# Skunk Works Robotics Team 1983: Robot Design Documentation

2016 Design and Build Team

April 1, 2016

**Abstract**

Skunk Works Robotics Team 1983 is a part of the FIRST community that inspires and challenges young minds to have the hardest fun they will ever have though a fast paced and intense six weeks of robot building. In addition to design challenges we have struggled with scheduling and allotting sufficient time for the different parts of the robot to get done. This season, we used a scheduling tool, Gantt Project. It is a visual representation that concretely gives deadlines and helps predict future work and integration needed. We have a student who is responsible to make, change, and assure of the execution of the schedule. In addition to this we are doing more to document the decisions we made, lessons we learned, and success we had through the build season. This document describes the steps we took from kick off to our first competition of the year to build the robot so that others, as well as ourselves, might learn from the mistakes we made and reflect on the work we have done and how to make it better.

Designing the robot was a great challenge this year because we strove to be able to drive under the low bar while having a low and high shooter, ball collector, and climber. All of the components and necessary electrical elements to make a functional robot required many longs nights working on Autodesk Inventor and in the shop. One of the largest problems that we had was that whenever we realized how tight the the time schedule was we tried to assemble parts of the robot, but did so incorrectly.

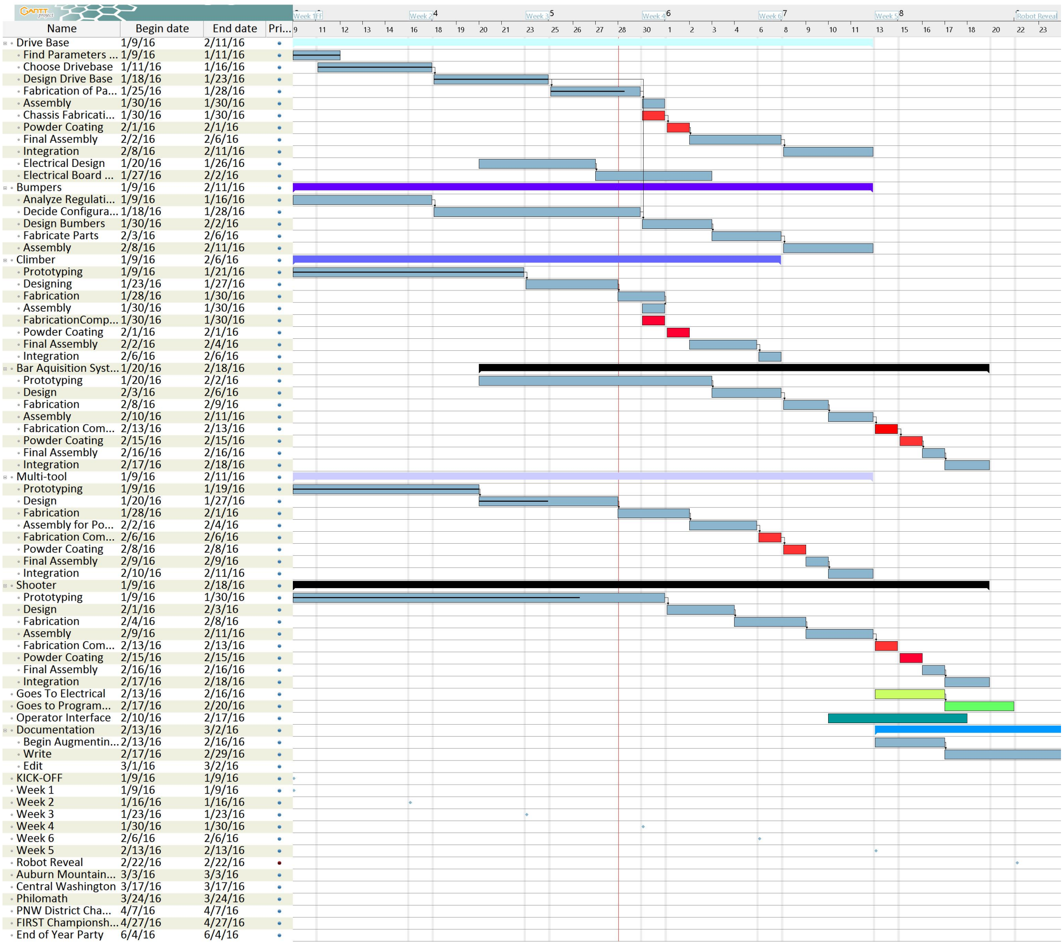
## 1 Introduction

January 9, 2016, all teams across the world found out that with Stronghold, FIRST had created not only a complex game with many components, but also a game that favors a certain type of robot. The many defensive outerworks that required a strong and robust drive base and the fourteen-inch low bar greatly affected the end design of our robot. Including collecting, shooting, and climbing mechanisms our robot fits under the low bar and has a low center of gravity. We decided to go for this concept because, of the all of the defenses, the low bar is consistent, simple, and quick to go through. The low center of gravity will help our robot stay stable while going over the rock wall, ramparts, rough terrain, and the moat. To make sure that our drive base would not encounter problems going through the different outerworks we used Autodesk Inventor to create simple drawings that would help us see problems that we

could encounter because of our wheel size or spacing. After prototyping the different mechanisms that we wanted on our robot we we used Inventor to flush out the geometry of the mechanisms. However, this happened at different times for different mechanisms. The collector and climbing mechanisms were the first after the drive base to have designs fully done and powder coated. This happened because above everything else we wanted to make sure that we would be able to collect, shoot in the low goal, and also climb at the end of the match. The shooter mechanism was one that we could continue to prototype and change through the later weeks of the build season because we would make it so that it could fit into the robot with the given geometry the climber and collector already had. We coordinated this by using Gantt Project to have a visual of the schedule. To ensure that we follow the schedule and deliver the robot to the electrical and programming teams on time we had a student responsible for maintaining and regulating the schedule. With the help of the schedule, design skills of the members on our team, and long hours we designed our robot.

# 2 Schedule

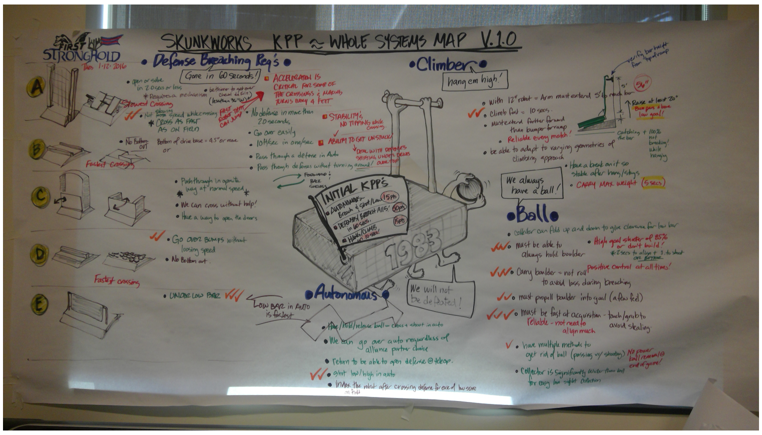
## 2.1 Gantt Project




Gantt Project is a free scheduling and management tool that is an alternative to Microsoft Project for smaller projects. It's a powerful tool that is easily modifiable and very visual. It relates different tasks to create a linear structure of the processes the system has to go under to go from an idea to a mechanism on the robot. Last year we tried to use Excel to track our progress. However, this year we wanted to make sure that we had a visual that is intuitive and easily modifiable. Gantt Project has many capabilities like creating interdependencies to change the dates of a task to follow the schedule of another system the task is dependent on. In addition it relates people to specific tasks and also relates their contact information to provide a central location for information that is easily and quickly available. Our team has just started using this application this year and have only begun to uncover the potential it has to help us manage our resources and work that we need to do. In the following years we hope to develop our skills and continue to use Gantt Project to keep ourselves on track and on schedule.

### 2.2 Prototyping

At the beginning of all build seasons there is a surge of creativity that we use to create and envision our robot. To make sure that we consolidate our team's ideas we have a meeting involving all members of the team to come up with what our team finds to be the most important for a robot to have and also ways that a robot would be able to address those criteria. One of our amazing mentors draws up sketches of our ideas on to a poster so that we can consolidate what our teams finds to be important for the robot to have and do.




After discussing ideas we choose a few mechanisms or concepts to pursue and prototype to prove that it could work in real life. The level of detail for these prototypes are different, the more unsure we are about the idea, the more concrete the prototype has to be. For example, our drive base had prototyping done quickly because we need a base to build up from to have set dimensions to make the other parts of our robot. Systems like the shooter and collector system become more complicated because they had some serious geometry to figure out before they could go into the designing stages. This did end up making the shooter systems take much longer and also need many more iterations than any other part of the robot.

Good prototyping is essential for good robot design and building because it sets the foundation of a specific design and reveals physical challenges with the design earlier on.

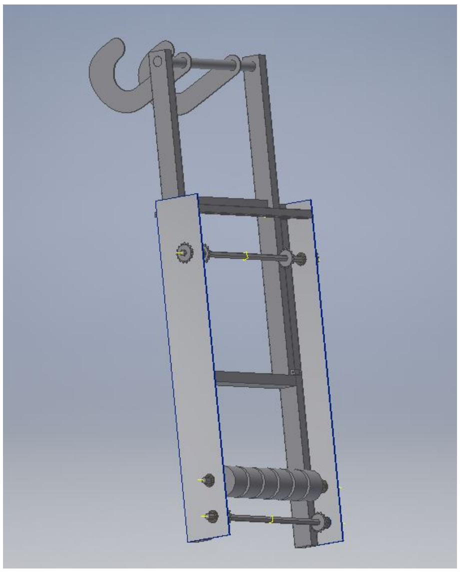
#### 2.2.1 Climber

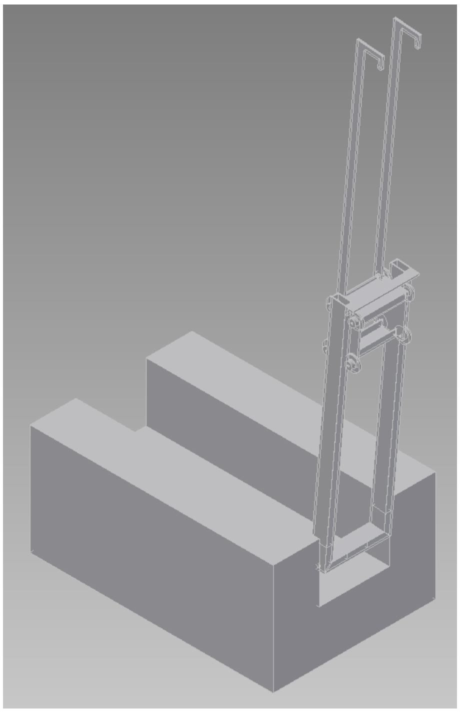
When prototyping the climber, a number of ideas were taken into consideration. The major ideas presented were a telescoping arm, a grappling hook mechanism that would be a hook attached to a rope and shot, and an arm actuated by a spring. The climber that was decided upon utilizes a folding arm to reach the tower bar as well as a latching hook to clasp the bar and hoist the robot up. This was decided as the best option due to the reliability and high integrity of the design, as shown through the decision making matrix shown below. Since the arm also has the potential to fold it is useful due to the size constraints of the robot. The grappling hook did not seem as accurate because the programming would have to alter every game if it got damaged in any way, but the main reason

why it wasn't chosen was because our team has never used a grappling hook. Another design that was not chosen was the spring design was too complex, could only be used once per game, and was a safety concern. The reason the spring design was a safety concern because one of the designs relied upon a small pin to be attached, and if the pin fell loose it could harm people by releasing unintentionally. However, one of the last design that was considered, an elevator, had lots of benefits including that our team has made an elevator before and the design would be sturdy. Therefore, the latching hook was seen as the quickest and simplest option, along with the

| Category | Elevator Design 1 | Elevator Design 2 | Four-Bar Linkage | Telescoping Arm |
|---|---|---|---|---|
| Weight | 3 | 3 | 2 | 2 |
| Complexity (of design) | 3 | 3 | 2 | 2 |
| Speed (lifting robot) | 2 | 2 | 3 | 3 |
| Prep time (setting up for climb) | 3 | 3 | 2 | 3 |
| knowledge of design | 1 | 1 | 2 | 3 |
| Build time | 3 | 3 | 2 | 2 |
| 3 robots | 3 | 3 | 2 | 2 |
| Reliability | 3 | 3 | 2 | 3 |
| Compactness | 3 | 3 | 2 | 2 |
| Scores | 24 | 24 | 19 | 22 |

The design that was chosen to be prototyping was the elevator. There were two variations of one design that were pursued in prototyping the elevator mechanism. The design used constant force springs as stored energy to grab onto the bar fast in the final seconds of the match. There were two stages to the elevator: one had the hooks attached to it and the other had the springs. It would have been able to hoist up after the buzzer because of the constant force springs, but this type of design has to use a large portion of the weight from the robot. It would take up a lot of space in the robot as well as possibly taking a long time to deploy. Although the elevator design proved to be reliable, other factors like complexity took it out of the robot design. The design that was chosen was actually a four bar linkage arm.



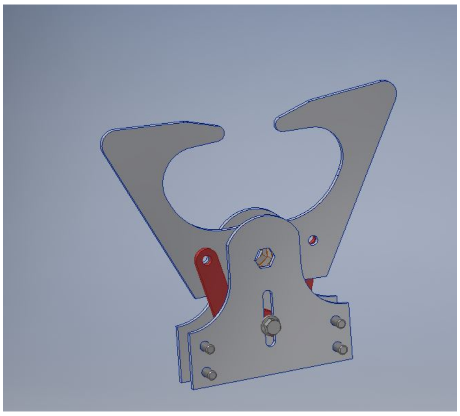


### 2.2.2 Hook

We first started to think of a bunch of different ideas for a claw before continuing the design of any. We made a list under each of the ideas whether it could be adapted to come from the underneath, the side, or the top of the bar. At first we were thinking that coming up on the side of the wall was a better option, but then we realized that due to the design of the climber it would be more challenging to make that work and not necessarily more accurate. From there

we chose two designs to proceed with and continue to investigate before the actual design process: the "broken heart" and the "under biter." After exploring both of these we came up with other ideas that we wanted to investigate further as well. These were the "pen clicker," the "venus-bar trap," and the "croc."

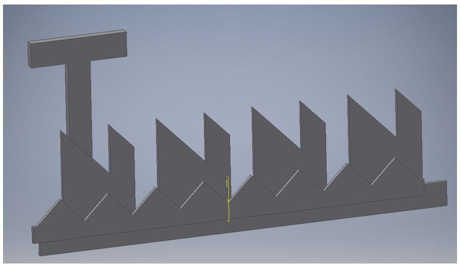
The "broken heart" (seen below) is a self-locking hook that opens symmetrically when pushed onto the bar and automatically returns to its original position. When force is applied to the overlapping teeth on either half of the hook, the halves are pushed past the center line, locking the hook onto the bar. This idea uses the bar as an actuator to secure itself closed, while the triangle wedges allow for the least force to open them. They also curve back into themselves and use the weight of the robot to pull itself up.



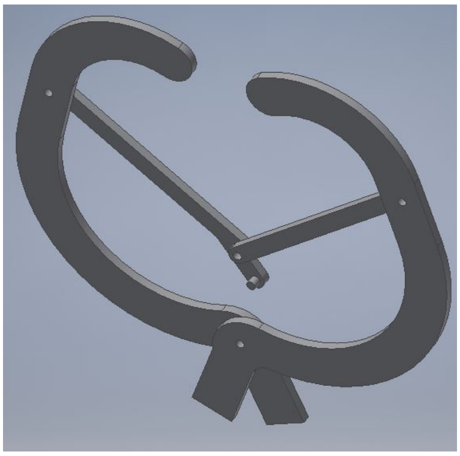
The "under biter" (seen below), despite its name, grabs over the top of the bar. It has a candy cane-like shape that is able to grab over the bar. Soon after the bottom piece swings up, being actuated by a string that pulls it up. There are two of the candy canes sandwiching a spacer that allows for equal spacing. The bottom piece rides on a pivot in the candy canes as well. This design could not be modified to be anything else but a hook that grabs over the bar, not to the side or under.

The "pen click" (seen below) allows for the bar to be used to our advantage in order to secure the robot. It used the bar to automatically attach without

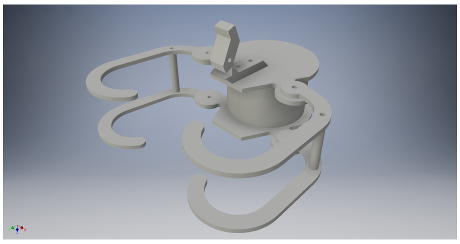
using motors or pneumatics to actuate it. We were originally drawn to this idea because of it's ability to latch by just a push against the bar like a pen, but we realized that this action was far too complicated to be designed and manufactured in our limited amount of time. The clicking mechanism would also not be as reliable as our other designs.



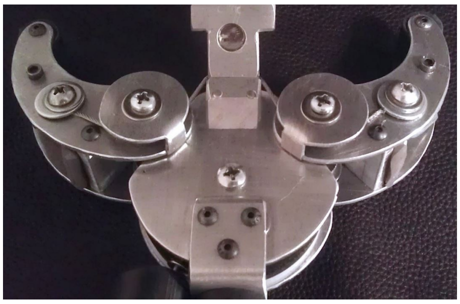
The "croc" (seen below) starts opened when trying to attach to the bar and it uses the braces that are attached on the inside to close the hooks. In the open position the braces are bent upward towards the opening with a pin to not allow them to over extend. When the hooks are closed the bar is passively kept inside by the weight of the robot.



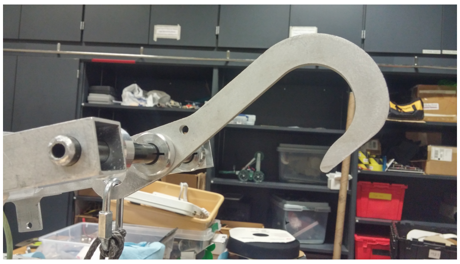
The "venus-bar trap" (seen below) is based of a grappling hook that was found online. It has two hooks that are held open through tension between strings. The tension is kept with a breakaway piece in the middle, and when the string tension is released there is a piece of elastic that is kept around the central drum to close the hooks. The struggle with this design is the breakaway piece combined with elastic. The worry is the elastic would get stretched out easily and have to be replaced constantly. The breakaway piece could be easily tampered with while kept in storage during the match, which would lead to unreliability.



The picture below is where the inspiration of this design came from. Since the part was very expensive to buy, we began looking up pictures of it and modifying their design to meet our necessities.



We ended up choosing a design very close to our original in the sense that it was basically a candy cane shape again. We went through the design process as you can see with a complex idea at first and then stripping it of unnecessary stages. Thus, the design became simpler and simpler until we finally ended with a simplistic and basic design that did not need to fully encompass the bar and close. We decided to exclude these attributes when refining because we found them unnecessarily complex for something that would be precariously placed on the end of a fast moving four bar linkage (see climber section under Design). The picture below is the final and most simple design to date.

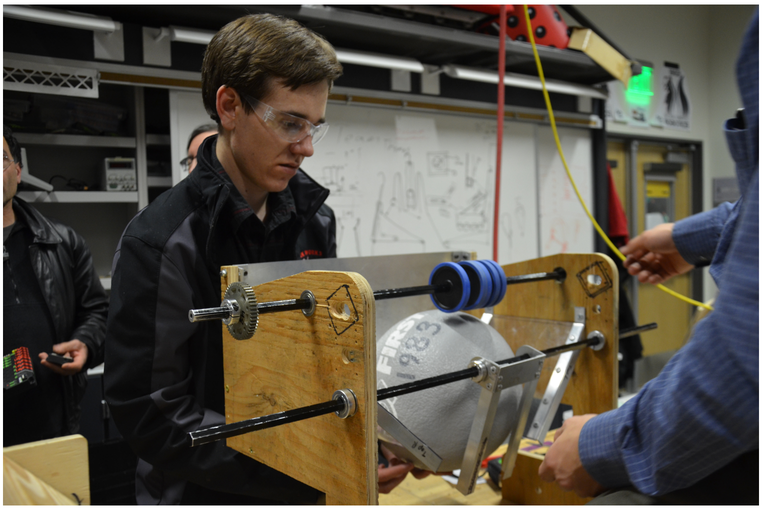


#### 2.2.3 Shooter Systems

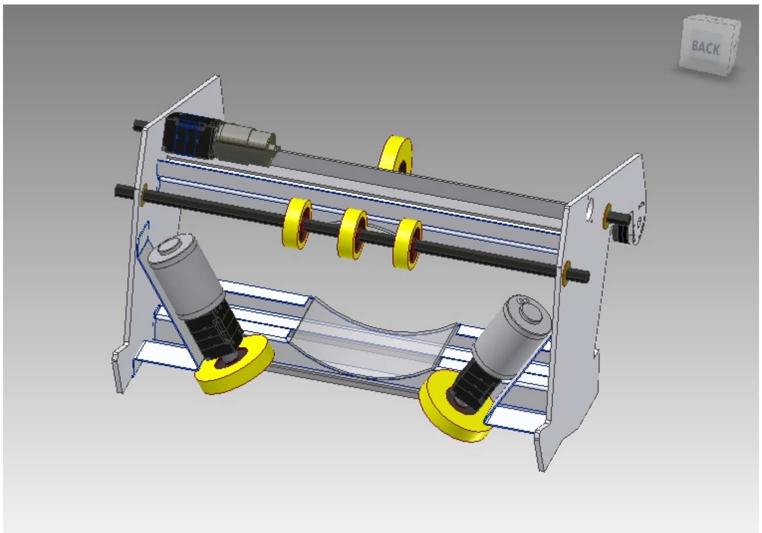
When we began prototyping the shooter there were many ideas we wanted to test out. However, we only chose two to completely follow through with making. We continued to follow through with two of the prototypes for a longer amount of time than the week set aside for prototyping. There was an idea of a catapult, but we decided that it would not be precise enough for such a small scoring area. The other prototypes were fly wheel shooters.

**Shooter 1**

This prototype used the fly wheel shooter method to shoot the ball. It was a design using a turning hex shaft to collect the ball onto a ramp and throw it the other way out. This method eventually turned out to be one of our final choices as a shooter design, but it required many changes after the prototyping phase.



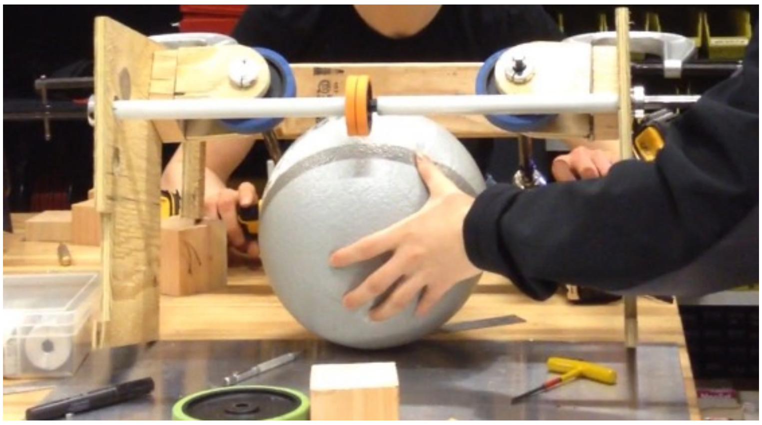
Our first idea was to collect the ball with a 3 7/8 inch wheel at the top into a piece of polycarbonate and metal attached together. The ball would be collected into the curved piece of polycarbonate by the wheel on the axle, then the whole collector would rotate backwards to shoot.




A different design that fixed the faults of the first design was collecting with two wheels on the ends of an axle and adding three 2 3/8 inch wheels at the top axle to collect and shoot. We had replaced one 3 7/8 inch wheel with three smaller ones because we wanted more thrust, and after some prototyping we came to a conclusion that less compression dispersed over a larger area provided more thrust. In addition, the first axle would be placed diagonally below the second axle so that it could collect then secure the ball between the two axles. Finally, having two wheels at the sides provided more thrust than one wheel at the top.

### Shooter 2

After the first few initial prototyping ideas, we also began working with a shooter with two horizontal wheels that collected and shot the ball.



To see which wheel size would be best, we constructed a shooting apparatus mounted to a stool with which we could easily test which diameter would allow for the fastest and longest shot. We first oriented the shooter so that the ball was 19.5 in. above the ground and shooting straight forward. We then shot it ten times per iteration and collected data on how far it went. In order to take

that data and determine the velocity, we had to first calculate the amount of time it took the ball to reach the ground, or $t$. We used the following equation for the height of the ball, or $y$, set the initial vertical velocity to 0, and, through algebraic manipulation, solved for $t$. The constant for the acceleration of gravity was represented by $g$, and the variable for initial height was represented by $h$.

$$y = \frac{1}{2}gt^2 + 0t + h$$

$$t = \sqrt{\frac{h * 2}{g}}$$

To calculate the velocity ($v$) of the shot, $t$ was inserted into the following equation, where $d$ represents the distance:

$$v = \frac{d}{t}$$

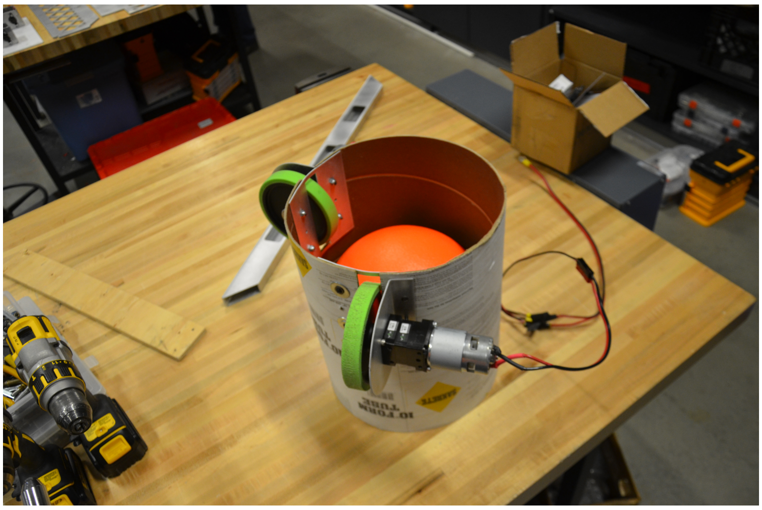
Using this process, we gathered the following results:

| Wheel Diameter (in) | Compressed to (in) | Distance shot (m) | Time to Ground (sec) | Velocity (m/sec) |
|---|---|---|---|---|
| 4 | 8 | 1.9 | 0.32 | 5.9 |
| | | 2.1 | 0.32 | 6.7 |
| | | 2.1 | 0.32 | 6.7 |
| | | 2.1 | 0.32 | 6.7 |
| | | 2.1 | 0.32 | 6.7 |
| | | 2.1 | 0.32 | 6.5 |
| | | 2.2 | 0.32 | 6.8 |
| | | 2.2 | 0.32 | 7.0 |
| | | 2.4 | 0.32 | 7.7 |
| | | 2.1 | 0.32 | 6.7 |
| Wheel Diameter (in) | Compression to (in) | Distance shot (m) | Time to Ground (sec) | Velocity (m/sec) |
| 5 | 7 | 2.3 | 0.32 | 7.3 |
| | | 2.4 | 0.32 | 7.4 |
| | | 2.57 | 0.32 | 8.1 |
| | | 2.59 | 0.32 | 8.1 |
| | | 2.69 | 0.32 | 8.5 |
| | | 2.72 | 0.32 | 8.5 |
| | | 2.74 | 0.32 | 8.6 |
| | | 2.82 | 0.32 | 8.9 |
| | | 2.84 | 0.32 | 8.9 |
| | | 2.77 | 0.32 | 8.7 |
| | | 2.64 | 0.32 | 8.3 |
| Wheel Diameter (in) | Compression to (in) | Distance shot (m) | Time to Ground (sec) | Velocity (m/sec) |
| 6 | 6 | 3.5 | 0.32 | 10.9 |
| | | 3.6 | 0.32 | 11.2 |
| | | 3.56 | 0.32 | 11.2 |
| | | 3.68 | 0.32 | 11.6 |
| | | 3.71 | 0.32 | 11.7 |
| | | 3.76 | 0.32 | 11.8 |
| | | 3.81 | 0.32 | 12.0 |
| | | 3.89 | 0.32 | 12.2 |
| | | 4.06 | 0.32 | 12.8 |
| | | 4.19 | 0.32 | 13.2 |
| | | 3.77 | 0.32 | 11.9 |
| Wheel Diameter (in) | Compression to (in) | Distance shot (m) | Time to Ground (sec) | Velocity (m/sec) |
| 4 | 6 | 1.8 | 0.32 | 5.6 |
| | | 1.9 | 0.32 | 5.8 |
| | | 1.88 | 0.32 | 5.9 |
| | | 1.88 | 0.32 | 5.9 |
| | | 1.91 | 0.32 | 6.0 |
| | | 1.93 | 0.32 | 6.1 |
| | | 1.93 | 0.32 | 6.1 |
| | | 1.96 | 0.32 | 6.2 |
| | | 1.98 | 0.32 | 6.2 |
| | | 1.98 | 0.32 | 6.2 |
| | | 1.91 | 0.32 | 6.0 |

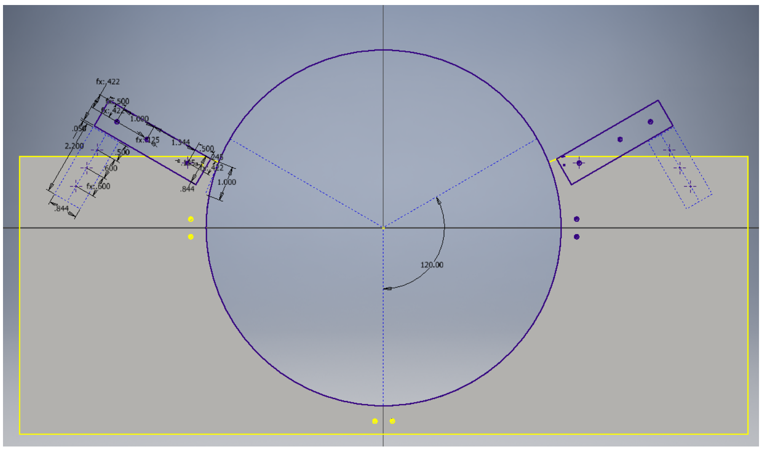
As can be seen, as the wheel size increased the velocity increased; at a 4 in. diameter we had a velocity of 6.7 m/s, at 5 in. 8.3 m/s, and at 6 in. 11.9 m/s. However, we were not sure whether it was the greater speed of the of the wheels due to their size or the greater compression on the ball that caused the increase in velocity. Therefore, we did another test with 4 in. wheels but at a compression to 6 in. instead of 8 in. This caused a decrease in velocity by .7 m/s, so we concluded that the largest wheels placed the furthest apart would

be ideal, so long as they could retain sufficient grip on the boulder. Thus, we decided on a 1 in. compression and wheel diameters of 6 in. However, moving on we decided to use 4-in. instead of 5- or 6-in. wheels because there was not enough space to fit either due to the proximity of the climber when the shooter was folded back.

We then noticed two major flaws with the design: it was ineffective at collecting the boulder and it could potentially become inaccurate if the two separately powered wheels spun at different speeds. In order to fix the inaccuracy, we introduced a tube with the same diameter as the ball and placed the wheels on it such that they were 120 degrees apart from each other rotating about the origin of the tube. This created 3 points of contact between the two wheels and the back of the tube (see top down geometry). Ideally, the walls of the "mortar" design would keep the ball flying straight until it had completely left the shooter.



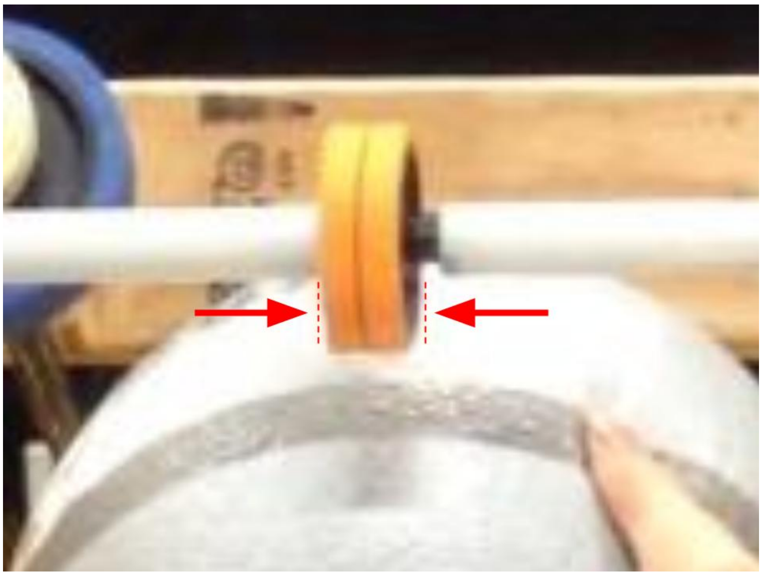
The Mortar




Top Down Geometry

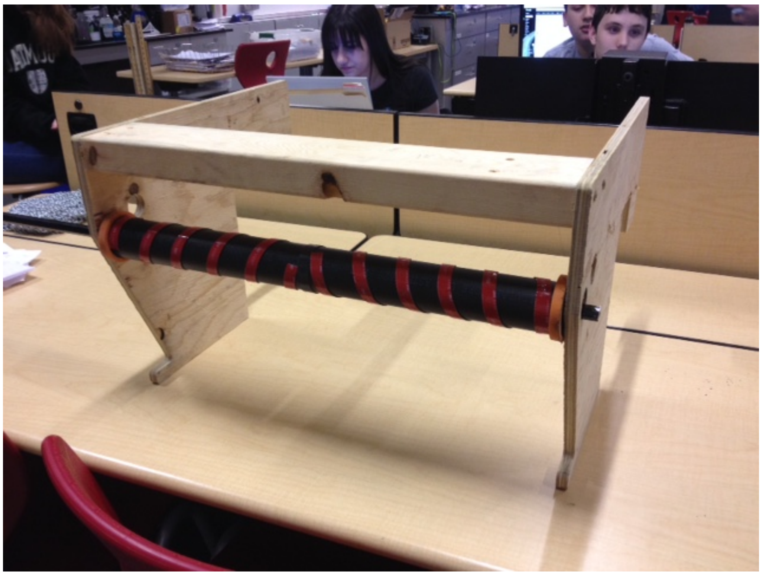
In the CAD sketch above, the rectangles represent the wheel position relative to the mortar tube. Not only would the tube ensure the ball shot out in the correct direction, but it also provided spin on the ball by having the third point of contact (the back of the tube) remain stationary. We tested both topspin and backspin, and we determined that backspin was better because it caused the ball to fly flat, making our shots more predictable.

As for the collector, our current design had a very narrow opening (the end of the tube) for intake, making it nearly impossible for a driver to obtain boulders. In order to widen the opening, we added a horizontal bar in front of the tube with wheels positioned in equal intervals along it. This increased the collection space to about 20 in. However, we quickly discovered that our current collector design not only did not center the ball, but it also kept it moving through in a straight line so that it could not be moved to the side by a funnel, as seen below on a similar design.



When the ball receives force from the side, it cannot move sideways because it is pushing against the side of the wheel.

With the iteration above, we tried only using one wheel in the center of the bar so the ball would only go in when the ball was already nearly centered, but it increased collection time and relied heavily on driver skill. Instead, we removed the wheel, put a PVC pipe around the bar, and spiraled tape around it on either side (an idea from Team 319) in order to pull the ball to the center. Ball guides were also added to prevent the ball from missing the ramp. The final design for the collector can be seen below.



At that point, we were feeling good about our design and began to design it in Autodesk Inventor.

#### 2.2.4 Collector and Multi-tool

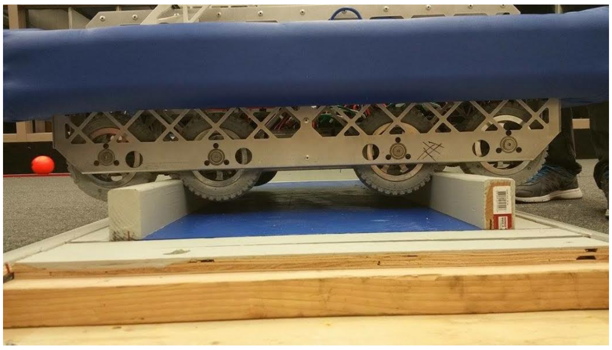
The collector for the boulder would be in the front of the robot, but we realized that it could have multiple functions so that we would need fewer singular mechanisms for separate design challenges that are on the field. The portcullis and cheval de frise are two defenses that need more than a strong drive base to conquer. We also wanted to add features on the collector so that we could lift the portcullis over the robot and lower the cheval de frise to be able to get over it. For later competitions, we also wanted to develop a replacement for the collector that had a shooter integrated into the multi-tool. We started off with looking at catapults, but it did not seem like an efficient solution for shooting because it was hard to gain a reliable aim. It also could not easily replace the collector. Another one of the methods was the fly wheel shooter mentioned previously. This method was superior because it had a wheel with a high torque and it had a consistent aim. From that idea two separate ideas were developed.

### 2.3 Design

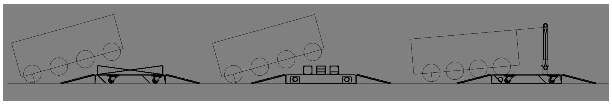
#### 2.3.1 Drive Base

Looking at Stronghold, the first thing we noticed was how important having a strong and versatile drive base that would be able to traverse the difficult defenses placed before it. The first decision was what wheels to use. Because of the forces that would affect the robot while traveling over the defenses, it was obvious that some sort of shock absorption system was going to be crucial. While designs for having a real suspension were thrown around, we decided pneumatic wheels would provide the same relative safety without the added weight and complexity a suspension would require. This quickly reduced the number of choices we had to 6 inch or eight inch wheels. Our prototyping

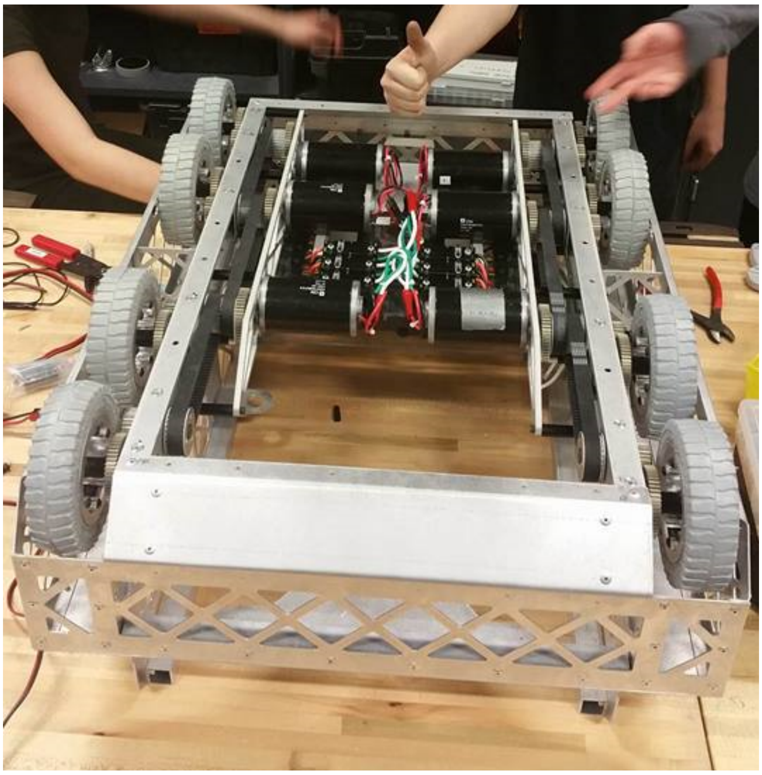
proved eight inch wheels would be more advantageous for crossing defenses, but the six inch wheels would also perform adequately. The important benefit six inch wheels give is that it more easily allows for a lower robot. Knowing that we had a height limit of around fourteen inches, we figured fitting everything into the cramped space was going to be difficult. Lowering the robot another two inches allowed more space for electronics and proper support for our hanging mechanism. For those reasons our final choice were six inch pneumatic wheels and hubs from West Coast Products.



With wheel type decided, the next step was to define their placement using CAD. The two biggest factors in deciding their placement were the ability to cross under the low bar while keeping in mind the ramp would angle the robot slightly up, and crossing the moat..

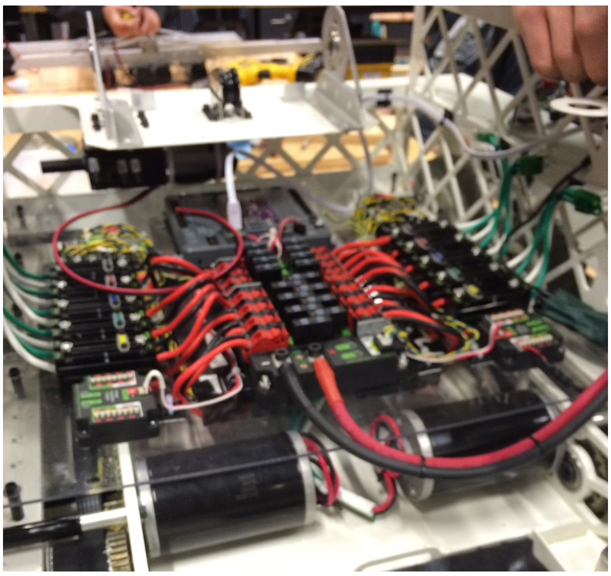


One of the first things we decided to do away with from previous years' drive bases were the shifting gearboxes. Over the years we've realized that] they ended up being more of a gimmick that ended up being ignored or actually slowed down drivers. In an effort to spread the weight as evenly as possible, the six CIMs in our drive base got separated. We strayed away from the traditional gearboxes this year, deciding that it was highly likely parts would break from the violent nature of the game. If we had used one gearbox to power all the wheels centrally, failure within it would have meant our robot would be unable to move on the field. So, we instead connected all the wheels with belts and gears to power our 14.4 foot per second drive bas

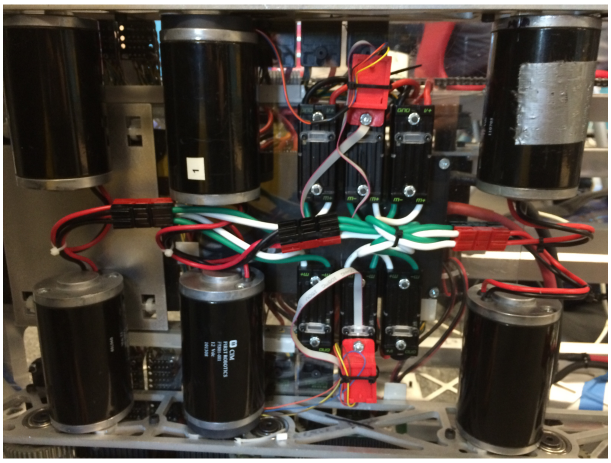


The main reason our wheels are spaced the way they are is because there was no other belt size available from our source when we were building the drive base. If we could have we would have had the center wheels closer together to allow easier turning, but we ended with them farther apart because we couldn't source belts in time to build it any other way.

#### 2.3.2 Electrical Board



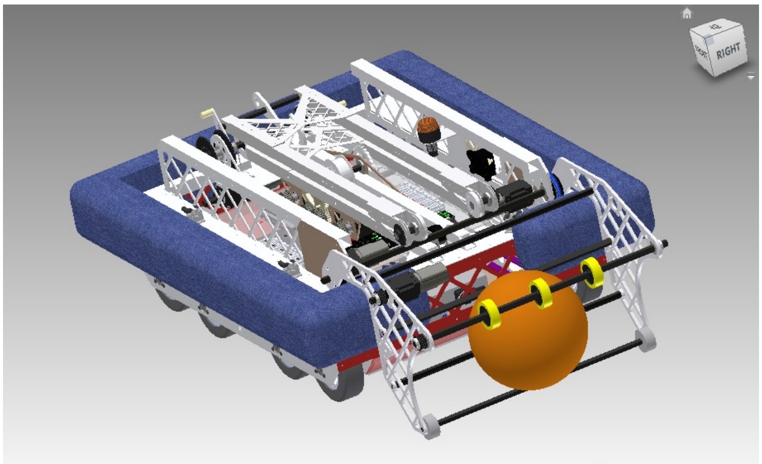
Most of the robot's control system is located on a removable polycarbonate board on standoffs above the drivetrain. The layout of the electronics on the board was designed jointly by the electrical and design subteams. The largest constraint in the design was arranging electronics so that they didn't interfere with other parts on the robot, since vertical space was limited to just 2 inches above the board and constrained by drive motors below the board. The board was fabricated and the parts on it assembled independently of the rest of the robot, allowing for a very quick integration into the robot after both the board and the robot were ready. We used countersunk fasteners for everything to avoid interferences between fasteners and motors, as the drive motors are in contact with the board. Once the board was fastened to the robot, the only remaining integration was to connect motors to motor controllers, sensors to the CAN bus, and connect the radio and circuit breaker.

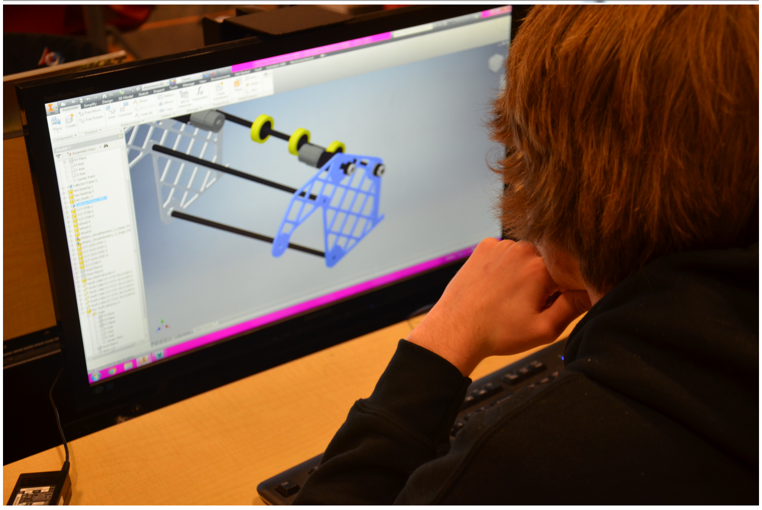


To maximize the available space and streamline wire routing, we placed the six drive motor controllers on the bottom of the board, making use of a gap between two of the CIMs. Since the power distribution board was on top of the fastening holes, we used countersunk screws to fasten these motor controllers so that other components on the topside could sit flat on the board. The motor controller power and CAN bus wires connect to the top via slots cut outward from the controllers.

### 2.3.3 Collector and Multi-tool

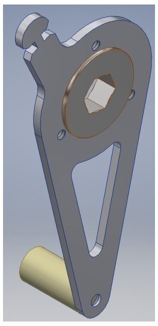
The collector is a simpler version of our shooter. Instead of shooting towards the high goal, the collector is designed to aim for the low goal. The shooter 1 has the same collecting method as this collector. It first collects the ball through two shafts, the top one containing three wheels. The collecting range was increased by curving the frames inwards, so the ball can be collected even when it is rolled towards the side of the collector. The curved side makes space for the ball to be collected and centered towards the center through the spinning wheels. There are two supporting shafts in the back to then secure the ball in one position while moving around so that it can be accurately be shot out. An RS775 motor is connected on the inner part of the left side frame, and the wheels have a diameter of 2.375.



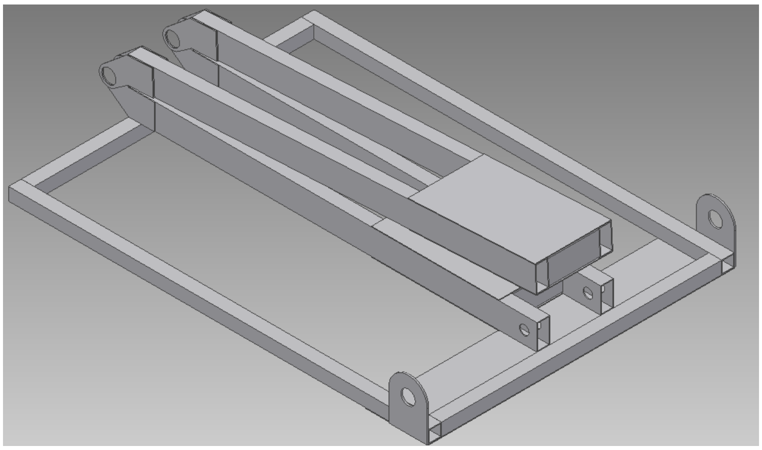


#### 2.3.4 Climber

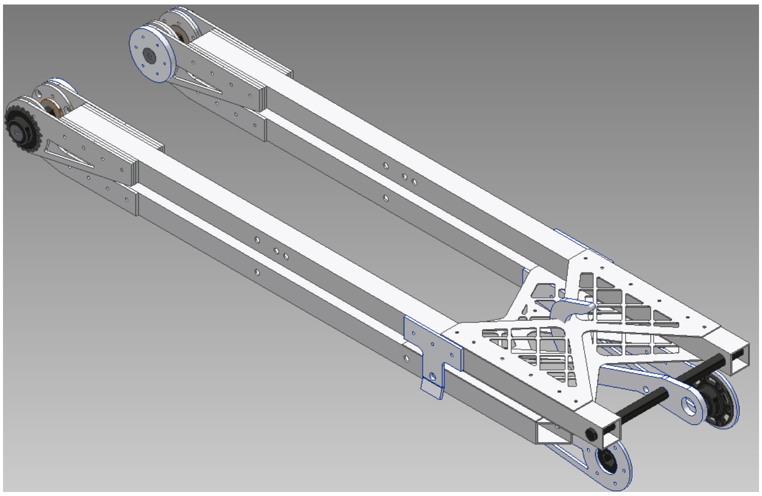
The linkage arm climber was chosen to be designed and put on the robot. This design is put on top of the robot and can climb to below five feet from the ground. It was not prototyped. There were some concerns that the chain used to drive the arm up and down would fall off, so a chain tensioner was added. It also has five motors, so it climbs very fast. Since this was a light mechanism, it was decided to not put holes in the climber because, while holes are sometimes needed to lighten heavy loads, it was decided that the climber could benefit from the strength. When people driving the practice robot beat up the climber while going under the low bar, it was decided that the reason the climber was being moved so much was because the top and bottom arms weren't attached, so a latch was needed and designed using a servo motor.



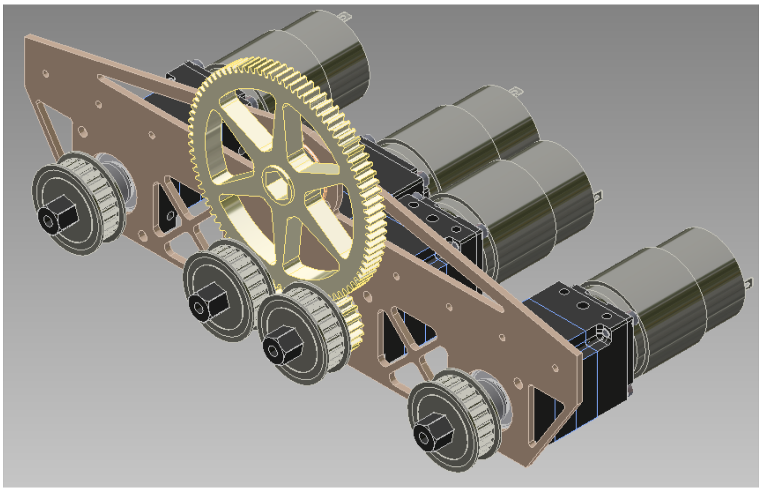
This is the design for the tensioner. It is attached to a spring so it can keep the chain tight.



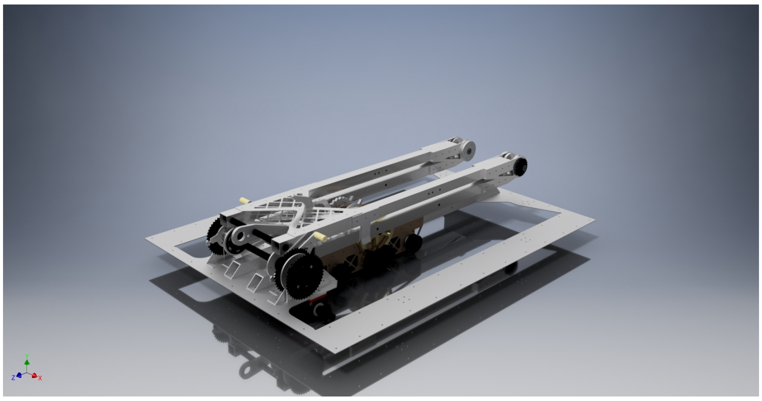
This is the climber that was initially designed. It does not contain a hook because the design of the hook was dependent on the design of the climber. This was designed to prove the geometry of the folding arm, so it does not have the right material assigned and did not explicitly show how all parts were assembled or attached together.



This is the final design. Two significant changes is the assembly now contains a hook and a guiding plate. It contains everything except pop rivets and bolts.



The winch was designed to prevent the extending part of the climber assembly from having to pull the robot upwards. One of the hardest parts of the design was fitting the four motors in to our robot. We did this by using a belt and gear system that had the motors mounted side by side.



Full Final Climber Design

#### 2.3.5 Hook

Our final design is basically the same design as the beginning of our prototyping and design phase. We started off with a simple design and made it more and more complicated before we had to make it more and more simple. In the beginning we wanted to fully surround the bar, but as we progressed through the season we realized this was unnecessary. We kept revising our design, removing complexity and aspects such as making the design passive and then making it simply an open shape. We ended up back where we started with a final design very similar to one of out originals of a candy cane-esque shaped hook with only small modifications, such as a guiding end to the hook just in case the climber had a slight margin of error.

### 2.3.6 Shooter Systems

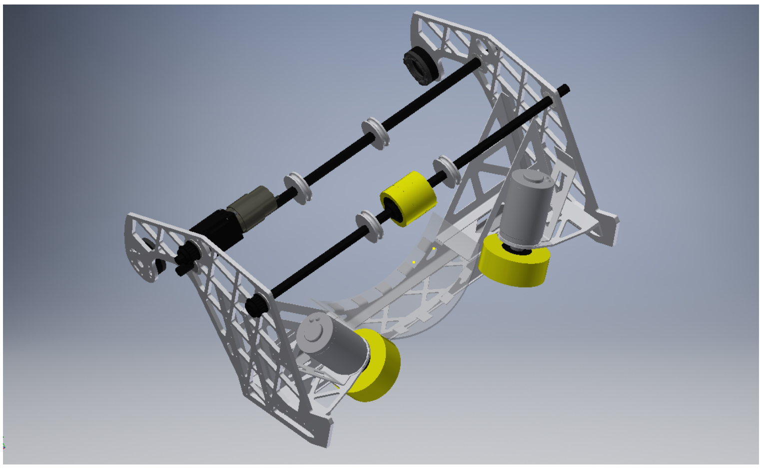
Both ideas from prototyping were continued to the design phase as it was too difficult to tell which would be the best option without actually building them. From these two designs, a third arose that was eventually cut and used on the robot.

#### Shooter 1

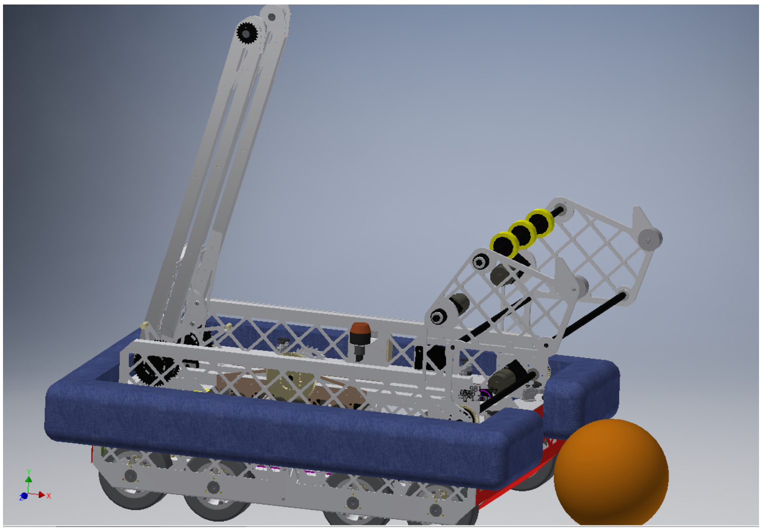
This focuses on collecting and shooting on the same side. The shooter collects the ball using four-inch wheels at the bottom and a hex shaft at the top into the ramp. The shooter wheels are attached with the wheel mounts at the sides.

Our first draft of the shooter has two wheels that connected to CIM motors that were each on top of the wheels. The shooter itself would then rotate upwards while the robot moved around, and then position itself to the angle needed for shooting. The rotating shooter was an ideal choice because we would have more flexibility in terms of the location for our shooting point. Collecting and shooting in the same direction would make it less awkward for positioning when shooting versus collecting one side and shooting out the other. There were two centering wheel mechanisms that moved the ball onto the ramp before it was actually collected into the robot. This prevented the ball from being collected into the robot in some random position and ensured that the hex shafts secured and held it when the whole shooter moved. There was an idea to change the collecting wheels to be horizontal and raised from their original positions because they captured the ball more towards the center rather than the bottom part of the ball, as it did when it was angled and a little lower during the prototyping. However, this version never made its way into the design.

These pictures show the original design of the shooter.



The shooter in front view.



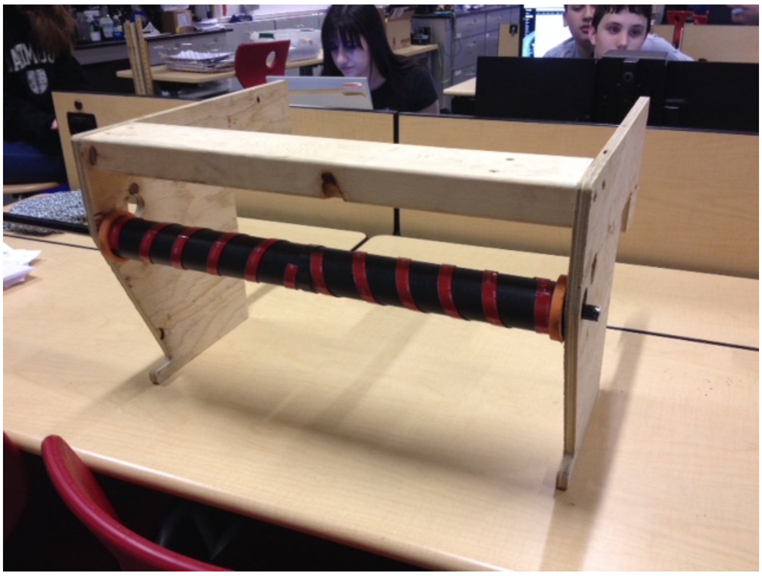
The shooter on the whole assembly.

Our second draft of the design only had one change to it, which was curving the side frames based off of the same geometry that was used on the collector. This version of the shooter was never cut nor finalized, as we quickly made more changes.

The final version of the shooter 1 is quite different from the original model. Instead of one wheel, there are two wheels at each side of the collector. We decided to add another wheel so that we would have a stronger grip on the boulders. The side frames are not curved inward but instead frame exactly where the wheels touch the ball because they are mounted on the sides in a way that cutting inward would not be a viable option. The side Colson wheels were moved back because the ball was touching them before it was in contact with the top friction wheels, which were added to center the ball in the correct position before collecting. As a result, the two axles that collect and secure the ball were also moved back so that the distance between the wheels and the axles did not change.

**Shooter 2**

The final design for the second shooter had a lot of similarities to that of the first shooter, but the path of the ball through the arm differed in multiple ways. The first difference was with the collector, which was a lexan pipe with tape wrapped around it in a spiral (see image below).



The spiral ran opposite directions from each end of the pipe in order to center the ball in the middle of the arm. Next, the ball was pulled into a second bar with two wheels that held it until it was ready to shoot. When shooting, the robot moved to a fixed point near the high goal, the arm rotated back to a pre-determined angle, and the wheels on the second bar propelled the ball into the next stage, which featured a tube with two wheels at the back.

The two wheels and the other side of the tube formed three points of contact with the ball, so the wheels were angled so that the points were in thirds of the tube. Having the one stationary point produced backspin, which prevented the ball from moving unpredictably in the air. Moreover, the flight path produced by backspin allowed for an easier shot than with topspin, which would cause the ball to bend downwards slightly as it flew towards the goal, potentially causing a miss.

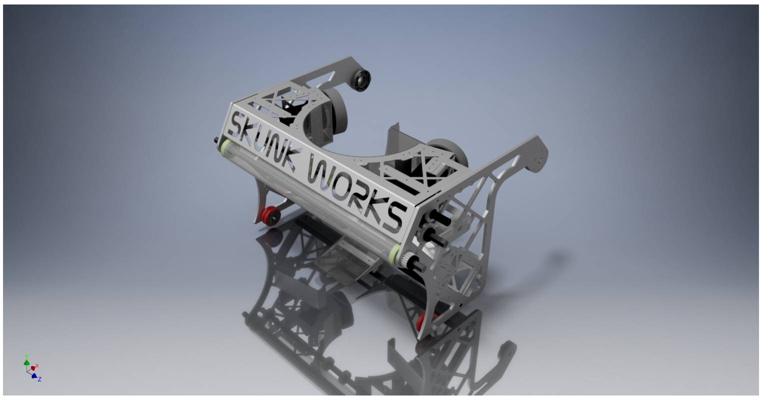
Another difference was that with our first iteration, the tube was much taller and made up most of the arm. This interfered with the ball collection and added extra weight. We then decided to go with a shorter tube but with the same wheels. In the first iteration, the ramp also went all the way across the arm, which did not fit within the bumper constraints. This would also compromise the structural integrity of the shooter since it would be able to warp due to the flexibility of the plastic. To solve the space problem, we made a ramp that was 4.86 in. across and held in the middle of the shooter with a hex shaft and multiple braces.

Because of the weight of the entire robot, we were required to decrease the weight of the shooter to 15 lbs. or lower. We were around 17 lbs., so many parts were cheesed and reduced to a thickness of 1/20 in. We were unable to meet the 15 lbs. limit, but luckily the rest of the robot came in at least five pounds underweight, allowing us to progress with the assembly without weight concerns.

Then another problem arose: the wheels and tube of the shooter were interfering with the climber. At the start of the match before the shooter deploys, it has to stay within the perimeter of the drive base frame, so it must be rotated

back toward the climber. In order to fit in the base frame without interfering with the climber, the wheels were moved to be approximately 106 degrees away from the third point of contact. We also had to change the wheel size from 4.5 in. to 3.75 in. in diameter. As a result, many braces had to be altered and re-positioned.

After checking the assembly once again, we discovered that it was too tall. Furthermore, per recent changes to the collector, we decided to redesign our shooter to roll up the portcullis using exposed wheels on the front instead of a hook on the bottom. This required a redesign of the side panels, which, were at that point so convoluted in their renderings in CAD that changing them would result in broken constraints and projected geometry. Other braces had to be altered as well, but not completely reconstructed in CAD.




Final Shooter 2 Assembly

We decided not to use this design because of its inability to include a simple hard stop, which was determined to be a necessity in order to ensure accuracy. It could not have a hard stop because at the beginning of the game it needed to be rotated farther back than it would be when shooting in order to stay within the frame perimeter.

#### 2.3.7 Shooter 3

The third shooter was a mix between the first and second shooters. The first shooter was able to use a hard stop to aim, but it could not collect well. The second shooter had a full-width collector, but it could not have a simple hard stop. Both parts were fairly complicated. Therefore, the third shooter used the second shooter's collector along with the first's shooting mechanism.

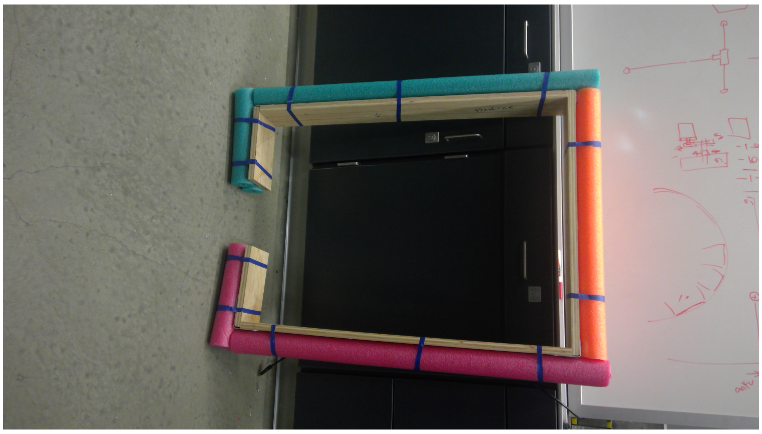
Shooter 3 Final Design

## 2.4 Assembly

### 2.4.1 Drive Base

Assembling the drive base was a lengthy process that involved many rebuilds. Because we didn't put every fastener in the CAD model, we ended up finding interferences that we didn't think of. The worst problem was in the CIM mounting. With the encoders we used, the CIMs needed more space so they could actually be mounted to the plate they rested on. When we began assembling the drive train, a standoff holding the CIM plate ended up interfering with the gears. We had to turn two pairs of them down .1 inches so they would fit. Every time we want to change or update something on the wheels or the transmission, the riveted side plates need to come off and re-assembled. With the precise spacers and balance, this is no small task. While the robot is pretty reliable, when it does break, a lot of effort will be required to fix the problem. **Bumpers**

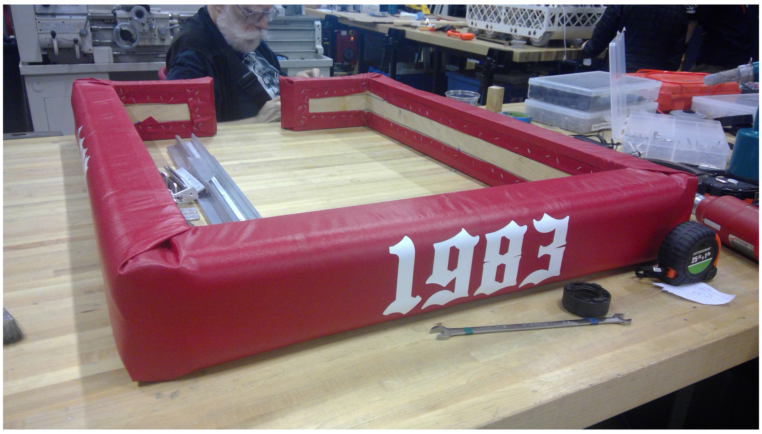
For the 2016 competition season, students built three bumpers: a blue bumper, a red bumper, and a practice bumper for the practice robot. The bumpers needed to be designed in Autodesk Inventor 2016 to give us an idea of what they would look like on the chassis. We also had to have a space at the front of the robot for the ball to be collected by the collector mechanism. After getting a good idea of what the bumpers would look like on the drive base, the next step was to start getting the right amount of plywood and angle brackets to assemble the bumper system. We had to cut the plywood to the exact dimensions that were necessary to be incorporated with the drive base.



Interior of Bumper System

There were two sides to the cloth and we had to make a choice between what type of fabric we wanted to use. One side was slippery and the other was not. For defensive purposes–getting pinned by another robot–the slippery side would be easier to maneuver and get out of that friction pin, so it was chosen instead of the normal side.

The next step after building the interior of the bumper system was to wrap the bumpers in fabric and iron on the numbers. We had to figure out how much fabric to cut for the bumpers and at what location to cut the fabric. We did not have a set amount of staples to use for the fabric, so we employed what we thought was necessary. When stapling the fabric to the plywood, it was necessary to staple at a 45 degree angle in opposite directions in order for the fabric to be sturdy and durable

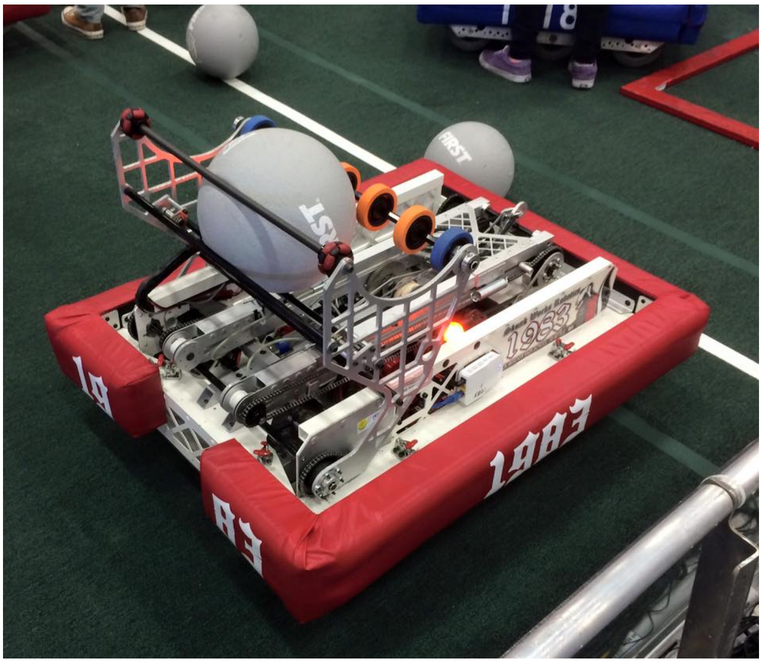



Final Product of the Bumper System.

#### 2.4.2 Collector and Multi-tool

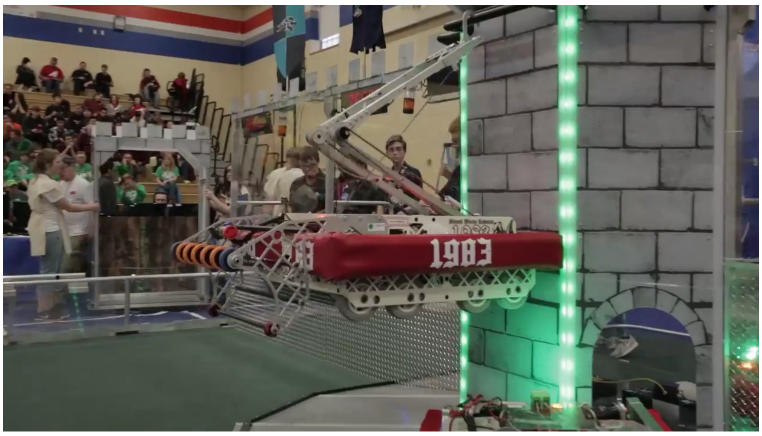
Assembling the collector did not take a long time, but it was cut numerous times and re-assembled once due to geometry miscalculations. The first time the collector was assembled it was 3 inches too tall for the robot. We then had

to shrink the height of the collector and also put it on the whole assembly before cutting out again to ensure that we had the right calculations and that it did not interfere with any of the other robot's performances.




### 2.4.3 Climber

When the climber was designed the encoders on the motors were forgotten, so the ratchet could not fit with the motors in the way. The solution was to grind down the ratchet so it can fit over the motors. While being designed there was also an incorrect spacer length so it had to be adjusted. While being assembled the bearings and spring tensioners were installed backwards, the tension in the springs themselves had to be corrected, and the left and right springs for the chain tensioner were installed on the wrong sides.



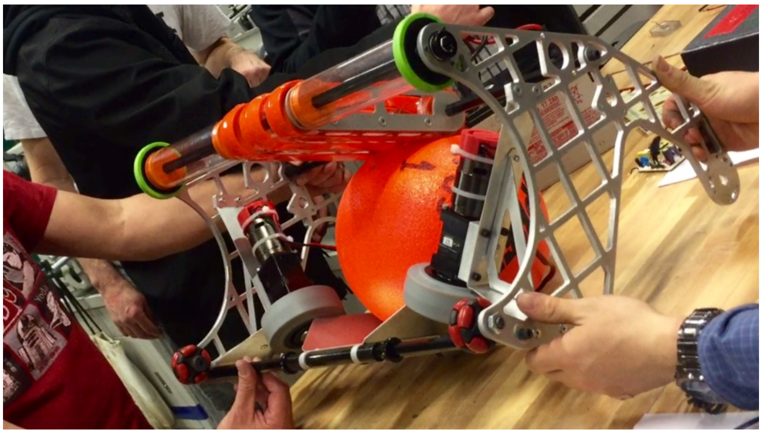
### 2.4.4 Hook

The hook required no assembly. It was simply cut and attached to the climber.

### 2.4.5 Shooter

After the shooter had been mostly assembled, two problems arose: it could not shoot far enough and it would rip the ball if it collected in the wrong spots. The latter was a result of the circular cut-out on the front of the side panels, which allowed the ball to become trapped between the panels and green wheels meant to lift the portcullis. This was solved by adding a straight metal piece on either side to close the gap. Additional ball guides were mounted to the motors to better center the ball.

The first issue was a result of excessive compression. When the ball was being shot, the relatively small distance between the rollers and the bottom plate did not allow it to move quickly. In order to fix this, the bottom plate was redesigned so that the ball would not be resting on it when in contact with the shooting wheels. The boulder only would reach the plate when in a storage position, having little affect on the resulting shot.



## 2.5 Performance

### 2.5.1 Drive Base

From our first competition, the drive base has run without any major problems. After rigorous testing on the practice robot, we realized the front and back of the robot would go through a lot of stress from ramming into the defenses. We added a 1x2 aluminum tube behind each wedge and a poly carbonate plate to the outside of the drive base to avoid any performance-reducing damage. At our third event, Philomath, a belt slipped off the front right sprocket. We didn't even notice it was off until after the match, meaning the design worked perfectly as designed, able to take damage from the field and other robots and continue performing.

### 2.5.2 Collector and Multi-tool

The first time the collector was being tested, one of the omni wheels broke because the robot itself was dropped on the ground, and the small wheel was one of the first things that received the impact from the fall. It seemed to do fine after the wheel had been changed. It was not tested after it had been reassembled from the miscalculations. During the Auburn Mountainview competition, the collector collected all the balls from the expected range and did not have any problems when handing them to our alliance shooters.

### 2.5.3 Climber

While testing the programming for the climber it was going forward instead of up and hitting the wall. It was also found that when one of the gears had spokes in it, the gear kept getting caught and interfered with the robot climbing. During testing the climber, the hook would also not deploy in time to catch the bar, so it had to be fixed using bungee cords. When we tested our practice robot on our practice field it was found that the climber was hitting the low goal because it was on the top of the robot and, therefore, causing damage to both, so a small PVC pipe was added to keep a damaged joint in place. To improve performance our climber used 7750 motors to run closer to peak efficiency and peak torque. This also allows the climber to climb very quickly: within our goal of 5 seconds. At 65 percent power the climber climbs to the correct height in 1.5 seconds, so our new goal is less then a second. The climb height is only limited by the strength of the pulley. While performing at Auburn Mountainview the climber worked most of the time, and the times it missed was because the robot was just slightly not in the right spot or because the bunjee cord for the hook was too loose.

### 2.5.4 Shooter System and Updated Multi-tool

At the Central Washington district event, the new shooter and multi-tool replaced the old one. Unfortunately, it did not perform as well as hoped. While the wheels on the front could lift the portcullis, they did not lift it as quickly as the ones on the old collector had because there were only two of them. The shooter was also fairly ineffective because it did not have enough thrust. A few shots were made, but many others were missed. However, the shooter system is still improved over the old collector for low goal shots because it still has greater thrust, so low goal shots are only missed if the robot is not aiming well enough rather than because it could not push the ball forward quickly enough.