



University of Cincinnati  
College of Engineering and Applied Science  
Department of Mechanical and Materials Engineering

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: **Auto Design II**

Group : **Bearcat Solar Car**

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## **SECTION 1**

### **INTRODUCTION**

The University of Cincinnati Bearcat Solar Car is a design, build, test, and race team with the intention of competing in the American Solar Challenge (ASC) and the Formular Sun Grand Prix (FSGP). The organization goal is building an operation solar power race car to race in these two competitions. The organization believes that the best way to design and fabricate the vehicle was to breakdown the component then divides them among sub – teams. As of the Spring 2022, some components had been made such as the chassis, suspension, wheel, seat, etc. For this year, fall 2022 to Spring 2023, the organization drive to have a mechanically functional vehicle which now have 5 aspects. These aspects were divided into 5 sub – teams which are headed by fifth year Mechanical Engineering Technology (MET) students. Each of the sub-teams has functioned as a senior design project and each one has had to make design decisions within their individual sub team design.

## **SECTION 2**

### **ENGINEERING STANDARD & CODES**

During the creation of the vehicle, the team followed American Solar Challenge and American Welding Standards (AWS) regulations. The American Solar Challenge regulations were used to guide the constraints that control the design of the solar car. The standards and codes used during the duration of the design of the solar car can be found in the appendix of the document.

## **SECTION 3**

### **CONSTRAIN**

In the appendix of the document, you will find the rules and regulations of the car design that we were constrained to when designing our parts. These rules and regulations were some of our constraints and not the most difficult to work around. At the start of this design, we knew only had 2 semesters to really design and build our projects. We started with a limited and tight budget considering our lack of electrical components. Lastly, we were constrained by the frame and suspension of the car that already existed.

## **SECTION 4**

### **SCHEDULE**

The official start of the collaborative design project in late August 2022 with our first meeting of the semester on the 29th. This set the clock for the deadlines we needed to make with the PDVR, VDP, race admission, the tech expo, and the race itself. We had finished the PVDR by the 17th of November 2022 for our designs to be checked for eligibility to race. The VDR was due at registration and was filled out for reference next year but not submitted. The race admission had to be completed by July 2nd, 2023. We needed to decide on whether to race and at that point it was determined we needed the money to finish the car rather than risk paying to race without a functioning car. The tech expo was our final deadline to have every project done if not on the car by April 6th, 2023, for the expo to present the projects to faculty and judges.

## **SECTION 5**

### **AXEL & MOTOR MOUNT SUB-TEAM**

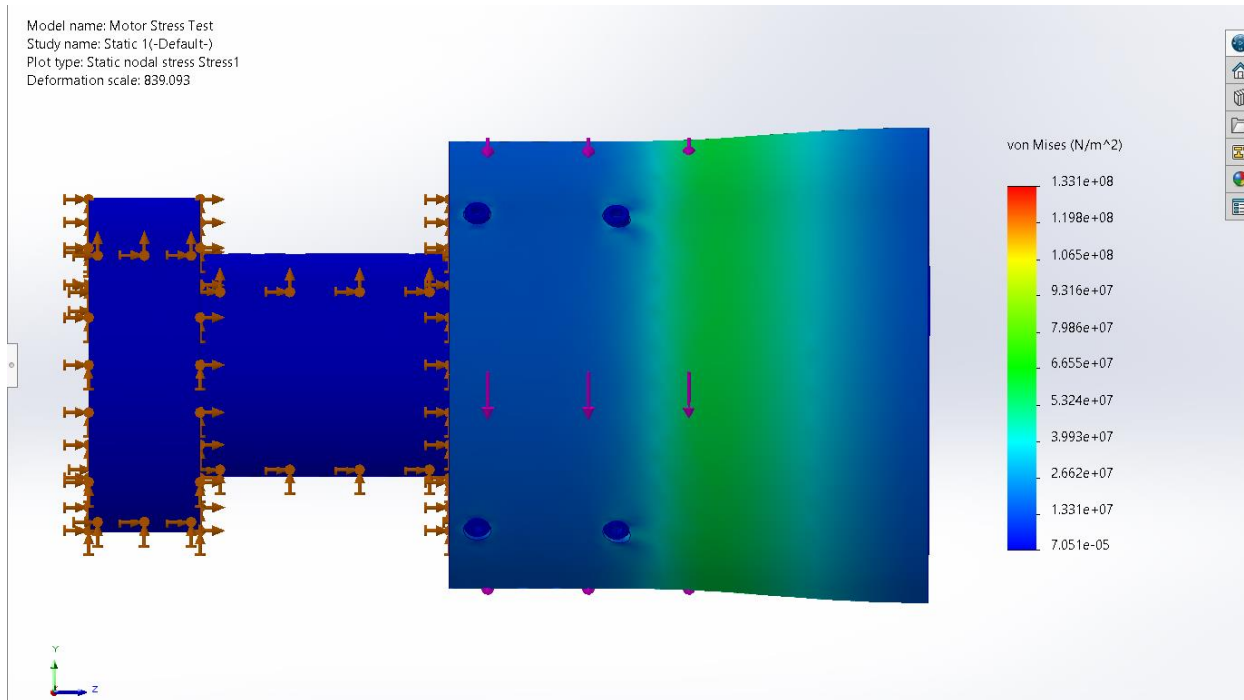
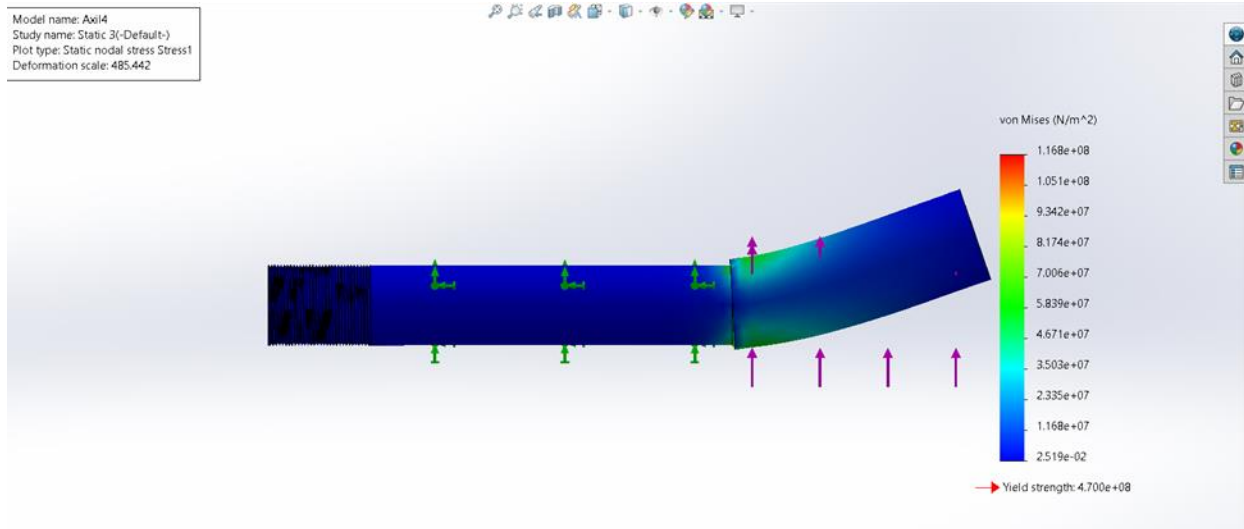
Mueller, Drake (MET)

#### **5.1 Design Goals**

The original design goal was to fix the car's front axles, to fix its issue with the wheels colliding with the car, and to alter the car's height to be within racing standards. It was later discovered that the car was above the minimum height. Later I took on the design of the car's motor mounting problem since the axle design was done.

#### **5.2 Assumptions/ Inputs**

Without the actual specifications of the motor or anything more than a rough estimate of the weight of the car when finished, some assumptions had to be made when simulating the effects of the car on my designs. I reassure that the axles wouldn't break or bend under the weight of the car. To prove this, I simulated them under the entirety of the estimated weight of the car, 1000 lbs. I also tested the torsional capabilities of the screws and motor mount with an average value I found of torsional load on a passenger car wheel of 17000 Nm.



### 5.3 What did you need from other teams to complete your design

To complete my design fully I needed to work with the electrical team for expected forces the motor would apply to my design and when creating a test fixture for them to test said motor. I also needed to work with the breaking team to ensure my axles would be able to fit in their design.

#### 5.4 What did you owe to other teams to enable their designs

What I owed the electrical team was a test mount for the motor and a way to mount the motor on the car that would allow it to be taken off again. What I owed the breaking team was communication about how the axles would interact and affect their design.

#### 5.5 Lessons learned in design

I learned that open communication is not only an absolute necessity, but it can also drastically affect the outcome of mechanisms being compatible with each other. All communication should also be well documented to prevent any confusion and show total transparency in the design. I learned about the value of material compatibility for welding and that just because it's all steel doesn't ensure an easy joining of the two.

#### 5.6 What worked well and should be carried forward

I believe the mechanical team had decent communication and helped each other with their design sometimes. I think the communication and cross-team help was very productive and should absolutely be continued for future projects.

#### 5.7 What did not work and should be changed in the future

I believe there wasn't enough documentation of designs and almost no documentation about meeting or design notes during meetings. I think this would help with everyone's understanding of each other, and the overall build of the car. I believe the chassis of the car and its suspension are heavy, non-aerodynamic, and or made mounting anything to it difficult. I believe the entire chassis should be scrapped as well as the suspension design, at least in the rear of the car.

#### 5.8 Anything you spent a lot of effort on and wouldn't want to do again

I spent a lot of effort on machining the axles and wouldn't want to personally machine 6160 steel again. I would have made the design a little thicker and used a more machinable material for them to save time and effort.

### 5.9 Lessons learned in manufacturing

In the manufacturing of the car, I learned the importance of an accommodating chassis that can more easily have something like a motor or brakes mounted to it. I also learned the importance of material compatibility when I started work on getting the motor mount affixed to the car.

### 5.10 Processes you figured out that should be documented

I think all meetings, official and unofficial, should be documented in some way. The level of detail should be up to those who are meeting but I believe a more successful design and manufacturing process would be achieved if more notes were taken of meeting so everyone could remember exactly what was said about the design, how far away it is from being finished, and exactly what was supposed to happen or what wasn't supposed to happen.

### 5.11 Issues during manufacturing/ assembly

During the manufacturing of the axles, I had a lot of issues with exterior and interior threading. Internally I didn't know what the threads were supposed to be as it wasn't called out on the drawings of the previous model, so I had to hunt that information down. The exterior threads were much more difficult though. The metal was simply too hard but that wasn't known for a lot of time. When I attempted to thread my first axle the die wouldn't cut into the metal, and it was believed that the die wasn't sharp enough to cut it so a new one was ordered. The second die was also unable to cut the metal. When used the axle would spin in the lathe because the teeth of the chuck, no matter how hard they were tightened down with a breaker bar, couldn't even make a mark on the part as it spun. The axles were then taken to the VPC shop and the machinist there was unable to properly thread my first axle. Days before the expo the second axle I made was able to be manually threaded without a die but by this time I only had one completed since the first one that was made had irrecoverable damage to the threaded area. This meant the axles could not be put on in time for expo.

There were issues with the motor mounting as well when having them manufactured. The material chosen for manufacturing it was 304 Stainless steel and was chosen for its strength and machinability. The design I went with though was difficult to machine and caused multiple taps to break during its manufacture for one of the mounts. The design was necessary to

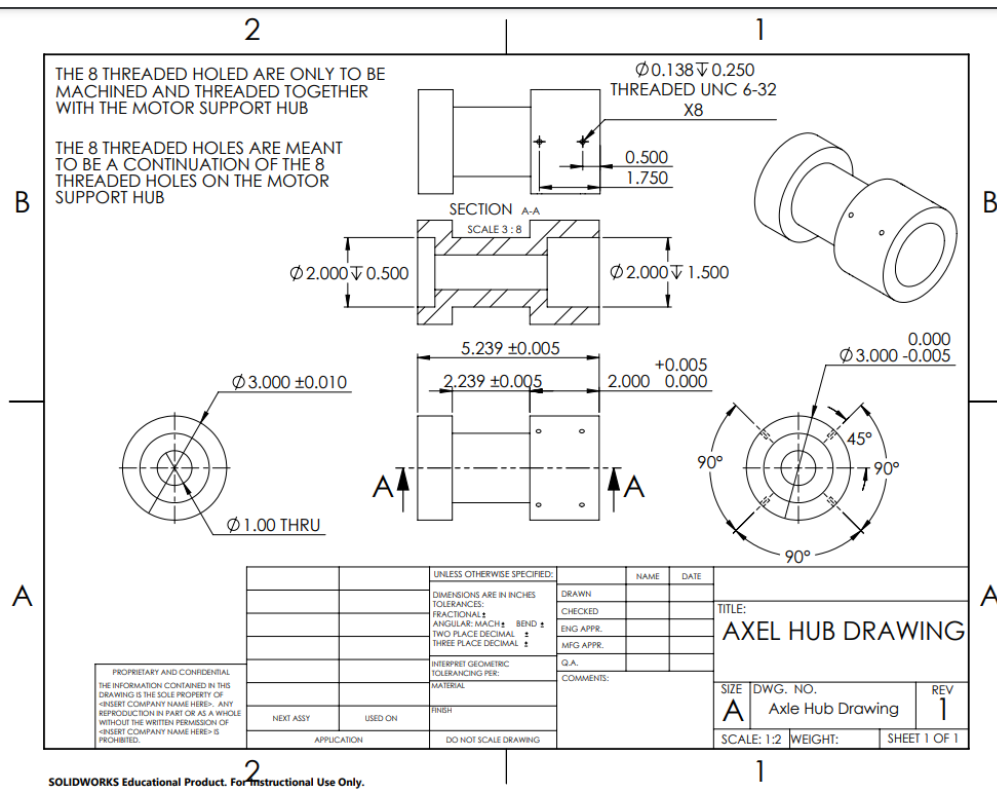
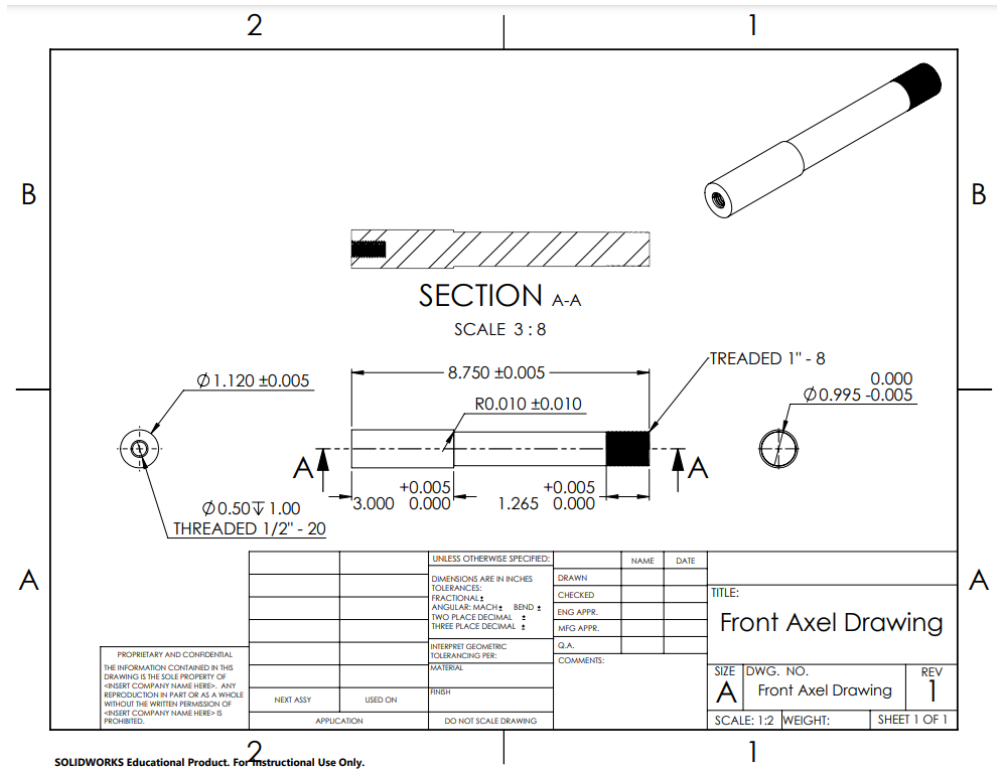
accommodate the suspension's shortcomings but was now also causing the manufacturing of it to be altered to avoid wasted time and perfectly good taps, so the hole was drilled in a new spot and threaded. While one of the motor mounts was able to be put on the car there were other assembly obstacles that were in the way. The car's design requires an intermediary plate to allow the wheel and the motor to fit together. Without this plate and with my design being able to accommodate the motor and not the old axles if it was put on the car would be on 3 wheels until the plate was finished. With the tech expo days away, it was decided that it would be best to keep the car on 4 wheels for the expo, so it was not added to the car.

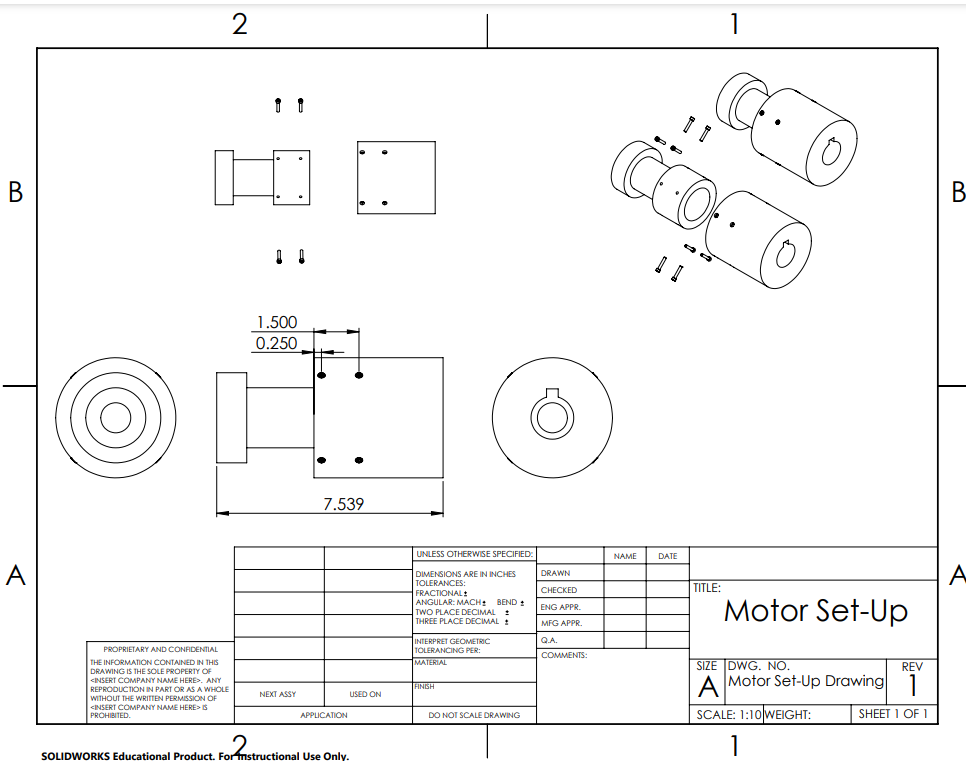
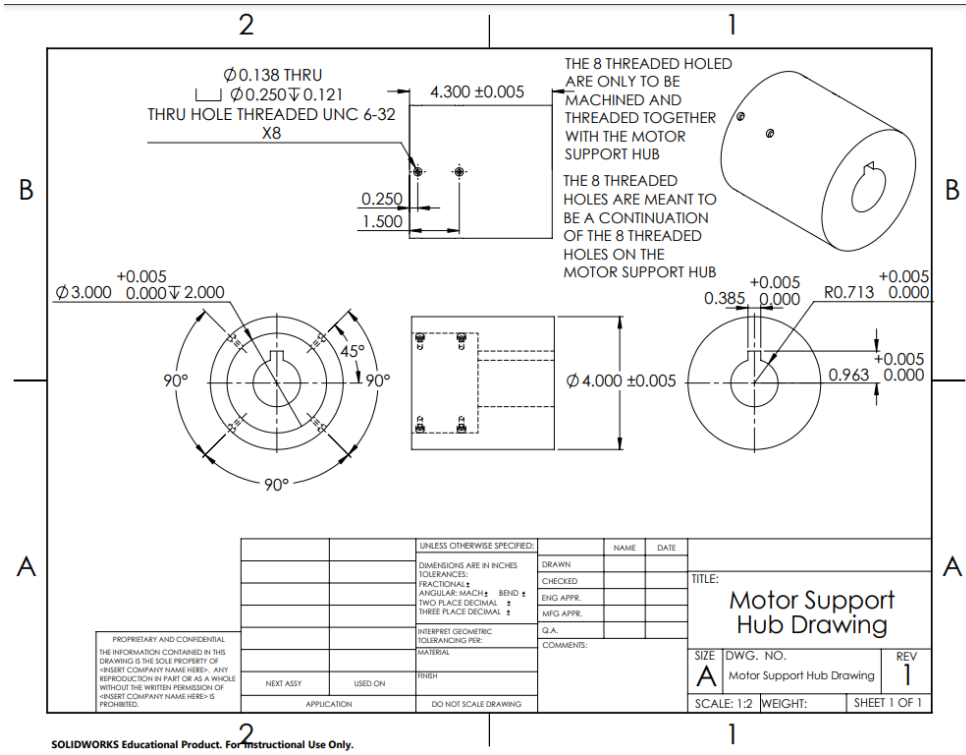
#### 5.12 Overall assessment of the design

My overall assessment of my own design is it would be sufficient to mount the motor to the car and prevent the wheels of the car from colliding with the car under normal conditions. The axles were not able to be put on the car because I was having a lot of trouble threading 6160 steel without a die. Since it was weeks of time spent just trying to get them threaded or ordering a new die and trying again. The Tuesday before the Expo was when I was able to get the axles threaded but by that time the breaks had been welded onto the car already in the expectation that the axels threads wouldn't be on yet or that after they were on there wouldn't be enough time to weld the braking system on. It was decided that having a braking system on the car was more important than the axles for the tech expo. The motor mount also was not able to be mounted to the car as the plate used to attach the wheel to the car was not made before the expo. That would mean if the motor mount was attached to the car, we wouldn't have been able to have all 4 wheels for the expo. Since it would have made moving the car much more difficult and since that plate still has not yet been made the motor mount still cannot be put onto the car.

My overall assessment of the design of the car itself is that it should be used as a teaching project for future members of the team rather than as any significant project being built to race. It would be expensive to keep working on this car with its current chassis so it could possibly race once. Besides the electrical work that would have to be done to make sure it is race ready and abiding by all competition rules it is unnecessarily heavy, rigid, and non-aerodynamic.

5.13 Drawing





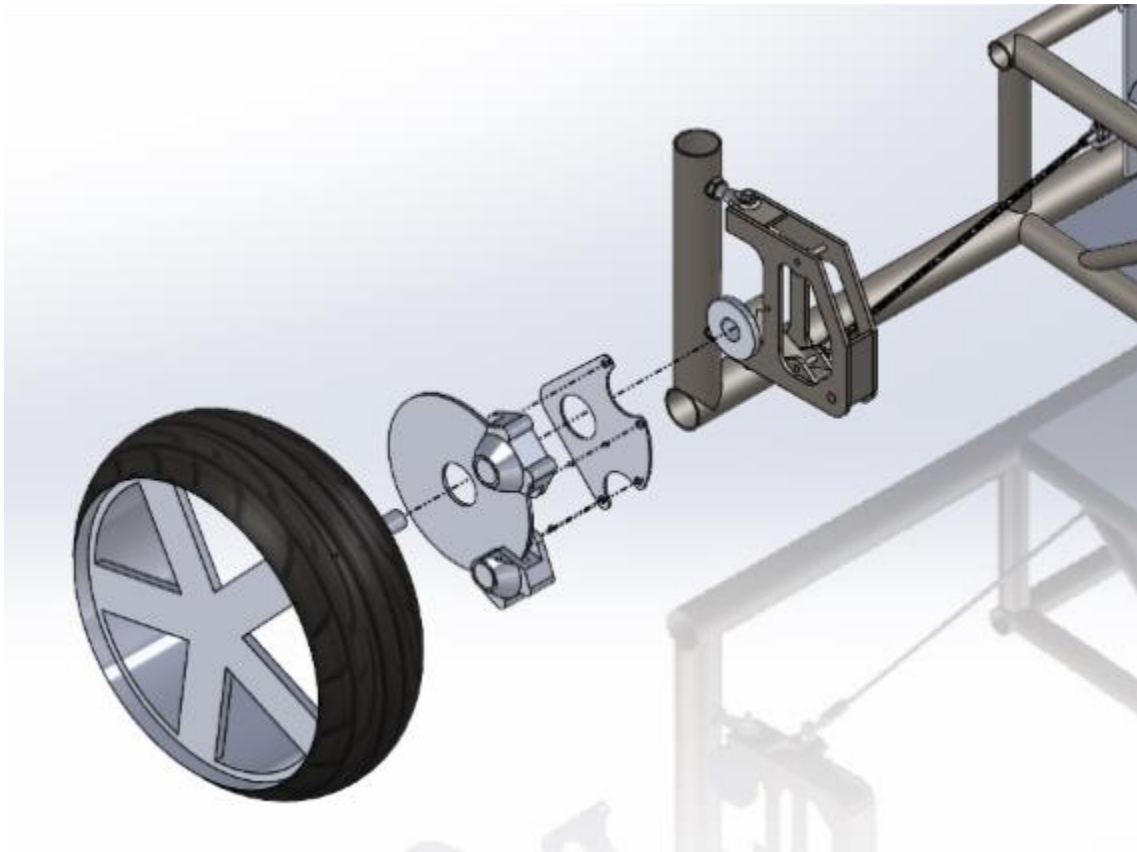
## SECTION 6

### BRAKE MOUNTING SUB-TEAM

DiGiacomo, Luke (MET)

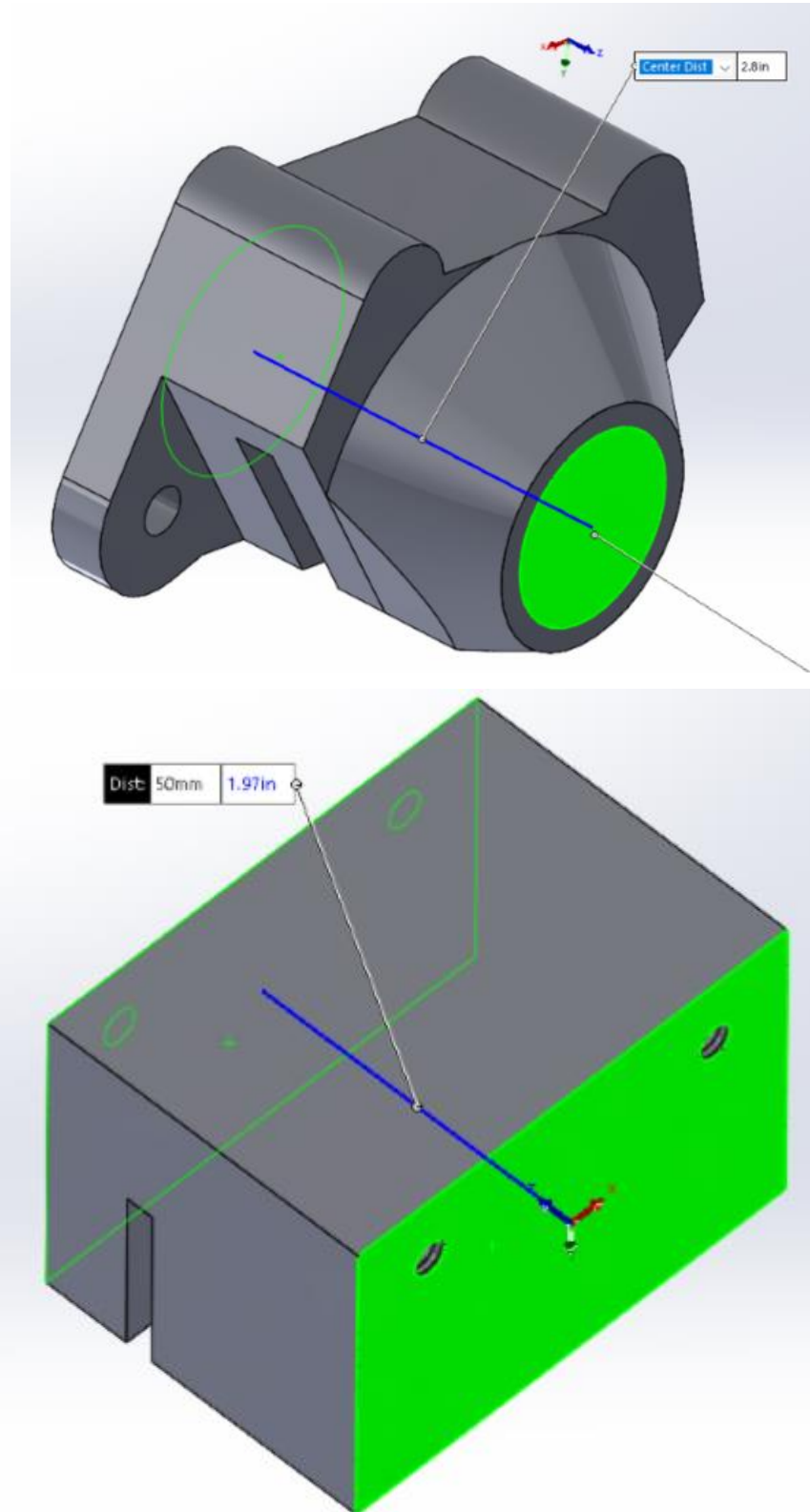
#### 6.1 Design Goals

The design goal was to mount calipers to the available rotor and hub. The 2022 solar car team purchased a wheel and manufactured axles for the vehicle. The 2023 sub team was given the task of figuring out a way to mount the brakes of the vehicle. The 2022 team also purchased braking rotors and calipers. The calipers were single piston MCP go kart calipers. Six total calipers were purchased to mount to the frame. These calipers had no place to mount to the frame of the vehicle. To mount these calipers the sub team purchased a foot by two-foot, eighth inch 4130 steel sheet to fabricate a location to mount the calipers.



The previous team had not begun to develop a mounting system for brakes. The constraint that restricted design the most was the decision to reuse last year's frame and axle. The space between the hub and the mounting plate was dimensioned to fit 1.97-inch wide MCP go kart calipers. The final design needed space for 2.8-inch wide Brembo PG34 calipers. To allow

for this additional clearance the sub team had to place one inch spacer on the bolts connecting the wheel hub to the axle. This allowed the new calipers to fit within the front axle assembly.



## 6.2 Assumptions / Inputs

When the design began the sub-team believed the proper calipers for the vehicle were purchased by the previous year's team. The sub team performed brake calculations to determine the efficacy of three single piston calipers stopping the rotor. The calculations revealed the current components are not compatible to effectively brake the vehicle. To solve this issue the sub team began to adjust the values on the brake calculation to determine what aspect of the vehicle can be adjusted to brake the vehicle. When increasing the number of pistons braking on the rotor from three to four, the calculations returned an effective braking force. The difficult decision was made to purchase new calipers and scrap the previously purchased brakes. The team decided to purchase 4 twin-piston Brembo PG34 calipers. This would increase the number of pistons acting on the rotor from three to four.



## 6.3 Other teams

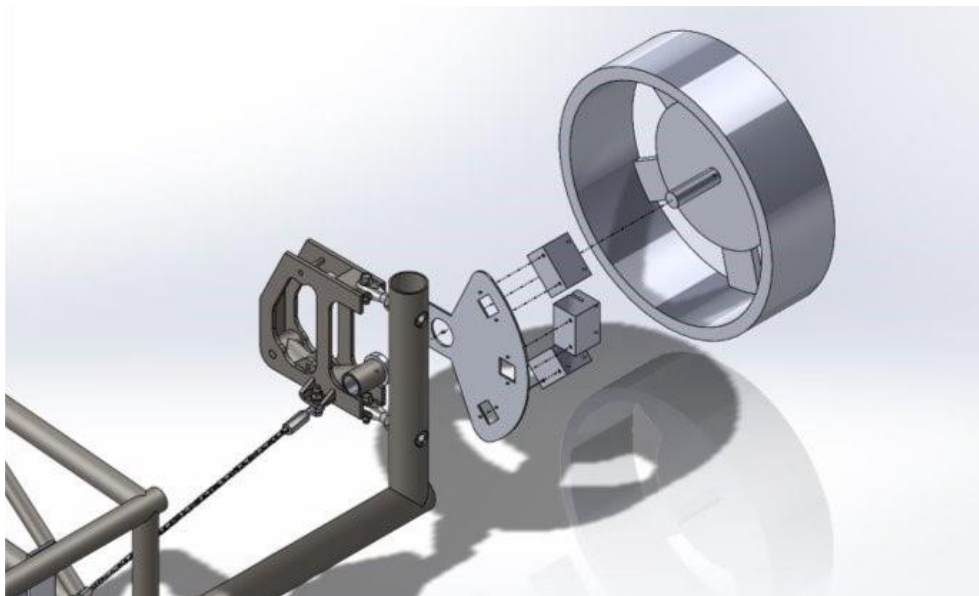
To complete the design, the sub team needed to work with the pedal and parking brake systems sub-team. Once the brakes had been successfully mounted, the pedal sub team and brake sub team had to work together to purchase the proper brake lines and fittings to enable these components to work together. The pedal sub team was responsible for designing and ordering the proper components for the brake lines. Together both brake and pedal sub team assembled and bled the

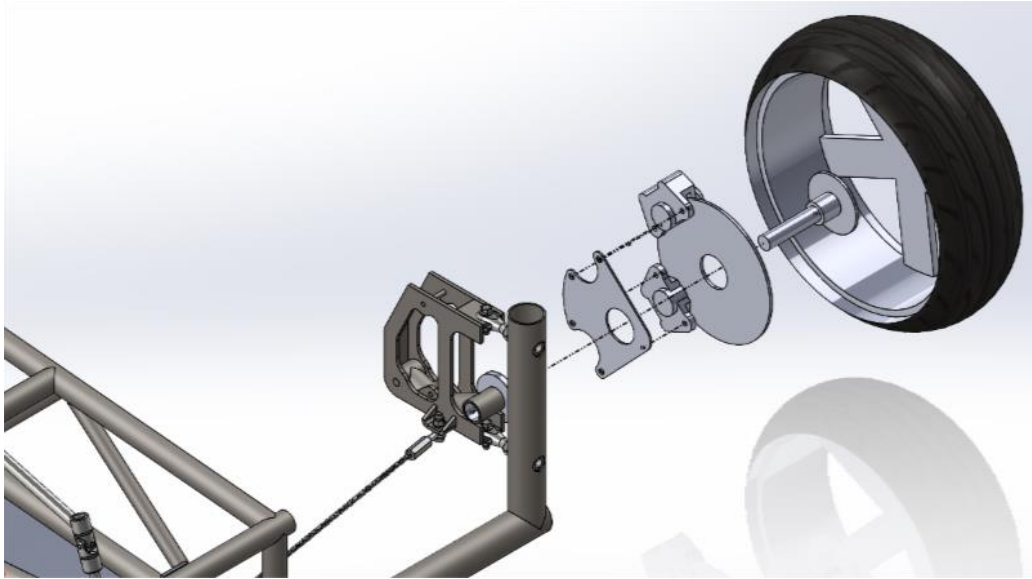
#### 6.4 Contribution

To enable others design, the sub team had to secure the calipers to the mounting brackets while still allowing the brake lines to be run to the calipers. The Brembo calipers had specific input and outputs to use while bleeding the brakes. When the pedal sub team was running brake line to the calipers the sub team made sure to design the mounting to allow the lines to be threaded to the calipers without interfering with the suspension.

#### 6.5 Lessons learned in design

The lesson learned from this design is to be willing to pivot design aspects based on feedback. At the beginning of the project the sub team had created work and drawn parts to be cut from the 4130 steel sheet to fit three MCP calipers. Once we began to receive positive, helpful feedback from our new professor starting in the spring the lack of brake calculation led to the discovery that the current components were not going to achieve our desired output. The first assembly below shows the old assembly that was no longer viable, the second is the final and correct assembly. It was disappointing to have to scrap the available components we had for a project that was already trying to conserve resources. The realization that without allocating funds to new calipers the possibility of a functioning braking system was impossible. A vote was conducted by the sub teams to spend funds to do this, and the sub teams agreed this was the best use of our limited resources.





#### 6.6 What worked

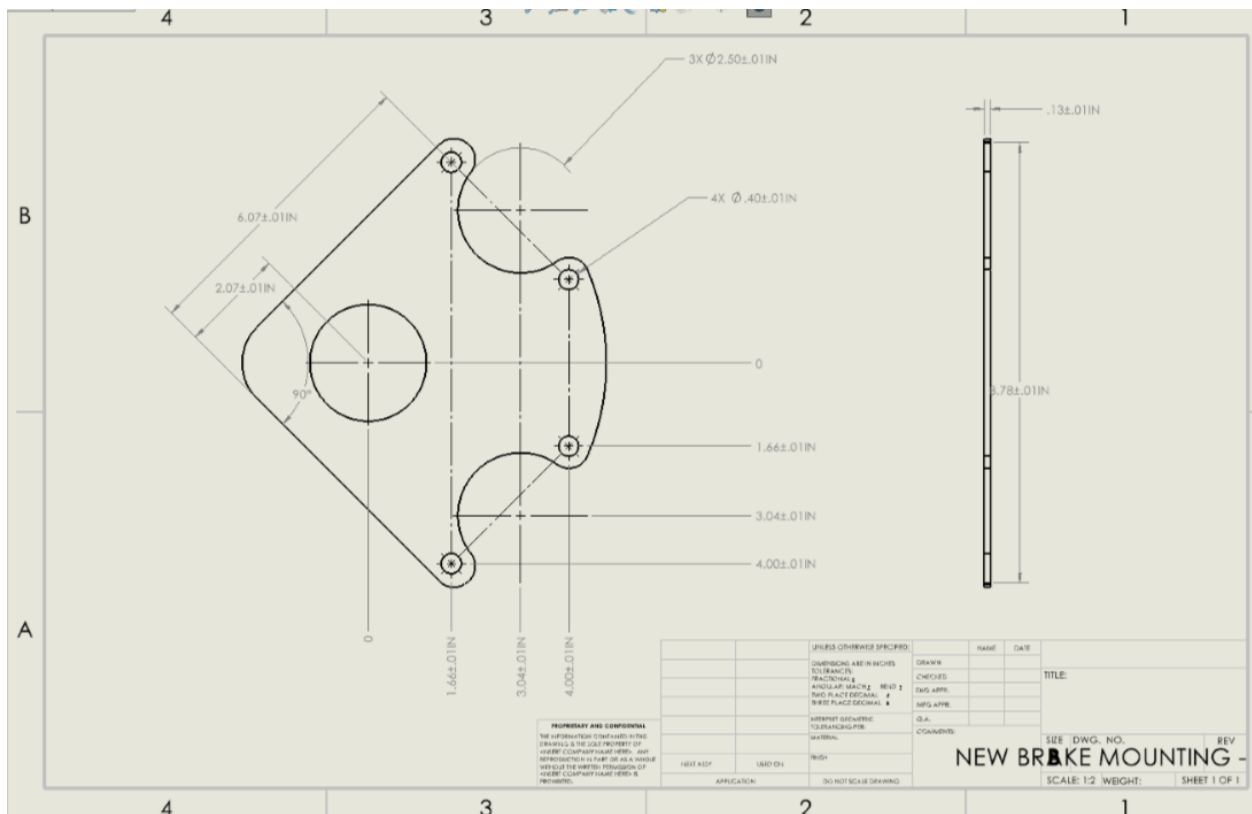
The new calipers purchased after the calculations were a large investment for the sub-team. The future mechanical team will be invested in creating a new frame for the solar car. This frame should be designed around the components they are going to use. The largest constraint for the front axle design was to create a way to mount brakes in a system that was not designed to fit these calipers. The frame and axle were built to fit the dimensions for an MCP brake caliper. When the system required Brembo calipers that meant the design had to be adjusted to fit the new component. If any components from this design are to be reused, the new frame should be designed with these components in mind. The Brembo calipers should be reused because they are new and effective brakes.

#### 6.7 What did not work

The sub assembly of the front tires were not designed with tolerances for the Brembo calipers. The next mechanical team should design the front wheels and their axles with intended tolerances for the size of calipers that should be used for the weight of their vehicle. The future of this design needs to be based on the components dimension instead of the frame driving how the components will be assembled like the sub team was constrained to do this year.

6.8 Lessons learned in manufacturing

I learned how the process of plasma cutting and welding. While manufacturing the part necessary for the brake mounting system the sub team completed various fabricating tasks. The brake mounting system consisted of an eighth inch 4130 steel sheet cut into the plates shown in the drawings below. These drawings were used to generate DXFs for cutting. This was completed at VPC by the sub team using a plasma cutter. The part was then MIG welded to the frame and used to secure the caliper to rotor. This fabricating was a new skill the sub team practiced. The ability to successfully produce this assembly was thanks to the help the sub team had from staff and fellow students at VPC.



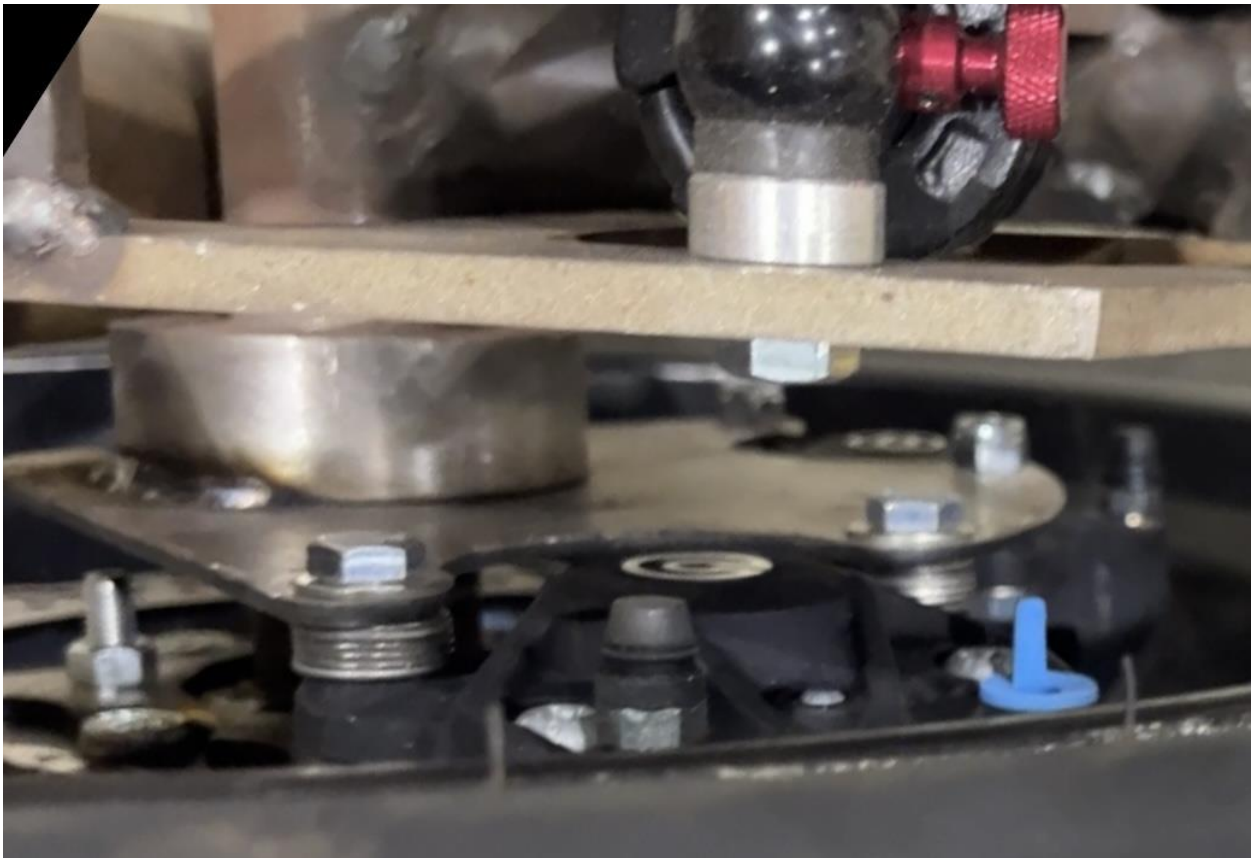
6.9 Process

Using excel and equations the pedal and braking sub teams completed brake calculations. Most of these calculations were new for the sub teams and were a learning experience to not just accept the components that were given to use by the previous year's team, but to do our own work to determine the best components given the data we have.

<b>Master Cylinder Selection</b>							
<b>Car Specifications</b>				<b>Brake System Component Specs</b>			
Car Weight	700 lb	Bias Bar Length	2.25 in				
Driver Weight	200 lb	Foot Force at Lockup	45 lb				
CG Height	11 in	Total Pedal Length	4 in				
Max Braking Acceleration	0.6 g						
Static Weight Distribution	47.75 % Front	<b>Front Brakes</b>					
Wheelbase	83 in	Rotor Diameter		9.33 in			
Tire Rolling Radius	9 in	<b>Front Calipers</b>					
		# Pistons	Diameter (in)	Area (in <sup>2</sup> )			
		4	1.3	5.309291585			
<b>Vehicle Dynamics Calculations</b>							
Total Weight	900 lb			Total Area	5.309291585		
Static Front Weight	429.75 lb			Pad mu	0.4		
Static Rear Weight	470.25 lb			<b>Front Master Cylinder</b>			
Longitudinal Weight Transfer	71.566 lb			Diameter		0.875 in	
Dynamic Front Weight	501.316			Area		0.6013204689 in <sup>2</sup>	
Dynamic Rear Weight	398.684						
Front Weight Distribution	55.702						
<b>Brake Balance</b>				<b>Rear Brakes</b>			
<b>Estimate Brake Balnce from Dynamic Weight Distribution</b>				Rotor Diameter		0 in	
<b>Fronts should lock up first for stability</b>				<b>Rear Calipers</b>		NA	
Front	100.000 %	# Pistons	Diameter (in)	Area (in <sup>2</sup> )			
Rear	0.000 %	0	0	0		0	
		0	0	0		0	
				Total Area	0		
<b>Torque</b>				Pad mu		0	
<b>Torque</b>				Pad mu		0	
Front Torque	112.8 lb*ft			<b>Rear Master Cylinder</b>			
Rear Torque	89.7 lb*ft			Diameter		0 in	
				Area		0 in <sup>2</sup>	
<b>Front Brakes</b>							
Braking Force	540.000 lb						
Front Line Pressure	490.555 psi						
Front Master Input Force	294.981 lb						

### 6.10 Issues

The spacing of the brakes required very detailed dimensioning. Because the frame of the car was unable to be redesigned it was an issue to fit the calipers to the rotor accurately. This meant that the distance between the welded plate and the calipers had to be adjusted. Quarter inch spacers were used to allow the brake calipers to effectively interface with the rotors. The image below shows the spacers and the final assembly. These spacers were used to accurately place the caliper on the rotors.



### 6.11 Overall assessment of the design

The design was successful. The sub team was able to complete a system to mount the brakes within the constraint of reusing the frame and axles from last year's team. The resulting mechanically functioning braking system should be a building tool for the future solar car program to test battery and motor capabilities. While these sub teams are using the mechanically functioning but heavy current iteration, the future mechanical teams should begin to create a lightweight frame and axles that accommodate the desired calipers.

## SECTION 7

### PEDAL SYSTEM & PARKING BRAKE

Helton, Alex (MET) / Mayer, Corey (MET)

#### 7.1 Design Goals

The design goal for the pedal cluster system was to design the car's first functioning pedal cluster. This involved mounting two previously bought MCP master cylinders side by side and creating a brake pedal running off these as well as an acceleration pedal mount. This pedal cluster involved running the brake lines from the MCP brake master cylinders to the calipers. The design goal for the parking brake was to design and build the car's first parking brake system.

It was required from the rules of the competition that the car must have a dual, balanced braking system so that if one system should fail, the solar car can still be stopped. The two systems must be operationally independent and must operate from a single foot pedal. The braking system can be front/rear or redundant. Which our system is front wheel redundant. Left/right redundancy is not permitted. Hydraulic systems must have separate master cylinders. It was required that the car must be able to repeatedly stop at speeds of 50 km/h (31 mph) or greater, with an average deceleration, on level wetted pavement, exceeding  $4.72 \text{ m/s}^2$ . This deceleration rate was used in our calculations. The parking brake shall be able to hold the car in place without wheel chocks on dry pavement under either a forward or rearward force equal to 10% of the car's weight in fully loaded condition.

#### 7.2 Assumptions/ Inputs

To start this project, we had two MCP master cylinders bought by last year's team. The design was started using these master cylinders to keep from purchasing new. After performing brake calculations with the master cylinders and calipers bought from last year's team it was noticed our car would not stop so the decision was made that the brake mounting team needed to get new calipers to meet our required deceleration rate. We were also given the acceleration pedal to mount that was purchased by the electrical team.

<b>Torque</b>			Pad mu		0
Front Torque	112.8	lb*ft	<b>Rear Master Cylinder</b>		
Rear Torque	89.7	lb*ft	Diameter		0 in
			Area		0 in <sup>2</sup>
<b>Front Brakes</b>					
Braking Force	540.000	lb			
Front Line Pressure	490.555	psi			
Front Master Input Force	294.981	lb			
<b>Master Cylinder Selection</b>					
<b>Car Specifications</b>			<b>Brake System Component Specs</b>		
Car Weight	700	lb	Bias Bar Length		2.25 in
Driver Weight	200	lb	Foot Force at Lockup		45 lb
CG Height	11	in	Total Pedal Length		4 in
Max Braking Acceleration	0.6	g	<b>Front Brakes</b>		
Static Weight Distribution	47.75	% Front	Rotor Diameter		9.33 in
Wheelbase	83	in	<b>Front Calipers</b>		
Tire Rolling Radius	9	in	# Pistons	Diameter (in)	Area (in <sup>2</sup> )
<b>Vehicle Dynamics Calculations</b>				4	1.3
Total Weight	900	lb		Total Area	5.309291585
Static Front Weight	429.75	lb	Pad mu		0.4
Static Rear Weight	470.25	lb	<b>Front Master Cylinder</b>		
Longitudinal Weight Transfer	71.566	lb	Diameter		0.875 in
Dynamic Front Weight	501.316		Area		0.6013204689 in <sup>2</sup>
Dynamic Rear Weight	398.684		<b>Rear Brakes</b>		
Front Weight Distribution	55.702		Rotor Diameter		0 in
<b>Brake Balance</b>			<b>Rear Calipers</b>	NA	
Estimate Brake Balance from Dynamic Weight Distribution			# Pistons	Diameter (in)	Area (in <sup>2</sup> )
Fronts should lock up first for stability				0	0
Front	100.000	%		0	0
Rear	0.000	%		0	0
			Total Area		0

### 7.3 What did you need from other teams to complete your design

For us to complete our design, we needed to work with Luke on the brake mounting team to ensure that our master cylinder size, brake caliper size and quantity would meet our required deceleration rate. Also, we worked with Luke when ordering our brake lines and all the fittings to ensure we ordered the correct parts, fittings, as well as the correct length of line.

### 7.4 What did you owe to other teams to enable their designs?

We owed the steering team the height that our pedal cluster would reach as well as the location to ensure our pedal cluster design would not interfere with their design for the steering of our car.

We also owed the brake mounting team a functioning brake pedal with brake fluid and line for his caliper mounts to be actuated.

We owed the electrical team a mounting bracket for the acceleration pedal which was given to us.

#### 7.5 Lessons learned in design.

One lesson we learned was to ensure the parts that are ordered operate in the way that is expected. For example, our parking brake master cylinder ended up being a push master cylinder instead of a pull master cylinder. We resolved this instead of buying a new one by reconfiguring the parking brake lever to activate the master cylinder when the lever is pulled back.



Another lesson we learned is ensuring that our design does not interfere with others. We had to make sure our pedal cluster did not collide with any steering component.

#### 7.6 What worked well and should be carried forward?

The design of our pedal cluster worked really well for the space we were given to work with. The pedals are in a location that is easily accessible for the driver and out of the way for the driver. The master cylinders that we used were also easy to work with when designing a brake pedal.

#### 7.7 What did not work and should be changed in the future?

Although the pedal cluster worked out really well the brake lines could be hidden better and should be looked at in the future to better protect them. The other thing that can be looked at in the future is the parking brake system. The guide piece of metal below the connecting piece could be worn down and need to be changed or a better guide for the connecting piece can be made and implemented.

If the frame of the car is redesigned, we feel the current pedal cluster would work great in the new design of the frame. However, it should be shifted more to the right for ease of access to the driver. The parking brake we feel is in a good spot but could be better positioned in a new frame as there was not much room to work with and put in two systems.

#### 7.8 Anything you spent a lot of effort on and wouldn't want to do again.

One thing that took more time than anticipated was scheduling time to use the machines at VPC. Safety is very important, and we understand that but if we can use a welder and saws in the shop where our car is we shouldn't have to try for two weeks to get a drill press to drill two holes.

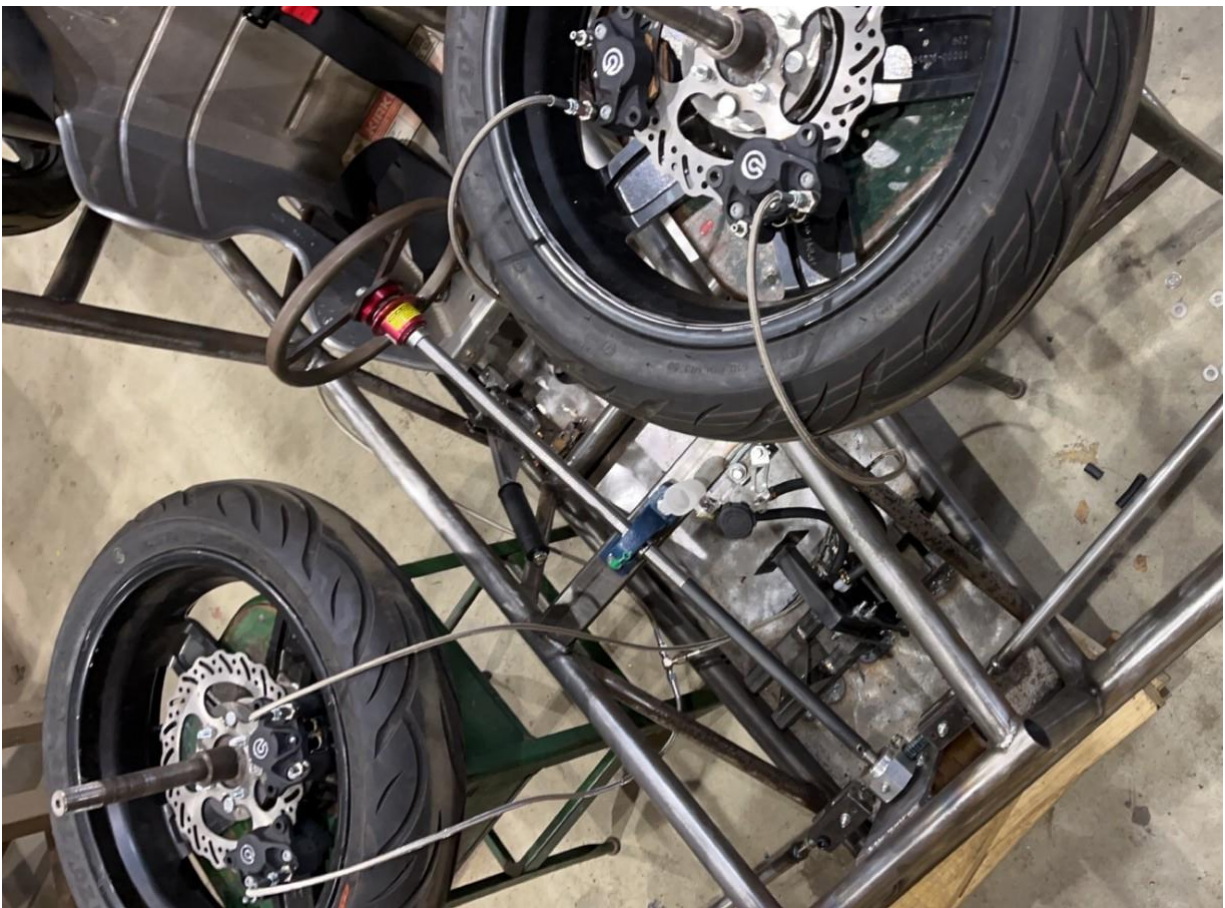
#### 7.9 Lessons learned in manufacturing.

A lesson learned in manufacturing is to ensure that the right tools are available. We went several times to VPC to try and use the drill press for the holes in the brake pedal and could not get in. We ended up using a drill by hand and got the job done but the holes would be straighter if we used a drill press. Another lesson learned throughout the manufacturing process is to use a

scrap piece of metal when welding to ensure you are on the right voltage and wire feed speed. This will result in cleaner beads and an overall better-looking weld.

#### 7.10 Processes you figured out that should be documented

A process that we worked on, along with Luke, was bleeding the brake. This was done by connecting the brake lines and all the fittings to the master cylinders and brake calipers. Then we opened the bleed valves on the calipers. Then we poured the brake fluid into the fluid reservoirs which ran to the master cylinders. Then we pumped the brake pedal and topped off the fluid reservoirs until the fluid came out of the bleed valves to get all the air out of the braking system. The fluid reservoirs should be checked periodically to ensure there is enough fluid in the system. Another tip on bleeding the brakes would be to have the brake calipers raised up to be the highest point in the system, as pictured below.

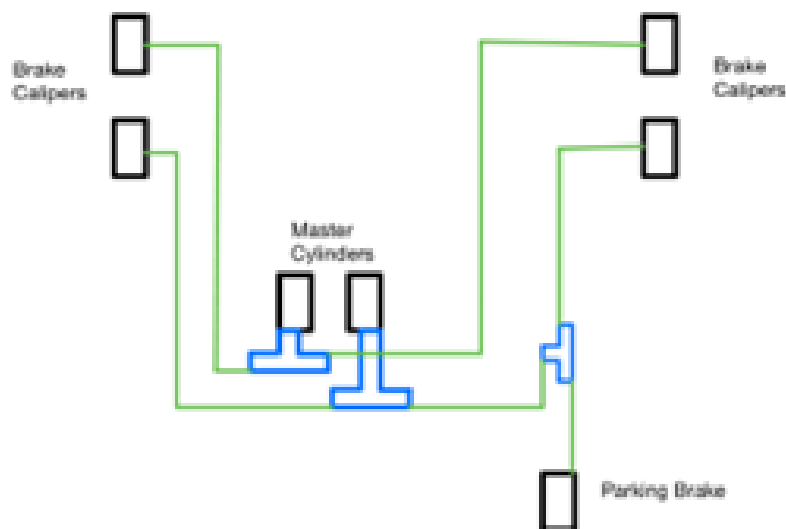


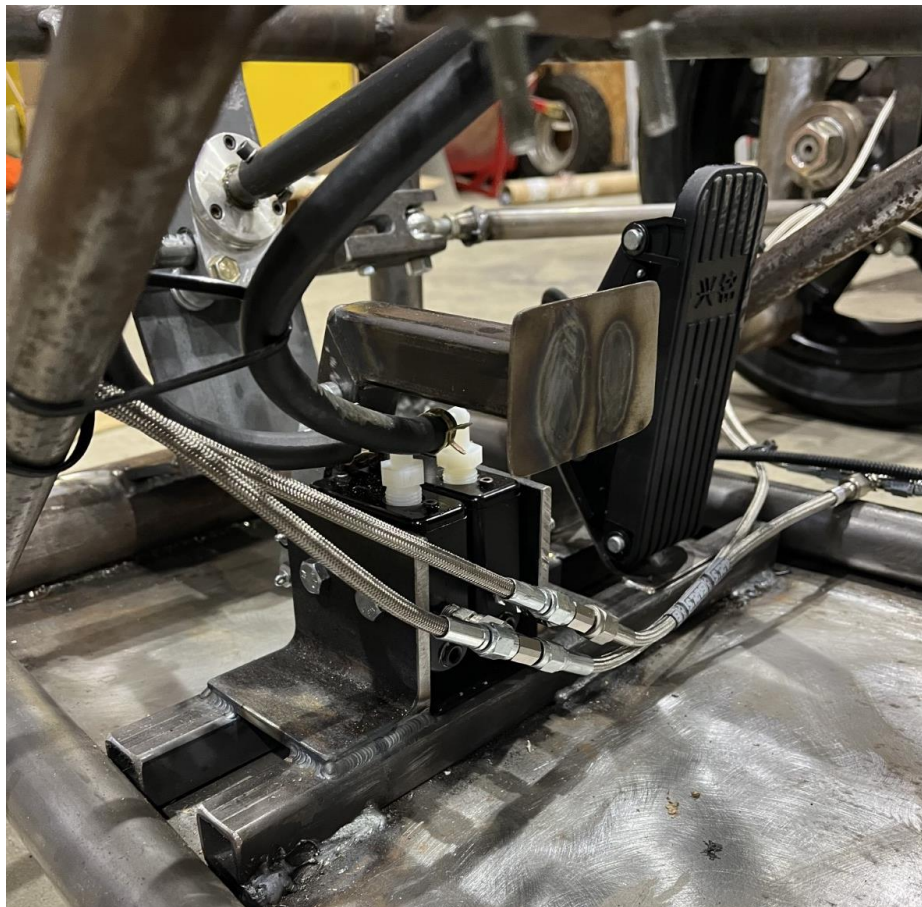
### 7.11 Issues during manufacturing/ assembly

One issue we ran into during the assembly and manufacturing stage was the amount of space we had to work with. Our original plans on the parking brake would not have fit when we went to manufacture our drawing sheets. An audible was made and a new design was created in order to accommodate for the lack of space we had to work with.

### 7.12 Overall assessment of the design

Overall, our design was a success in that it meets all the requirements of the rules of the competition. We were also successful in creating a fully mechanically functioning pedal cluster as well as a parking brake system. In our design, we mounted the master cylinders next to each other and the brake pedal mounts between the two master cylinders. These master cylinders are fed with brake line fluid by two fluid reservoirs mounted above. These master cylinders run to 4 calipers, 2 on each wheel using a two-way redundancy to ensure the car will still brake even with failure. This two-way system can be displayed below. Our mount for the acceleration pedal makes the pedal perpendicular to the floorboard which makes it easier for the driver to access based on how parallel the driver's legs are to the pedal cluster when sitting in the car. As mentioned above the parking brake was our biggest issue that was solved. Given the size of the frame and how much room there is inside the car, we were pretty limited on where it could be placed. The design of it is mechanically functionable but if we were being critical, it could be improved.





## SECTION 8

### SOLAR PANEL ARRAY SUPPORT SUB-TEAM

Nguyen, Thai (MET)

#### 8.1 Design Goals

From the conceptualization of the solar car, there has always been the intention of having a solar panel “wing” attached to the tail end of the vehicle. The initial design has a wooden frame with a metal bracket holding a single solar panel. The locking mechanism, theoretically, utilizes a pin placed through the 1.5 inches steel rod and for rotational – orienting mechanic, there is a steel castle nut welded onto the rod with a PVC pipe end fit to the castle nut. This is the initial design that the previous solar car team fabricated, however this design is not able to hold the panels securely and the pin design could jam or bend if they are struck. The wooden frame could also be a potential fire hazard and it does not comply with the new solar panel the solar team had ordered. The solar panel array is an isolated project and does not require to coordinate with mechanical during the fabrication stage.

The objective is to design a brand-new support structure intended to hold the new solar panel with the parameters set out by the American Solar Challenge. The design would be aerodynamic, with a limited front cross – sectional area. The array needs to be adjustable to any angle, relatively, normal to the sunlight for optimal energy. The support is required to have the capability of maintaining its designated adjusted angle from the force of front and side wind of (at least) 30 mph. The array would also need to support the combine panel weight.

#### 8.2 Component List

The new solar panel is from Renogy, model RNG – 175DB – H, which is a flexible solar panel with 175 Watt and 12 Volt. The solar cell type is monocrystalline with 36 cells per panel, each panel weight 6.2lbs and the dimension of the panel is 59.2in x 26.5in x 0.08in. Upon discussion with the Solar Car team management, the orientation of the panel was decided with placing 4 full side solar panels together side (long – side together) and the combine size is 59.2in x 106in x 0.08in with the approximate weight of 24.8lb.

The newly designed solar panel array support utilizes aluminum bar as the base skeleton of the support array. The aluminum bar was used to ensure the sturdiness of frame without

adding too much significant weight to the tail end of the vehicle. The bar is 1 inch thick and uses 8 pieces of 3 feet long bar along with 1 piece of 10ft long bar. When assembled, the frame will be held together by a 2 inches long silver open extended gusset for single rail with the totality of 16 pieces, and the excess bar length will be trimmed down to match the size of the solar panel.

To address the matter of holding the 0.08 inches thick solar panel, a screw in trim would be used. The screw in trim is made from aluminum with an inside width being  $\frac{5}{32}$  in and a hook like shape rather than a U shape. The reason behind this is because the extra space is to compensate for the possible flex from the wing and the hook shape is to account for the power converter box on the solar panel. The trim will be installed along the side of the frame and the extra length will be trimmed down to fit the panel.

For rotating mechanisms, it will be utilizing a mounted steel ball bearing with cast iron housing. The usage of a bearing in this case is to ensure the panel can rotate smoothly without hindering and to handle the load of the frame. The suggested bearing can fit a shaft 1.5 inches diameter and use a set screw to securely mount the bearing on the shaft. The radial load capacity would be 7300 lbs. (dynamic) 4450 lbs. (static) while having the maximum speed of 4100 rpm. While the bearing performance specification is much higher compared to the need, the high performance is to account for redundancy, durability, and if the bearing fails, it would easily be replaced. The bearing would also act as a secondary holding mechanism, in case the locking mechanism fails, the solar panel would not fall off the vehicle.

Regarding the lock mechanism, there would be a mounted collar design that would act as a clamp to hold the array support in place when the driver rotated to the desired angle. The objective was to allow the driver to clamp down the array as quickly as possible without complex mechanism and tooling. To accomplish this objective, the design would utilize 3 pieces of 303 stainless steel with 1.5 inches diameter shaft collar ensure a secure hold on the steel pipe and 1 piece 304 Stainless Steel plate acting at the mounting plate between the collar and the array skeleton. As mentioned above, the collar is made of 303 stainless steels with a 1.5-inch diameter to ensure with fit with the rod and each collar has 2 screws in point to connect the 2 halves together. While the tail rod diameter claims to be 1.5-inch exact in diameter, the diameter is slightly higher between 1.53-inches to 1.52-inches in diameter. Using this advantage, the collar with a 1.5-inch diameter with not only fit on the steel rod but also has enough space in between

to clamp down, generating a clamp force. The clamping force will be generated from force of the 2-screw holding the 2 halves together with the friction force generate from the contact between the 2-half made with steel pipe. The screw on the collar would make the assemble easily adjusted and secure, simply by loosen the screw with a hex wrench. For the mounting plate, the 304 stainless steel plate with the base dimension of 3in x 6in x 1.24in are utilized. For the plate to be used would require to be machined into the appropriate dimension shown on the draw below. The machine channels on the plate are not only acting as a locator point for the collar to be placed into but also a contact surface for the welding point between the collar and the plate.

### 8.3 Collar Clamp Force Calculation

Since the collar assembly is acting as the locking mechanism for the array assembly, the clamp force needed to be calculated to determine the minimal force required to hold the panel. To calculate the collar clamp force, these are the things needed to be considered, Dragload – Resulting Torque from panel – Require Friction Force – Normal Force – Clamp Force. Drag loads are due to lateral (horizontal) loads generated due to high wind. This is to be considered as the array assembly function like a wing and would have an effect of drag.

Given the build of the pane is rectangular with the dimension being 4.93 ft by 8.83 ft, it would be a big flat plate, there for the coefficient of drag would be as such ( $c_d = 1.28$ ). Another condition would be that the panel must maintain its position at 40 mph wind ( $v_{wind} = 58.67 \frac{ft}{s}$ ) and the  $p_{air} = 0.00237 \frac{slug}{ft^3}$ . Afterward, the drag force from the wind would apply a torque force to the panel to displace the panel from position. For this calculation, the radius arm would be half the length of the panel (from the panel end to the contact point between the panel and pipe) which is 2.467 ft. Then applied force would be the force of the wind (calculated based on the panel area, pressure of air, coefficient of drag). The last step to find the minimum required force would be the friction force and normal force. To find it, the coefficient friction (static), radius arm of panel and radius of the pipe are needed. The coefficient friction (static) in this case would be 0.7 because the contact of material is steel to steel (steel collar to steel pipe), the  $R_{arm (panel)} = 2.467 ft$  and the  $r_{arm (pipe)} = 0.0625 ft$ . From there, used the friction and the coefficients of friction to find the normal force, which is equivalent to the minimum required clamp force.

With all previous calculations considered, the actual assembly clamp force can be calculated to evaluate the design. A 18-8 stainless steel socket head screw with 0.25 inch, would have the material yield strength of 70,000 psi, resulting in a proof load of 59,500 psi (85% of yield strength) and a target stress of 44,625 psi (75% of proof load). From there the clamp force per collar can be calculated based on these values and the calculation is listed below.

### Calculate Dragload

$$\text{Width} = 59.2 \text{ in} = 4.93 \text{ ft}$$

$$\text{Length} = 106 \text{ in} = 8.83 \text{ ft}$$

$$\text{Arm}_{\text{length}} = 29.6 \text{ in} = 2.467 \text{ ft}$$

$$v_{\text{wind}} = 40 \text{ mph} = 58.667 \frac{\text{ft}}{\text{s}}$$

$$\text{air density} = 1.229 \frac{\text{kg}}{\text{m}^3} = 0.00237 \frac{\text{slug}}{\text{ft}^3}$$

$$c_d = \frac{D}{\rho v^2 \frac{A}{2}}$$

$$c_{d \text{ flat plate}} = 1.28$$

$$D = c_d \frac{\rho_{\text{air}} v^2}{2} A$$

$$D_{\text{load}} = 1.28 * \frac{0.00237 \frac{\text{slug}}{\text{ft}^3} * \left(58.667 \frac{\text{ft}}{\text{s}}\right)^2}{2} (4.94 \text{ ft} * 8.83 \text{ ft}) = 227.26$$

### Calculate resulting torque from panel

$$\tau = Fr$$

$$F_{\text{wind}} = A * P * c_d$$

$$F_{\text{wind}} = (4.93 \text{ ft} * 8.83 \text{ ft}) * [0.00256 * 40^2] * 1.28 = 228.22 \text{ lb}_f$$

$$\tau = 228.22 \text{ lb}_f * 2.467 \text{ ft} = 563.01 \text{ lb}_f \text{ ft}$$

### Calculate require friction force

$$F_f = F_N \mu$$

$$\mu_{static} = 0.7$$

$$r = 0.75in = 0.0625ft$$

$$R = 29.6in = 2.467ft$$

$$F_{fr} = \frac{F_{wind}R}{r}$$

$$F_{fr} = \frac{228.22lb_f(2.467ft)}{0.0625ft} = 9008.3 lb_f$$

### Find normal force

$$F_N = \frac{F_{fr}}{\mu_{static}} = \frac{9,008.3lb_f}{0.7} = 12,869lb_f$$

### Find clamp force

*Material Yield Strength = 70,000psi*

*Proof load = 59,500 psi (85% of yield strength)*

*$\sigma_{target} = 44,625 psi$  (75% of Proof Load)*

$$D_{screw} = 0.25in$$

$$L_{length} = 0.625in$$

$$Thread_{per\ inch} = 28$$

$$n = 17.5 in$$

$$Area_{stress} = \frac{\pi}{4} * \left( D_{screw} - \frac{0.9743}{n} \right)^2$$

$$\frac{\pi}{4} * \left( 0.25 - \frac{0.9743}{17.5} \right)^2 = 0.31 in^2$$

$$F_{clamp\ load} = \sigma_{target} * Area_{stress}$$

$$F_{clamp\ load} = 44,625 psi * 0.0491in^2 = 13,614.7lb_f$$

$$F_{clamp\ per\ collar} = 13,614 lb_f * 2 = 27,229.4 lb_f$$

$$\Sigma F_{clamp\ collar} = 27,229.4 lb_f * 3 = 81,688.21 lb_f$$

## 8.4 Design Process

The solar array support is an independent mechanical system as it enables the array to be adjustable, normal to the sunlight. The design does not interfere with the other mechanical elements on the vehicle beside influencing the vehicle aerodynamic and possibility electrical. For solar array support to be utilized, the chassis would be needed along with the solar panel. The chassis was passed down from the previous year's senior and the new solar array support is built as a replacement for the previous support panel as well as compatible to the new solar panel from Renogy. Secondly, the new solar panel is required for the new design array as the intention was the array would be the new housing for the panel.

With that in mind, both require material to be present and it has contributed to the completion of the design. While it does not relate to other mechanical projects, it does have a relation to the electrical team project. Each of the solar panels has cables coming out of the panel which connect to a battery. The design of the array allows for gaps between the mounted panel, letting the cable run underneath the array. While the mechanical system to complete, the electrical element in the array would be to figure out the solar panel cable management and mounting position to enable adjustment along with maintenance.

## 8.5 Lessons learned in design.

The design stage is where the conceptualization of the solar array began. During this stage, I had to look at the previous design along with discussing with the UC Solar Car executive members what they were looking for in the new design. Cross referencing these information's with the American Solar Challenge is how I understand the constraint of the design and the need of the team. The array skeleton design was based on the initial design, but I wanted to reduce the weight of the frame and avoided using wood as it would create a fire hazard. To reduce the weight, low cost, and easy to machine, I decided to use 1 – inch thick aluminum bar which would fit all the criteria I wanted. The difficulty about this design is the adjustable mechanic and locking mechanism of the entire array.

Initially, there were different methods on how the array could be adjusted. One would be creating a gearbox with a handle and turning the handle would adjust the angle of the panel then

have a small hinge inside to lock the panel in position. The second would be utilizing only bearing in all the mounting point and it would act as the rotational mechanic and locking mechanism through a set screw. Lastly, the design would use a combination of the bearing for rotational mechanism and a collar assembly, resembling the bearing build, to be the array locking mechanism. From the three initial concepts, evaluation was done to see which would be the best for the design function as all the concepts had pros and cons.

For the first design, the benefit of this design is that it eases use for the driver and has the potential to be used for a long time if maintenance properly. To adjust the array angle, theoretical, the driver can bring the vehicle to a full stop, go under the panel, unlock the gearbox, turn the handle until it reaches the desire angle, lock the gear, and get back to the seat. In theory it is a useful design, however when applied to reality, it where the drawback present itself which include the design, fabrication of the gearbox, mounting location, and maintenance. The gearbox design itself is quite complicated as there are a lot of design elements going into each of the components (gear size, ratio, the box size, tool wear testing, etc.). Since the mounting surface is only the surface of the 1.5-inch steel pipe, there is not a surface to work with along with the fact there is no flat surface to mount the box on. Assuming some component of the box would be fabricated, along with many moving parts, performing maintenance on the gearbox would be an issue if the person is not trained properly. Overall, for the first design, the concept is good, but it is ambitious and overdesigned for the team's need. For the second design and third design, both share similar aspect as both have the bearing housing over, however, the second only use the bearing housing and using set screw as a locking mechanism. The benefit of the second design is that it is simple and easy to perform maintenance on. All the driver needed to do is unlock the set screw, rotate the array then lock in by turning the set screw and if the set screw is worn out or the bearing broke, both can be replaced easily with aftermarket part. However, the drawback of the design is that the set screw does not guarantee a secure hold with as there is only one point of applied force, furthermore, the driver could not apply sufficient to lock in the set screw resulting in the array going off set angle. Another drawback would be cost, the bearing housing itself is quite expensive and if we purchased multiple parts, it would not be financially beneficial for the club. Therefore, the third design was created to address the drawback of the second design by introducing the collar assembly. The collar assembly was inspired by looking at pipe clamp as the pipe clamp applied force around the pipe rather than just one point of the pipe. In addition to

that, the collar assembly component is not expensive compared to the bearing housing and could easily be fabricated in house. The only drawback of the design is to make the assembly, the plate needs to be machine which is time consuming and requires welding to combine the collar to the plate.

The takeaway from the design stage is evaluating the different concept design and seeing which is suitable for the project's requirement. This can be done by carefully analyzing the design with the model and cross reference with the cost to see which design is worth the investment toward the project. Furthermore, it is also a stage where material selection is crucial as it can have many effects on design concept and performance.

## 8.6 Fabrication and Assembly Process

At this stage of the project, the design concept is being realized and things must be adjusted as problems arise. Once the new solar panel is ordered, the aluminum bar is ordered along with a 1 inch's thick corner bracket as the base for the array skeleton. When the bar is cut down to the desired size and the bar wing is attached with the 1 inch's bracket. While the initial thought the 1 inch's corner bracket is sufficient to hold the bar, after assembly, the wing bent the point of connection and therefore, require adjustment toward the design. To address the matter, a 2 inch open extended gusset bracket is chosen to replace the corner bracket. The corner bracket has one point of contact at each axis (x – y axis) with an L shape and open extended gusset bracket has two points of contact at each axis (x – y axis) with a triangle shape. The new component increases the number of contacts which increases the secure hold on the wing while improving the structural support at the wing through the triangle shape. The theory was proven when the open extend gusset bracket was added into the array skeleton in place of the corner bracket and there was no sign of bending that the joint.

For the cast iron bearing housing, the component is rated to fit a 1.5 – inches diameter shaft. The housing is quite sturdy as it is made of cast iron and the performance fits with the needs of the project. However, a problem arises when attempting to fit the bearing onto the pipe. While the bearing housing is rated to fit 1.5 inches pipe, the pipe diameter is slightly bigger than what record at 1.52 – 1.53 inches depending on the pipe's location. As a result, the fit between the pipe and the bearing housing is an extremely tight fit. To get the housing onto the pipe, we

needed to shear the material of the pipe off and to accomplish this task, we used a brute force to push the bearing onto the pipe.

For the collar assembly, the two materials required are the 3 pieces of 303 stainless steel half collar and 1 piece of 304 multipurpose stainless-steel bar. The stainless-steel bar needed to be machined to match the required specification of the assembly and the collar needed to be welded onto the plate to unite the two parts. During the machining process, I had to revisit the lesson I learned from the machining class, and what needed to be done to get it machine. I used the milling machine in the VPC facility and consultant the staff there to assist me in process. To set up the milling machine, I needed to find the right size of cutter, spindle speed, set the cutting fluid, mark the bar to see the outline of the cut, placement of the steel bar, and zeroing the setup. Once the machine set up is complete, I needed to see how much material I can take per cut, and it was 0.03 inches to 0.06 inches per cut depending on the travel length of the mill. With that in mind, the total machining time was 8 – 9 hours as I had to adjust the travel speed to avoid tool breaking. Once the machine process is complete, I use the drill press to put in 2 - 0.25 inches through hole on the plate as a point to connect it to the array skeleton.

To complete the collar assembly, the half collar needed to be combined with the machine plate through welding. To ensure the 3 pieces of collar are in alignment during welding process, a 1.5 diameter steel pipe was utilized as an alignment tool, attach all the collar together make sure the piece is in contact with each other as well as level. The collars were then tack welded together through TIG-welding and with that completed, the combine collar would then be tack welded onto the stainless – steel plate within the machine channel. TIG (Tungsten Inert Gas) is a process that uses a non-consumable tungsten electrode that delivers current to the welding arc and an inert gas (usually argon) is used to protect, cool the tungsten, and weld puddle. TIG welding can be used for stainless – steel welding which is why it was chosen as the welding method because the welded material is 303 and 304 stainless – steel and it is a much easier welding method with less room for error compared to other methods. Initially, I didn't have much success in welding the 2 pieces together as I did not have much experience in welding so the welding process with accomplished with the assistance of Drake Muller.

In the initial design, the solar array support would have 4 rotating mechanisms at each of the wing joints. However, the quantity was decreased to 2 rotating mechanisms at the 2 center

wing joints. The reason for this is because the pipe does not extend all the way toward the end of the support while the one near the rolling cage is needed by the electrical team and would be closed off, preventing access. This was discussed with the electrical team and so compromises were made to ensure both projects can be completed. The array assembly, collar assembly and the bearing housing are then mounted by several 1-inch-long hex bolts. The 4 panels would then be mounted along the spine of the support array to ensure the panel is secure and the added metal trim along the outline of the support decreases the wing vibration while the vehicle is moving. Lastly, the excess aluminum bar was trimmed down using an angle grinder.

### 8.7 Suggestion for the future

With all the components of the solar array support built and assembled, there are things that work well and things that could be improved upon. For the things that work well would be the collar assembly along with the array skeleton. The build of the array skeleton is quite sturdy, it does not bend on the weight of the panel, while being relatively lightweight at 30lbs to 35lbs with the panel attached. The array skeleton could be removed from the vehicle and be utilized as a solar panel testing console separately with the combination of a stand and the collar assembly. The collar assembly is another component that works well and could be utilized more in the future project related to the panel. While the bearing housing is a good component, it is quite costly and it is a tight fit. The collar assembly can easily be machined, lighter weight compared to the cast iron bearing housing, easy to operate with a hex tool and cheaper in comparison. The collar assembly can be used to replace the bearing housing, making the collar rotational, and secondary locking mechanism for the array. Furthermore, the collar assembly can be used in conjunction with array skeleton, separate from the vehicle, as a solar panel to battery testing station due to the fact it can be adjusted, normal to the sunlight.

For things that could be improved upon, it would include the mounting of the metal trim, and the process of getting cast iron bearing housing on the pipe. Firstly, the metal trim is mounted on by pinning the trim using a screw. While it does work, the trim could easily pop out of place as it did during the transport to the expo. This was improved upon by adding the disk to the screw as a means to increase the surface contact to the trim, however this is not the permanent solution to the problem. Second would be the process in which the cast iron bearing housing is mounted on the pipe. As mentioned earlier, to get the housing onto the pipe, we needed to shear the

material of the pipe off and to accomplish this task, we used a brute force to push the bearing onto the pipe. While this had work, there is room for error for this method which would include the possibility of damaging the component and injury. If a second collar assembly is utilized to replace the bearing housing, then all of this would be avoided. These are some of the improvements that should be considered and referred to for future projects related to the mounting of the solar panel.

#### 8.8 Things for considerations

Something that had caused me a lot of grief is the removal of a steel hex castle nut welding onto the pipe. The steel castle nut was welded all around the pipe which needed to be removed for the newly designed array support. The cast nut was intended for the previous design and has limited adjustment angle. The previous array support was not completed and has plastic PVC pipe to hold the panel along with wood which can be a fire hazard. If the decision is to weld something onto something else, then one must be certain that the project related to it is compatible for future use and complete. To remove the steel castle nut, we utilize different tooling to carefully remove the welded part without cutting into or damaging the steel pipe. The entire process took 2 weeks and 4 – 2 hours cutting session to remove the part. The tool use includes an angle grinder, a Dremel and some sandpaper to buff out the rough surface. The entire process was time consuming and hindered the progress of the project. Once again, before welding material, especially toward a chassis, one should consider the impact it would have on future project.

#### 8.9 Processes that should be documented.

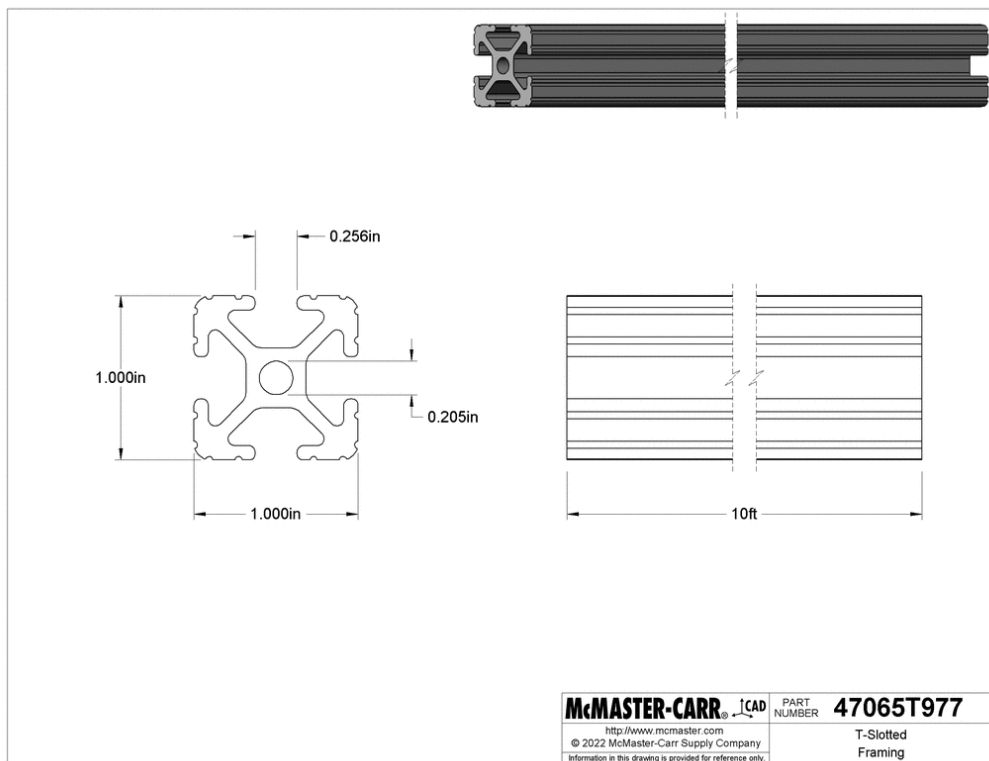
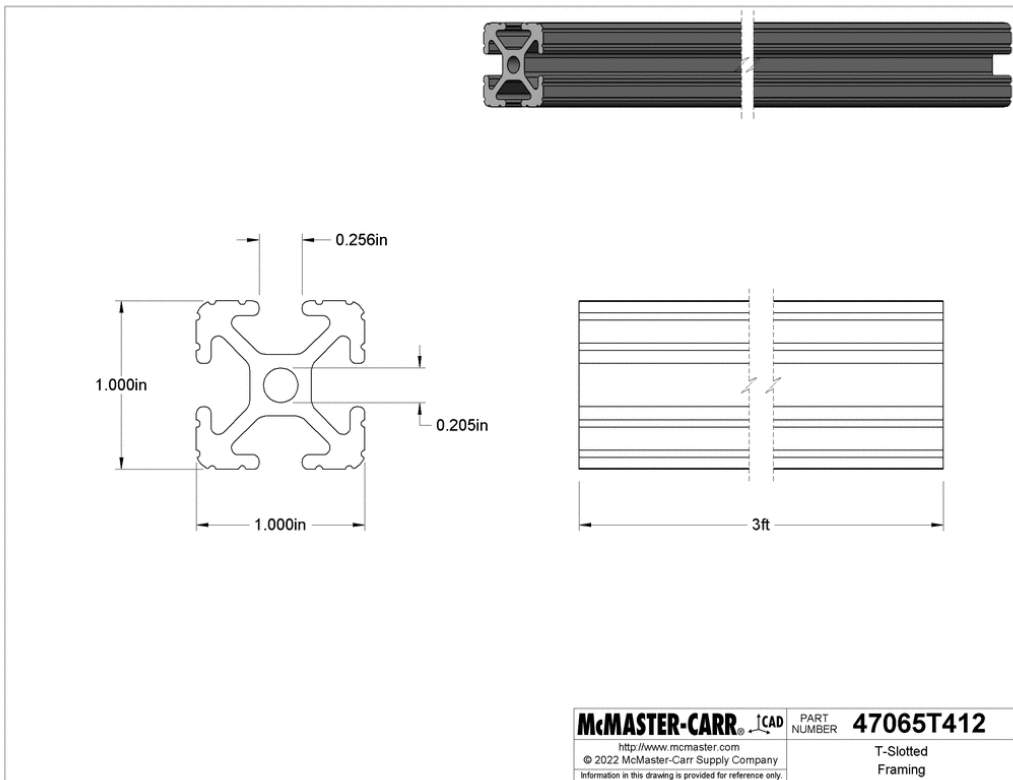
The progress which should be documented would be the design and manufacturing process. There are a lot of thoughts and ideas that go through these proceedings. Different design concepts, method of fabrication, and error occur during the process. The different design concept is specialty something that should be recorded. At the time of the project, someone might not have the time, nor investment to develop these concepts into reality, this can serve as a design pool for those in the future to refer to when they are looking for new idea for a certain design. The evaluation of these design concepts should be documented as it can show the benefit of each of the concepts and someone reading this report would be able to see whether they have the same

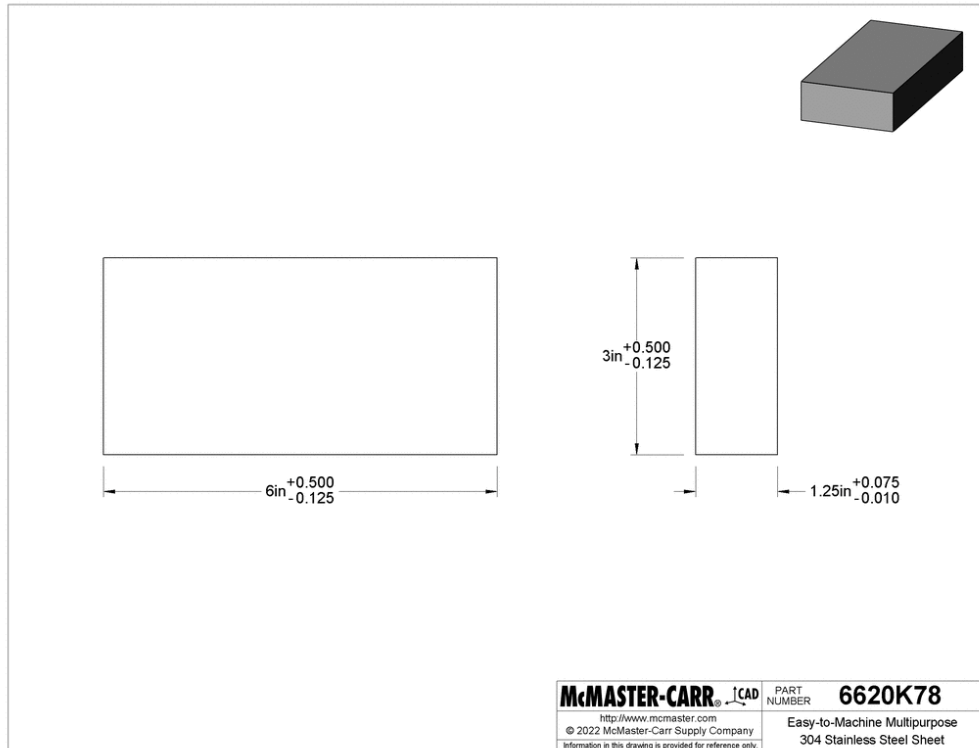
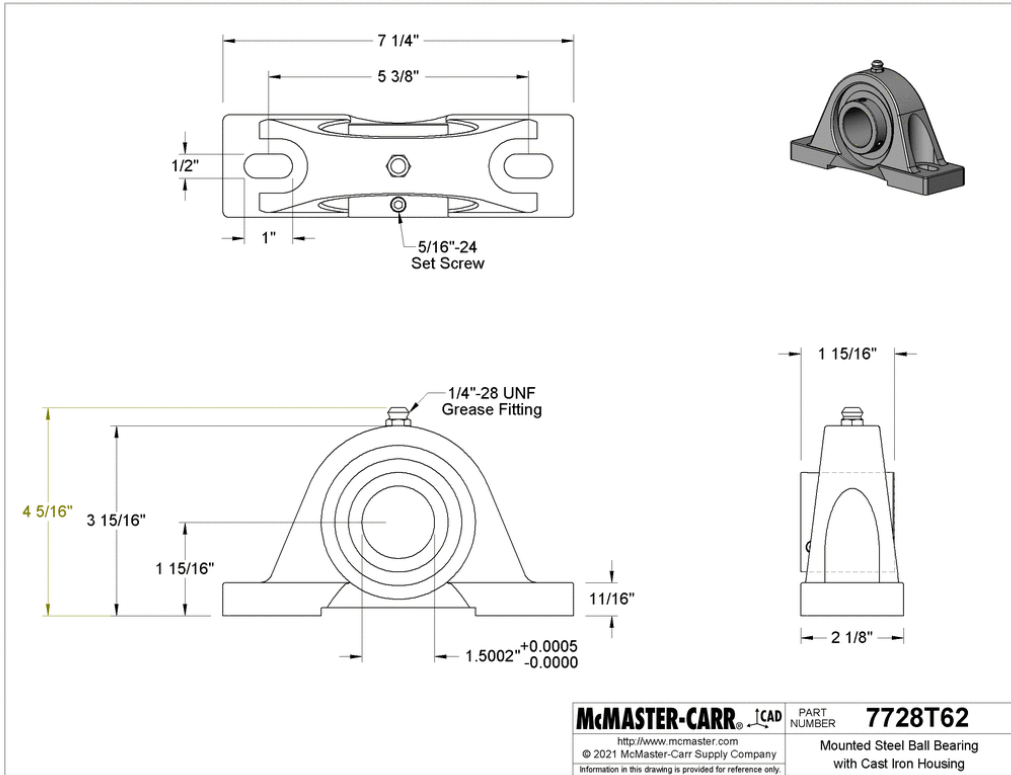
idea. While these things seem irrelevant at first but for those reading this document, information such as this becomes important as it serves as lessons, inspiration, and reminder for future use.

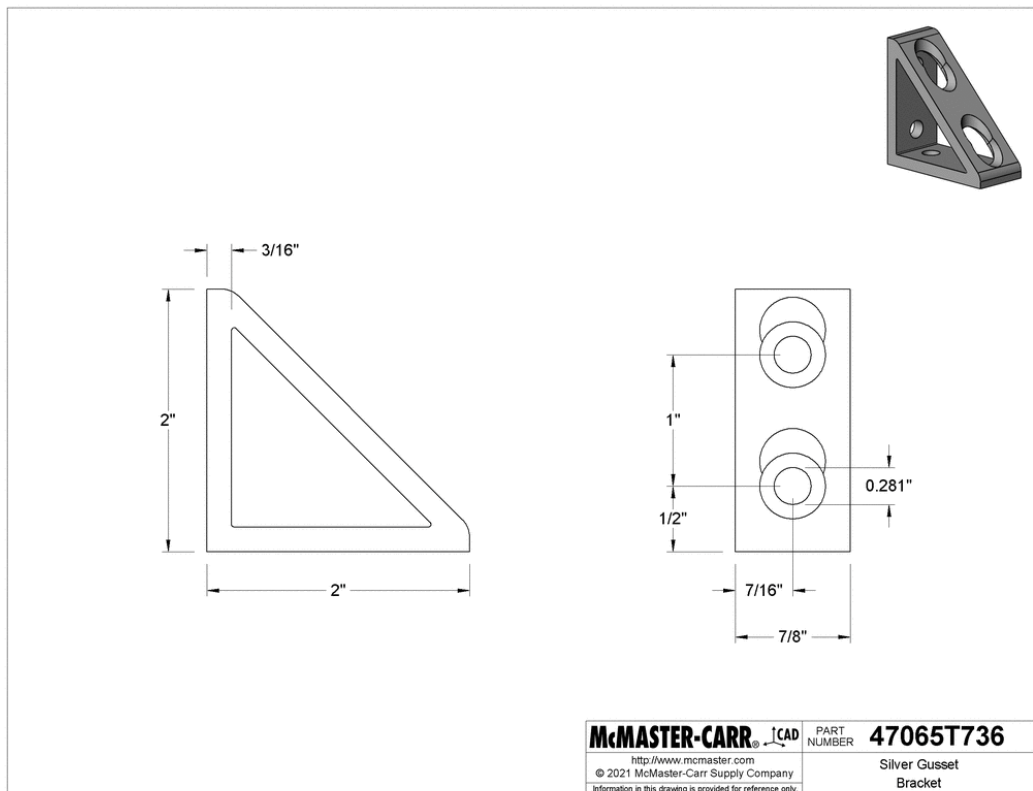
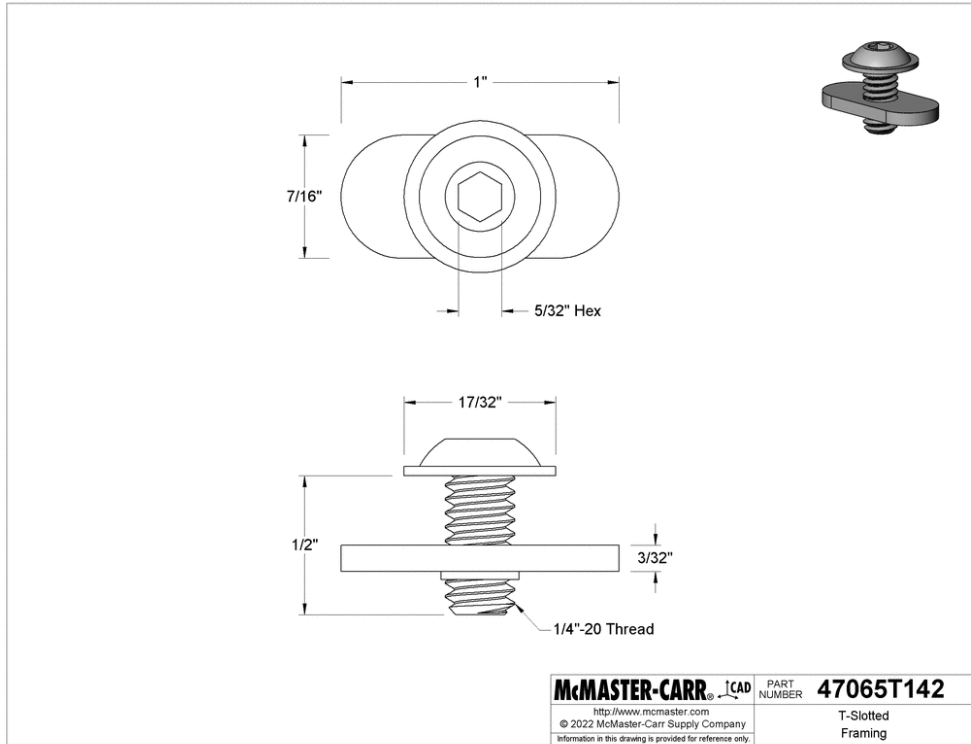
#### 8.10 Overall assessment of the design

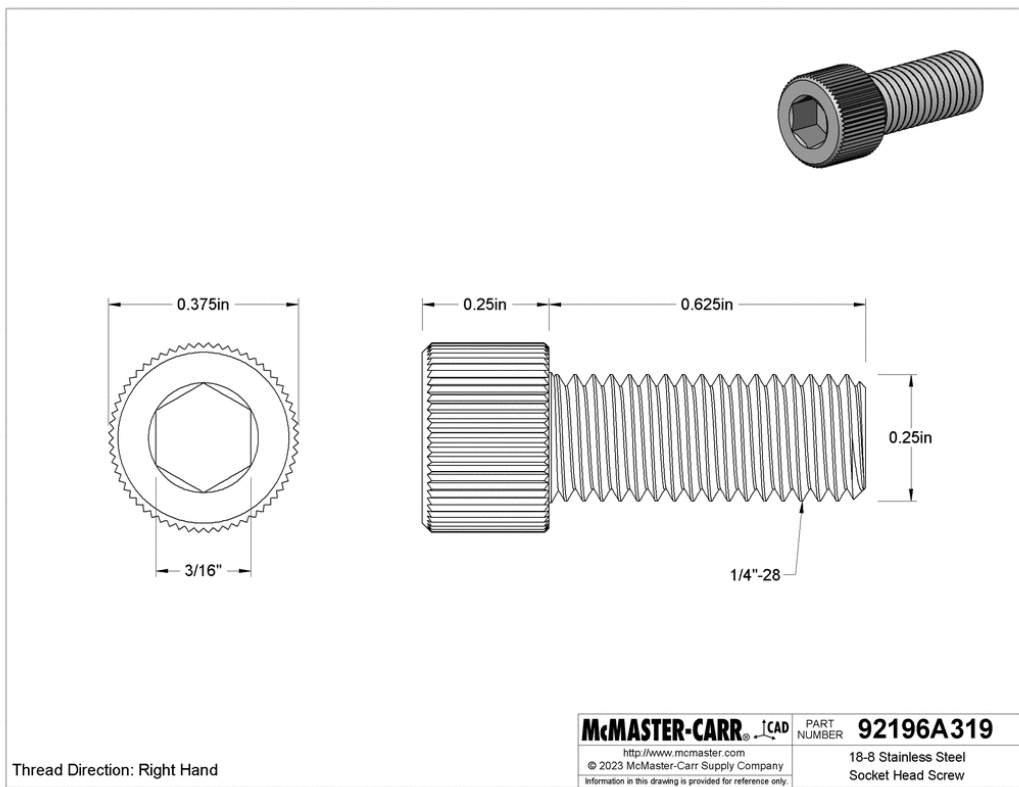
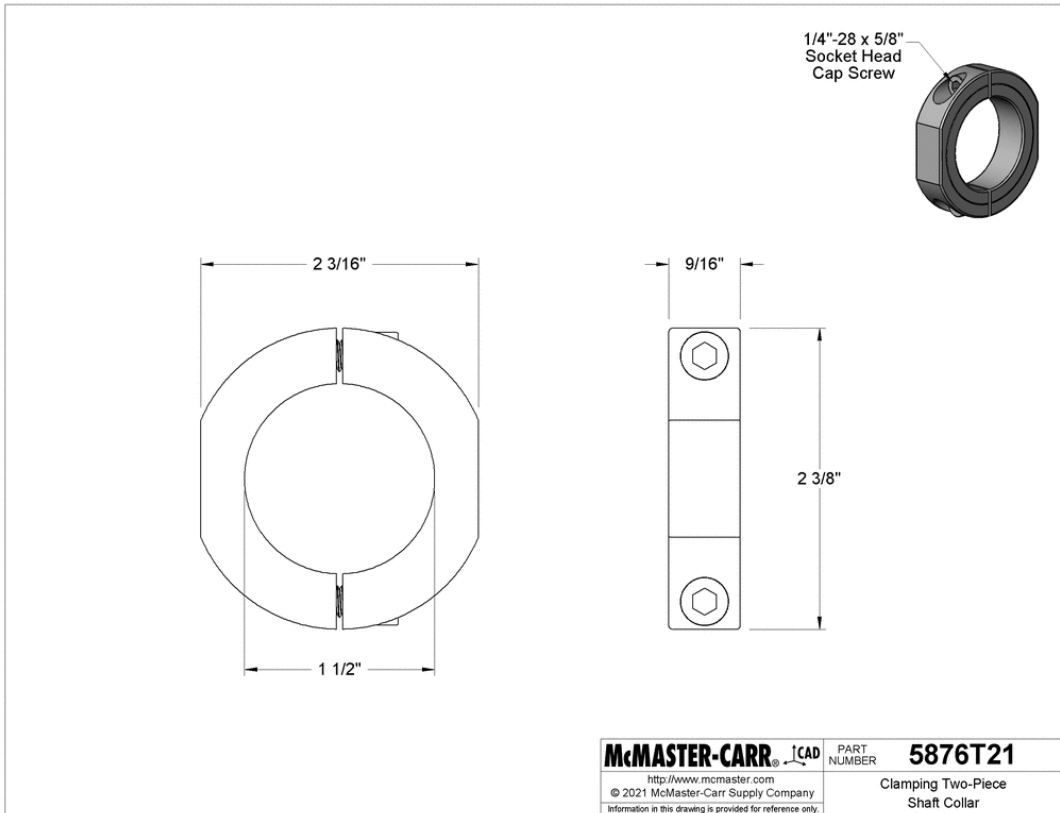
The new solar panel array support is built with the purpose of holding 4 Renogy Solar Panels, adjustable function to optimize solar energy collection, and maintain the adjusted angle from the force of front and side wind of (at least) 30 mph. The reduced weight of the design is accomplished by the aluminum bar acting as the skeleton frame for the support, the locking mechanism is achieved by the collar assembly and the rotational mechanic is done by the cast iron bearing housing. The array can maintain its position due to the clamp force provided by the collar assembly with the calculation being found in sub – section 8.3. The bending of the wing is prevented by using 2 inches long silver open extended gusset. Overall, the new design of the support was a success as it accomplished the requirement set out by the UC Solar Car team and the parameter of the American Solar Challenge. As it may, there are improvements that can be made to the design to increase its performance and they are listed in sub – section 8.7.

8.11 Component Drawing

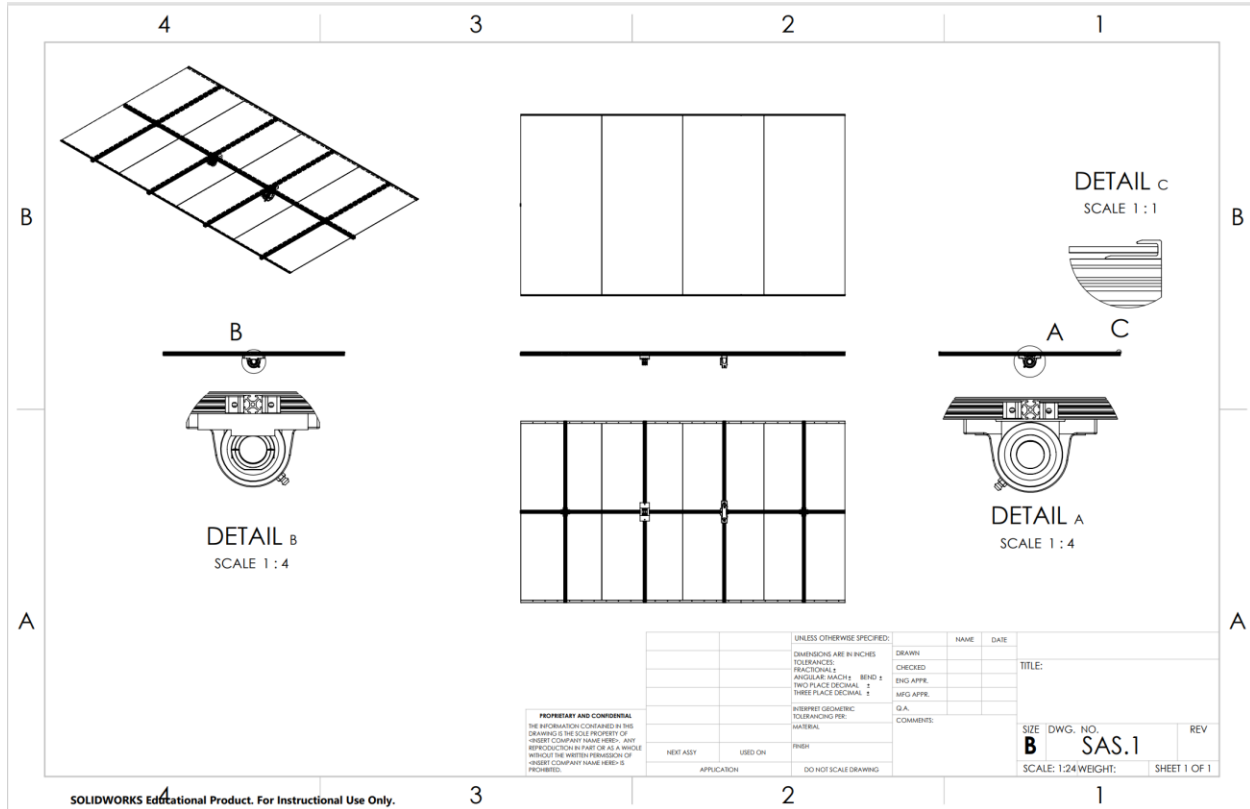












## SECTION 9

### STEERING SUB-TEAM

Lose, Jamie (MET) / Ehlers, James (MET)

#### 9.1 Design Goals

The design goal for the 2022-2023 steering portion of the UC Solar Car was to successfully create a reliable steering system utilizing some of the parts and locations of the previous year's system. After inspecting the rack & pinion and checking it with the competition regulations, we decided to move forward with the existing rack & pinion as it was in good condition and allowed us to satisfy competition requirements of steering ratio & angle of deflection. However, aspects from the previous car's design that we emphasized changing included incorporating a direct steering shaft to pinion gear connection, thicker tie rods, left/right hand threaded ball tie rod ends, and a system in which all bolts in shear underwent double-shear instead of single shear. These solutions all provided a fix to the major issues with the safety and performance of the car. For example, the previous tie rods were 3/8" in OD, which resulted in extensive bowing. Additionally, the previous shaft connected to the pinion by a means of socket heads, without any sort of mechanical design to safely fasten the connection. The images below

provide a visualization of some of these issues from the previous car, such as the bowed tie rods, and faulty shaft-to-pinion connection.



## 9.2 Assumptions/ Inputs

The assumption that we made at the start of the year was that a fully functional steering system was possible in the current frame that we were constrained by, as we re-used as many steering components from the previous team as possible. These components included the rack and pinion, brackets on the front wheel/suspension that the tie rods fasten to, steering wheel, and tires. As documented from the previous year's team, the rack and pinion provided a sufficient steering angle for the car to pass inspection, so to limit any chance of error, we decided it was best to build upon the rack and pinion that we knew would perform a certain way. Because the rack was a fully manufactured part, we assumed that it was unsafe to make any physical changes to the rack, but to instead incorporated the design to work around the rack parameters. For example, this prevented us from drilling holes, trimming material, or welding any new material to the rack.

## 9.3 What did you need from other teams to complete your design

The steering assembly design was independent in terms of communication with other subassemblies. We needed to share our design with the pedals team, to ensure they have clearance under the tie rods for the pedals to operate freely. We assumed there would be ample clearance, but it is always good to double check. We also needed to collaborate with the wheel hub team lead to verify how we will attach the ends of the tie rods. As a connection bracket was already welded onto the inside of the wheel hub (as seen below), we used this pre-existing connection point. Communication with wheel hubs was just to confirm this connection point works for both parties.



#### 9.4 Lessons learned in design

A lesson learned in design that we found extremely helpful was to be open minded during the design stage. Periodically, we would have conversations with the machinists at VPC to discuss the practicality of our design. Similarly, to the real world, a design may work in theory, but sometimes may be extremely challenging or even impossible to manufacture under the design requirements. For example, one of our goals was to directly connect the steering shaft to the pinion. The rack and pinion were mounted to the vertical plate on the frame and sat at a horizontal angle. The solid-piece steering shaft obviously came in at an angle, creating a problem when trying to figure out how to line up the pinion end to the shaft end. Our first design proposed a solution to machine an angled spacer at the pinion in order to compensate for this angle and align the components together. This required diligent calculations with figuring out proper dimensions, and ultimately created a strict machining tolerance in order for the design to properly work. Once figuring out how complex this issue could become, we decided that instead of spending precious time calculating angles and lengths, we could instead torch the vertical plate and manually bend it until the pinion and shaft are aligned. Once aligned, the plate was able to cool and solidify to a hardened state, with a newly welded material connecting the once vertical plate to the bottom of the frame. An image is shown below to illustrate this design realization and progression of the steering system. The image on the left shows what the plate looked like before, and the image on the right shows the bended plate after heat was applied to it.



## 9.5 What worked well and should be carried forward?

The components on our steering system that we believe worked the best and should be used in the future are the connection method between the shaft/pinion, the connection between the rack and tie rods, and the connection between the tie rods and front wheel/suspension. The connection between the shaft and pinion was mechanically fastened by a pin inserted through both components, secured by a washer and nut on the other side. In order to make this work properly, we had to drill out an opening in our solid shaft to hollow out the inside of it. This would allow the ID of the shaft to slide over the pinion in a tight, press fit. This alone would not provide sufficient fastening, so we drilled a thru-hole through the hollow shaft so that the pin could act as the mechanical fastener in that assembly. Assuming the same rack and pinion will be used in the future, this design method works and is easy to replicate if needed.

Additionally, we are proud of the way our connections turned out between the tie rod ends, front wheels/suspension, and rack ends. The rack and wheel hub adapters that we designed/manufactured ensured that there would not be a “lag” when the wheel is turned back in forth. To prevent the lag from occurring, we designed our adapter pieces with the intent of keeping them from wiggling back and forth in a vertical or horizontal direction. This wiggling action would create a lag when the wheel is turned and would cause the force to be lost from the wheel. However, this was prevented by a number of ways. When connecting the tie rod ends to the front wheel hub/suspension, they fastened to the welded brackets. By measuring out the inside wall-to-inside wall length of the bracket and the thickness of it, we designed our adapter to tightly slide over the bottom lip of the bracket and sit perfectly between the inside walls of it. For the rack adapter pieces, we designed the adapter to be able to slide over the diameter of the rack like a glove. We did this by drilling out the inside of the adapter piece to essentially match the OD of the rack, keeping it from wiggling back and forth. The spacers that we added to the threaded rod end allowed the ball to gyro back and forth, allowing the tie rods to perform properly. Images illustrating these processes are provided below:



#### 9.6 What did not work and should be changed in the future?

In the steering system, an area that we would have liked to change is the sizing width of one of the wheel hub adapters. When machining our parts on the ProtoTrak mill, we accidentally trimmed the stock material too small for the left sided adapter, giving a bit too much space between the inside walls of the welded bracket on the hubs and our adapter piece. Functionally, our part worked, but there was a slight wiggle on the left piece that would happen when turning

the wheel (the right side was noticeably tighter and worked as designed). However, we were not able to notice this right away because we did not connect the tie rods until a few days before the deadline. In the future, I would have tried to finish assembling the system as early as possible to give time to fix potential problems that arise when putting components together.

### 9.7 Lessons learned in manufacturing

One fabrication lesson that we learned throughout the semester is how much time it takes to machine parts compared to how long I thought it would take. In total we manufactured five parts, four of which took multiple steps to complete on multiple machines. This included modeling, dimensioning, obtaining material, machining, and clean up. We saved our manufacturing towards the latter half of the semester, and it required many late nights in order to wrap our project up in time. This was especially due to the fact we had little machining knowledge going into this project. We took a machining lab junior year, but needed a refresher before we began machining these parts this time around. The machine shop was also only open to students 6 p.m. to 9 p.m. on select weekdays which was difficult for two reasons. One being we had a specific time to get machining done and had to adjust our schedules accordingly. If I was free during the middle of the day, or on weekends, I was unable to get a lot of work done towards the end of the semester. The second reason the 3-hour window made it hard was that was everyone's window, so often I would find myself having to wait in line for help setting up a machine due to it being crowded.

### 9.8 Issues throughout semester

In hindsight, there were a few things we could have approached differently. The first is ordering and machining parts as soon as possible. I feel as if we may have stayed in the design phase too long, underestimating the time it takes to physically put plans into action. There was downtime on occasion, where we may have thought “oh we’ll let's just handle that next week” and towards the end of the semester I wished I would have been more on the ball early on. Another issue we had was getting a 3D model up and running as a team. Our files were all corrupt and some parts were even mis-dimensioned or scaled wrong. I think in hindsight getting the model all squared away early on would be beneficial for the entire solar car team. A last issue we ran into was the tolerancing on our exterior connection blocks was slightly off. The

manufacturing of our connector blocks went well, but the block fit in the wheel hub bracket with a little play (in the location shown below). This caused some lag in our steering system, but the connection block was the only method we could think of to attach everything. Our blocks didn't even initially fit onto the bracket, we had to fillet away some material on the connection pieces due to the weld beads being in the way.



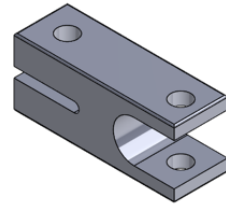
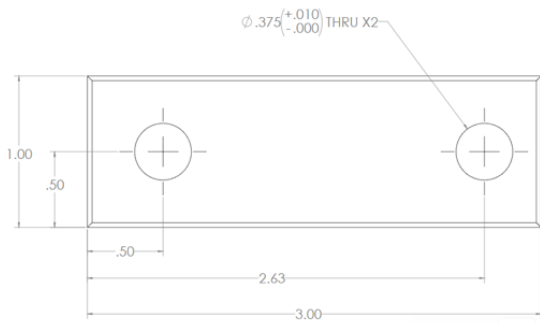
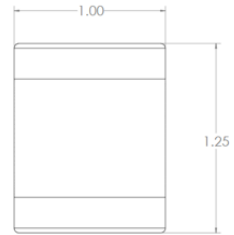
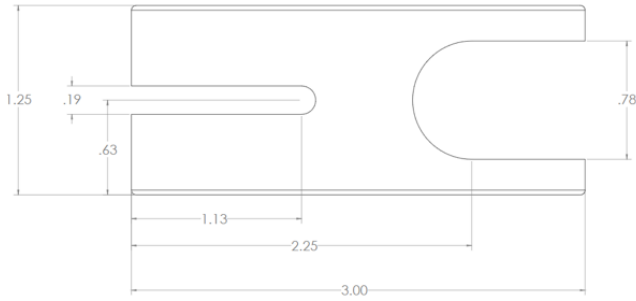
#### 9.9 Overall assessment of the design

Overall, we are both happy with what we were able to accomplish with the steering system on the 2023 UC Solar Car. Especially considering we were making corrections to a system that was already in place, which limited our design options. We also attempted to utilize as many existing parts from the previous design as possible for monetary purposes. I think our idea of a direct connection to eliminate the U-joint system worked great. Taking out linkages allowed us to reduce the amount of potential failure spots. We also initially intended to place a wedge between the pinion housing and the back plate to angle the pinion shaft directly into the bored steering

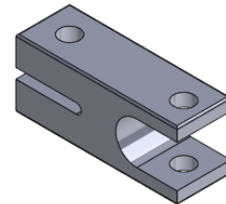
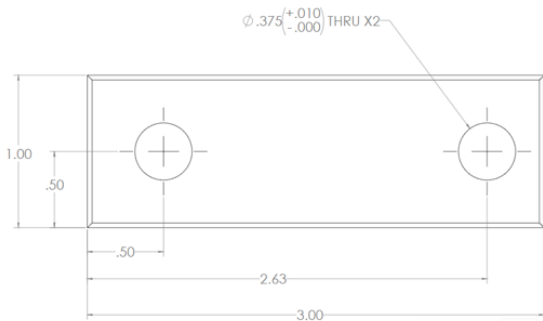
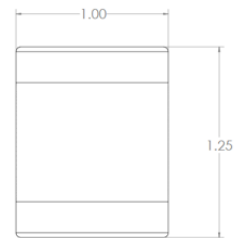
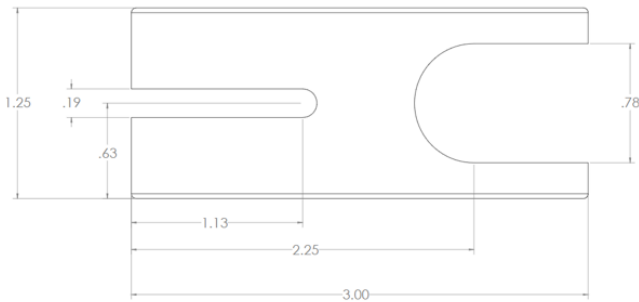
shaft. Halfway through the semester we got the idea to just leave the pinion housing connected the way it is, and to just bend the back plate to that angle and reweld it (as shown below). I liked how we were able to make changes on the fly, and not let our original idea blind us from a better solution.

The fabrication of all 4 of our connection blocks was slightly tedious but considering our situation it had to be done. In a perfect world we get these quoted and machined from a shop but would have eaten away at valuable funds the club could have used elsewhere. I think the suggestion to utilize both left- and right-hand threads at the end of the tie rods was great, and it proved a smart decision as we needed to adjust these to get our alignment right during assembly. One area I think we could have improved upon was the exterior connection of the rod end bearings to the wheel hub as we mentioned earlier. We envisioned and modeled a perfect fit of the blocks into the U-shaped bracket welded onto the outside of the wheel hub. This would restrict movement of this connector block and allow the bearing to handle all rotation and movement. We forgot about the weld bead that lies inside the U bracket, which causes us to grind off material creating a fillet on the corners and edges of the connection block. We had to guess and check this until the block finally fit, but there ultimately some wiggle laterally between the block and the inside of the U bracket. This then created a lag in our steering system between when you turn the wheel and when the tires actually move, which is not ideal. Which circling back to something I mentioned in a previous section, if we had done this manufacturing earlier and discovered this, we would have ample time to make two more blocks that fit better. Unfortunately, by the time we discovered this issue it was too late to make this correction. All things considered we are both happy with the progress we made this year and learned a lot from this process!

Listed below are drawings for our manufactured components on the steering system:



REV	DATE	BY	CHK	APP
1				



REV	DATE	BY	CHK	APP
1				



2. Order parts & plan manufacturing early!

Plan for the unexpected when it comes to purchasing and fabrication. The lead times of parts, and time it takes to machine can be unexpected at times. Mistakes happen, so plan for the worst-case scenario or keep back up plans in mind.

3. Communicate with others!

Establishing a good working model for the entire team is helpful for everyone. This visual will help guide you with part placement and can be vital in finding component interferences early on. A model will also give you all of the dimensions and quantities of what parts you need, this was especially useful with steering as there were a lot of purchase components and tons of hardware. A good design is important, but how this design flows with the rest of the car is equally as important.



## SECTION 10

### OVERALL CONCLUSION

The goal of the UC Bearcat Solar Car organization is to design, build, test and race a solar power race car in the American Solar Challenge along with the Formula Sun Grand Prix. With the completion of the 5 senior design projects, the current solar car is now a mechanical functional vehicle and to be fully operational making it one step closer to the goal the organization set out. For the car to be fully in operation, it would need the inclusion of the electrical components which include battery, control system, motor etc. In addition to that, it would also require an aero – shell to go over the chassis. While the vehicle now has operational mechanical functions, improvement can still be made as suggested in the sub – team project assessment. The main priority for the Bearcat Solar Car is to have operational solar power solar car and it can be achieve if the changes and suggestion made by the members are meet.