wind. Any wet surface could have the potential to create a slippery work space, being unsafe for workers. In addition, protection from wind is important when dealing with solar panels because wind force can pose as a danger to workers. Any gust of wind would make it difficult for workers during assembly.

Some aspects of the large-scale would be different from the small-scale canopy. First the base frame would be cut from four pieces, to size at about 58’’ x 12’’, shown Figure 11. Holes would be placed at the corners just like the small-scale would be.

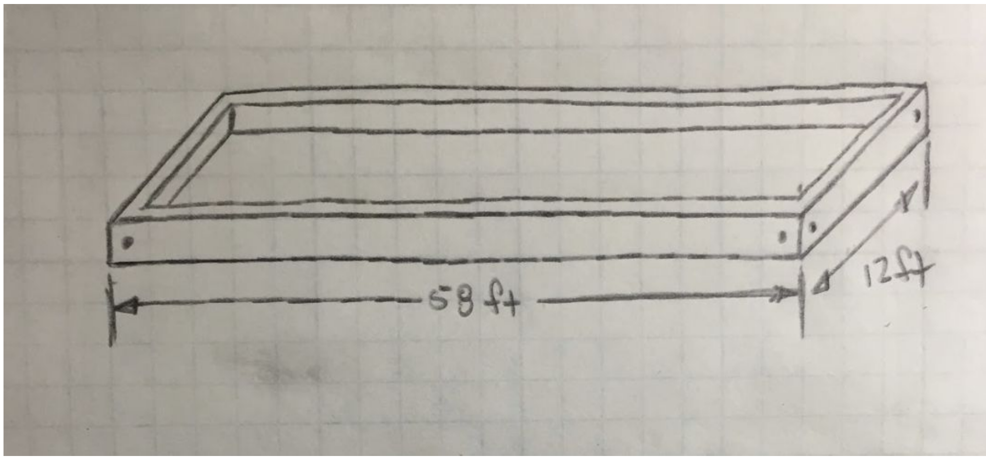


Figure 55. Sketch of large-scale base frame.

When making the frames that the solar panels rest on, this would be different. Ideally, each row of six (6) solar panels would have its own frame. This would result in ten (10) solar frames to be manufactured and assembled. The width of the solar frame would be the same as the small-scale, but be much longer to have six (6) solar panels resting on them. This would make the longest part of each solar frame at about seventeen (17) feet long, shown in Figure 12.

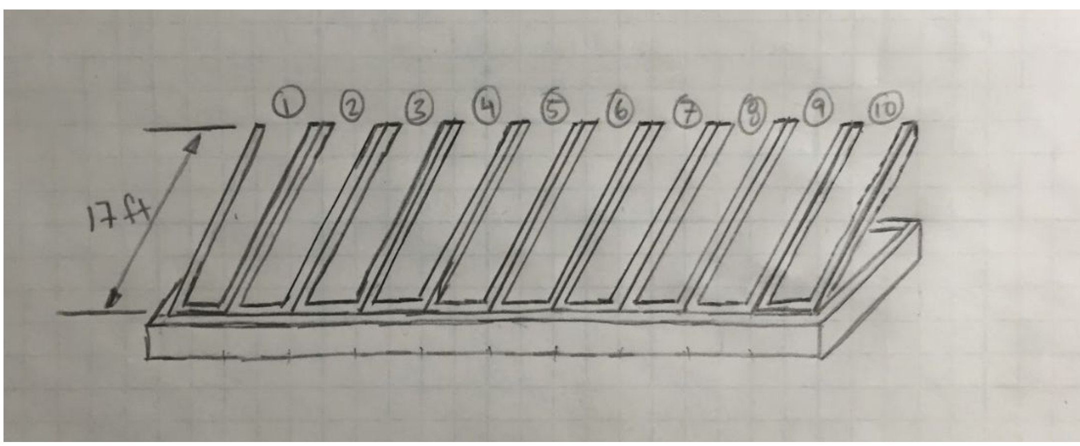


Figure 56. Sketch of solar frames attached to base frame. Notice, square tubing is not included in this figure.

The assembly of the square tubing and brackets would be the same as the small-scale, with the exception of the length of the square tubing. Again because the height of this would be about two (2) times larger than the small scale, the square tubing used would correlate to the appropriate length. In addition and to clarify, because the base frame one giant square, there would not be a place to have the square tubing inside the frame to connect to. In order to combat this, a support piece, such as a piece of hollow rectangular tubing, would be placed on top of the base frame parallel to the longest side, shown in Figure 13. This would provide a spot for the vertical square tubing to rest and be supported on.

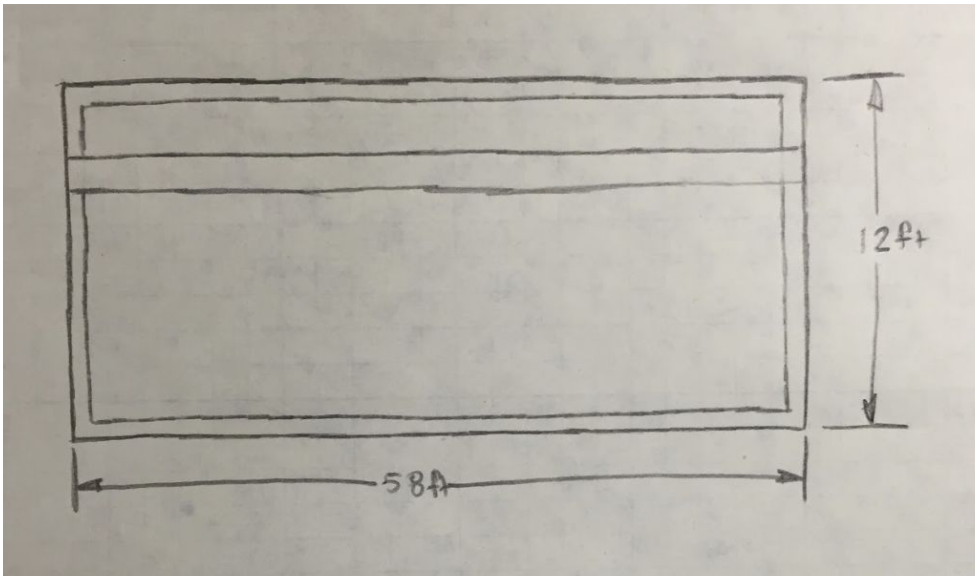


Figure 57. A bird's eye view of hollow rectangular tubing on top of the base frame.

Now imagine what the skeleton of the large-scale assembly consists of so far:

1. Rectangular base, about 58' x 12'
2. One (1) 58' long hollow square tube that is attached and is placed on top of the base frame, parallel with the longest side.
3. Twenty (20) vertical pieces of square tubing at about 12' tall, resting on the long hollow square tubing.
4. Two (2) 90 degree brackets each at the base of the square tubing
5. Ten (10) frames to hold solar panels at approximately 45 degree angle
6. Two (2) 45 degree and two (2) 135 degree modified L-brackets per frame holding the solar panels

Assembling part 1. and 2. can be assembled on the ground of an open warehouse. When assembling parts 3 through 6, height is an issue. A scissor lift can be a safe means of reaching that height, safer than using a ladder for this application.

The next step would involve solar panel placement and using the Gator Clamps. Similarly to the small-scale assembly, the solar panels on the large-scale assembly would be installed row-by-row from the bottom to the top. At each placement of the solar panel, four Gator Clamps would be used to secure each solar panel. Again, these would be tightened from the bottom. Something to think about is the difficulty of getting solar panels up onto the solar frame at a relatively tall point in the installation. A solution to this would be hooking each solar panel with cords that would not damage the solar panels to a Gradall, then using a Gradall to carefully place the solar panels in the general area where it would need to be installed. Hovering near the spot of installation, a worker would come from underneath on a scissor lift and slowly and precisely move the panel into place. Here, the worker would continue to use the Gator Clamps to attach the solar panels to the solar frame. Using a tool set to a standardized torque, the worker can quickly tighten the clamps to the desired torque.

After the large-scale assembled is built, it can be hoisted onto a flatbed semi-truck with a Gradall and cords. After being secured to the flatbed a teamster, someone who transports equipment, would deliver this assembly to the site for installation to interface with the rail system.

Wire and Circuit manufacturing

Additional manufacturing was needed to construct connections for the solar panel electrical circuit. The team needed to add in-line fuse holder cable with the solar panel cables and direct it into the Solar Power Charge Controller, so to make this connection the team had to first cut the MC4 solar panel cable so that the copper would be exposed and soldered the MC4 cable and the in-line fuse holder cable together and secure them with shrink wrap. With this minor manufacturing addition, it will ensure a proper connection and no power loss due to improper interaction.

Conclusions and Recommendations for Future Work

Overall the Solar Team has successfully met all design requirements. An off-the-shelf solution for a clamp that can help service the array from underneath was found with the gator clamps. They a cheap way for the panels to be clamped from underneath. They also clamp well to the 0.797” lip clearance available on the solar panel frame, it is also feasible to clamp other types of solar panel frames using this camping mechanism. The team was able to fully install and uninstall any panel on the solar array, from underneath. The structure itself was very stable and did not lean or sway. The various FEA that was done on the clamp and the structure members prove that the prototype will be able to sustain wind forces up to 2537 N and a maximum solar panel weight load of 471 N. The prototype was also cost effective, substantially reducing the amount of money that was originally thought to be spent on a design like this.

Although we believe the project to have been successful, we would have liked to avoid a re-scoping of the project in the first place. All was not perfect starting the second semester, better communication between the Team and the advisors could have prevented a re-scoping in the first place. Keeping everyone accountable and adhering to strict tasks and deadlines could have drastically improved our performance and in turn our project. A recommendation for the years to come is to properly communicate and hold everyone accountable for portions of the project that they are assigned to.

The solar team has learned a lot through the year. Francisco has learned about the various types of solar racking options available in the market today. Many racking systems are specifically made to work and interact with specific railings and configurations. A lot of these can prove to be useful for solar energy collection but they lack the serviceability from underneath as mst systems are placed on rooftops. Francisco also learned about the various types of clamping mechanisms that are available, many which provide a clamping force that clamps the panel from the top. This helped to better understand how solar racking and clamping mechanisms interact and appropriately find a solution that would benefit the sub team's project.

As for Jordan, he learned more about the process needed to apply wind loading for a project. Going through the common standard procedures that many engineers have to do to ensure that the design will not fail in application is important to have exposure to when transitioning into being a professional engineer. Jordan also learned how to properly set up a cable management system, the different types of systems available on the market to understand the different applications that they would be designed for, and see which one would fit this project's goal.

Patrick has learned more about the manufacturing process and how it interfaces with design engineering. When developing a product it is first designed by an engineer and then is brought to the manufacturer. Some things that can be easily designed on a CAD program can be difficult to manufacture. Patrick also learned about the importance of constant communication with others working on the same project. In order to have a project run smoothly and efficient, staying in communication constantly with others to make sure what needs to be completed gets finished, especially during times where there are many things going on at the same time.

The team is exceptionally pleased that they were able to re-scope the project and still provide a working prototype by the end of the year. Re-scoping set the team back to square 1 and the entire year long process was streamlined into a few months. The team worked tirelessly to find and create solutions to the problem at hand and deliver a result that accomplished its goals and set a framework for the future classes to build on.

There are many way to improve upon the design that the solar team has come up with. The next phase for the solar sub team is to create an adjustable solar array that can change its pitch angle to a variety of different degrees. This would allow for the solar array to be more efficient in different areas of the world where solar collection is best done at certain angles not just 45°. The next step after that is to help automate the process. Utilizing sensors and motors it can be possible to automate the adjustable solar array and have it track the sun's position using weather data etc. This will help the solar array maintain peak energy generation at all times. Once the complete functionality of the solar array has been addressed then one team can focus on how it is possible to curve the structure to make it more aesthetically pleasing. Through this it is possible to have a state-of-the-art solar tracking array that will not only provide the sufficient energy the superway would need, but also a sight to see for the everyday traveler.

Some ways to improve the electrical components of this project would to be to manufacture/repurpose clamps to work as the cable management system, namely standing seam clamps, because it would allow the clips to grab onto the purlins better and not worry about them slipping off due to weather or any kind of movement. Having a more robust solar charge controller would be recommended as well because it will allow for more efficient solar panel circuit configurations without worrying if the solar charge controller will blow out.

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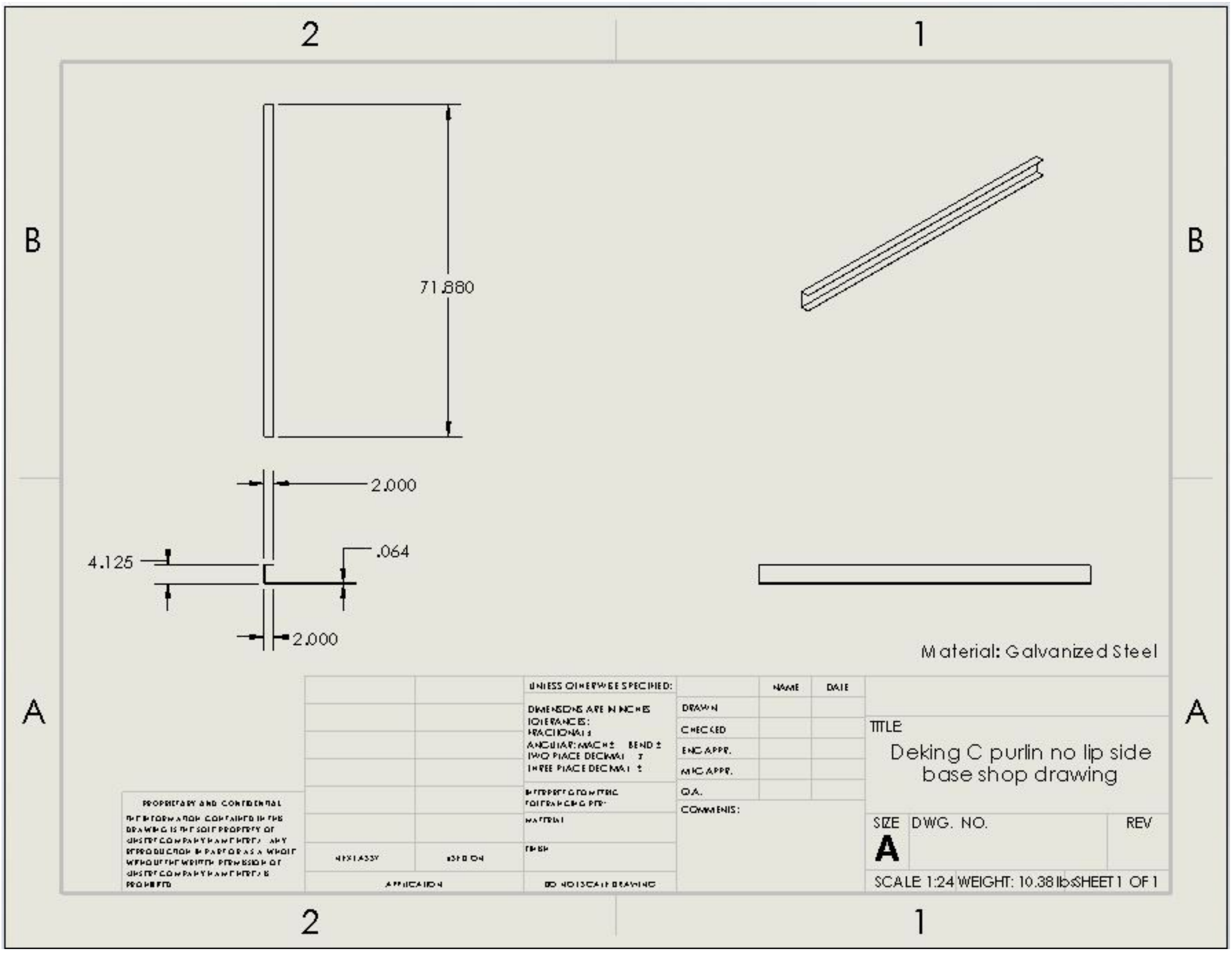
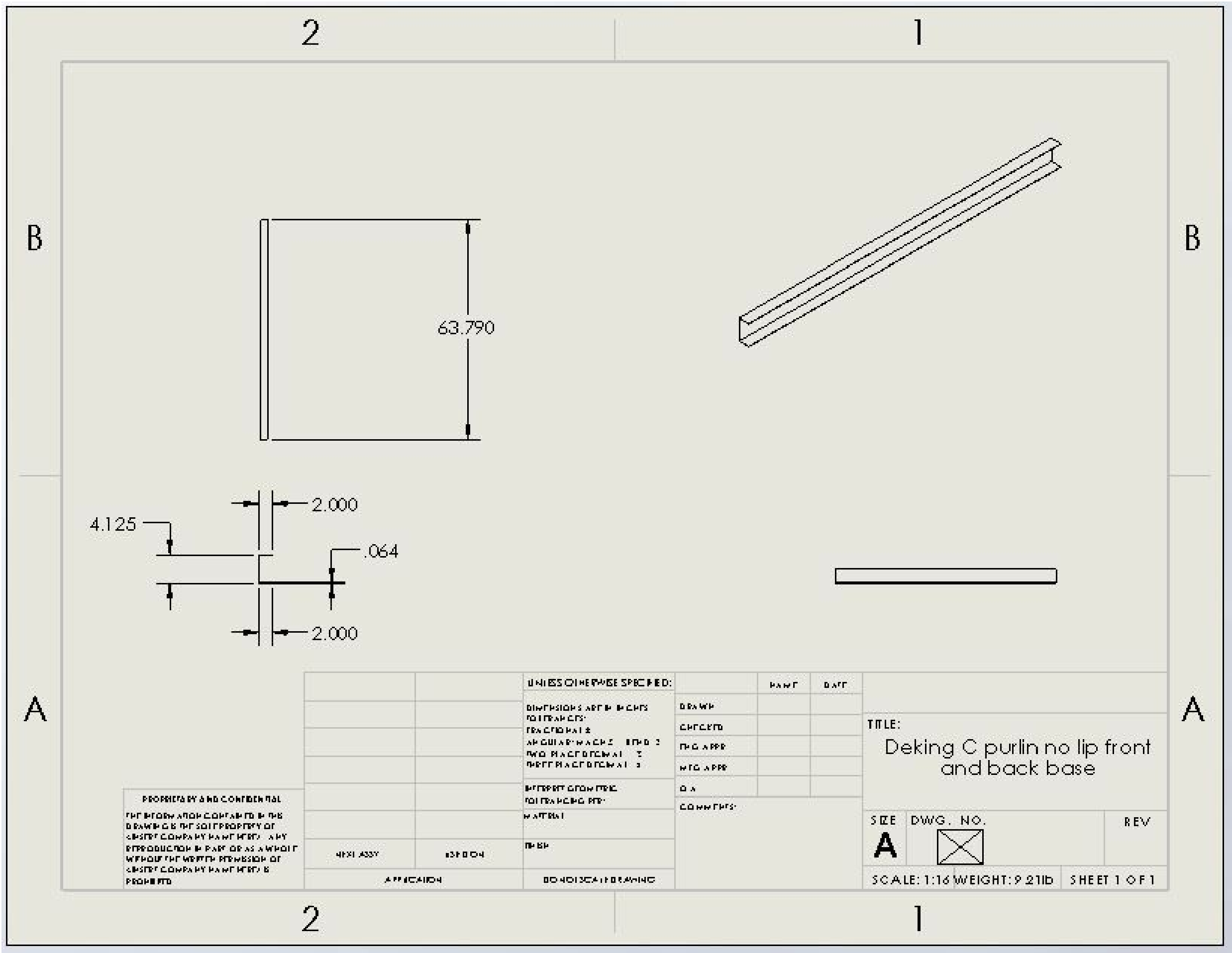
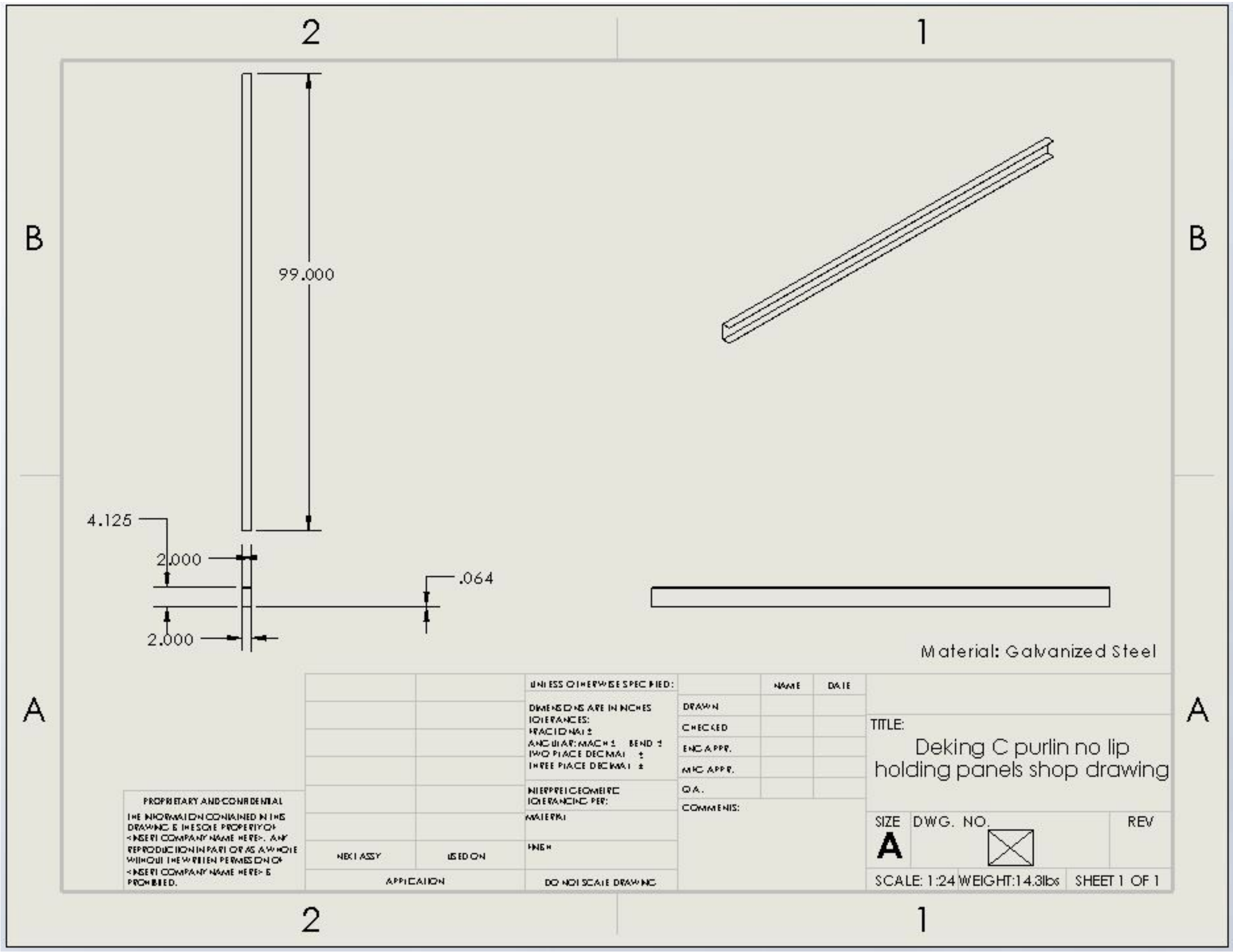
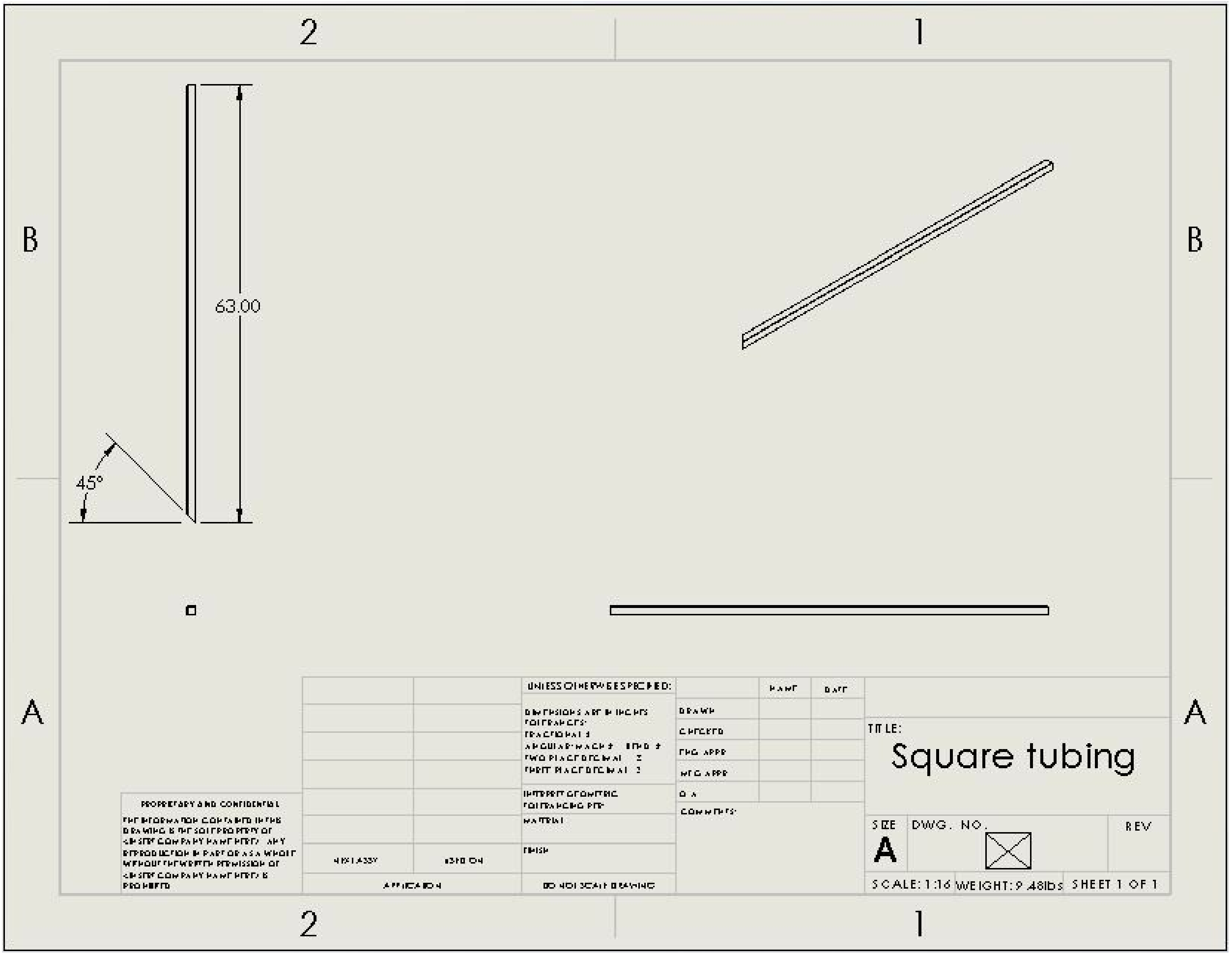
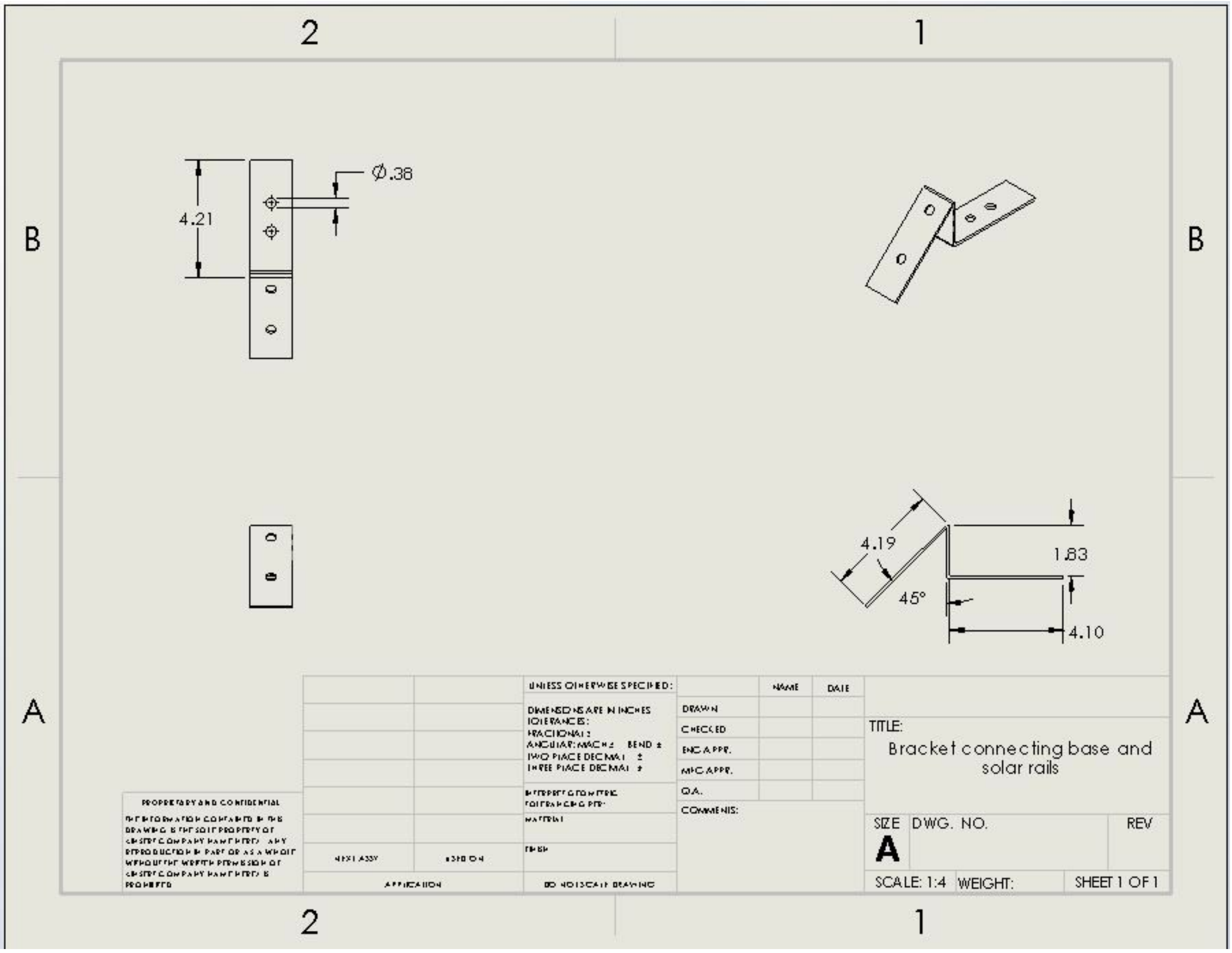
Appendices

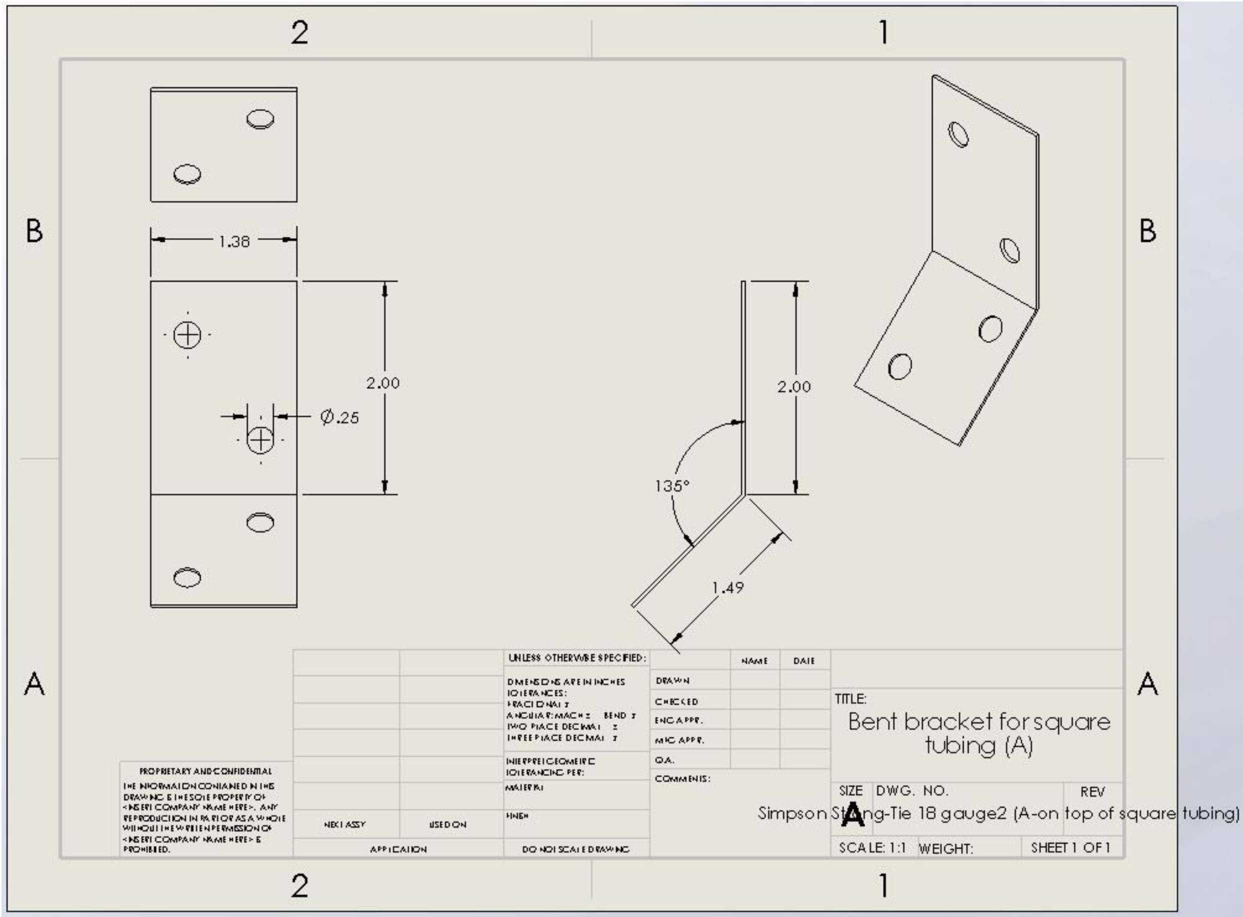

71.880
2.000
4.125
.064
2.000
Material: Galvanized Steel
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE
Deking C purlin no lip side base shop drawing
SIZE
A
DWG. NO.
REV
SCALE 1:24 WEIGHT: 10.38 lbs SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
APPLICATION
DO NOT SCALE DRAWING

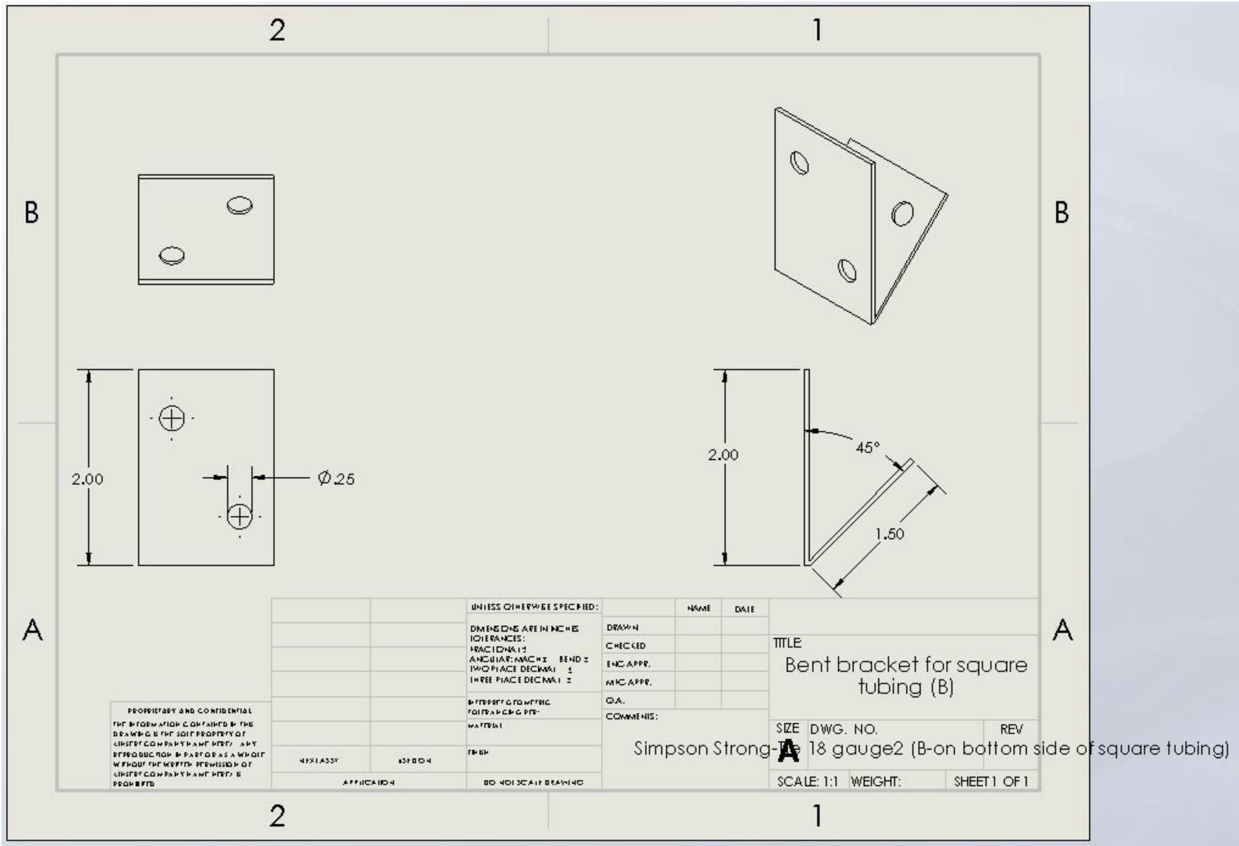

63.790
4.125
2.000
.064
2.000
TITLE:
Deking C purlin no lip front and back base
SIZE
A
DWG. NO.
REV
SCALE: 1:16
WEIGHT: 9.21lb
SHEET 1 OF 1


99.000
4.125
2.000
2.000
.064
Material: Galvanized Steel
TITLE:
Deking C purlin no lip holding panels shop drawing
SIZE A
DWG. NO.
REV
SCALE: 1:24 WEIGHT:14.3lbs
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING


63.00
45°
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
TITLE:
Square tubing
SIZE
A
DWG. NO.
REV
SCALE: 1:16
WEIGHT: 9.48lbs
SHEET 1 OF 1


2
1
B
A
Ø.38
4.21
4.19
1.83
45°
4.10
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Bracket connecting base and solar rails
SIZE
A
DWG. NO.
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING


1.38
2.00
Ø.25
135°
2.00
1.49
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Bent bracket for square tubing (A)
SIZE
DWG. NO.
REV
A
Simpson Strong-Tie 18 gauge2 (A-on top of square tubing)
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING



2
1
B
A
2.00
Ø.25
45°
1.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
PROPRIETARY AND CONFIDENTIAL
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
TITLE:
Bent bracket for square tubing (B)
SIZE
DWG. NO.
REV
A
Simpson Strong-Tie 18 gauge2 (B-on bottom side of square tubing)
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1