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Hinging, Propping, and Latching Mechanisms for Sunseeker Solar Car

Zachary Ruppenthal
zach.ruppenthal13@gmail.com

ME 4800 Final Report

Hinging, Propping, and Latching Mechanisms for Sunseeker Solar Car

Zach Ruppenthal

Landen Wallace

Ryan Zaharia

Group #4-21-22

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Abstract

In this project, designs for the hinging, propping, and latching mechanisms on the 2021 Sunseeker Solar Car were created. These designs allow for the car's array of solar panels to be held at any desired angle to maximize collection of solar power and give the team access to the battery and driver compartment. Removable telescoping prop rods with pin attachments are used to set the array at a desired angle. The hinging mechanism allows for the array to be lifted vertically prior to rotation in order to avoid interference with the car's roll cage. To accomplish this, two four-bar linkages were used to hinge the array to the body of the solar car. Latch pins were used to latch the array closed while the vehicle is in motion. There will be space on the underside of the car to actuate and de-actuate these pins. The mechanisms designed in this project will provide support for the array while the vehicle is being charged or repaired and keep the array secure while the car is in motion.

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1. Introduction

a. Background

The Sunseeker Solar Car Team is a student project team at Western Michigan University that designs, builds, and races solar-powered cars [1]. The team works out of the plastics lab in Floyd Hall, but due to COVID-19 restrictions, access to the lab is limited. The team has designed a car to be raced in the 2021 American Solar Challenge. The 2019 iteration of the team's solar car is shown in Figure 1.

Figure 1: Sunseeker's 2019 Solar Car

Sunseeker's 2021 vehicle will be a four-wheeled solar-powered car. The vehicle's wheel wells will be closed off by the aeroshell, and an array of solar panels will sit on top of the vehicle. The driver compartment is located in the right-hand side of the car while the battery box is in the left-hand side of the car.

The scope of this project consisted of designing the hinging, latching, and propping mechanisms for the 2021 Sunseeker Solar Car. These mechanisms are designed to be as lightweight, durable, and cost-effective as possible. The hinging allows for the array to be rotated about one edge while also avoiding interference between the canopy and roll cage. The propping mechanism allows for the array to be held at any desired angle to maximize the collection of solar energy. The latching mechanism holds the array in place while the vehicle is in motion while still allowing the team easy access to the latches to open the array.

b. American Solar Challenge Description

The American Solar Challenge is an event that challenges teams of college students to design, build, and race vehicles that run entirely on solar power. Teams participate in the American Solar Challenge itself as well as the Formula Sun Grand Prix [3].

The American Solar Challenge is a cross-country time/distance rally race for solar cars. The course for the challenge spans between 1,500 and 2,000 miles and passes through multiple cities across the U.S [3]. The 2021 course runs from Independence, MO to Santa Fe, New Mexico. The Formula Sun Grand Prix is also included in the American Solar Challenge. In this event, solar cars are raced around a grand prix or road style closed course. This part of the challenge gives cars a different test from the cross-country race by testing the ability of the cars to handle curves as well as more acceleration and braking. The two races require different strategies in order to maximize performance and save battery life.

c. Problem Description

In order for the 2021 Sunseeker Solar Car to function safely and maximize its capture of solar energy, designs needed to be made for the hinging, propping, and latching mechanisms between the array and lower aeroshell of the car. A hinging mechanism is necessary because it allows for the array of solar panels on the car to be lifted and allows access to the battery box, driver compartment, and wheel wells. It also provides an axis for the array to rotate about, which allows the angle of the array to be adjusted. This is critical because the angle of the array will need to be adjusted based off the position of the sun to maximize the capture of solar energy while the battery is charging. The hinges needed to be placed on the right-hand side of the vehicle because this would provide the easiest access to the battery box. It was also necessary for the hinging mechanism to translate the array vertically before allowing it to rotate because this allows the rotation of the array to avoid interference with the vehicle's roll cage. Figure 2 shows how the rotation of the array would interfere with the roll cage if there was not an initial vertical translation.

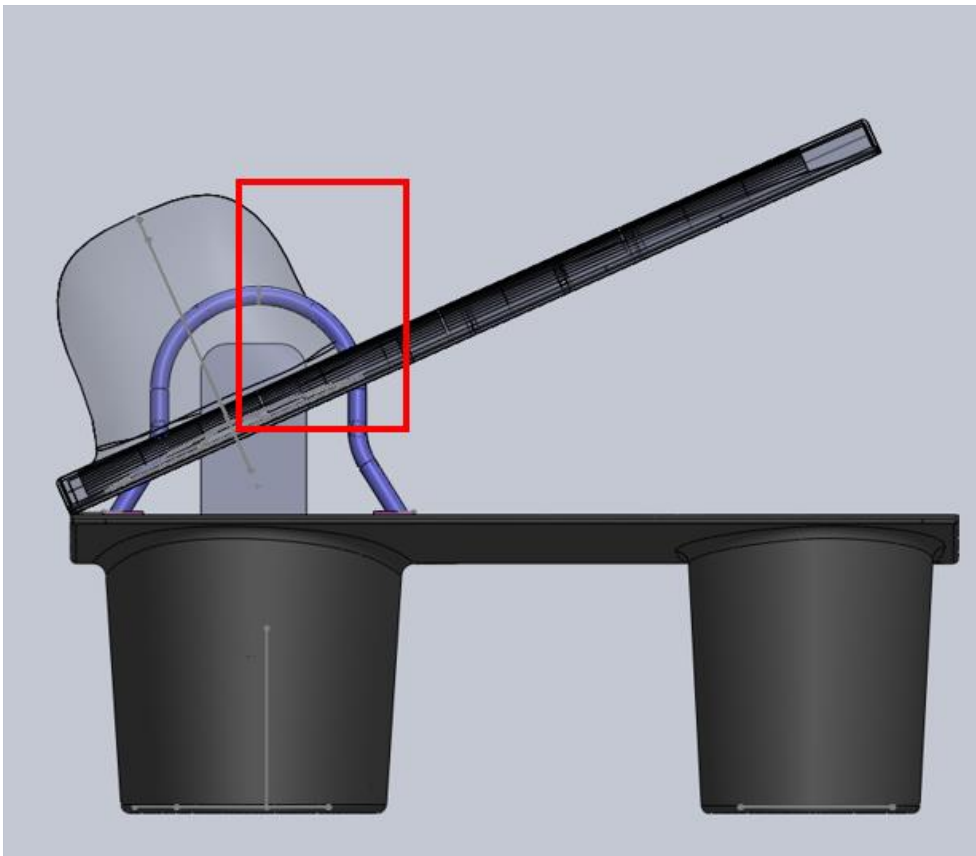

Figure 2: Rotational interference of the array and roll cage

A propping mechanism was necessary to hold the array at angles between 0 and 90 degrees with a precision of 10 degrees or less. This was necessary for optimizing the capture of solar energy. The mechanism also needed to be securely fastened to both the array and chassis of the car. This was required in the design because it would ensure that the wind could not blow the array enough to dislodge the prop rods. A latching mechanism was needed for the design because it would hold the array in a closed position while the vehicle is in motion. The design required that the latching could be locked and unlocked from the outside of the vehicle so that this could be done while the array is closed.

d. Solution Ideas and Alternatives

There were multiple ideas for solutions to each mechanism. For the hinging mechanisms, there were three designs that were considered. A decision matrix was used to determine the best choice out of the three hinge designs. The designs considered were a three-bar hinge, a four-bar hinge, and a butterfly hinge. Hinging designs were evaluated based on their capacity to translate vertically, production cost, weight, and strength. The butterfly hinge would not give the array an upward translation before rotation, so it was not a viable solution. The three-bar hinge design would save on cost and weight when compared to the four-bar hinge design, but the four-bar hinge design allowed for a greater vertical translation as well as greater rigidity. Based on the decision matrix, the four-bar hinge was the superior design. Table 1 shows the decision matrix used to choose a hinge design.

Possible Solutions		3-Bar Hinge	4-Bar Hinge	Butterfly Hinge
Criteria	Wt.			
Upward Translation	10	4	5	0
Production Cost	8	4	3	5
Strength	9	4	5	2
Weight	8	4	3	5
Weighted Scores		140	143	98

Table 1: Hinging Mechanism Decision Matrix

There were two different designs for the propping mechanism that were evaluated. One design used a rail to adjust the location of one end of the prop rod, which would adjust the angle of the array. The other design used removable telescoping prop rods with pin attachments. A decision matrix was used to evaluate the two propping designs. The designs were evaluated based on range of adjustable angles, weight, cost, and rigidity. The removable prop rod design was superior in weight, cost, and angle range. For these reasons, the removable prop rod design was shown to be the better of the two designs. Table 2 shows the decision matrix used to evaluate the two propping mechanism designs.

Possible Solutions		Telescoping Rods	Adjustable Rail Position
Criteria	Wt.		
Angle Range	10	5	3
Weight	8	5	3
Production Cost	8	4	3
Rigidity	9	4	5
Weighted Scores		158	124

Table 2: Propping Mechanism Decision Matrix

Two designs were considered for the latching mechanism. One solution used an internal spring-loaded pin system to hold the array in place while the vehicle was in motion. Figure 3 shows the proposed spring-loaded pin system. The other proposed solution for the latching mechanism was an externally accessible pin system to hold the array in a fixed position. These two designs were compared using a decision matrix that evaluated the two systems based on ease of access, production cost, durability, and weight. Both designs were scored equally on cost, durability, and weight, but the external pin system was deemed superior on ease of access. Because of this, it was shown to be the better of the two solutions. Table 3 shows the decision matrix used to choose a design for the latching mechanism.

Figure 3: Proposed spring-loaded pin system

Possible Solutions		Internal System	External System
Criteria	Wt.		
Ease of Access	10	3	5
Weight	8	5	5
Cost	8	5	5
Durability	9	4	4
Weighted Scores		146	166

Table 3: Latching Mechanism Decision Matrix

e. Project Goals and Benchmarking

Because of the great deal of design freedom in the American Solar Car Competition, the hinging, latching, and propping mechanisms on the solar vehicles of other teams will often need to function in different ways than they need to on the car built by the Sunseeker Solar Car Team. In fact, in some cases the mechanisms are nonexistent on the cars of other teams. For example, the newest solar vehicle made by the University of Michigan runs off a set of solar panels located in front of the driver compartment and does not need to ever be propped up [4]. Therefore, none of the mechanisms designed in this project are used on their vehicle.

There are some teams that use a similar propping and hinging designs, however. For example, Polytechnique Montréal's solar vehicle team has a car with a 4-bar hinge mechanism. Their car has the hinging shown in Figure 4. The hinging mechanism designed in this project provides the same ability to translate upward and then rotate about the side of the car. This design was optimized to be more lightweight and inexpensive, as well as to meet the needs of the Sunseeker vehicle.

Figure 4: Polytechnique Montreal Solar Vehicle Hinging

Previous Sunseeker vehicles have required similar mechanisms for hinging, propping, and latching the array in place. However, the Sunseeker vehicle is being redesigned constantly in order to optimize the vehicle's performance. For this reason, previous designs for these mechanisms used by Sunseeker may not be feasible in future vehicles due to other changes in the vehicle's design. For example, the 2016 Sunseeker vehicle had open wheel wells that were used for accessing an internal latching mechanism for the array. This would not be a viable solution for the 2021 vehicle because the wheel wells will be closed-off on this iteration of the car to optimize the vehicle's aerodynamic performance. These types of design changes require the constant updating of various mechanisms within the vehicle.

The goal of this project was to design mechanisms for the hinging, propping, and latching mechanisms that would function properly based on the layout of the 2021 iteration of the Sunseeker Solar Car. The mechanisms were also designed to weigh as little as possible in order to maximize the speed of the car and minimize the energy needed to propel the car forward. Additional design considerations included minimizing cost and maximizing the mechanisms' durability.

f. Aeroshell Material

The aeroshell of the 2021 Sunseeker vehicle will be made from carbon fiber honeycomb sandwich panels. This material has a relatively low strength, which means that attaching our mechanisms directly into the honeycomb material could result in failure. Because of this, our team designed hard point attachments for our mechanism. Hard points are attachments that use parts of a stronger material to distribute the load across a greater area of the honeycomb material. Some common hard point attachments use ferrules or threaded inserts to distribute the stress of a bolt or screw. However, hard points come in a variety of different types. In this design, it was crucial to create hard points that were optimal for each unique attachment point on the vehicle.

g. American Solar Challenge Regulations

Section 10.1.C of the American Solar Challenge Regulations (ASCR) outlines the requirements for securing the upper aeroshell to the chassis and lower aeroshell. “Two independent and different means of securing the solar collector” are required to be on the car at all times [5]. This requires redundancy in the case that a primary latching assembly fails, which did happen during a race in the past. The secondary securing method will consist of two safety lanyards, which have additional requirements set out in section 10.1.C. This section states that the lanyards and hardpoints that hold them must be able to survive the loads encountered if the primary securing method fails. The lanyard also cannot allow more than 600 mm of upward travel by the array, and its hardpoints “must be within 300 mm of the forwardmost point of the seam that splits the collector portion from the chassis,” [5]. Two lanyards are used in total, one at the front and one at the rear of the car, to add additional redundancy and safety.

2. Hinging Design

a. Overview

The hinging mechanism was designed with the intent to perform a set motion of lifting the array vertically and then pivot 90 degrees while clearing all potential collision points. These parameters were thought of when selecting through design solutions. Selecting a 4-bar mechanism to achieve our desired path of motion was a feasible solution. The 4-bar mechanism will help negate the need to have multiple people lift the array in order to access the body of the car. With the new hinging mechanism, the car will be easier to open and require less people to perform this task. During racing events the hinging mechanism will allow for the array to be adjusted to different angles to maximize solar light absorption.

The 4-bar mechanism will be unique since the motion is specifically designed for the Western Michigan University's solar car; the hinging and 4- bar mechanism will have to be manufactured. To proceed to manufacturing the 4-bar mechanism an unknown value must be found. The unknown value is when the array is in the closed position what is the minimum vertical displacement value required before rotation can occur. Opening the SolidWorks files for the 2021 vehicle and making small alterations of the assembled car was needed to achieve the specified motion.

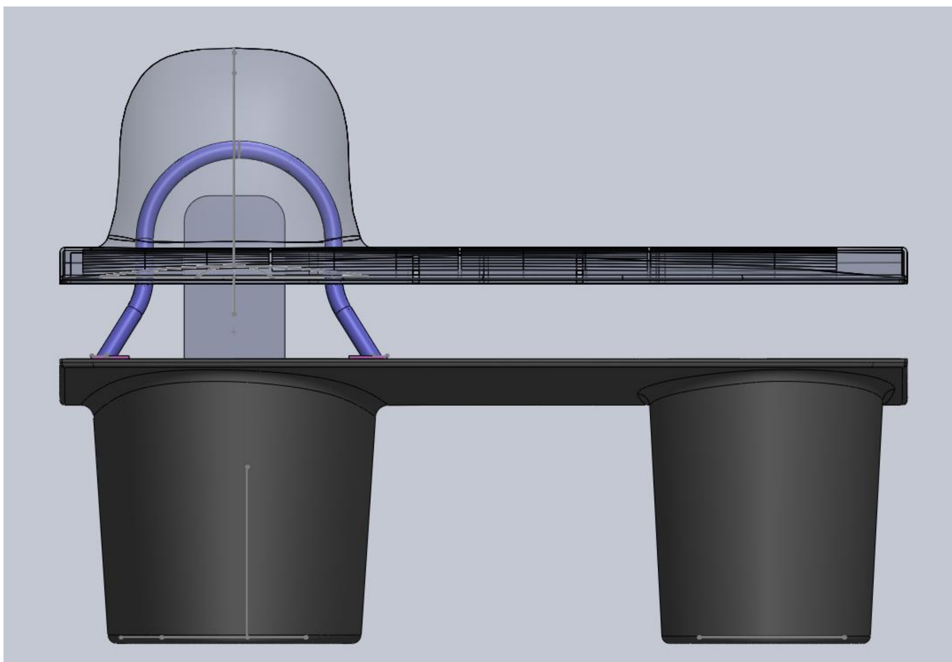

Figure 5: Sunseeker car with horizontal lift aspect

To find the minimum height, multiple trials were performed by varying the displacement height. Figure 5 shows the vertical displacement of 6 inches from the closed position of the array. Multiple simulations were performed at different heights and then pivot the array along a rotational axis to find when clearance is achieved. Clearance was modeled by using two methods, one was using SolidWorks' collision alert to be notified if the array touched the roll cage. The second method was visually examining the assembled model to see when rotation is occurring where is the closest point of contact of the roll cage to the array. The distance between the two parts was three dimensionally measured for each simulation. Figure 6 shows how the design that would avoid having the array collide into the roll cage.

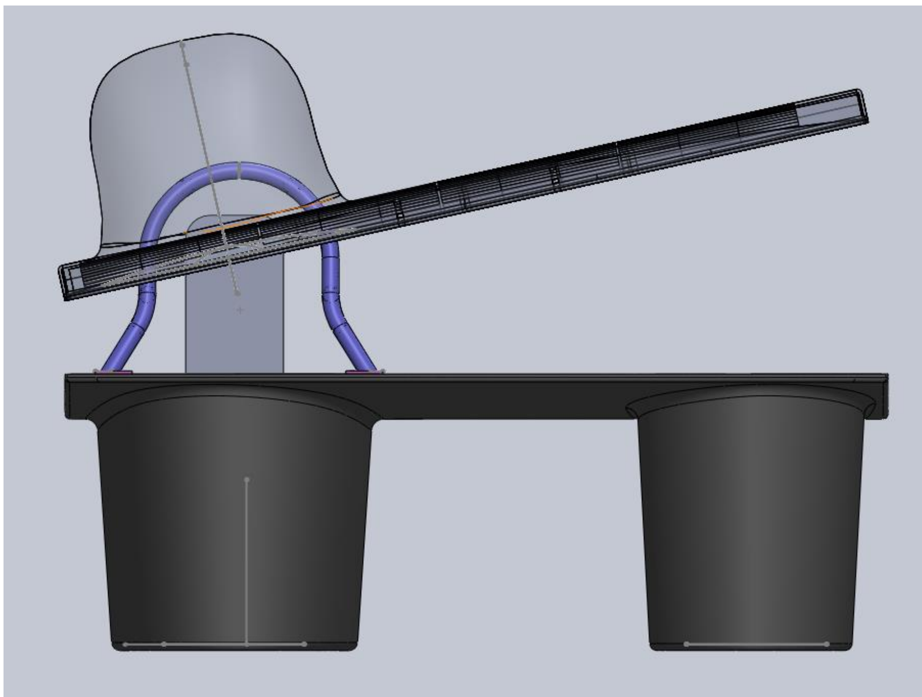

Figure 6: Rotational Clearance of Roll Cage.

Once clearance was achieved and the minimum vertical displacement height was found more trials were ran at greater heights. The additional trials were taken as a safety precaution so there is more of a clearance tolerance to decrease the likelihood of interference.

Trial Runs	Height Displacement (inches)	Clearance (inches)
1	4	0.94
2	5	1.13
3	6	1.22
5	7	1.5
6	7.5	1.51
7	8	1.74
8	8.5	1.95

Table 4: Height Displacement Clearance Findings.

From Table 4 the tabulated results show that as the displacement increases so does the clearance tolerance. Meaning that the higher the vertical displacement the less likely for interference with the roll cage will occur. From these findings the 4-bar mechanism was designed to achieve a lift of 6 inches vertically.

When designing the 4-bar mechanism it is important to keep in mind the 6-inch lift necessary to clear the roll cage. To achieve this, lift the mechanism will have to be oriented along the side of the vehicle near the driver's compartment. The 4-bar mechanism will have enough room to lift the array upwards of 6 inches. Since the coupler link will be the bar that has the connection point to the array. The motion of the coupler link is crucial. When defining the geometry of the mechanism it would be impractical to have the coupler link totter while lifting because it will cause the array to totter along with it. The coupler link should raise and stay parallel to the top surface of the chassis through the motion. To achieve this a parallelogram 4-bar linkage should be designed. Meaning that the coupler link and the ground link is the same distance. Also, the two-side links have the same length. This fixed geometry will allow for the coupler link to stay parallel with the chassis of the car. Figure 7 shows the geometry of our 4-bar solution.

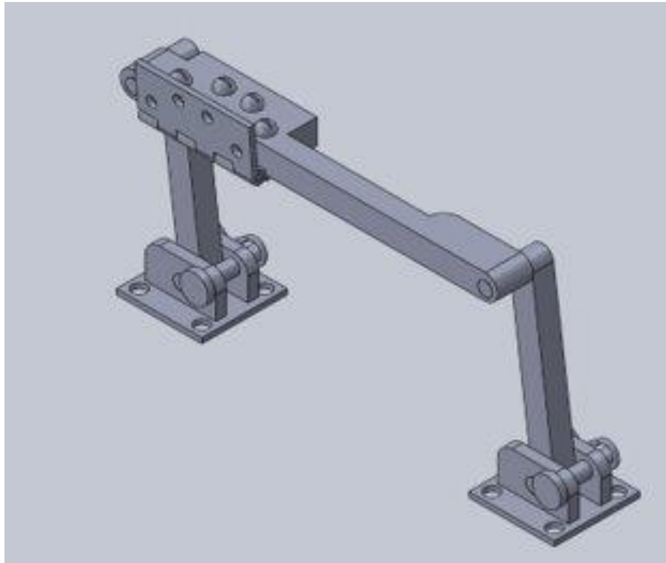

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Figure 7: 4-bar parallelogram mechanism.

After the defined lengths, the coupler link geometry must clear any other components of the mechanism when in motion. From the resting position when the array is in the closed position unit the mechanism is the full upright position. Figure 8 shows the top view of the 4-bar assembly laying in the closed position. The design of the coupler link allows the 4-bar to collide with itself.

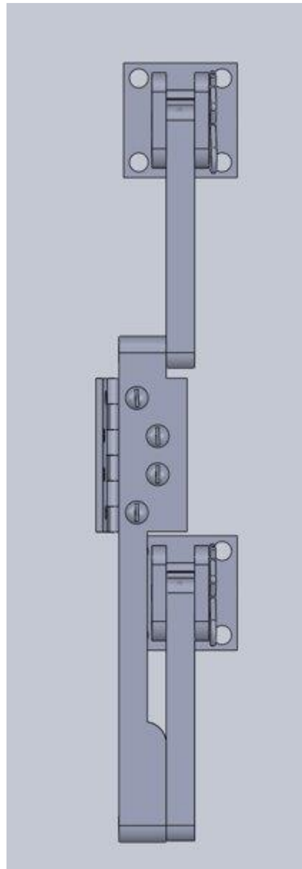


Figure 8: Top view of 4-bar mechanism.

Attached to the coupler link is a surface mount butt hinge assembly. One leaf of the hinge will be connected to the coupler and will be fixed by button head screws and the other side will be fastened with hex nuts shown in Figure 9. The hinge plate is needed to make full contact with the side wall of the array. A regular door hinge will not work because the pin joint will encounter the side wall of the array. The surface mount hinge allows for complete unlike a conventional butt hinge. With this geometric layout of the hinges in this orientation allows the array to rotate and not pinch or collide with the 4-bar mechanism.

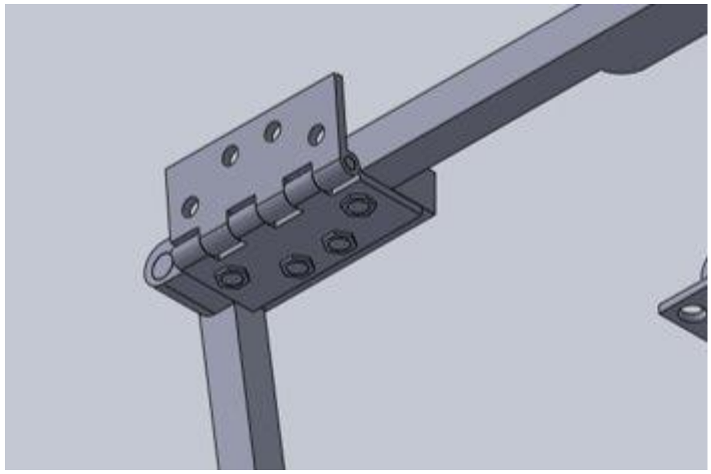


Figure 9: Bottom view of surface mount hinge attached to coupler link.

Since the mechanism is a parallelogram linkage which means that the side links can rotate 360 degrees around the joint. There will need to be some way to stop the 4-bar from continuously rotating and limit the motion. Thus, inside the mounting brackets there was a blockade added to prevent the motion from continuously extending. The blockade allows the 4-bar to be opened to 100°. Also, to prevent the mechanism from falling back down to the closed position; a clevis and cotter pin is added on the other side of the mounting bracket to lock the link in the upright position. Figure 10 shows the exploded view of the clevis and cotter pin and partially the blockade in-between the mounting bracket walls.

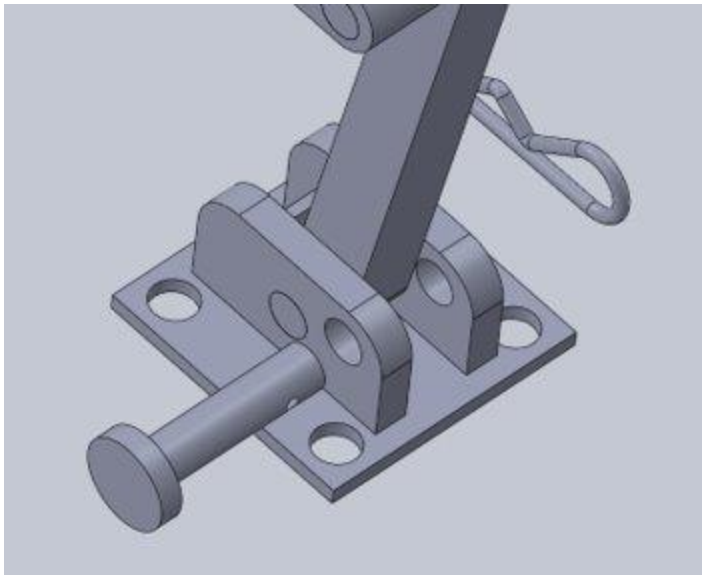


Figure 10: Mounting bracket design.

The vehicle will need two sets of 4 bar mechanisms to provide a satisfactory lift and rotation for the array. The placement locations are constrained due to the lack of structural support along the edge of the chassis. There is not enough support near the front or rear side of the chassis to place the hinging mechanisms on top of. All the structural support is near the driver's compartment. Once the location is finalized for our mechanism, they can be secured to the body of the vehicle. Button head screws are used to run through the base plate and fasten on the other side of the mounting surface with a hex nut. Figure 11 shows the location of our mechanism in the solar car.

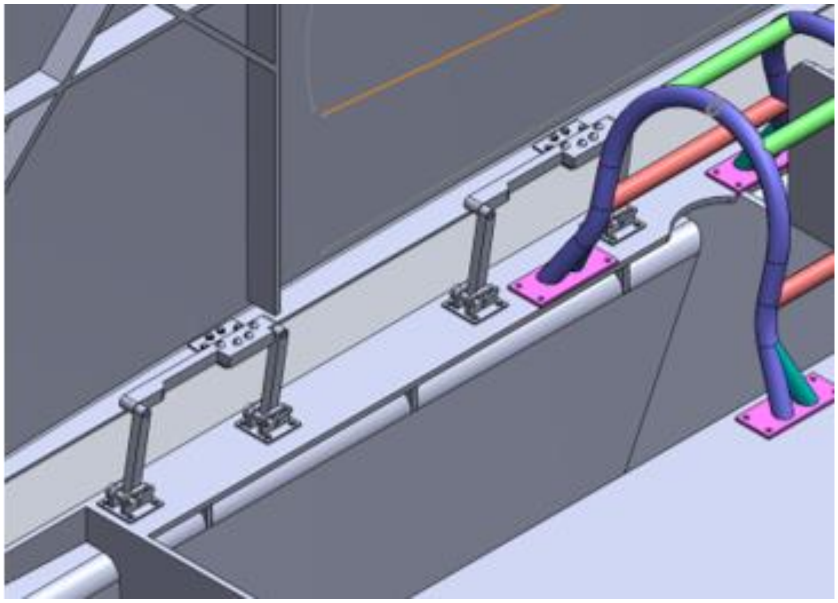


Figure 11: Hinging mechanism mounting locations.

To sandwich and better hold the array, on the outer side of the array there are two mounting plates which each plate has 4 button head bolts running through the plate, array, and the hinge leaf that connects to the array. The screw is then fasted down on the other side with hex nuts. The outside plate helps hold the array to the hinges better. Figure 12 shows the outside of the array with the base plates and button head bolts.

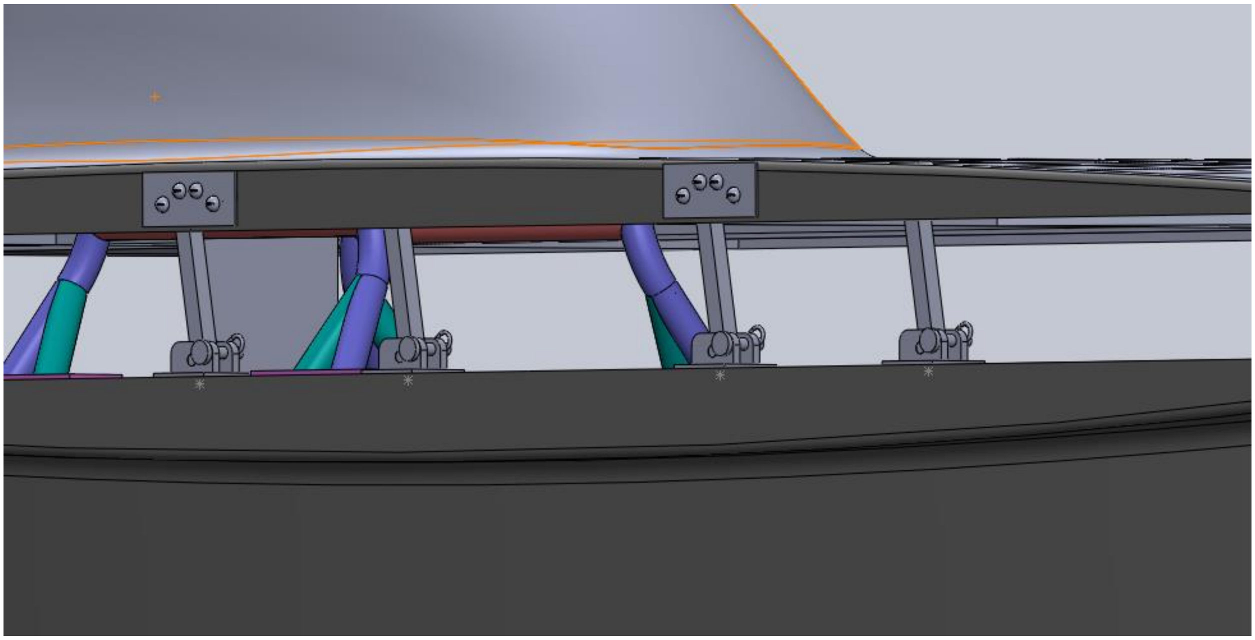


Figure 12: outside surface plates mounted to the array

With all the components of the mechanism secured to the vehicle. The hinging design can be simulated in SolidWorks to see if there are any collision points withing the system. Figure X shows the motion breakdown of the hinging working. Starting in the closed position the array is laying flush to the body of the vehicle. Then the 4-bar mechanism is used to lift the array 6 inches vertically and locked into place with the clevis and cotter pin. The array is then ready to be adjusted to the specified angle to maximize solar intake. In the most extreme case, the array will be opened to the 90 degrees position. Observing the motion there was no contact interference with the any component of the mechanism or the other parts of the vehicle. Figure 13 summarizes the motion of the hinging mechanism.

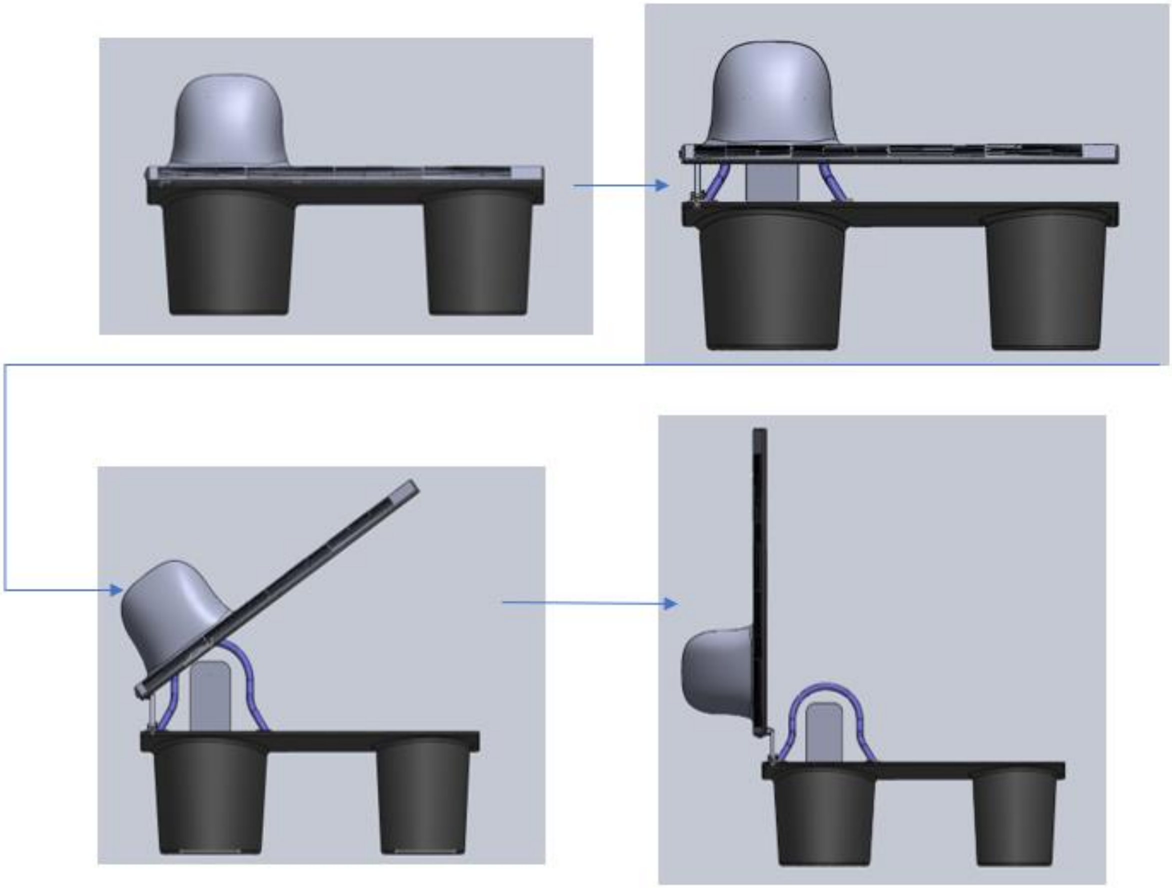


Figure 13: Guided motion of the array caused by the hinging mechanism.

The design of the hinging mechanism is shown to be a working solution for the given initial problem. With the geometrical constraints due to the location of the roll cage and the lack of structural support hinders the design freedom. The hinging mechanism functions accordingly to the desired motion. Now physically there must be an analysis done on the system to ensure the design will perform under acting forces.

b. **Stress Analysis**

In order to ensure that the hinges would not fail when under the full load of the array, a stress analysis was performed on the hinges. It was assumed that the hinges would be under the greatest stress when the array is at the 90-degree position because the prop rods would be under minimal load in this situation, so the hinges would be counteracting nearly the entire weight of the array. For this reason, the stress analysis on the hinges was performed for the 90-degree array position. The maximum load for one set of hinges in this situation was approximated using hand calculations, and a finite element analysis with this load was run on the hinges to determine the maximum stress in the hinges.

To begin this analysis, a free body diagram was created. The free body diagram created is a 2-D sketch modelling the locations of the loads on the array along the length of the car for the 90-degree array angle situation. In this diagram, the weight of the array is assumed to be 100 pounds, although the true weight could deviate slightly from this value, as the array has not yet been fabricated. The center of mass of the array was assumed to be at the midpoint of the car's length. The vertical force exerted by the prop rods was assumed to be zero. The diagram also shows the load that is present in each of the two hinges on the vehicle. The left side of the diagram represents the front of the car, while the right side of the vehicle represents the rear of the car. Figure 14 shows the free body diagram used in this analysis.

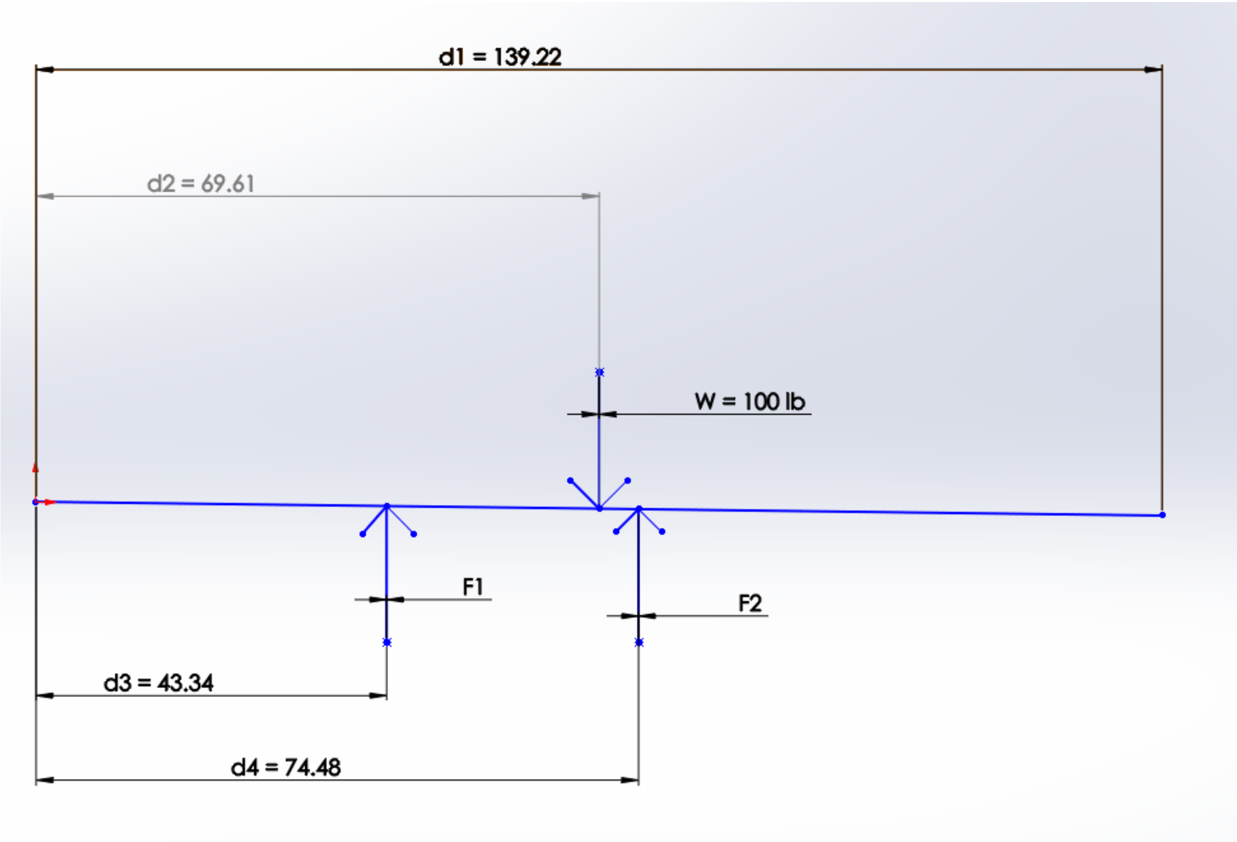


Figure 14: 90-degree Array Angle Free Body Diagram

The variables shown in the free body diagram are defined as follows:

$$W = Weight\ of\ Array$$

$$F_1 = Load\ Acting\ on\ Front\ Hinge$$

$$F_2 = Load\ Acting\ on\ Rear\ Hinge$$

$$d_1 = Length\ of\ Solar\ Car$$

$$d_2 = Distance\ from\ Front\ of\ Car\ to\ Array\ Center\ of\ Mass$$

$$d_3 = Distance\ from\ Front\ of\ Car\ to\ Front\ Hinge$$

$$d_4 = Distance\ from\ Front\ of\ Car\ to\ Rear\ Hinge$$

In order to solve for the load acting on each of the hinges, the assumption was made that there will be no internal moment present in hinges. In the true situation, there will be some moment present in each of the hinges. However, making this assumption will give an overestimate of the maximum force in one of the hinges as the loads will not be as evenly distributed. This means that the true safety factor will be higher than the safety factor calculated through this analysis. For this reason, this analysis will be able to conclude that the hinges will not fail if the safety factor is sufficiently high.

In order to solve for the F_1, the sum of moments equation was used about the rear hinge. Equation 1 was used to solve for F_1.

$$\sum M_2 = 0 = W * (d_4 - d_2) - F_1 * (d_4 - d_3) \qquad (1)$$

From Equation 1, F_1 was found to be 14.68 pounds. F_2 was then found by using the sum of forces equation in the vertical direction. Equation 2 was used to find F_2.

$$\sum F_y = 0 = F_2 + 14.68 - 100 \qquad (2)$$

From Equation 2, F_2 was found to be 85.32 pounds. This value is greater than the calculated load acting on the front hinge, so F_2 was used in the finite element analysis.

The finite element analysis was run in SolidWorks as a simulation. The hinge assembly used in the simulation consisted of the two hinge leaves and connecting pin. The faces were set to be parallel to each other in order to model the 90-degree array angle situation. In order to run the simulation, boundary conditions had to be chosen. The face of the hinge that was attached to the underside of the 4-bar mechanism was set as a fixed face, while the pin was set as a fixed hinge. The face of the hinge that was attached to the array had a distributed load totaling 85.32 pounds applied to it. The interface between the pin and the leaves was set to be a contact point with no penetration. The material for the hinge was set to be AISI 1020 steel, as it will likely be manufactured from this material. This material has a yield strength of 351.6 MPa. The mesh size was set to be .05 inches.

Once the boundary conditions were set, the simulation was run. The maximum stress in the hinge assembly found in the simulation was 208 MPa. Upon further inspection of the model, it was found that the maximum stress occurred at the inside of corners of the hinge leaves. Figure 15 shows the results of the finite element analysis. Figure 16 shows the location of the maximum stress. Additional simulation results can be found in Appendix B.

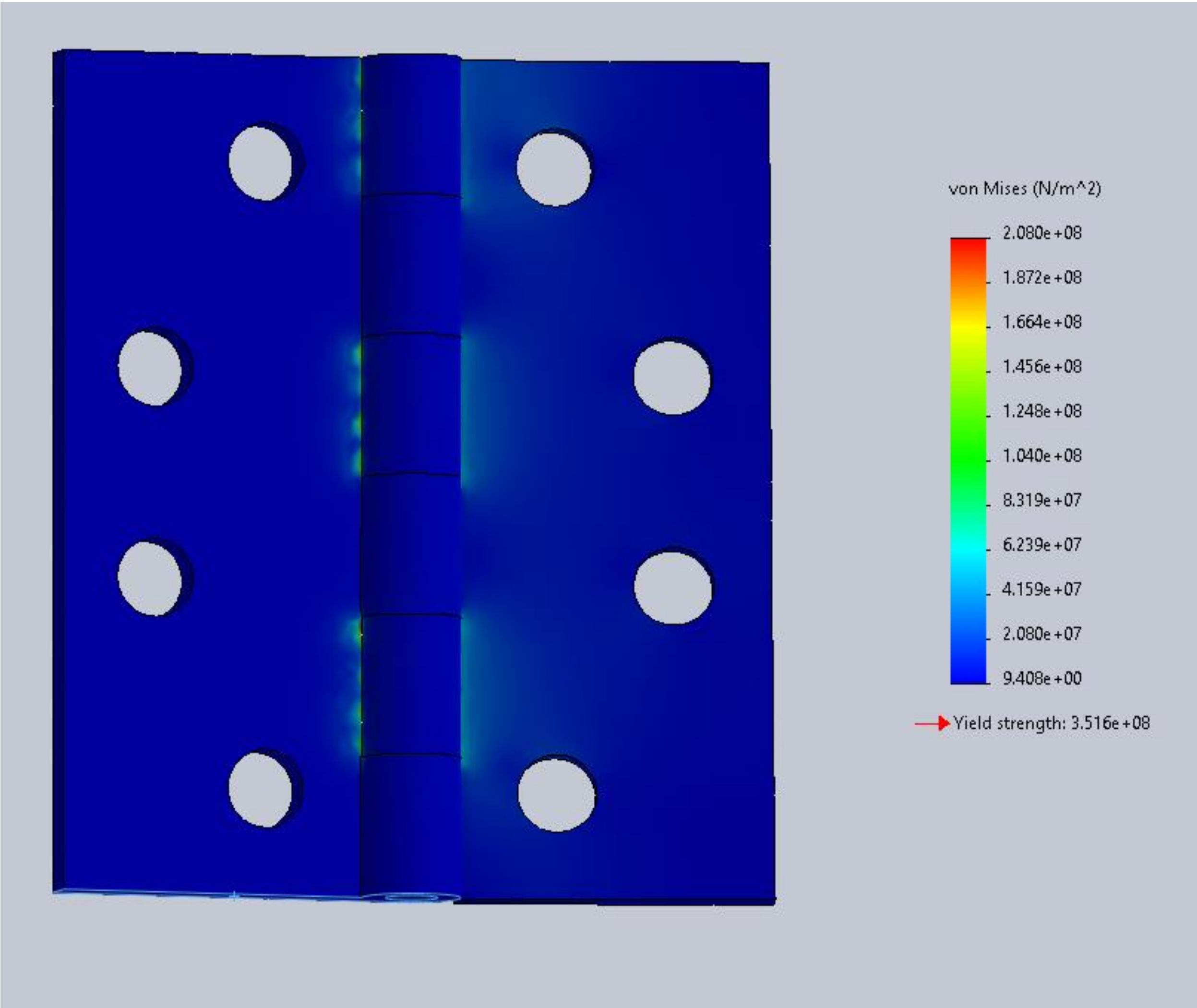


Figure 15: Hinge Assembly Simulation Results

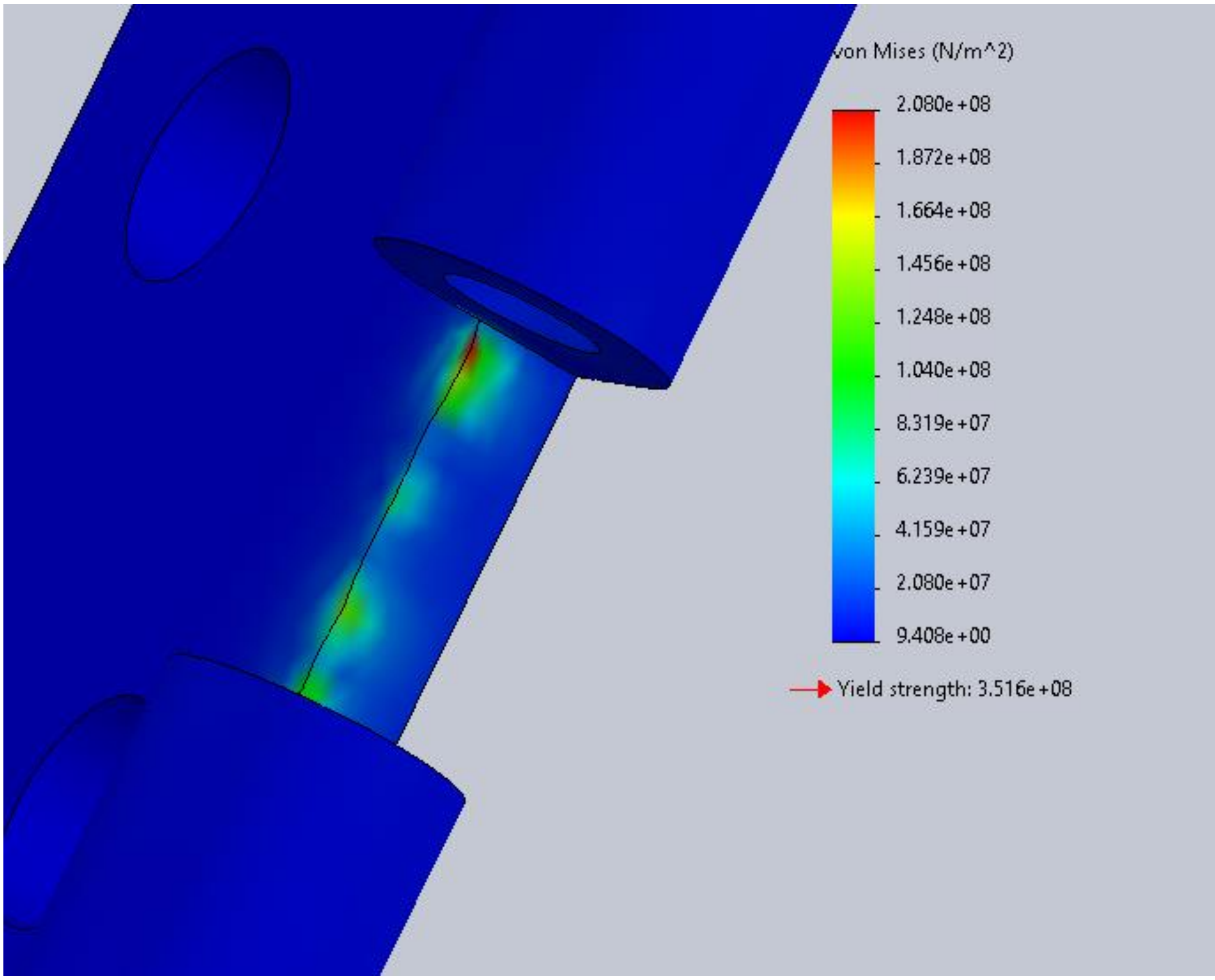


Figure 16: Maximum Stress Location in Simulation

The safety factor of the hinges was then calculated using Equation 3.

$$n = \frac{\sigma_y}{\sigma_{max}} \qquad (3)$$

Where:

$$n = Safety\ Factor$$

$$\sigma_y = Yield\ Strength$$

$$\sigma_{max} = Maximum\ Stress$$

From Equation 3, the safety factor of the hinges was found to be 1.69. This was deemed as a sufficient safety factor because this is the safety factor for the worst-case scenario. The hinge will not be under this large of a load in most situations, so fatigue failure is unlikely. Additionally, the true safety factor should be greater than the calculated value because the load value used in the simulation is an overestimate of the load acting on the rear hinge. Therefore, the true stress in the hinge will be lower than the value found in the analysis, which will result in the safety factor being greater.

3. Propping Design

a. Overview

The propping mechanism designed for the Sunseeker vehicle uses removable telescoping prop rods to hold the array at a required angle. The telescoping prop rods used in this design are commercially available, and two different sizes were used in the mechanism. The larger prop rod size telescopes from 26 inches to 61 inches. The smaller prop rod size telescopes from 16 inches to 40 inches. Figures 17 and 18 show the prop rods used in the design.

Figure 17: Small Telescoping Prop Rod

Figure 18: Large Telescoping Prop Rod

Two prop rods of each size are used in the mechanism, with one size being used at a time. The larger prop rods will be used when an array angle of 40 to 90 degrees is required, and the smaller prop rods will be used when an array angle of 10 to 30 degrees is required. When the array is required to sit at a 0 degree angle, it will simply be allowed to rest flat on the chassis. Two prop rods of the desired size will be used to prop up the array to provide sufficient support and distribute the load. The ends of the prop rod will be held to the chassis and the underside of the array by a clevis pin with a hairpin cotter pin to keep it locked in place. The larger prop rods have a pin-lock system that is used to adjust the length of the rod, which adjusts the angle of the array. Additional pin holes will be drilled into the larger prop rods in order to allow for a greater precision when adjusting the length of the prop rods. The smaller prop rods have a twist-lock system that adjusts the length of the rod. Approximately four inches will be cut from the length of the smaller prop rods in order to attain the smaller array angles of the 0-to-90-degree range. The prop rods must always be kept in the vehicle so that they are always available if needed. For this reason, they will be stored in the left-side pontoon of the vehicle when they are not in use. The two prop rods. Figure 19 shows the full assembly of one of the propping rods used in this mechanism. Figure 20 shows the full solar car assembly with the propping mechanism.

Figure 19: Propping Mechanism Assembly

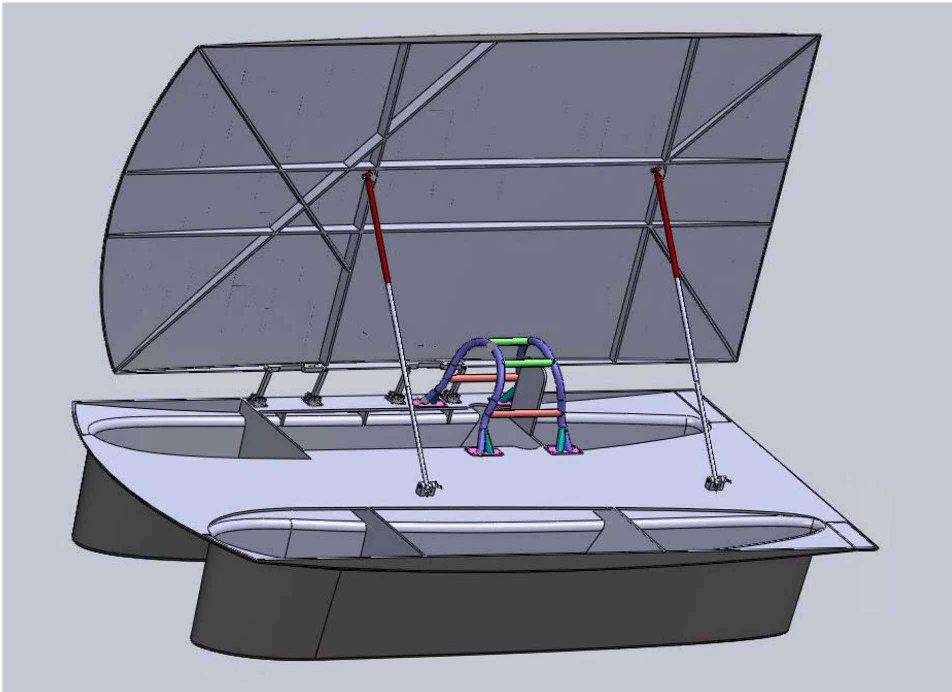


Figure 20: Solar Car Assembly with Propping Mechanism

b. Hard Point Attachments

In order to distribute the load exerted on the honeycomb panels at the attachment points of the propping mechanism, “hard points” were designed to distribute the load across a greater area and reduce the stress.

The upper end of the prop rods will be attached to the ribbing on the underside of the array. The ribbing pattern is shown in Figure 21. The prop rods will be attached to the two ribbing lines that run directly along the width of the car.

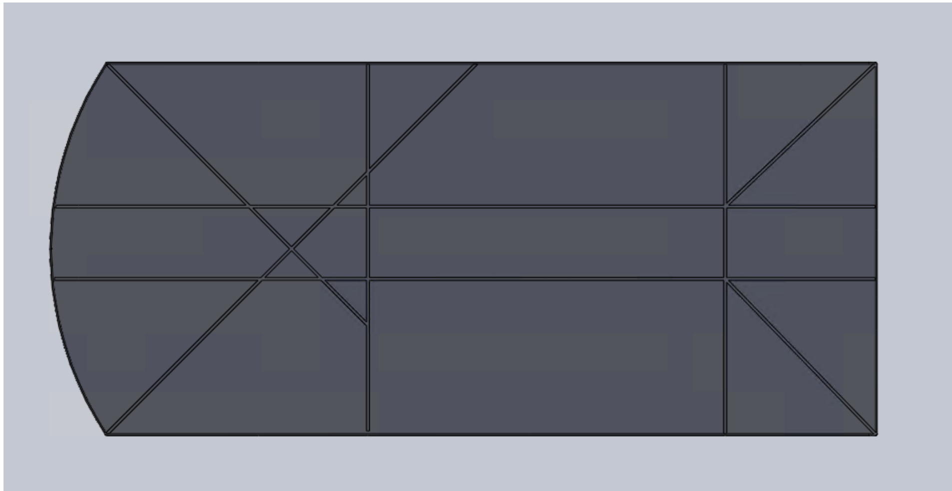


Figure 21: Array Underside Ribbing Pattern

In order to attach the prop rod to the ribbing, a hole will be drilled through the end of the prop rod and the ribbing at the attachment location. Aluminum plates will be attached to the outside of the ribbing using an adhesive to distribute the load across a greater area of the honeycomb sandwich that comprises the ribbing. The aluminum plates will also have holes drilled through them, and a clevis pin will run through the prop rod, aluminum plates, and honeycomb sandwich to hold the prop rod to the ribbing. A drill bushing will sit in the hole in the honeycomb sandwich in order to prevent deformation of the honeycomb material. A hairpin cotter pin will run through a hole in the clevis pin to keep it locked in place. Figure 22 shows the attachment between the upper end of the prop rod and the ribbing.

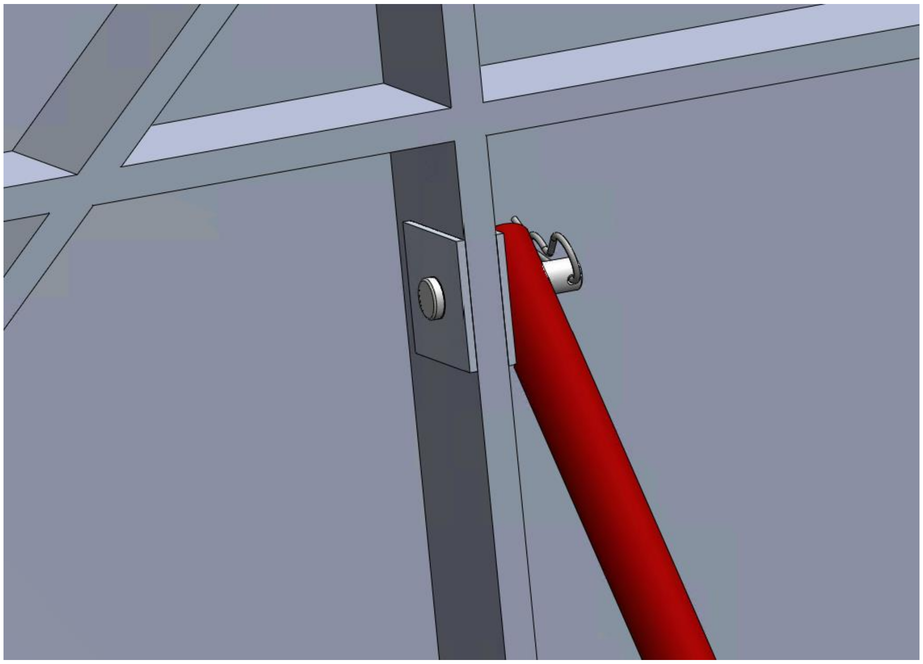


Figure 22: Prop Rod Array Attachment

The lower end of the prop rods will be attached to a pin support. This pin support will be held to the chassis by two screws. The screws will be screwed into a pair of threaded inserts in the chassis. Adhesive will be used to hold the threaded inserts in place in holes cut out of the honeycomb sandwich in the chassis. A clevis pin will run through the pin supports and lower end of the prop rod to attach the prop rod to the chassis. A hairpin cotter pin will run through a hole in the clevis pin to keep it locked in place. Figure 23 shows the attachment between the lower end of the prop rod and the chassis. Figure 24 shows the threaded inserts held in the honeycomb sandwich of the chassis.

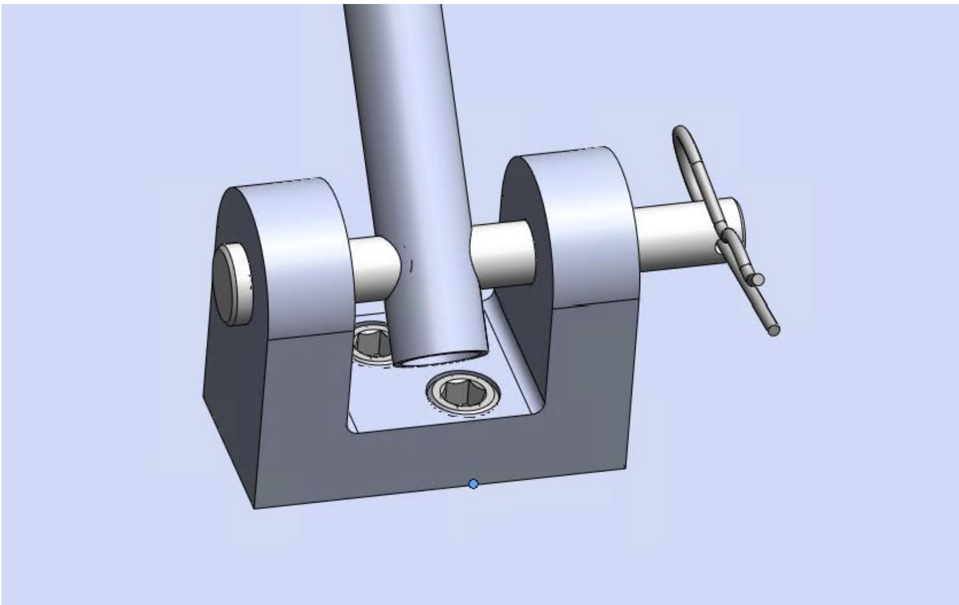


Figure 23: Prop Rod Chassis Attachment

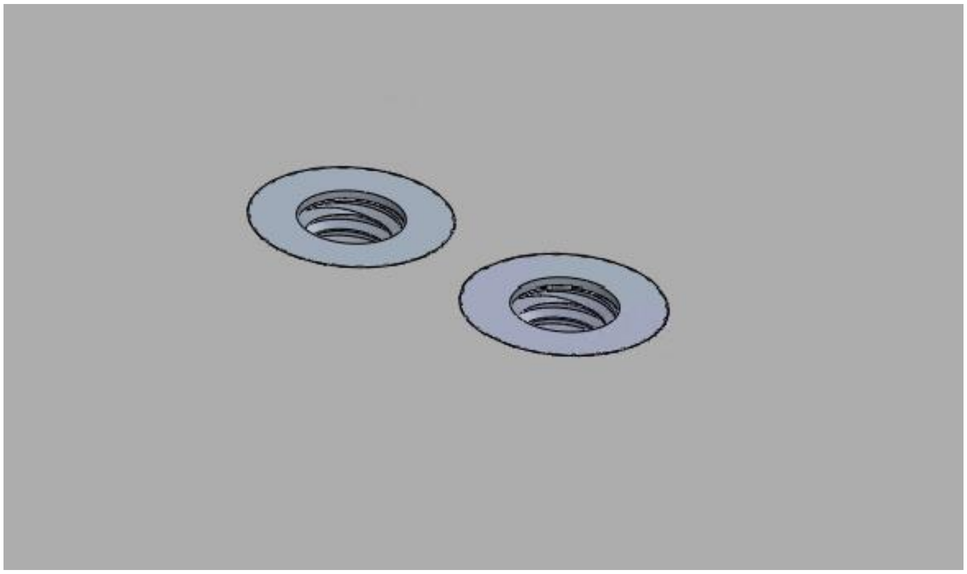


Figure 24: Threaded Inserts in Honeycomb Sandwich

c. Attachment Locations

The positions of the prop rod attachments needed to be calculated in order to achieve the desired range of angles for the array. The vertical distance between the array and chassis at the side of the vehicle where the hinges are located was 6 inches because this is the vertical displacement created by the hinging mechanism. The overall width of the vehicle is 66.5 inches. The maximum length of the larger prop rods was 61 inches. The array attachment positions were selected first. These attachments were placed 2.5 inches inside the longitudinal ribbing on the left side of the vehicle. This resulted in the distance between the hinged side of the array and the attachments being 37.87 inches. This location was chosen in order to avoid interference with the diagonal and longitudinal ribbing. As previously stated, the upper ends of the prop rods were attached directly to the ribbing running along the width of the car. Figure 25 shows the propping mechanism attachment locations on the array.

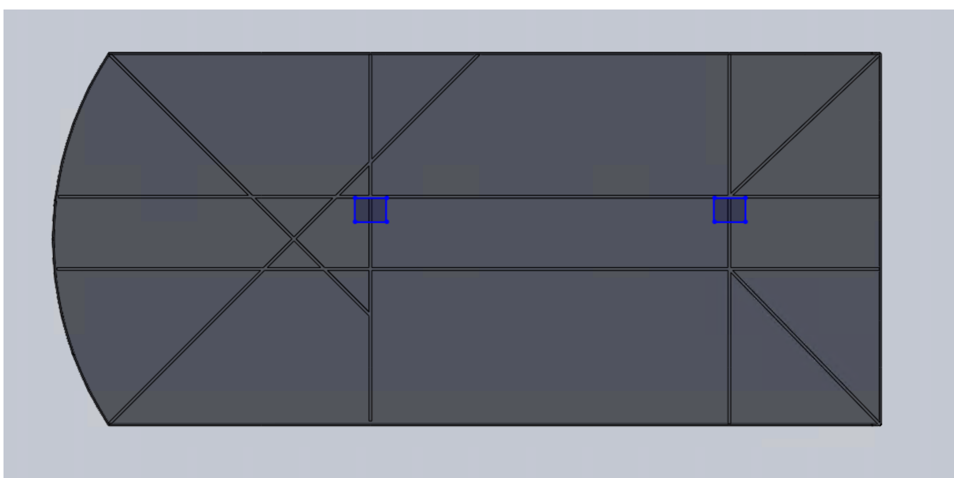


Figure 25: Propping Mechanism Attachment Locations on Array

In order to choose the attachment locations on the chassis, it was assumed that when the array angle was held at 90 degrees, the larger prop rods would be fully extended in the mechanism. This allowed a sketch of the 90-degree situation to be created that could be solved for the distance between the chassis attachments and the hinging side of the chassis using the Pythagorean Theorem. Figure 26 shows this sketch. Equation 4 was used to find the distance between the chassis attachments and the hinging side of the chassis.

$$w = \sqrt{{L_{max}}^2 - h^2} \qquad (4)$$

Where:

$$w = Distance\ Between\ Chassis\ Attachments\ and\ Hinging\ Side\ of\ Chassis$$

$$L_{max} = Maximum\ Length\ of\ Larger\ Prop\ Rods$$

$$h = Vertical\ Distance\ Between\ Array\ Attachments\ and\ Surface\ of\ Chassis$$

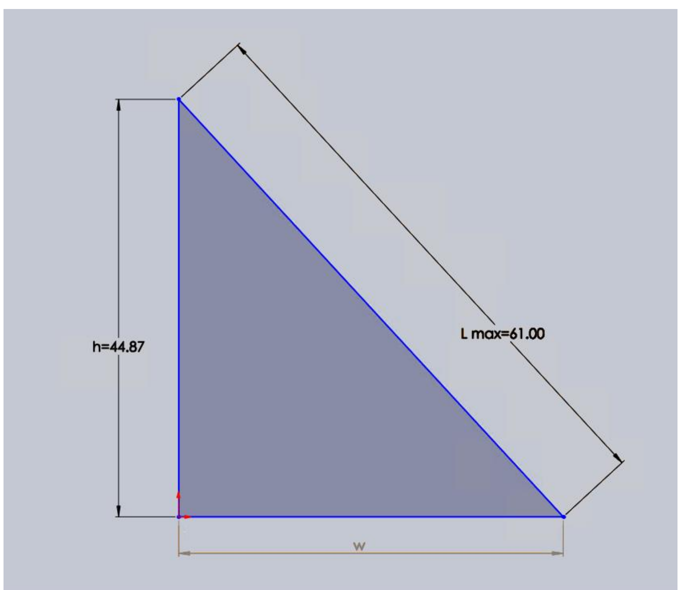


Figure 26: Side View Sketch of Propping System for Array Angle of 90 Degrees

From Equation 4, the distance between the chassis attachments and the hinging side of the chassis was found to be 41.20 inches. An analysis was then performed to determine if the prop rods used in this design would be able to achieve the required angle range with the calculated attachment locations.

For this analysis, a 2-D sketch of the system was first created. The known values for this sketch are the distance between the chassis attachments and the hinging side of the chassis, the distance between the array attachments and the hinging side of the array, and the vertical displacement created by the hinging mechanism. Prop rod length and array angle are the variables of interest in this analysis. Figure 27 shows the sketch used in this analysis.

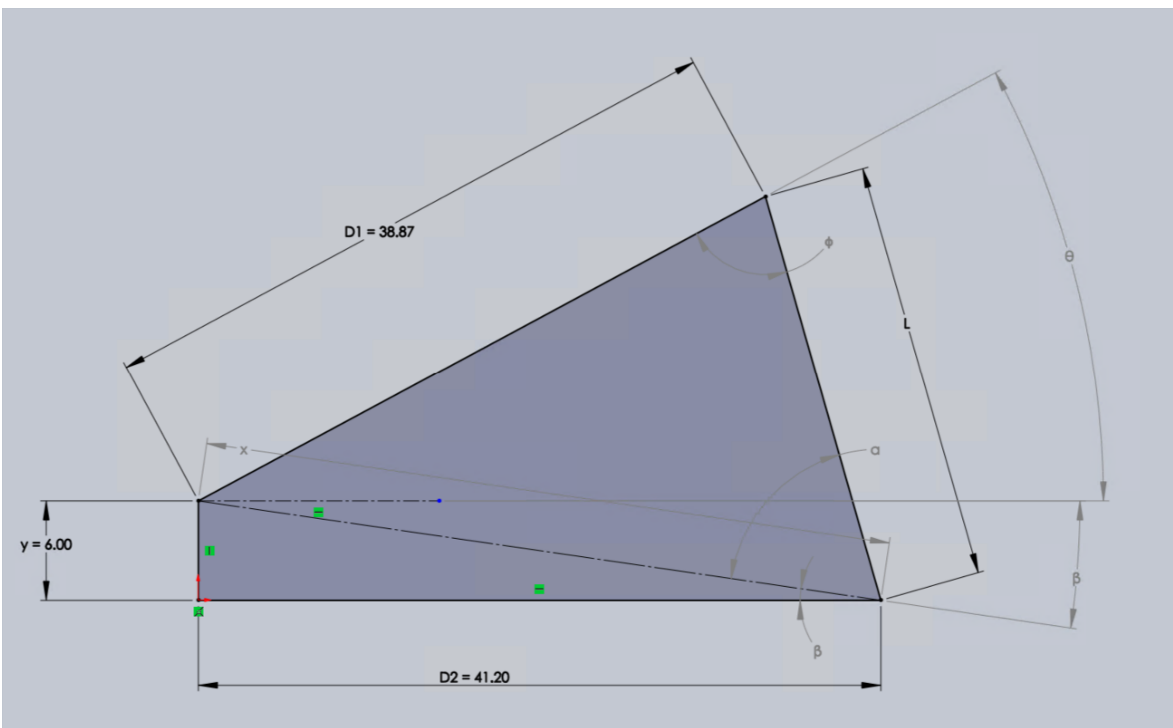


Figure 27: Side View Sketch of Propping System for General Case

In this sketch, critical dimensions were defined as follows:

$$D_1 = Distance\ Between\ Array\ Attachments\ and\ Hinging\ Side\ of\ Array$$

$$D_2 = Distance\ Between\ Chassis\ Attachments\ and\ Hinging\ Side\ of\ Chassis$$

$$y = Vertical\ Displacement\ of\ Hinging\ Mechanism$$

$$L = Length\ of\ Prop\ Rod$$

$$\theta = Angle\ of\ Array$$

α, β, ϕ, and x were variables created based off the sketch geometry to assist in the analysis. All lengths in this sketch are measured in inches, and all angles in this sketch were measured in degrees. From this sketch, x was first solved for through the Pythagorean Theorem. Equation 5 was used to solve for x.

$$x = \sqrt{{D_2}^2 + y^2} \qquad (5)$$

From Equation 5, x was found to be 41.63 inches. Next, β was solved using trigonometric relationships. Equation 6 was used to solve for β.

$$\beta = \tan^{-1}\left(\frac{y}{D_2}\right) \qquad (6)$$

From Equation 6, β was found to be 8.29°. ϕ and α were then defined as functions of L using the Law of Cosines. Equations 7 and 8 were used to define ϕ and α respectively.

$$\phi = \cos^{-1}\left(\frac{L^2+{D_1}^2-x^2}{2*L*D_1}\right) \qquad (7)$$

$$\alpha = \cos^{-1}\left(\frac{L^2+x^2-{D_1}^2}{2*L*x}\right) \qquad (8)$$

θ was then defined as a function of L using Triangle Sum Theorem. Equation 9 was used to define θ.

$$\theta = 180 - \phi - \alpha - \beta \qquad (9)$$

After plugging in all known values, Equation 9 simplifies to Equation 10, which is the relationship between array angle and prop rod length for the system.

$$\theta = 171.71 - \cos^{-1}\left(\frac{L^2-222.2}{77.74L}\right) - \cos^{-1}\left(\frac{L^2+222.2}{83.26L}\right) \qquad (10)$$

After the relationship between array angle and prop rod length was found, the relationship was plotted, and prop rod lengths corresponding to the array angle values necessary for this design were found graphically. Figure 28 shows a plot of the relationship between the prop rod length and array angle. Table x shows tabulated values of prop rod lengths and array angles necessary for the design.

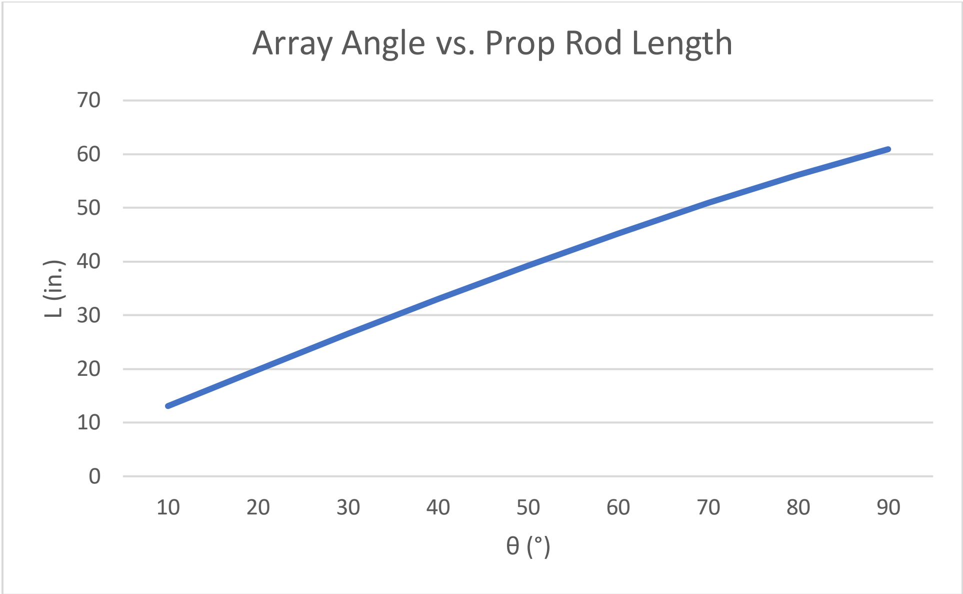


Figure 28: Plot of Array Angle vs. Prop Rod Length

θ (°)	L (in.)
0	N/A
10	13.08
20	19.85
30	26.53
40	33.02
50	39.28
60	45.24
70	50.86
80	56.1
90	60.92

Table 5: Tabulated Values of Prop Rod Lengths Corresponding to Required Array Angles

Table 5 shows that the smallest necessary prop rod length for the given attachment locations is 13.08 inches, which is less than the 16-inch minimum length of the smaller prop rod size used in the design. In order to accommodate this length, two inches will be cut from the length of the smaller prop rods to allow them to telescope a minimum length of 12 inches. Additionally, the larger prop rods will need to have additional dowel holes drilled in them to allow them to lock at the lengths required by the design. Based off Table 5 and the prop rod modifications, the smaller prop rods will be used when an array angle of 10 to 30 degrees is required, and the larger prop rods will be used when an array angle of 40 to 90 degrees is required. With these modifications, the calculated propping locations on the chassis will suffice. These attachment locations will need to be offset 6 inches laterally from the array attachment locations to account for the 6-inch lateral displacement of the hinging mechanism. Figure 29 shows the propping attachment locations on the chassis.

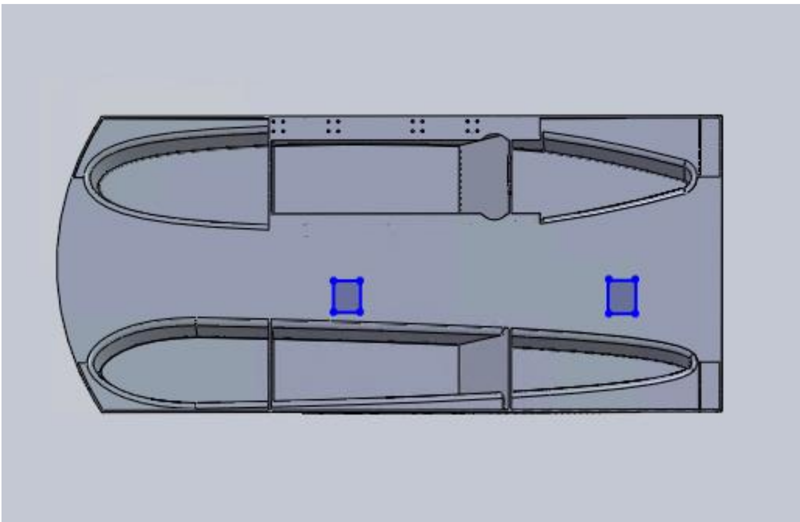


Figure 29: Propping Attachment Locations on Chassis

4. Latching Design

a. Overview

The latching mechanism underwent several iterations before protruding pins were chosen. The first designs involved wire and pulley assemblies to actuate spring loaded latches mounted internally. These designs were abandoned due to several concerns with the mechanism, including stretching of the wires, nonuniform actuation, overcomplexity, and lack of immediate verification of a latched or unlatched state. The other design that was considered was internally mounted spring-return latches that would be actuated by pushrods inserted into access ports. This solution addressed several concerns from the pulley system, but the latch state was still not easily verifiable. This design also did not address one of the key goals of the project, that one person could reasonably unlatch and hinge the array alone. The need for three to four latches in total would have required one person at each port actuating the latches simultaneously then lifting the array so it would not immediately latch again.

b. Mounts

It was determined that the most effective latching mechanism would be clevis pins mounted directly to the array that protrude through the bottom of the chassis while the array is closed. In this position, hairpin cotter pins will be inserted into the clevis pins to secure the array in the closed position. This design did not raise the issues the other solutions did by being a simple mechanism with fewer points of failure, by having individual actuation, and possibly most importantly, by allowing visual verification of a latched state. The clevis/cotter pin assembly is shown in Figure 30 below.

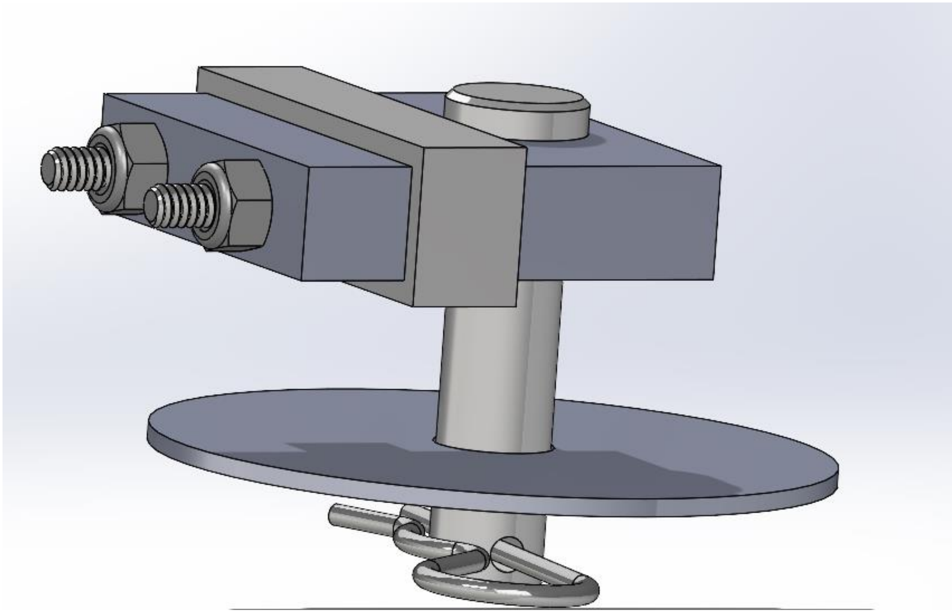


Figure 30: Clevis latching pin with locking hairpin cotter pin

In addition to the primary latching method, steel cable lanyards will be used to satisfy section 10.1.C of the ASCR. Due to the requirement of less than 600 mm of upward movement, these lanyards will have to be removable. Clevis and cotter pin assemblies were designed to mount each lanyard to the array ribs and the chassis, as shown in Figure 31 and 32, respectively.

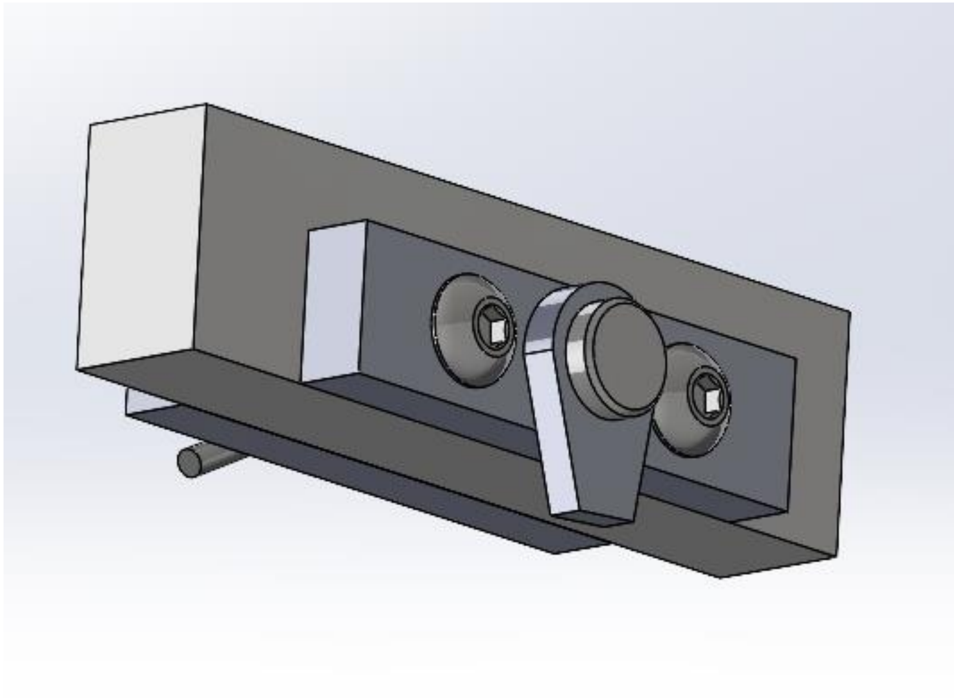


Figure 31: Removable Array Rib Mount

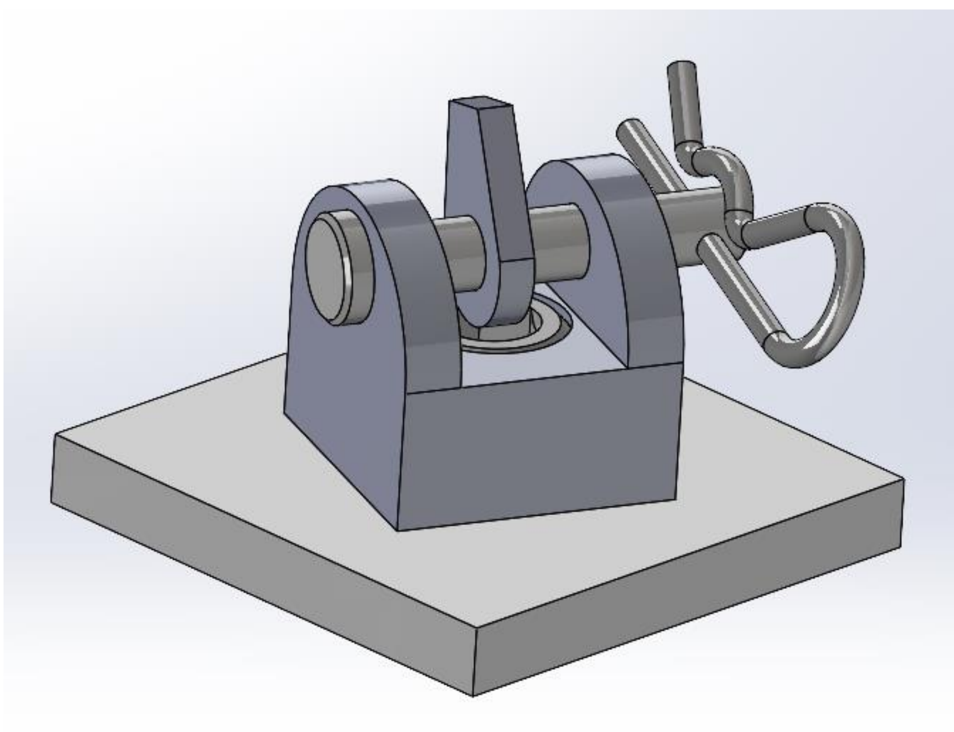


Figure 32: Removable Chassis Pin Mount

c. Mounting Locations

Initial plans for mounting points included fixing them directly to the surface of the aeroshell using hardpoints. This plan was abandoned as the solar cells covered everything but a small area around the driver compartment. That meant the latch pins must be mounted on the support ribs of the aeroshell, which constrained the potential locations further. The forward latches must be mounted within 4 inches of the forwardmost point of the diagonal support ribs in order to avoid interference with the wheel wells and be easily accessible. Locations chosen for the rear latches were on the lateral support rib, within 3 inches of each side of the car. Additionally, the lanyard mounts were located on each longitudinal rib, about 10 inches from each edge to satisfy location requirements set in the ASCR. The rear lanyard was not required by the ASCR, it was included as an additional measure of redundancy. Figure 33 and 34 show mounting locations on the array and lower aeroshell, respectively.

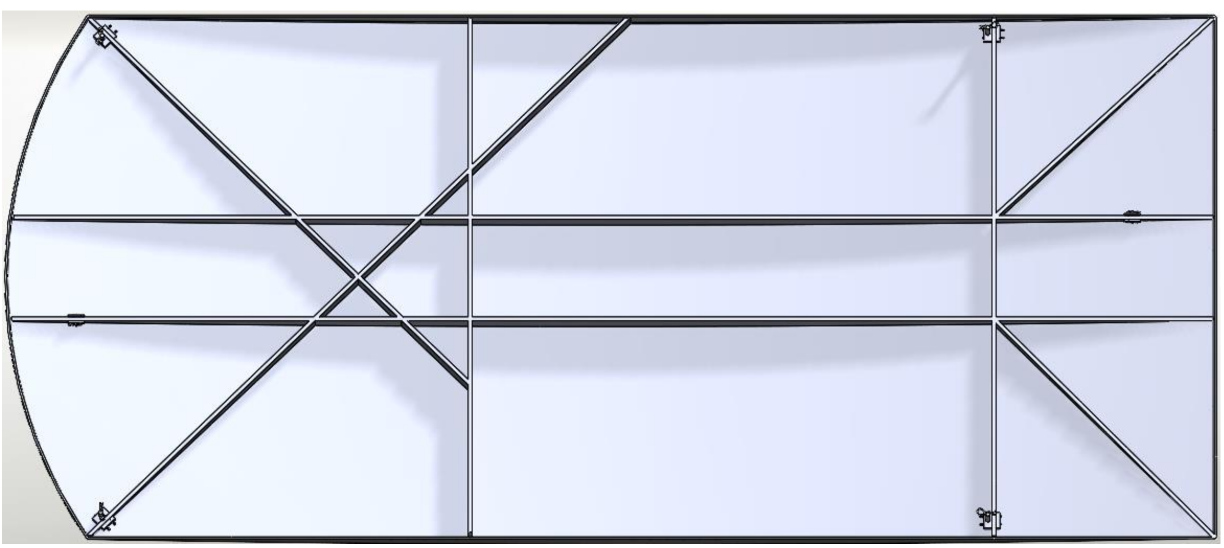


Figure 33: Array Latch and Lanyard Mount Locations (view from below)

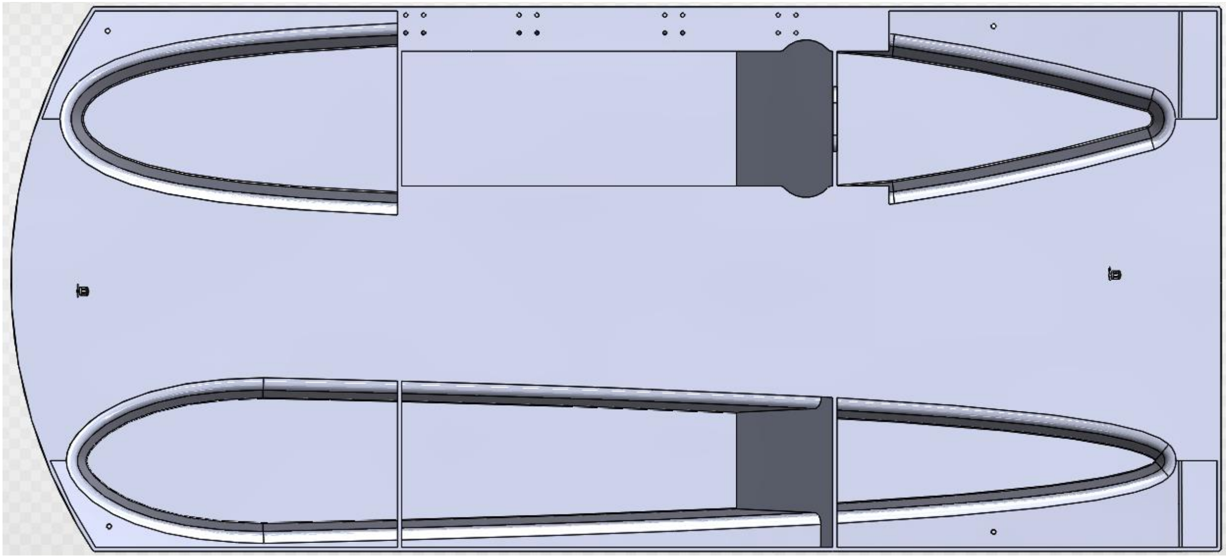


Figure 34: Lower Aeroshell Latch and Lanyard Mount Locations

5. Conclusions

a. Impacts on Engineering Solutions in Global, Economic, Environmental, and Societal Contexts

Solar-powered vehicle technology has the potential to make a greatly reduce carbon emissions generated by cars and allow vehicles to be powered by renewable energy. Even if vehicles were partially powered by solar energy, this would provide great benefits to the environment. This technology would also significantly reduce the amount of money spent on gasoline.

The mechanisms designed in this project support the advancement of solar-powered vehicle technology. They ensure that the array of solar panels can be adjusted and held closed safely, and they allow for solar capture to be optimized based off the position of the sun. These are two crucial features in vehicles that are being powered by solar energy. There will likely be an increasing number of solar-powered vehicles being built in the future, and the hinging, propping, and latching mechanisms designed in this project could serve as inspiration in the designs of these vehicles.

b. Recommendations

The hinging, propping, and latching mechanisms designed in this project meet all design requirements for use in the 2021 iteration of the Sunseeker Solar Car. They will support the safety, functionality, and optimization of solar capture for the Sunseeker vehicle. Additionally, it is possible that these mechanisms could be used in future iterations of the Sunseeker Solar Car. Other teams competing in the American Solar Challenge with similar vehicle layouts may also be able to use these mechanisms in their vehicles or create similar mechanisms inspired by these designs. However, the Sunseeker vehicle is constantly being redesigned in order to optimize performance. For this reason, these designs may not be applicable to future iterations of the Sunseeker vehicle. This also applies to the vehicles of other teams competing in the American Solar Challenge. The car layouts of these teams vary greatly, and teams are always redesigning their vehicles. Because of the varying designs and continuous improvement of solar-powered vehicles, the specific needs and layout of each vehicle iteration must be evaluated in order to determine if the designs created in this project would be viable solutions to another team's solar car or a future iteration of the Sunseeker vehicle.

6. References

[1] “Our History.” *WMU Solar Car*, wmich.edu/sunseeker/.

[2] “Formula Sun Grand Prix.” *American Solar Challenge*, www.americansolarchallenge.org/about/formula-sun-grand-prix/.

[3] *American Solar Challenge*, www.americansolarchallenge.org/about/american-solar-challenge/.

[4] “Accueil.” *Esteban Voiture Solaire*, 15 Sept. 2020, esteban.polymtl.ca/en/.

[5] *2021 Regulations*. 15 Oct. 2020, www.americansolarchallenge.org/ASC/wp-content/uploads/2020/10/ASC2021-Regs-EXTERNAL-RELEASE-A.pdf.

[6] “25-2525.” *80/20 Inc.*, 8020.net/25-2525.html.

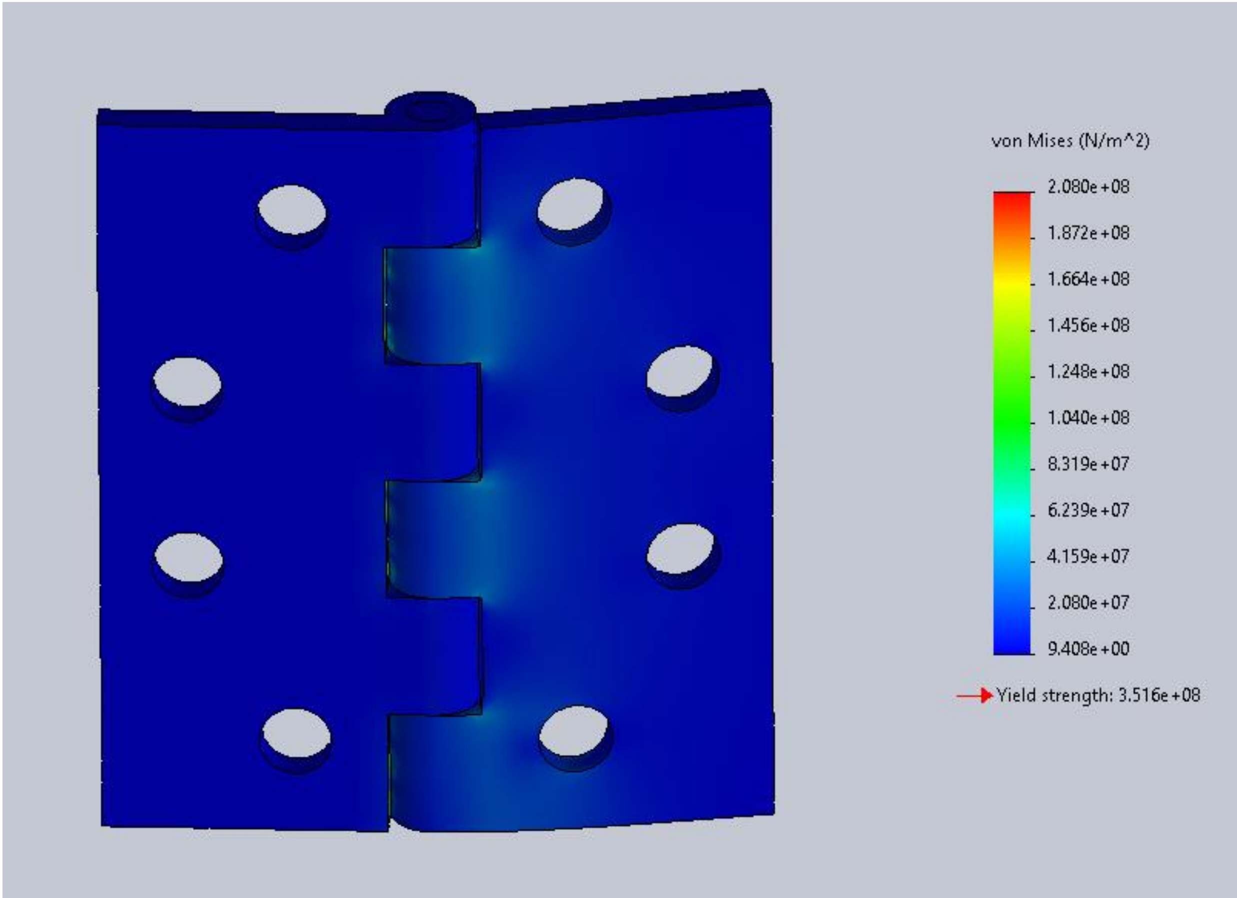
[7] “75-3479.” *80/20 Inc.*, 8020.net/75-3479.html.

7. Appendices

A. Cost Analysis

Item	Cost per Unit	Quantity	Cost
Telescoping Prop Rod (Large)	$38.27	2	$76.54
Telescoping Prop Rod (Small)	$15.48	2	$30.96
.5 in. Dia. Clevis Pin (2 in. Usable Length)	$10.56 (for Pack of 10)	1	$10.56
.5 in. Dia. Clevis Pin (3.75 in. Usable Length)	$8.03 (for Pack of 5)	1	$8.03
Hairpin Cotter Pin	$6.14 (for Pack of 50)	1	$6.14
Carbon Fiber to Aluminum Adhesive	Supplied by Sunseeker	N/A	N/A
Drill Bushing	$8.96	2	$17.92
3/8-16 SHCS	$6.14 (for Pack of 25)	1	$6.14
3/8-16 Threaded Insert	$3.64	6	$21.84
Prop Rod Lower Pin Support	Provided by Sponsor	2	N/A
Prop Rod Upper Support Aluminum Plates	Provided by Sponsor	4	N/A
.5 in Dia. Clevis Pin (1.75 in. usable length)	$9.91 (Pack of 10)	1	$9.91
.5 in Dia. Clevis Pin (3.25 in. usable length)	$16.32 (Pack of 10)	1	$16.32
10-24 button head hex drive screw 2.5in usable length partially threaded(0.88 in of threading)	$14.33 (Pack of 50)	1	$14.33
Stainless Steel Washer (3in. OD)	$2.97	8	$23.76
Nylon Locknuts (10-24)	$5.70 (Pack of 100)	1	$5.70
Eye-to-Eye Lanyards (18in long)	10.14	2	$20.28
1/4 in Dia Clevis Pin (1-3/16 usable length)	$7.04 (Pack of 25)	1	$7.04
Small Hairpin Cotter Pin (for 1/4 in clevis)	$9.64 (Pack of 100)	1	$9.64
10-24 button head hex drive screw 1in length fully threaded	$10.38 (Pack of 50)	1	$10.38
Latch Pin Mount (Machined)	Provided by Sponsor	2	N/A
Rear Latch Pin Mount (Counterbored for Clevis)	Provided by Sponsor	2	N/A
Latch Mount Backside (Machined)	Provided by Sponsor	4	N/A
Lanyard Mount	Provided by Sponsor	4	N/A
Lanyard Base	Provided by Sponsor	4	N/A
Mounting brackets	provided by Sponsor	4	N/A
Coupler link	provided by Sponsor	2	N/A
Vertical link	provided by Sponsor	4	N/A
Outside surface plate	provided by Sponsor	2	N/A
Hinges	$41.19	2	$82.38
Nuts (25 in a pack)	$3.56	1	$3.56
Rounded bolt (3/8") for array bracket	$3.72	8	$29.76
Rounded bolt (3/8") for coupler (2 in a pack)	$3.67	4	$14.68
		Total	$425.87

B. FEA Results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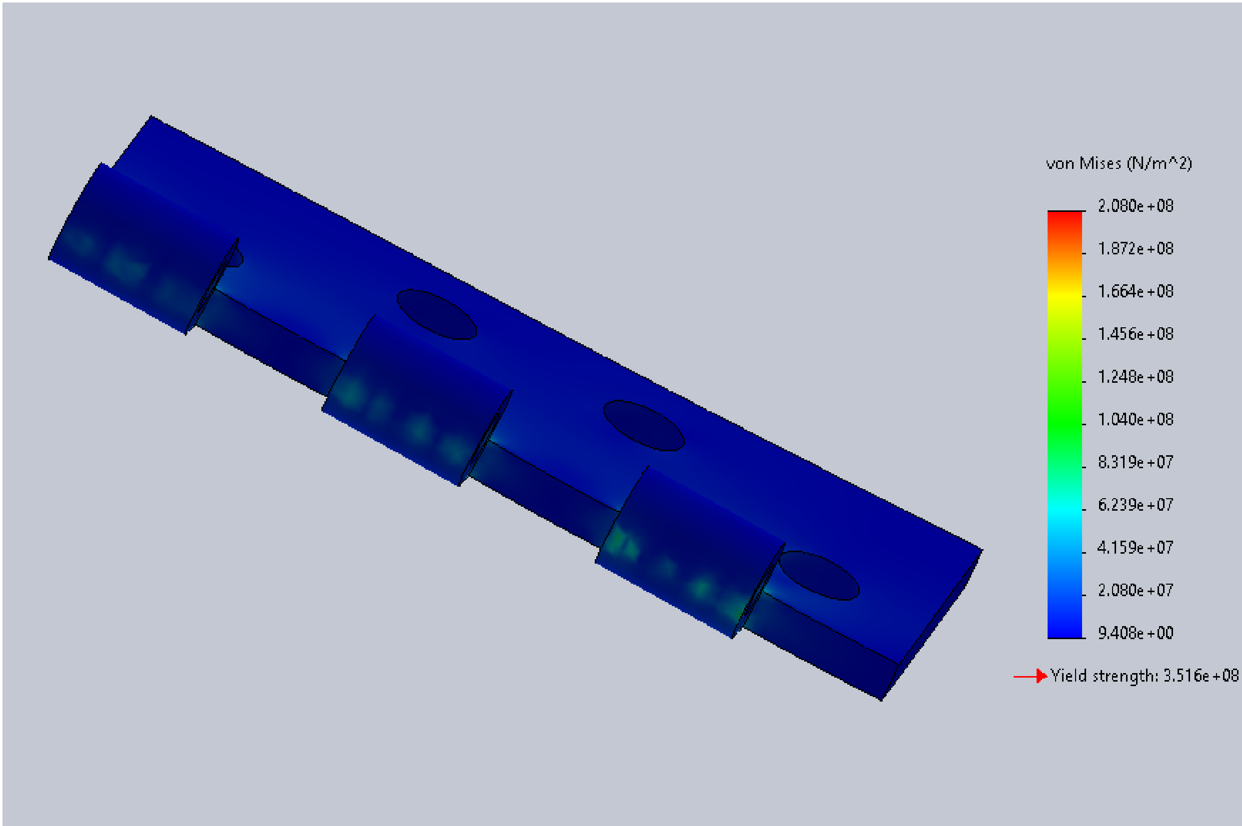
Yield strength: 3.516e+08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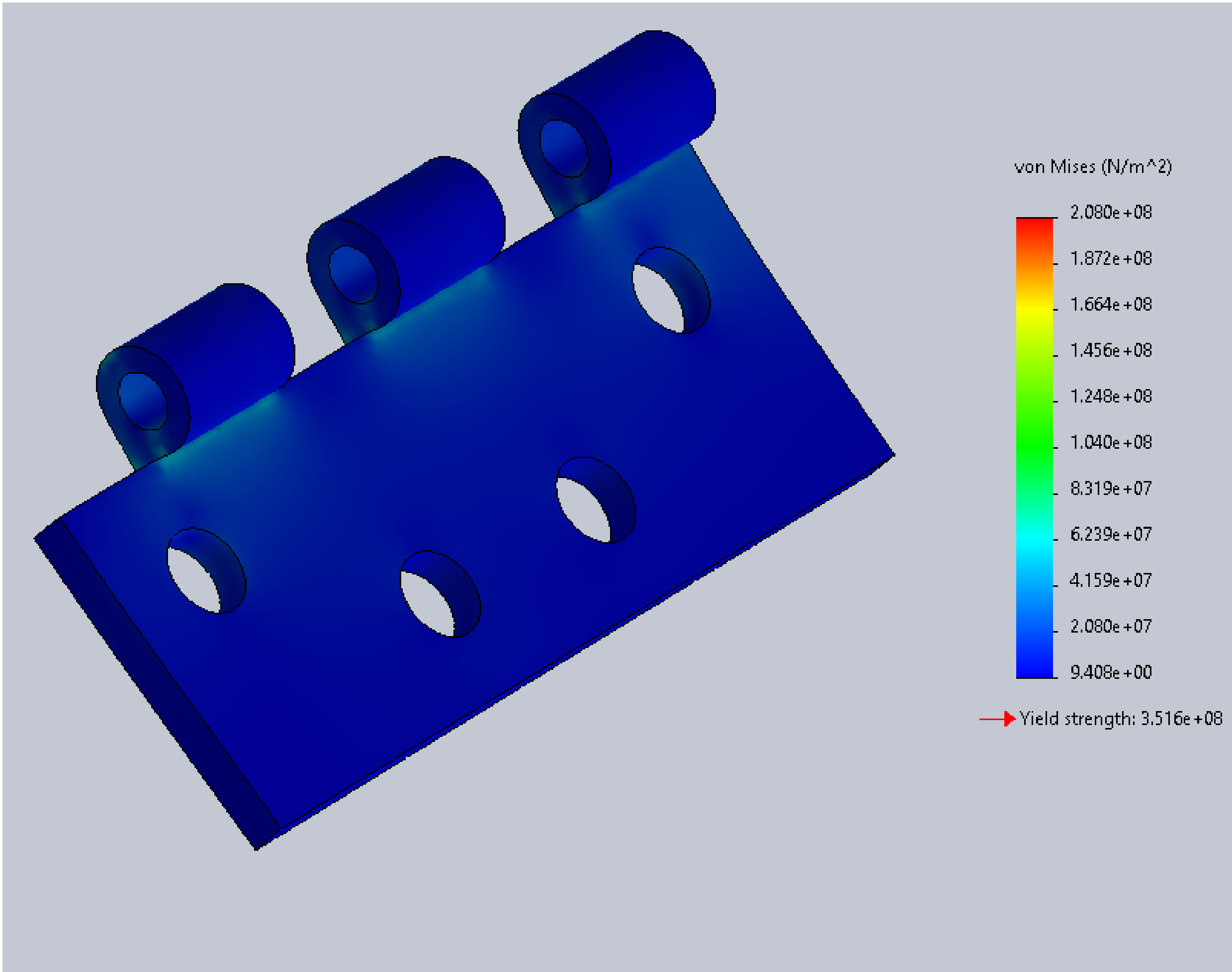
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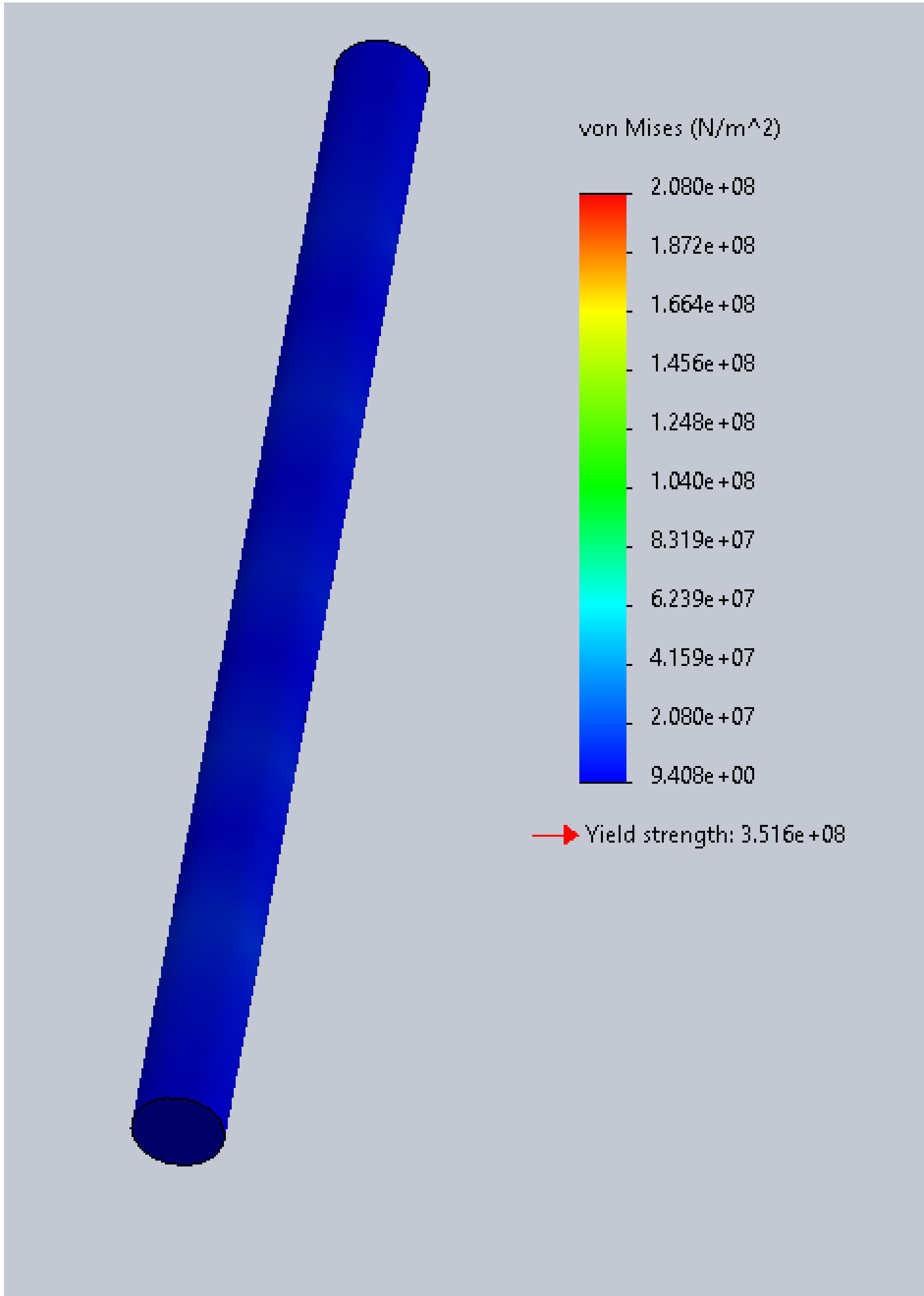
Yield strength: 3.516e+08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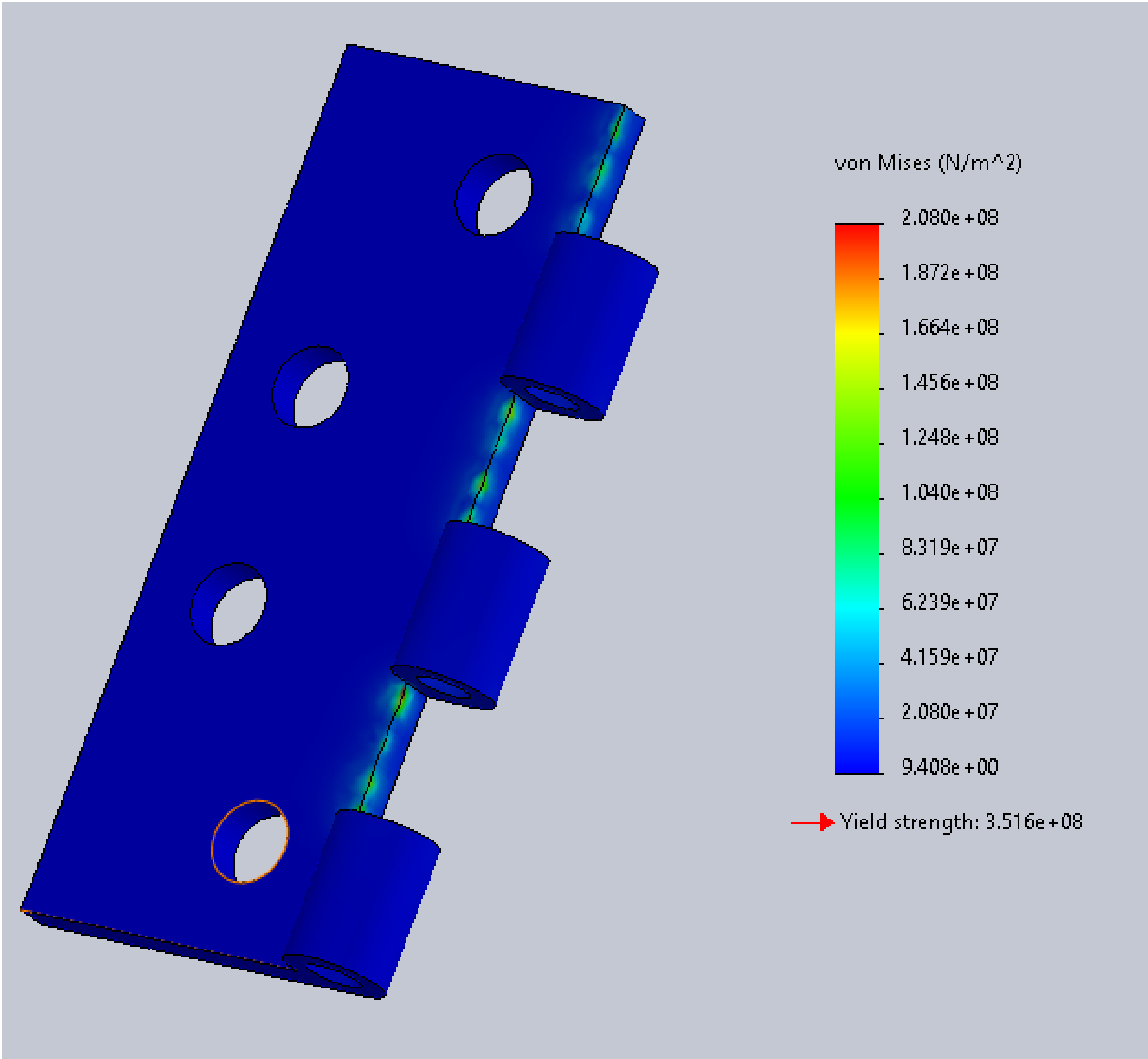
Yield strength: 3.516e+08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1.248e+08
1.040e+08
8.319e+07
6.239e+07
4.159e+07
2.080e+07
9.408e+00
Yield strength: 3.516e+08

C. Resumes

Zachary Ruppenthal

1503 Tecumseh Drive
McHenry, IL 60050
(815) 355-2923 | zach.ruppenthal13@gmail.com

Career Objective

Motivated, detail-oriented mechanical engineering student with previous internship experience. Possess hands-on experience as well as CAD skills. Seeking full-time employment upon graduation.

Professional Experience

Undergraduate Research Assistant | Western Michigan University | September 2020 to Present

- Verify design of high-speed test apparatus by reviewing models in MASTA
- Develop a set of detailed drawings using AutoCAD
- Work with vendors to develop a cost of fabrication and construction of the test stand

Engineering Intern | Critical Care Diagnostics, Inc. | June 2020 to September 2020

- Designed test fixture to be used in testing of product changes
- Utilized CAD software to design parts and assemblies used in fixture
- Developed test protocol to allow for testing to be duplicated

Engineering Intern | Humphrey Products | April 2019 to April 2020

- Designed fixtures used in the testing of new products and technology using CAD software
- Carried out testing on new products and technology. Tested for flow rates, pull-in voltages, and various other parameters
- Organized data in Excel and created graphs in order to provide a visual of testing results

Education

Bachelor of Science | Expected Graduation Date: April 2021| Western Michigan University

- Major: Mechanical Engineering
- Cumulative GPA: 3.9/4.0

Skills / Certifications

- SolidWorks / Solid Edge / AutoCAD
- MATLAB
- Six Sigma Green Belt
- Microsoft Office
- Soldering
- Critical Thinking
- Time Management
- LabVIEW

Activities

- Tau Beta Pi Engineering Honor Society
- Sunseeker Solar Car Team
- Volunteer Work (Kalamazoo Nature Center, Salvation Army, etc.)
- Member of Lee Honors College

Awards

- College of Engineering and Applied Sciences Scholarship
- Mechanical and Aerospace Merit Scholarship Award
- Dean's List
- TowerPinkster Endowed Scholarship

4715 Dover Hills Dr, Kalamazoo, MI, 49009 – (715) 929-0836 – landenwallace20@gmail.com

Objective

Self-driven aerospace engineering student with internship experience seeking a full time engineering position.

Education

Western Michigan University
Bachelor of Science in Engineering
Major: Aerospace Engineering, Minor: Math
Expected Graduation: April 2022
GPA: 3.3

Activities/Honors

AIAA WMU chapter UAS division Lead Engineer 2017-2019
Lee Honors College

Experience

Maintenance/Facilities Intern, Parker Hannifin FSC Division, Otsego MI (March 2018-present)

- Assisted maintenance technicians in upkeep of various machining and assembly machines concerning their Programmable Logic Controllers
- Coordinated upgrades of various obsolete PLC's and safety devices
- Assisted Facilities Department with various installations and upgrades of production machines
- Assisted Facilities Department with various upkeep and improvements of the facility
- Consolidated backups and other information of all PLC systems in the facility

Maintenance Intern, Nicolet Plastics, Mountain WI (June 2016 – August 2016)

- Assisted maintenance technicians in upkeep of injection molding presses, including periodical checkups and major repair projects
- Assisting in maintenance projects has helped me understand the human aspect of engineering. A machine should accomplish its task while being accessible to operators and maintenance technicians
- Completed projects including total design, fabrication, and assembly of various machine and facilities improvements

Skills

Strong interpersonal skills
Strong oral and written communication skills
Hands-on mechanical experience
AutoCAD 3D solid modeling

RYAN ZAHARIA

501 N Reese St. South Lyon, Michigan. 48178
248-719-9492 ∠Ryan@aerodesignservices.com

SUMMARY

Seeking an apprenticeship to become a licensed DER (Designated Engineering Representative) for the FAA. Reliable and competent engineering that is eager to expand my existing knowledge primarily in the field of aviation, automotive, and manufacturing field. Having ample leadership experience, a persistent work ethic, solid organizational skills, and innovative thinking to ensure success.

EDUCATION

Western Michigan University, *Kalamazoo, MI* — *Sept 2018-Present*
Bachelor of Science, Mechanical Engineering — *Exp. Grad April 2021*

- GPA: 3.35

Siena Heights University, *Adrian, MI* — *Sept 2017-July 2018*
Bachelor of Science, Mechanical Engineering — *Exp. Grad NA*

- GPA: 4.00
- Dean's list- Fall 2017, Summer 2018

PROFESSIONAL EXPERIENCE

AeroDesign Services, *New Hudson, MI* — *June 2016-Present*
Director of Quality, and Injection Mold Operator

- Inspected and ensured quality in parts and manufacturing from both incoming and outgoing products are in compliance to the company's requirements.
- Certify newly received material is the correct material for jobs.
- Collaborate with firm executives and customers on project details.
- Operate VanDorm 170-ton press.

MENTORSHIP

Richard Saltivan, DAR, *Roswell, NM* — *July 2020-Present*

- Trained under DAR, Richard Saltivan, for FAA form 8130-3 (Authorized Release Certificate, Airworthiness Approval Tag).

Don Zaharia, CEO of AeroDesign Services

- Preformed Certificate of Conformance for airlines.
- Conformed structural repair on a Falcon 20.
- Taught machine operations in manufacturing.
- Engineering and manufacturing management.

SKILLS

- Computer applications: AutoCAD, SolidWorks, MATLAB, MS Office, Maple.
- Able to take lead when collaborating in a teamwork environment.
- Well-developed knowledge in manufacturing processes and practices.