Small Sized Soccer Robot Chassis Mechanical Design and Fabrication

A Major Qualifying Project Report submitted to the faculty of

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Abstract

The Small Sized Soccer Robots MQP project is an academic year long project which has the final goal of designing and fabricating a team of robots which will compete in the Robocup league. The rationale behind the project is to create a WPI Robocup team which will over the years be a reoccurring MQP project and improve upon itself on a competitive stage. To compete in the Robocup league a team must design and create a team of six working robots that can play a full game of soccer against another team while following the Robocup rules and work independently from a controller and autonomously. The team was split into three different sub-teams consisting of mechanical, electrical, and software development to complete this project over the course of the given project year. As a member of the Mechanical team our goal is designing and manufacturing robot hardware. The final design was arrived upon through multiple weeks of research on opposing teams along with trial and error throughout the manufacturing process. This final design which I created was a full working chassis design for the robot. Once this design was made dynamic and static analyses were done on the robot to prove my design was feasible. After this theoretical analysis was finished the robot was manufactured within Washburn Labs on WPI campus, using CAM software and mill technology. We are currently able to produce two theoretically working physical prototypes which have both been utilized extensively. While at the moment a full team of six robots has not been achieved, the work done is still within our goal as one successful robot means that it can be copied to form the rest of the team.

Acknowledgements

I would like to acknowledge the many people who helped make this project possible over the span of the academic year. First thanks go to both advisors Siavash Farzan of the Robotics Engineering Department and Alireza Ebadi of the Mechanical Engineering Department. Both advisors played an important role in the success of the mechanical sub-team's work over the course of this project. Next, thanks go to Joshua Cuneo and Stephen Bitar of the Computer Science and Electrical Engineering Departments for the weekly feedback on the sub-team's progress.

Final thanks go to the entire staff of the Washburn Machine shop, especially to Joel Harris, for all their weekly help. Without their efforts and patience, this project would not have been able to make it as far as it has in the span of time which has passed.

Authorship Page

This report was fully written and edited by David Lapointe as his final submission of project work over WPI's A, B, and C terms. Besides writing the report the author was responsible for research and finalizing the design of the chassis of the project's robots. In the second phase he helped create the initial CAD design of the robot along with final designs of said robot's chassis. Once these designs were finalized, the first prototype of the chassis was manufactured. In the final phase David took control of the manufacturing side of the project and assembly of the first prototype. Once the first prototype was put together a second and more refined robot was then manufactured.

Over the course of the project, work was put in by three other individuals from the Mechanical sub-team. Conner Christensen was responsible for initial research on the drive system of the robot. He also was irreplaceable with his work on the final CAD design of the robot and all its sub-assemblies and drawings. Finally, Conner designed, printed and put together the initial kicker system of the robot.

Miya Judy was the third member of the mechanical sub-team but was only part of the project through phases one and two. Miya was responsible for initial research in phase one on the kicker system within the robot along with other research on many different aspects of the project.

Evan Vadeboncoeur was the final member of the mechanical sub-team who was also part of the computer science and electrical teams as well. Evan joined the mechanical team in phase two and helped with 3D printing of parts and assembly of the robots' sub-systems. Evan's main and most important contributions, however, came from his work as a liaison between the mechanical and other sub-teams.

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Executive Summary

This report is based around the Robocup competition where teams design and manufacture a team of six robots to compete against other teams in a small-sided game of soccer. Following are the efforts of the Mechanical sub-team in achieving the goal of this project. As a member of the mechanical sub-team, I was responsible for the design and fabrication of the mechanical aspects of the robot. This includes the chassis of said robot along with any other manufacturable or altered mechanical aspects. Once these systems were designed and finalized, I manufactured and assembled the robots which would then be passed onto the other two teams for testing and integration.

The mechanical sub-team divided our project into three phases. The first phase was the research and initial design phase. In this phase the team used multiple different decision matrices to finalize a design for the three different systems of the robot. These decision matrices were filled with design aspects from multiple different Robocup teams in attempts to find the perfect combination of designs. In the second phase the team focused on the design and initial manufacturing of the robot. Using SolidWorks, the team took the final decisions from last phases decision matrices and put them into a 3D model. Next, we were able to finally visualize our robot's design and make design changes as needed to make the robot more feasible in terms of manufacturing and functionality. Once the design of the robot had been modeled the team 3D printed the parts and assembled a physical prototype. Next the team was able to use the 3D printed prototype for troubleshooting and refinement of the initial design. Once certain parts of the design were finalized, they were then manufactured in Washburn shops to start a finalized prototype. In the third and final phase of the project the team focused on manufacturing and assembling multiple robots. Using machining mills in Washburn Shops on WPI's campus and 3D printers, the team was able to manufacture multiple parts of the robots and use those manufactured parts to refine the final design and process of manufacturing. The first prototype was manufactured and then passed off to the ECE sub-team for testing on their end. This prototype needed refinement and multiple changes were made and incorporated into the next robot.

Chapter 1 – Background

The Robocup soccer league commenced in 1997 and since then has evolved into a world-renowned competition which many prestigious universities have joined and continue to compete in. This robot league has been stated as, by itself, as a landmark project in the field of robotics. What this means is that while the competition itself doesn't bring upon massive social or economic change, it does further advance the field in its own right. The Robocup league made this "challenge" of soccer playing robots with one long term goal in mind since the beginning. That goal is that one day a team or robots will be able to beat the previous world cup champions in a FIFA regulated game of soccer. The importance of this league is the advancement in human robotics technology. With people competing in this competition every single year and making more advanced and smarter robots, that gap between machine and man is slowly getting smaller. If the long-term goal of making a team of robots that can beat the world champions in a regulated game of soccer comes true, then that will be a huge step in human advancement of robotic technology.

This is where our Major Qualifying Project comes into play. As stated before, every year more teams compete with more advanced robots in hopes of being crowned as the best team in the world and simultaneously moving the field of robotics farther into the future. Our project in its simplest form is to design and create a robot for a small sized soccer robot team to hopefully compete in robocup in the future. As this is the first year of this project and as a team, we are designing our robot, and this sets up a base for future project teams. By starting the journey into the robocup world, we are effectively part of the goal of the Robocup league, which is to better advance robotics technologies through challenging yet fun competition. Our project is also a great way for WPI students to grow and learn in the Tech school environment. Most of what is asked for from this project is very tedious and intricate, so every member of this project will have to go out of their comfort zone to learn. By starting this project, it allows motivated and interested future WPI students to join in the Robocup dream of showing the boundless limits of robotics technology.

With Robocup being as big as it is and having been around as long as it has, there is a wide base of knowledge on the topic subject. The most reputable source is the Robocup website. This database is full of over 300 published scientific papers. This database is a focal point for gathering information on aspects for a team's robot whether that team is brand new like ours or if they have been a functioning team for over a decade. Along with this there is another massive database of information which a team can grab from. This database is none other than the Team Description Papers (TDP's) of already existing and competing teams. The TDP's provide summarized descriptions and details on each team's yearly design. Each competing team releases one of these papers yearly when they compete which are open to the public. Successful teams like the CM Dragons, Robojackets, and SKUBA are among the few that we referenced during our own robot teams' design. Each paper typically consists of mechanical, electrical, and software sections which hit the major points of each robot in summary. In the mechanical section the chassis and its design are then described briefly. The kicker then driver systems. The electrical section gives details on all the wiring of the PCB boards and other electrical systems within the robot. Finally, the software section talks about the software used to implement the logistics and strategy of the robot. What must be talked about however is that these TDP's give brief descriptions of each section with their main focuses being on the changes made in each section of the robot from previous years. What this means is that the knowledge base we are taking from is limited in terms of the teams' initial designs and thought process leaving a small gap in knowledge of where they are and where we should be starting from.

With all the knowledge we can pull from the Robocup league itself and other competing teams, we are able to also find a "gold standard" for a Robocup team. This gold standard can be seen through highly competitive teams like the CM Dragons [1] or Robojackets [2]. These teams are able to over the years perfect the current top standard for a small sized soccer robot. When aiming to design our team we can look towards them for all three sub aspects of the robot, those being mechanical, electrical, and software. They have each made and continue to advance the technology used in a small sized soccer robot. From their lightweight compact designs all the way to their in-depth code, we can use them as a beacon for the future of this project and what to strive for. However, even though they may be the gold standard now, every year improvements are made to their team, this furthering that standard and forcing us to catch up, this s just the nature of a robotics league like this.

Chapter 2 – Design and Development

2.1– Mechanical System Overview

This project was split up into three different sub-teams, with those being the electrical, coding, and lastly the mechanical team. As part of the mechanical sub-team, we had to take on the role of designing and manufacturing the robots for our team. This included the chassis, drive, and ball control mechanisms of each individual robot. With our team being three people in size during the first phase we decided to split those three sub-sections of the mechanical design amongst ourselves. Out of the three I was in charge of the Chassis design and feasibility whose main functionality is to effectively hold all parts of the robot and serve as a base. Without having a well-designed chassis, the robot can run into many roadblocks in its future development. Some constraints of the Robots chassis are defined in the rules of robocup such as a diameter of no more than 0.18 meters and a height of no taller than 0.15 meters. The rest of the robot's chassis design is up to our team to design and figure out. With this being my responsibility, I broke it down into three categories where a decision needed to be made before an initial design could be created. These categories were material, layers, and connection points. The material will impact the weight and cost of the robot heavily. The layers will change the height of the robot and affect the amount of space within the robot to hold its mechatronics and electrical systems. Finally, the connections points serve as a way to connect the different layers of the robot and will drastically affect its weight and stability.

For the material of the chassis, I looked at the choices of plastic, aluminum, and steel. Below in Table 1 is the decision matrix for the materials. I considered aspects of the material like its cost, weight, manufacturability, and more. Looking at the plastic option it can be seen that it was the cheapest option and also the easiest to manufacture but its lack of durability is why it wasn't chosen because with the overall weight of the robot we couldn't risk having a chassis that would break under pressure. Next, I looked at steel which was extremely durable and was cost effective but had very low manufacturability and was also too heavy. This led me to the last choice of aluminum which is durable and cost effective on top of a relatively easy manufacturability. Finally, you will see that in the table is a column for weight. This does not refer to the weight of the material but instead refers to the importance of the choice at the time. A row of criteria which was thought to be of more importance to consider was given a higher weight value, the score then given to the criteria was multiplied to that criterion after it was assessed and that gave a final weighted value. Once this was chosen, I moved onto the next decision that needed to be made.

Table 1. Chassis Material Decision Matrix

Criteria	**Weight**	Plastic		Aluminum		Steel	
	1-10	Score	Weighted	Score	Weighted	Score	Weighted
Cost	7	9	63	7	63	8	56
Weight	8	8	64	7	56	5	40
Manufactorability	7	9	63	8	56	6	42
Adaptability	5	7	35	7	35	6	30
Durability	9	2	18	9	81	10	90
Recoverability	6	2	12	8	48	7	42
Total Score			255		325		300

With aluminum as the chassis material, I had to next decide on the amount of layers of our robot. This would eventually affect the height and weight of the robot. What must be recognized here as well is that these robots move much faster than we initially anticipated, and I wanted to make sure our robot was stable enough. Table 2 shows the Decision matrix I used for this decision. As seen, the weights and type of criterion are different from those of the material. Factors such as stability weren't needed when thinking about a material but are needed when thinking about the layers. What stays the same though is the desire for high manufacturability and cost efficiency. The first option we considered was one that multiple competing teams in Robocup have used in the past. This was the single layered robot. This was immediately the most complicated of the choices and to design and manufacture a single base robot took much more knowledge and research than our project time allowed. With this decision made it was between a double or triple layered robot. With the given height requirements from the Robocup league these options are quite similar. In the end, however, I decided that adding a third layer complicated the future design much more than needs be for the mechanical and electrical teams as more layers means more thought into where every electrical and mechatronic component is placed.

Table 2. Chassis Layers Decision Matrix

Criteria	**Weight**	Base Plate		Double Plate		Triple Plate	
	1-10	Score	Weighted	Score	Weighted	Score	Weighted
Recoverability	6	4	24	8	48	7	42
Stability	6	7	42	9	54	6	36
Manufactorability	8	6	48	6	48	5	40
Cost	7	8	56	7	49	6	42
Weight	8	8	56	7	56	6	48
Total Score			234		255		208

Finally, the last decision was the connection points between the robots' two layers. This decision was the easiest since it was between only two options, but both still had their benefits. As seen below in Table 3, the two options were standoffs from the bottom to the top plate and then metal plates which would be fabricated to connect the plates and almost act as walls. When looking at the connection plates they are quite tempting in the initial design, this was because I liked how they set up a box shape for the internals of the robot which made it easy to visualize. These plates are also very sturdy and offer lots of stability for the chassis. What ultimately helped me make my decision was that intense manufacturability the plates over the standoffs. With the limited knowledge and resources, we have for manufacturing, I decided to go with purchased male to female hex standoffs because they offer a good amount of stability and have zero manufacturing hassle.

Table 3. Chassis Connection Points Decision Matrix

Criteria	**Weight**	Standoffs		Plates	
	1-10	Score	Weighted	Score	Weighted
Recoverability	5	9	45	8	40
Manufactorability	6	8	48	6	36
Stability	9	8	72	9	81
Cost	7	9	63	7	49
Weight	8	8	64	6	48
Durability	8	6	48	9	72
Total Score			340		255

With these decisions finally made, the initial design of the robot could finally be worked on. By keeping it within the constraints it was now time to pull from previous TDP's and other teams designs to make our own. Along with that chassis bottom plate, a top plate also needed to be designed and this design was imperative because it was needed to maximize airflow and minimize weight. With this in my mind I moved to the next phase which was Conceptual Designs and Prototyping.

2.2- Conceptual Designs and Prototyping

With the design choices finalized and initial research done it was now time to move onto the actual design and prototype of our robot which took place in the end of the first phase and through the second. This conceptual design was started in Solid Works as I put together an initial concept of what we planned on manufacturing. Below in Figure 1 is an image of what that initial design looked like. As you can see from the model, the initial design has all of the previously decided on aspects. A viable baseplate that fit the necessary constraints was modeled with standoffs that attach it to a simple top plate which is easy to manufacture.

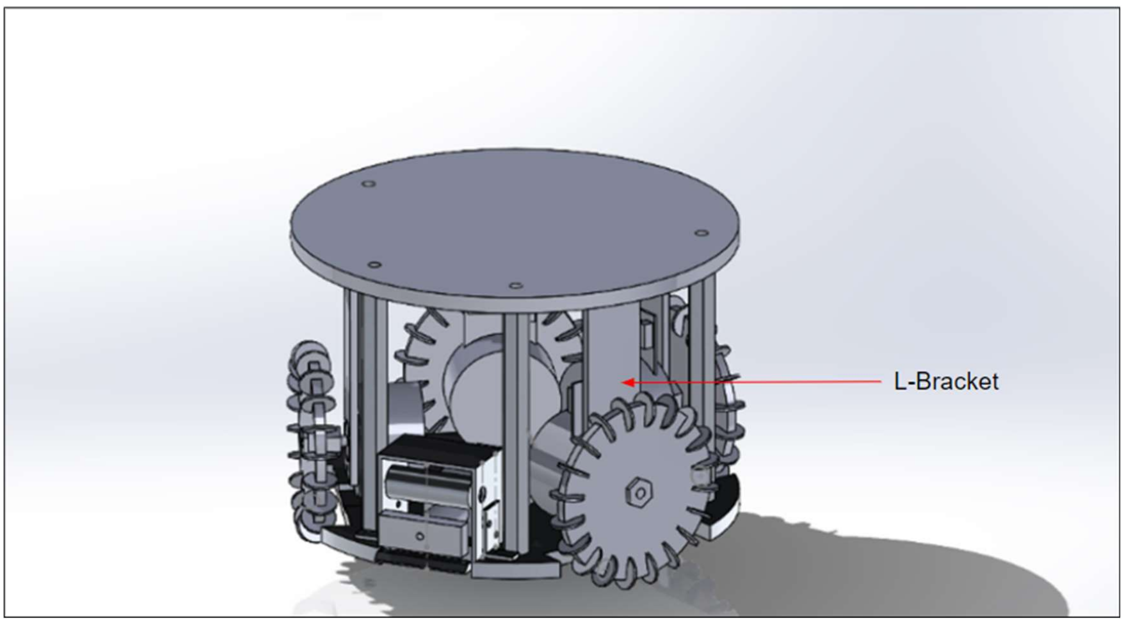

Figure 1. SolidWorks Initial CAD Model

After a discussion we as a team decided that the feasibility of manufacturing such a design was unrealistic. Shown below in Figure 2 is the second iteration CAD model of our robot. The largest mechanical change that I made between this one and the previous iteration is the L brackets which the wheels are connect to. In the first design they were much larger and connected to the top plate and hung downwards. The size and shape of those L brackets were very odd and made manufacturing much more difficult than needed be. In this new design the L brackets are much smaller and connected to the baseplate. The new L brackets are easy to manufacture since we can buy them in stock and then just drill a hole pattern into them. Another change which cant be seen in this image but will be shown later in the report is that a hole pattern has been cut into the top plate. The reason for this is to decrease unnecessary weight from the top plate along with adding a small amount of air flow for the PCB's.

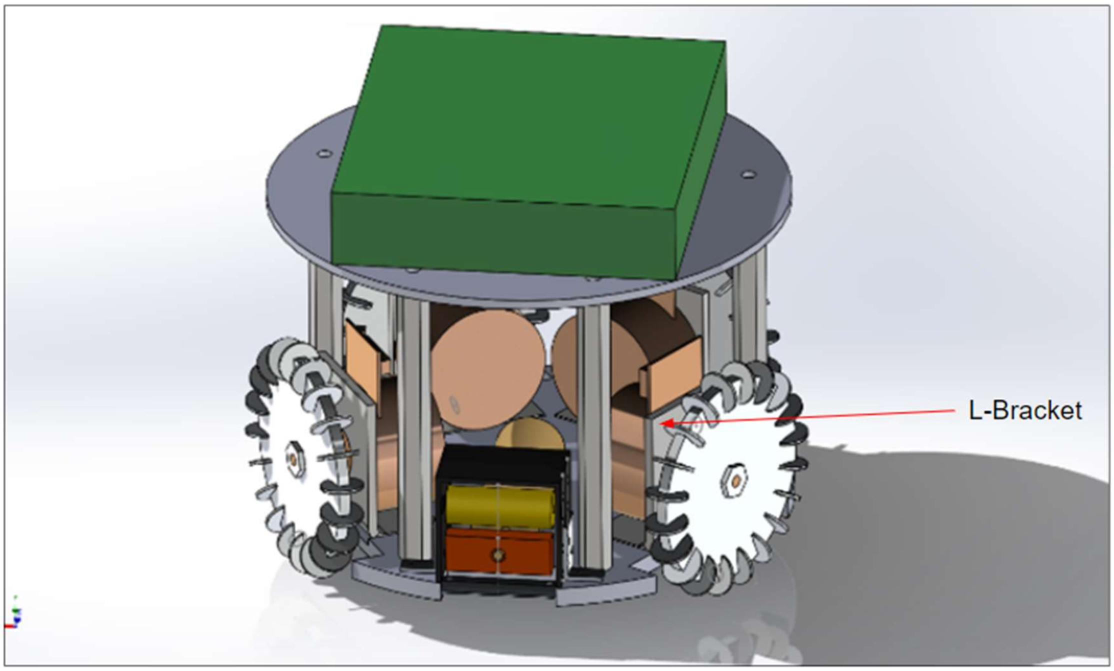

Figure 2. SolidWorks Second Iteration CAD Model

After the second round of changes, I moved to the next step which was to 3D print an initial prototype of the robot so that there was a physical visual of our design to show to the team and look at for manufacturing feasibility. After 3D printing the entirety of the robot was assembled and then brough to the Washburn shops on WPI's campus. It was shown to the lab monitor Joel Harris who helped me with the feasibility of our designs. We concluded that the top plate was easily manufacturable while the baseplate needed to be tweaked slightly. This change can be seen in the top-down view of a final CAD design worked on by Conner Christensen in Figure 3. In this design multiple changes were made on the inside of the model in terms of driver and ball control mechanisms but the only change with the chassis is the base plate. As seen in this top-down view the baseplate has been rounded on all sides to aid in manufacturing ease.

This is because the machine shop mills will use a 3/8 End Mill bit which cuts in a rounded path. By rounding all sharp edges, the machine can easily and safely cut the bottom plate.

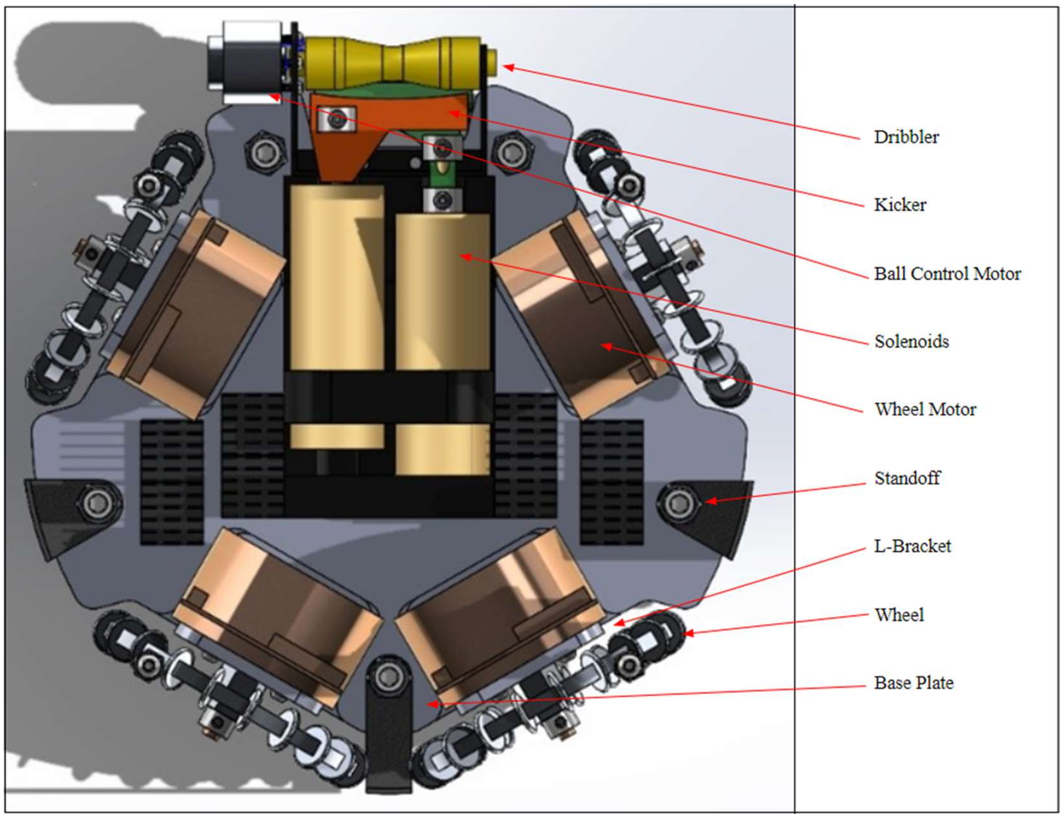

Figure 3. SolidWorks CAD Model Top View

With this final change made and a chassis design finalized, the next phase of the project was ready to begin. Now that the top plate, base plate, and L brackets were finalized it was time to make the first physical prototype of the robot. Below in figure 4 is an exploded view of that finalized robot design which shows the full assembly of the robot.

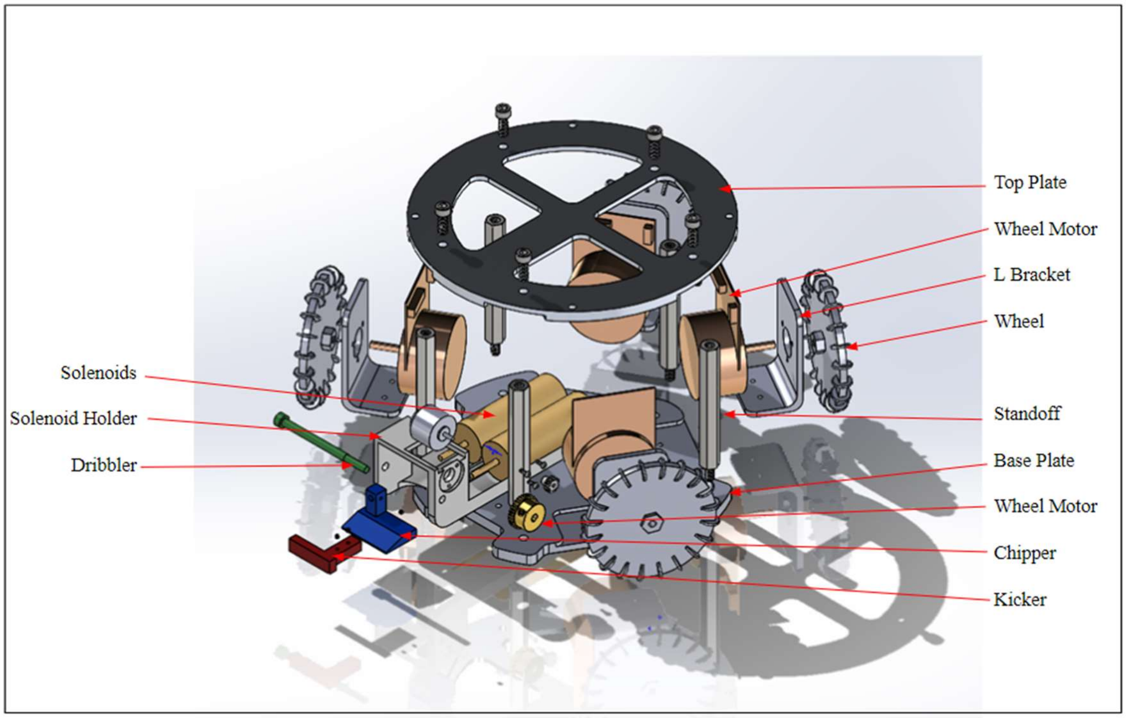

Figure 4. SolidWorks CAD Model Exploded View

2.3 – First Physical Prototype

The first physical prototype of the robot consists of a manufactured base plate, top plate, and four L Brackets with a hole pattern cut into them so they can hold the motors. This process ended up being far more laborious than initially expected as the CAM software that was used and the machines were much more difficult than originally thought. The first step in this process was of course learning that CAM software which was ESPRIT TNG. ESPRIT in essence is a program which allows you to take an stl file from any CAD software and make a code which tells the mills in Washburn shops how to cut said piece. Unfortunately, it is quite counter-intuitive and took much longer than expected to learn how to use it. After spending a couple weeks with the Washburn shop's staff, I was able to successfully make the necessary files to manufacture our parts of the robot. These files will be linked at the end of this report within the appendix. With these files made an NC code file was created and that is what has been used for the manufacturing.

With this file created it was now time to machine the parts. The first part to be manufactured was the base plate of the robot. The base plate was cut from a 7-inch x 7-inch piece of aluminum stock with a thickness of ¼ inch. Since the NC files made for this cut had a specific cutting path that traced the outside of the plate, I needed to use the Haas VM2 Mill. This machine worked similar to the Hass Mini Mills in Washburn shops however it was much newer and larger in size. To cut this part I had to drill the standoff hole pattern into the aluminum stock and then tap them with a 10-32 thread size so that it could be tightly fastened onto a base. This base was a much larger in size and thicker piece of aluminum where I drilled a matching hole pattern on its surface. Once the stock plate was fastened tightly to its base it was placed onto the bed of the VM2 Mill and tightened onto it. An important step was to tram the sides of the stock with a level so that I made sure the X and Y axes of the stock aligned with those of the machine.

The process of cutting the part was separated into multiple steps. First the NC file needed to be loaded onto the machine which involved placing it onto a flash drive which was inserted into the VM2 and then the 'Programs List' button was pressed. I then scrolled to the USB tab and chose my file name. Once it was loaded onto the machine, all three axes needed to be probed so that the machine knew exactly where to make the cut. By pressing the MDI command and then the 'Program/Conversions' button you were brought to a tab which had "tool commands" and "Probe Settings." By clicking the probe setting you could choose the commands for probing the X, Y, and Z axis. Once this is done you need to probe the tools you are using, which involves the previous step but rather than choosing the probe settings command you instead choose the tool commands and can then probe the tools within the machine. With everything set up the next step was to simulate the cut to make sure the machine could run it. This is as simple as clicking MEM, Setting Graph, Setting Graph, then START in that order. Once your simulation was finished, it was then time to cut the part. As shown below in Figure 5, is the first prototype of the base plate.

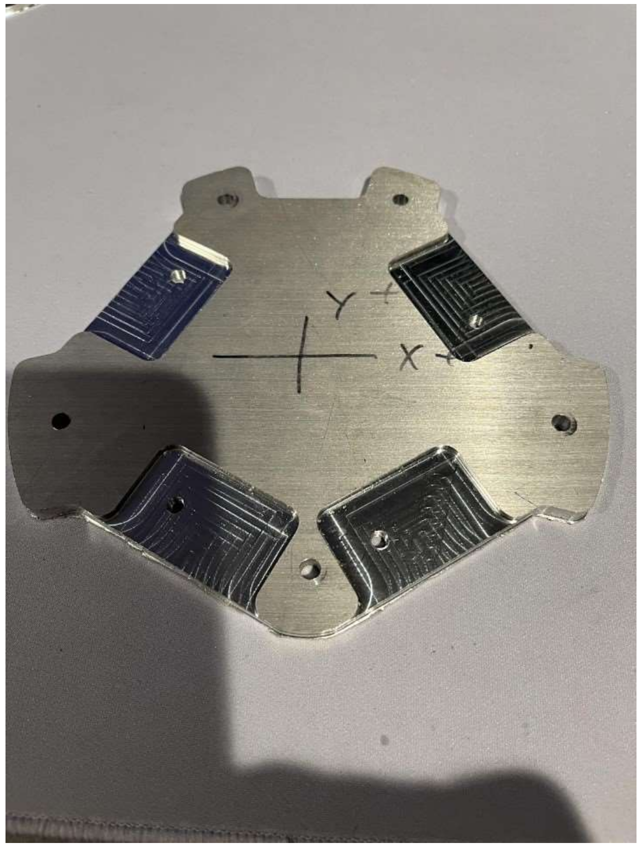

Figure 5. Base Plate First Prototype

Once this base plate was cut the same process needed to be repeated for the top plate. This was quite simple as the exact same steps were needed to be taken for the top plate. The only difference was the NC file which needed to be changed, but other than that everything else was identical. Below in Figure 6, the first top plate is shown. This cut was the quickest and easy to preform as the cutting file was straight forwards.

Figure 6. Top Plate First Prototype

Finally, the last step of the chassis was next. This was cutting the L Brackets so that they could be attached to the base plate and then motors could also be attached to the wheels as well. This was originally thought to be one of the easier parts of the chassis. Shown in Figure 7 is the assembled chassis with the L Brackets attached to the base plate. As you’ll notice the Motor mount holes have not yet been cut in this prototype.

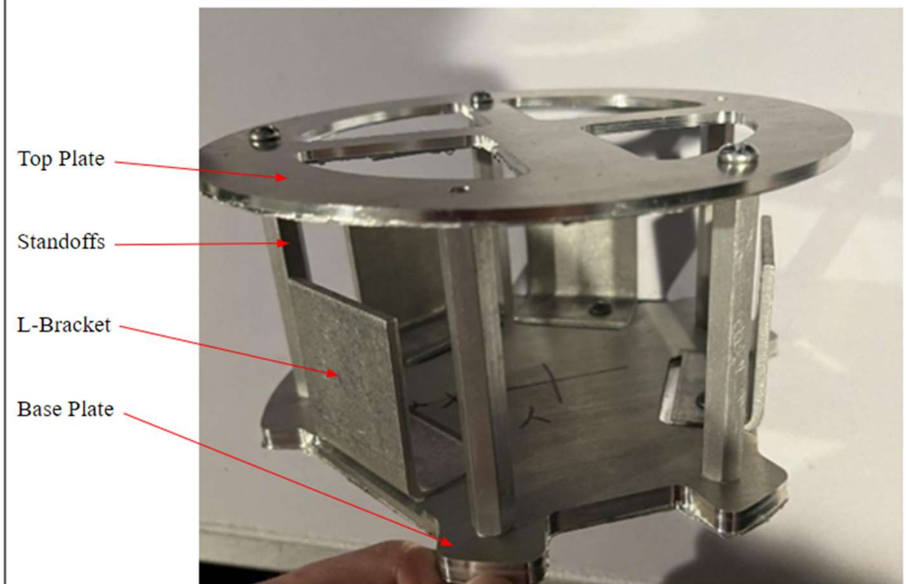

Figure 7. Chassis Prototype Without Motor Mount Holes

In Figure 7 it's clear to see the vision of what the chassis prototype should look like. Cutting the Motor mount holes changed the design and was a major cause of change between this prototype and the second. The reason for that change was because when the motor mount holes were cut, a drill press was used to make the holes. The thought process behind this was that we already had the drill bits in the correct sizes so why can't we just layout the pattern and drill them. Unfortunately, this was a mistake because the hole patterns did not come up successfully and were uneven and messy. This can be seen in Figure 8. The L Brackets were also accidentally bent while being clamped down to the bed of the drill press. With these mistakes decided I changed my mind and made a CAM file and NC code to cut the Brackets for the second prototype.

Figure 8. First Prototype L Brackets

With everything manufactured for the first time the first prototype of the robot was ready to be assembled. Once everything was placed together it was not the prettiest of products, but it performed in the primary function of being able to roll around as needed, which was a success for the first try.

2.4 – Second Physical Prototype

With the first prototype assembled, it was evident that many changes needed to be made to better the robot's chassis along with its performance. The smallest and first change was to make the tapped holes on the top plate through holes, so it was easier to attach the top plate to the standoffs. Once this was done more major changes needed to be made. The first of which was cleaning up the bottom plate. The first prototype of the bottom plate was much thicker than it needed to be. To remedy this, I manufactured another identical bottom plate and then planned the bottom surface with the mill to take of some of the material, giving us more clearance room. Another fix was also with the clearance of the robot. All the screws that attached any part of the chases together with the bottom plate protruded under the plate. To fix this I used a manual mill to surface these screws and make them flush with the baseplate.

With those fixes accomplished, the most major change of the L Brackets needed to be made. This was much simpler than expected as all I needed to do was make an NC file for the Hass Mini Mills in Washburn shops. This file told the machine to use two different tools to drill the hole pattern into the L brackets which we had pre purchased. By fastening them into a vise within the mill, all that needed to be done was to probe the Z and Y surfaces. The X surface was probed by using a different method called the x-min probe which would only probe one side of the bracket on the X axis. In Figure 9 you can see what these newly machined L Brackets look like which compared to the old one, are significantly cleaner and more precise.

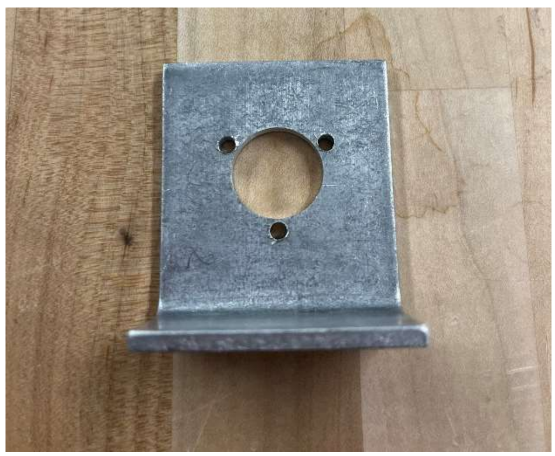

Figure 9. Mill Machined L Brackets

Once these changes were made, the newly manufactured second chassis prototype could be assembled. Show in Figure 10, you can see how the second prototype looked after being assembled. The changes are evident in how the new L brackets are significantly better than the first prototypes and are also much straighter.

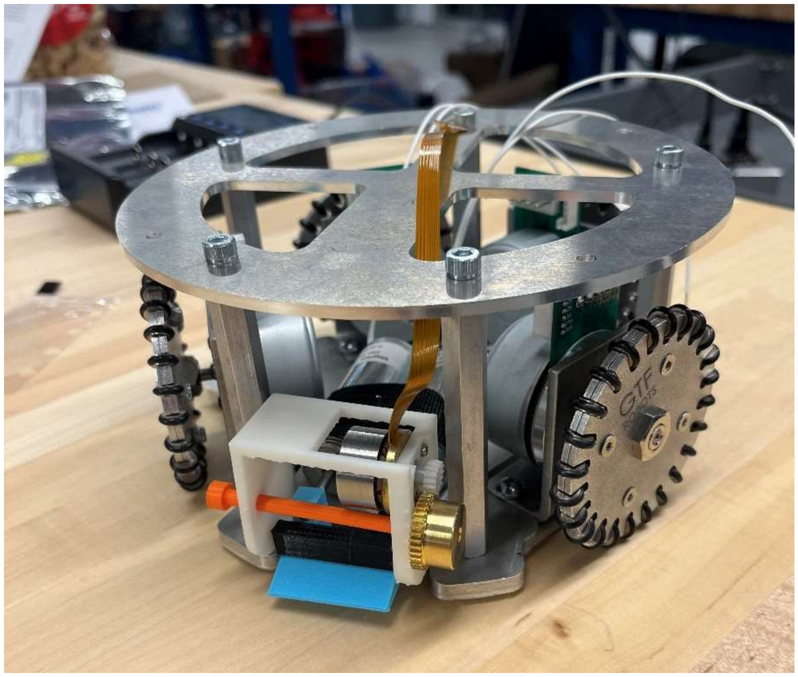

Figure 10. Second Physical Prototype

With the end of the third phase coming close I had been able to manufacture and assemble a robot which was handed over to the ECE sub-team for testing.

As a singular member of the Mechanical sub-team, I was responsible for one part of the robot and that was manufacturing its chassis and assembling what we had so that the other sub-teams were able to take over. Once passed over to these other sub-teams they would have the ability to test the robot and give us feedback on what needed to be changed and what could improve the performance of the robot. Unfortunately, I was unable to see the testing of the robot during my time on the project. To make up for this I did some static and dynamic analyses on the chassis plates to show that they were viable with the maximum stress that they could possibly encounter during actual testing. In this analysis the connection point holes on the plates are fixed and a weight of 40 kg was applied to the plates, gathering a minimum factor of safety (FOS) of around 3.1. Below in figures 11 and 12 you will see the static analysis on both the CAD designs for the top and bottom plates.

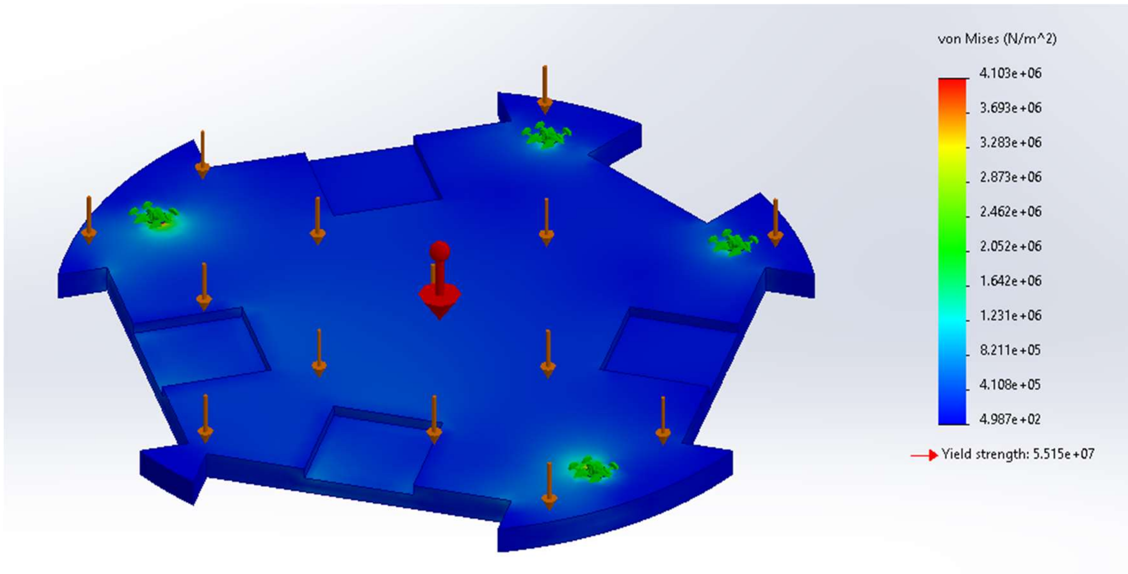

Figure 11. Static Analysis on Bottom Plate

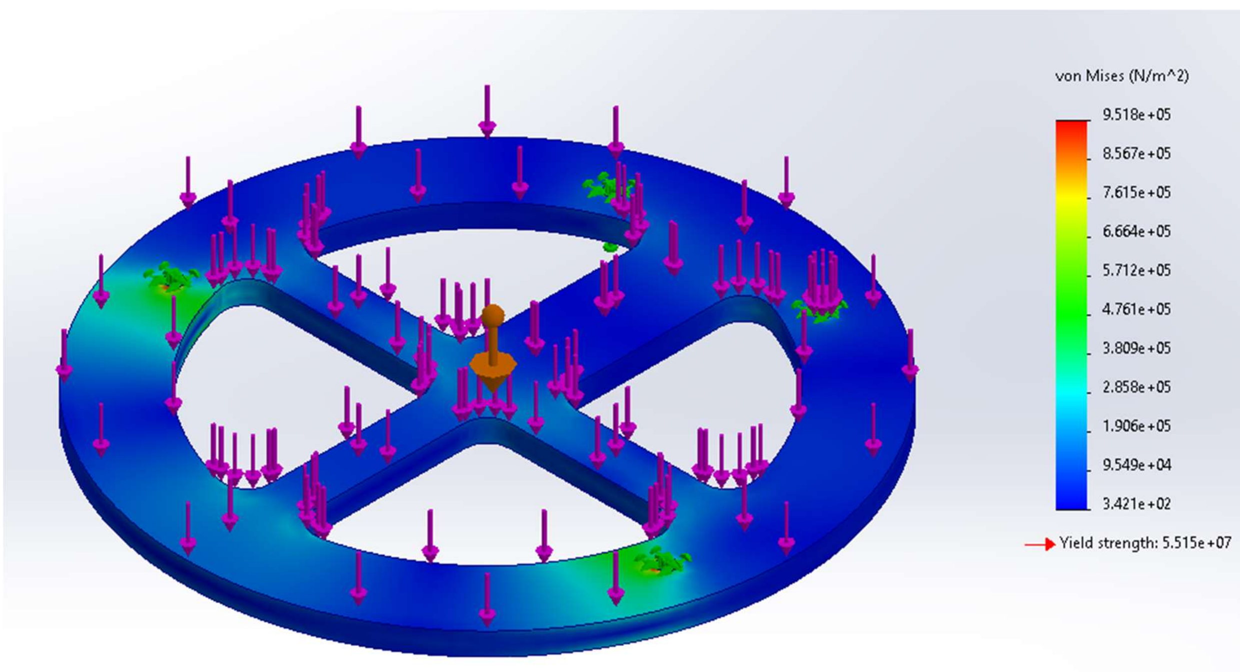

Figure 12. Static Analysis on Top Plate

While this analysis is theoretical it does prove that the top and bottom plates will be sufficient for this project. Using this I can assume that my designs will function properly when they are eventually tested by the other teams. I also did an impact analysis on the shell and wheels of the robot in the event of a collision with another robot. The parameters of the collision were with another robot that weighs 40 kg and at a max speed of 15 m/s. The shell of our robot is also fixed to all its degrees of freedom while the wheels are fixed to the L-brackets which are fixed to the base plate. In Figures 13 and 14 you can see the results of this simulation which result in a minimum Factor of Safety of 3.6.

15 m/s: 3.6 FOS

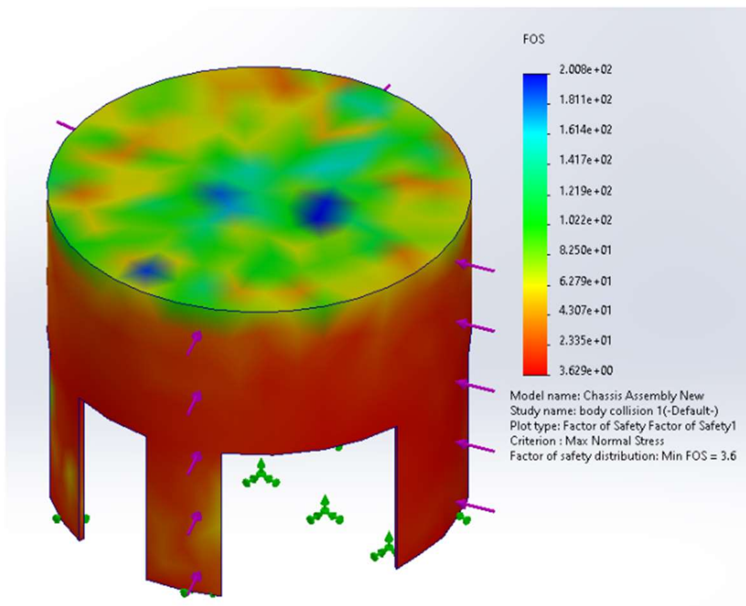

Figure 13. Shell 40 kg at 15 m/s Collision Analysis

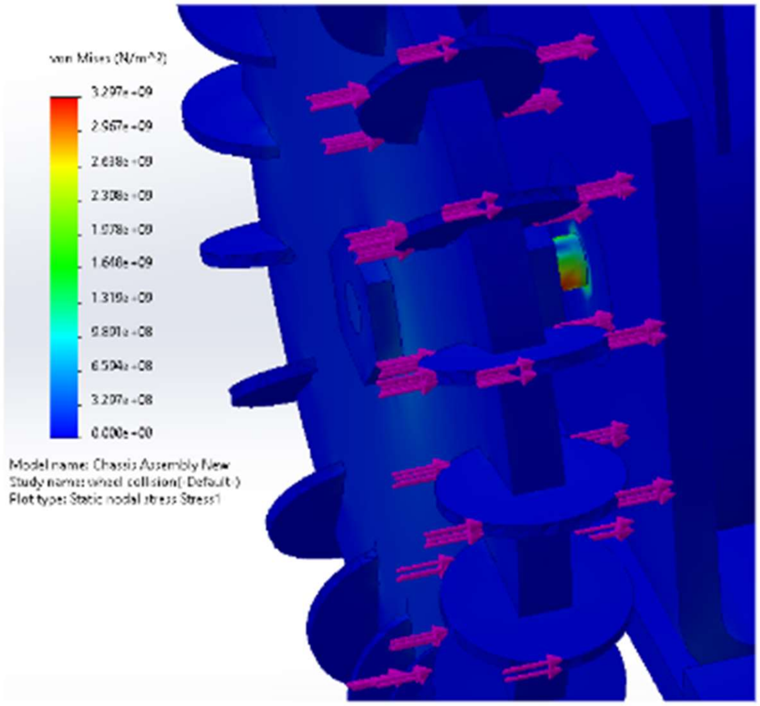

Figure 14. Wheel 40 kg at 6 m/s Collision Analysis

Chapter 3 – Discussion

This project was in its first year and was starting from complete scratch. There was no previous team working on this to create a base, we were that base that will be used in the future by other teams. This means that the work we did is important to future understanding and success. The hope is that what I did can allow future teams to focus on making improvements to my well-functioning chassis design. My work was centered around the physical aspect of the project and manufacturing the robot from our own design. This design is the first thing that future teams will look at. When looking at the original hope for the project this was clearly achieved. We made a theoretically functioning design for a robot that could compete in the Robocup competition.

Next are my physical results. This means the actual deliverable that came from the project which is two prototype robots that theoretically and manually function. By learning and manufacturing the physical systems of the robot, we have given future teams a physical prototype to work from. I personally think this is an extremely important delivery for the future of the project. After the first two phases, we got an actual look at what this should look like and a physical robot to make changes on, which will not be the case in the future. The next mechanical team for this MQP project won't have to spend most of their time creating a design from only TDP's and research and can instead look at our files and our prototypes and improve upon them.

When taking into account that we started with no base and our team consisted of only three members, I believe our final deliverable met our project objective. With the robots not needing to be different from each other in any way, if our performs exactly as we want it to then the rest of the team can be manufactured to join it.

When looking at our project over these past three terms it is hard not to compare ours to other teams' projects. Other teams like CM Dragons [3], SKUBA [4], and the Robojackets [5] have been working on their team for multiple years and had the time and resources to perfect their team. With their experience and previous robots, every year around this time they release a professional TDP and a functioning team with the only difference from previous years being improvements on the last team's robot. While our project is in its first year unlike these other teams, we still have made significant and impressive progress towards a WPI Robocup team. The hope is that in a couple years, by using our initial design, the WPI team can be improved upon and formed into one that can stand to be respected every year that it competes.

Finally, the limitations of this project must be talked about. The first being the need to learn and become comfortable which new engineering practices such as CAM software and machining. This problem could easily be addressed by members of the project taking a proactive approach and learning the basics of these processes before the project starts. As WPI students our group was prepared for a project of this caliber but came into it with enough knowledge on the subject to feel confident in having a deliverable at the end of the academic year. This knowledge was not what made for a slow start to our project as that could be attributed to the project being in its first year. Another limitation was our ability to manufacture. When looking at the best Robocup teams, you will see that they are unbelievably impressive and have complex designs. These designs have been thought about and improved upon for years to be the best that they possibly can. With that territory comes the need to have parts of their robot specially manufactured. Parts like the chassis, wheels and even the solenoids themselves are all custom made and not just purchased online. While WPI has the Washburn Shops machine lab which is well equipped with many machines and tools at our disposal, there is a limitation on what we can manufacture within these shops. Things such as custom wheels or specialized aluminum prints with complicated geometry are just not feasible on our campus. Unfortunately, we just don’t have the budget or time to make some of these parts even though they would be much more efficient and that is why the robot had to be very much simplified into a design that was feasible to manufacture with the constraints given. On the topic of the manufacturability limitation, another limitation was our budget. Many of these large and long-standing teams have a very large budget which they are able to spend on whatever they need for their robot team. Since we did not have this we changed our robot for these constraints which actually resulted in many pros being added. Some of these pros included are the ease of manufacturing and time. Our design takes very little time to manufacture and is quite a simple process, this was a massive pro for our team as time was our final major constraint. We had three terms from start to end of our project, so we had to make the most of it. Most teams within the robocup have had years of experience and time to work on their team, instead we only had a limited amount of time to get the most done. This limitation was unavoidable, but we made sure to account for it throughout the project.

With these limitations in place, we found a way to work around them as a team and change our project objectives to fir these limitations. Things like not manufacturing wheels or standoffs and only delivering one robot instead of a full team made the limitations not as daunting as they originally were. This along with our database of TDP's made up for any constraints that were placed on the project.

Chapter 4 – Conclusions and Recommendations

In conclusion our team was able to research, design, and manufacture a theoretically and manually working robot for a Robocup Small Sized Soccer team. Personally, I was able to help design and spearhead the manufacturing of two prototypes of our robot. Over multiple weeks we were able to create a physical and non-physical base for the future of the project. With CAD files and written research, the future teams will be able to bypass the difficulty of a lack of knowledge on the project topic and with two physical prototypes in which they can pull apart and improve upon from the beginning of their projects start.

From this project many lessons were learned by all members of our team, me especially. Coming into this project I knew very little about the actual mechanical design process and knew absolutely nothing about the manufacturing process. Over these past three academic terms, I worked with the team and learned what the design process means and what it takes to work on a project of this caliber. I learned even more about the manufacturing process as I spent countless hours within WPI's Washburn Shops. From these relentless hours I am lucky to say that I am now proficient in the use of ESPRIT CAM software along with a very extensive knowledge of how to use a Hass Mini Mill and Haas VM2 Mill. Along with these lessons I also learned many lessons on the front of working as a team. While I had worked in teams at WPI before, I had never experienced team work on a scale like this. Over the past three academic terms, I learned how to delegate work between members of the team and communicate what needs to get done and how to get it done within a short time frame.

Finally, my work on this project would never have gotten as far as it did without the preparations, I made through my four years here at WPI. While I am not a Robotics Engineering major but instead a Mechanical Engineer, many classes, and projects I worked as a part of at my time at WPI helped me achieve what I was able to. Classes like Intro to Computer Aided Design were obviously important for the completion of this project but other classes like Advanced Engineering Design taught me the basics I would need when taking on a project of this caliber. My time here taught me how to work with others and solve complex problems instead of giving up on them. My IQP (Interactive Qualifying Project) was, in my opinion, the most important class to my success here at WPI. By working on a large-scale project that took multiple weeks to complete, I learned how to prepare and work through difficult problems all while effectively communicating everything that was happening.

Chapter 5 – Broader Impacts

5.1 – Engineering Ethics

The mechanical engineering code of ethics, in essence, implores engineers to use their knowledge for the betterment of others and society. Along with this, honesty in their work and to be impartial as well. During this project I followed the engineering code of ethics during the entirety of its duration. While the base of our project required us to study and implement aspects of other teams' robots, no single part of our robot is a copied part from another team. While certain ideas and design were used in the design phase, all the work is original and reflects me and the team's own design process. Finally, this project in no way proposes any ethical or moral problems to come forth in the future. This project is solely for the advancement of human soccer robotic technology and for the growth of robotics knowledge within a group of people, that being those on the teams which strive to compete in the Robocup.

5.2 – Societal and Global Impacts

This project has very little to no societal or global impact on a large scale. This project centers around making a team of six soccer robots that compete in the Robocup competition against other teams of robots. Any lasting effect of society or a global scale will be centered around those competing individuals along with the knowledge on soccer playing robots. Those who are a part of the WPI small sized soccer robots MQP will be affected as they are now entered into the world of Robocup. They will gain the knowledge and desire to improve the WPI team's robot which will in turn affect the students who will follow in their footsteps in the future. The societal impact is on those who wish to join this team in the future, giving them a project that will never be fully finished as there are always improvements. Those improvements cause those in the future to continue the work. The global impact would be on the Robocup community along with the knowledge of soccer playing robots. This project's work will eventually make its way to the Robocup league in the future and compete against other teams. Adding another competing team will force other teams to improve their robots thus furthering the knowledge of small sized soccer robots. Along with this it will inspire connections made and collaboration across the globe as players share their goals and knowledge with each other.

5.3 – Environmental Impact

When working on any engineering project, no matter the size, it is crucial to look at the environmental effect said project will have. Our small sized soccer robot project won't have any major environmental impact but may have an effect on the small scale. Factors such as a large amount of energy consumption from manufacturing to the need to raw materials made of steel and other metals could have an effect on the environment. In short, this project isn't affecting environmental health firsthand but instead is adding to the demand of products which in mass quantities hurt the environment in how they are gathered. This coupled with the energy usage from multiple uses of large mills and other machines adds to the effect. Personally, I don't see this as an immediate problem for the project as the lack of major long-term effects on the environment outweigh the few small-scale effects we may have.

5.4 – Economic Factors

Economic factors are another very important aspect to consider while working on any engineering project. The easiest thing to look at is the cost of the project. Of course, the project will have some sort of cost throughout its course but moving forwards there are other more important factors to think about in terms of economic factors. The main thing to think about for this project is the effect on the market this project has. As a team we use lots of raw materials in its construction which overall affects the need for these materials in the market which can influence the price. Another thing is the heavy use of electronics. Over the course of this project, we had to either purchase or have a large amount of electronics donated to us which could affect the cost of these in the market for other teams. Finally, we asked for many sponsorships from large companies or groups which circulate money into our team to be used. While these effects are clear, I don't see any major economic factors coming from our project.

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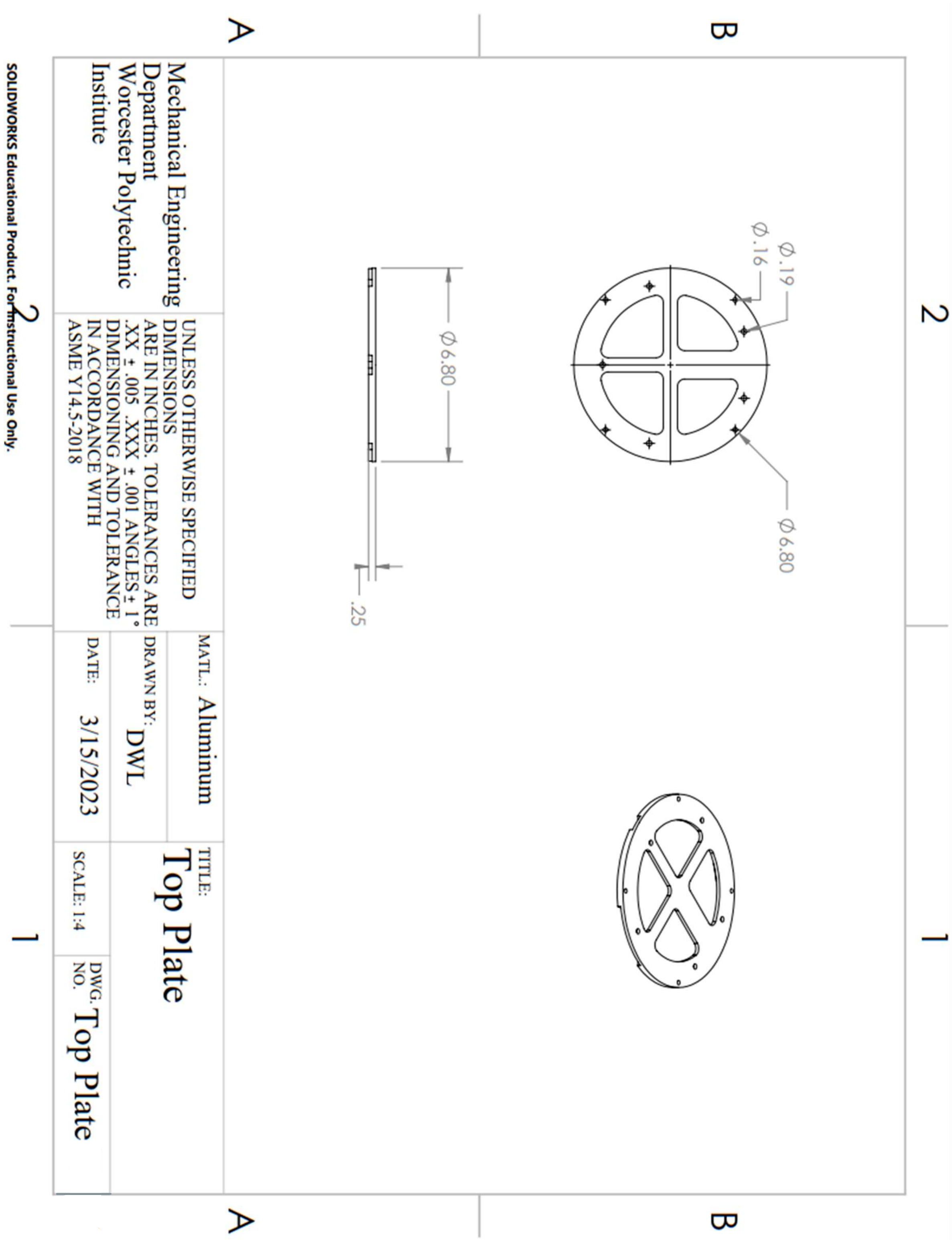
Appendix A: CAM Files

Small Sized Soccer Robots CAM Files

Appendix B CAD Drawings



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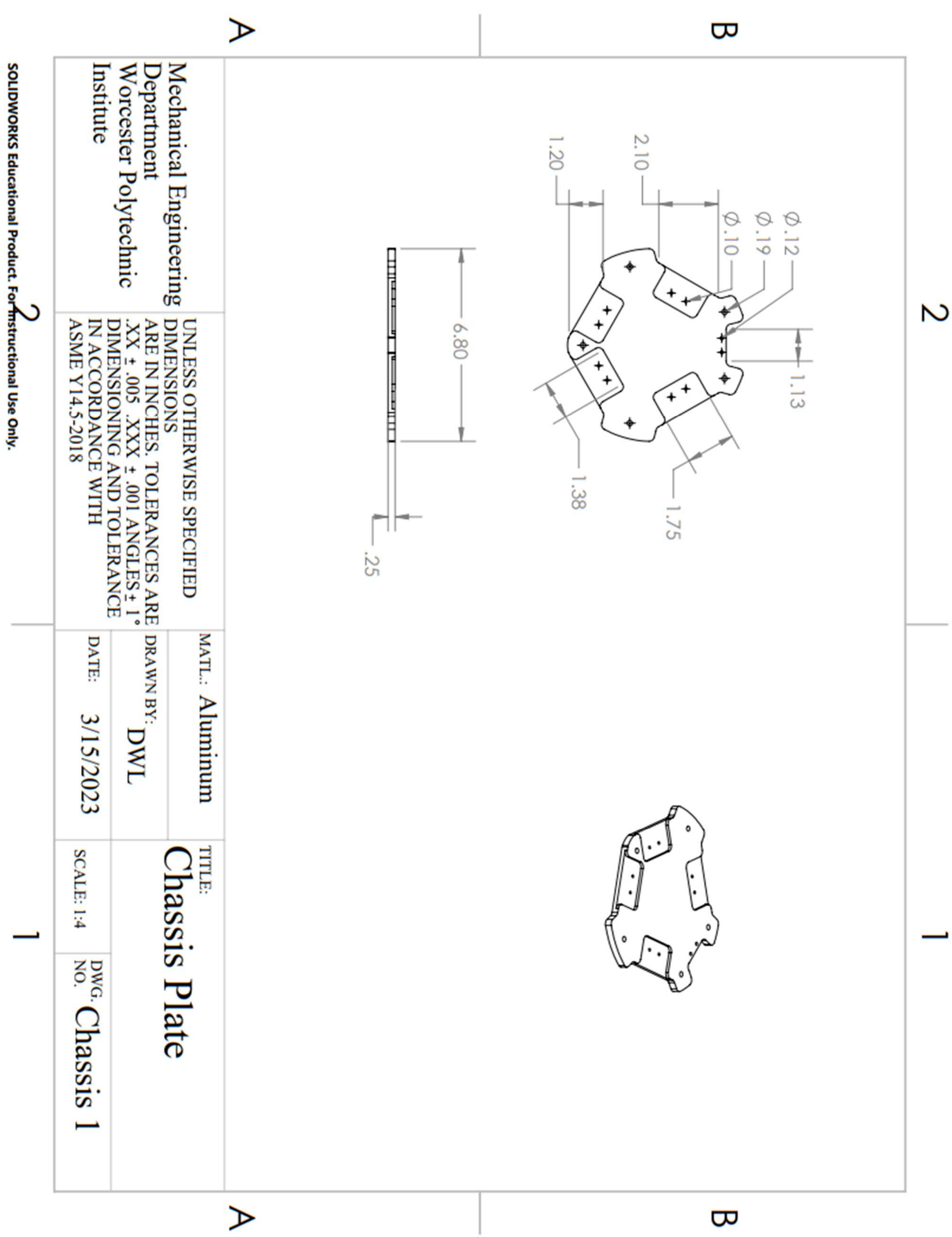

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Mechanical Engineering Department Worcester Polytechnic Institute
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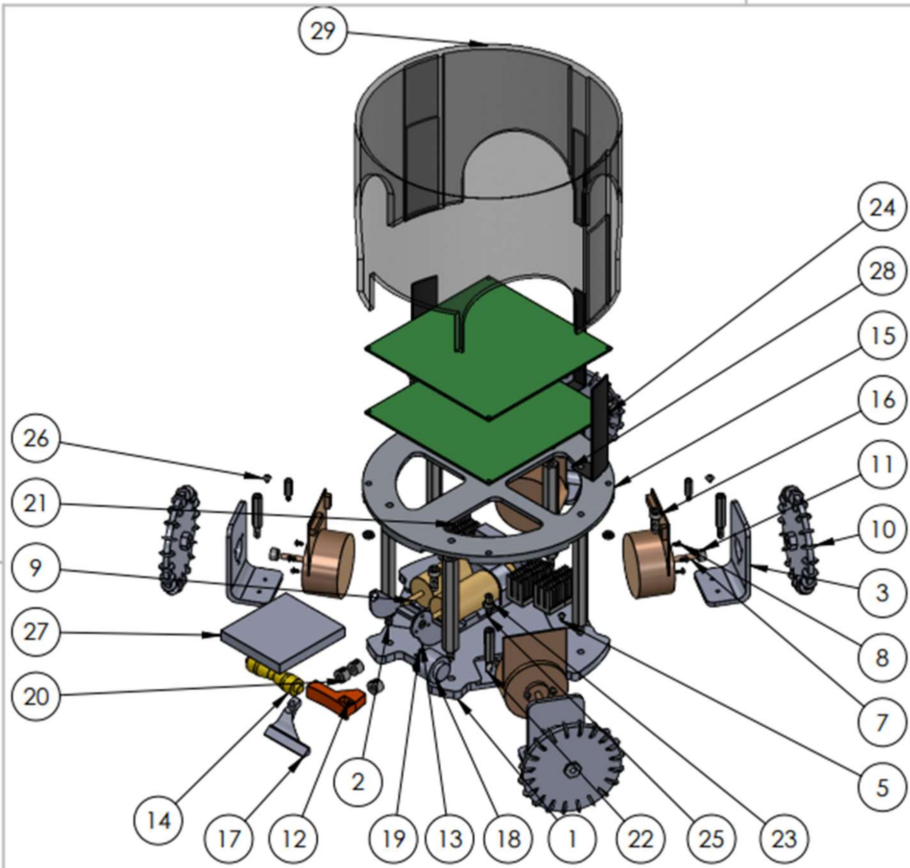

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5	92095A460	Button Head Hex Drive Screw	8
6	90710A025	18-8 Stainless Steel Thin Hex Nut	8
7	motor mockup		4
8	92095A456	Button Head Hex Drive Screw	12
9	Solenoid		2
10	omniwheel v2.0		4
11	6056N12	Carbon Steel Set Screw Collar	4
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13	ball control housing v2.0		1
14	roller v2.0		1
15	top plate v2.0		1
16	90128A942	Zinc-Plated Alloy Steel Socket Head Screw	5
17	chipper v3.0		1
18	dribbler motor mockup		1
19	92095A452	Button Head Hex Drive Screw	3
20	6432K17	Set Screw Shaft Collar	3
21	8822T913	Adhesive-Mount Heat Sink	8
22	91407A104	18-8 Stainless Steel Male-Female Hex Thread Adapter	4
23	90695A035	Steel Thin Hex Nut	4
24	PCB		2
25	98952A110	Aluminum Male-Female Threaded Hex Standoff	4
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28	shell brackets v3.0		1
29	shell cover v3.0		1

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