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**Mining M.E.C. Panthers**  
**NASA Lunar Robotics Senior Design Project**  
**100% Report**

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This B.S. thesis is written in partial fulfillment of the requirements in EML 4905.  
The contents represent the opinion of the authors and not the Department of  
Mechanical and Materials Engineering.

## Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Ronald Portorreal, Matthew Koza, and Sean Di Pasquale and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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## Abstract

Space exploration has been one of the most important revelations of the past and current century. As technologies advance alongside human knowledge, the drive and capabilities of mankind grows. Currently, the platform of discovery is Mars. The primary objective of the Mars program is to answer the question regarding the possibility of past or future life on the planet. In order to accomplish this goal a number of habitat characteristics must be determined through exploration. At the moment the robotic rovers assigned with the task of exploration face many obstacles they must overcome in order to navigate and excavate on any extraterrestrial terrain. These obstacles most directly affect the mobility system and communication system of the rover. Therefore having a reliable and efficient mobility and communication system is essential to a successful mission. M.E.C. Panthers is a team composed of mechanical, electrical and computer engineers at Florida International University that have undertaken the task of designing and building a model rover of reliability and efficiency. This report documents the entire design process and details pertaining to the rover prototype.

# 1. Introduction

## 1.1 Problem Statement

The progression of society has always depended on the intellectual growth of mankind. Along with this intellectual growth comes the desire to explore and discover the unknowns of the universe. The National Aeronautics and Space Administration (NASA) is an agency dedicated to the exploration of the universe's mysteries. In the 1960's the agency was able to send man to the moon and revolutionize space exploration for the entire world. Today's focus has shifted somewhat from the moon towards exploration of the planet Mars. Such a task requires the hard work and dedication of passionate scientist and engineers alike. This passion is something that must be cultivated in young adults to encourage their imagination. NASA accomplishes this through challenges such as the Robotic Mining competition.

The Robotic Mining Competition focused on a lunar environment demands the competitors to complete a functional design of a rover-like robotic vehicle with the capabilities of navigating through difficult terrain as well as excavating and transporting regolith samples across that terrain. At the start of the competition judges will perform various checks regarding the safety and communication capabilities of the rover. If the inspection is passed the team will be allowed to participate in the competition and be awarded a starting value of 1000 points. The robots will operate on a terrain that is meant to simulate a lunar environment. This presents many difficulties and constraints regarding the design of the rover. The most immediate is mobility; the density of the regolith which can range between 1.5 and 1.8 g/cm<sup>3</sup> when it is compacted and 0.75 g/cm<sup>3</sup> on the top 2 cm of the pit where it is raked to a fluffy condition. The looseness of the regolith introduces mobility issues which must be addressed with much attention being focused

on the possibility that if the rover is not mobile then it will not be able to complete its mission. Another issue is the mass of the rover, which cannot exceed 80 kg. Referencing the competition rules, 8 points are deducted for every kilogram of mass of the rover up to the 80 kg limit. This presents a problem with designing the rover with enough equipment to perform a difficult task while keeping the mass as low as possible. Along with the safety inspection mentioned earlier, the judges will also inspect the dust tolerance of the design. Due to the characteristics of the regolith, the design must be dust tolerant to prevent the regolith particles to enter any part of the system and possibly damage the durability or performance of any component. During the actual run, they will also consider how dust free the rover operates, in other words, how messy or dirty the rover operates while it moves through the terrain.

The second half of the design involves the communications part. For the competition attempt, the rover must be controlled from a separate room requiring the users to be able to communicate with the robot. However, similar to every other constraint there is a limit to the amount of average data used to communicate. For each 50 kb/s used, one mining point will be deducted. Therefore communication must be refined and efficient to avoid losing points. Regarding communication, there is an option to run the rover autonomously in order to receive extra points. This path of autonomously running the rover would present many more problems needing solutions in the design. Such a task would require adding sensors and intricate programming. To accomplish autonomy the rover would either have to travel across the terrain, travel across and excavate, travel across and excavate and drop off, or run for ten minutes continuously on its own. Depending on which task the rover was able to perform provides a certain amount of extra points, the last of which would be considered full autonomy and would reward the team with 500 mining points.

Accomplishing missions such as the exploration of the lunar surface is a difficult task that requires innovative ideas as well as proper funding. In addition, the overall cost of designing, building and testing a lunar rover must be considered. Therefore among the goals of the completion is that of being able to design the concept of an efficient rover. For the competition, the most pressing difficulties involve the mobility system and the communication system. The competition fosters a collective human perspective that NASA can use to implement new designs, while allowing young engineers to gain valuable hands on experience.

## 1.2 Motivation

NASA is determined to successfully explore the extraterrestrial surfaces through the use of mining rovers to gather data and testing samples. The primary objective of the team is to design the rover component of space missions as efficiently as possible implementing ideas not currently integrated in current rover designs. The rover being used at this moment is a six wheeled, car-sized robot that weighs 899 kg. The team will explore alternate designs to the current rover. Whether the stage is Mars, the moon or an asteroid excavation of regolith may aid in the possible extraction of Helium-3. Helium-3 is a non-radioactive gas that is scarce on Earth and is useful in many fields of work such as medicine and energy. This non-radioactive gas may be used to as fuel for nuclear fusion without creating radioactive byproducts and may resolve the world's dependency on fossil fuels. (Popular Mechanics, 2013)

## 1.3 Literature Survey

### 1.3.1 Tracks versus Wheels

The first thing that was looked at in the mining robot is the mobility. The term mobility is very important because it defines how well a vehicle can move over a given landscape. In Mars, the moon or an asteroid there are no roads. Automatically this puts wheeled vehicles at a disadvantage because wheeled vehicles see a decreased reliability when they are offroad. (Hornback, 1998)

Wheeled vehicles “offer better fuel economy and reliability” (Hornback, 1998) compared to tracked vehicles but only while on paved roads. It has been shown that for Army missions requiring “unrestricted terrain movement” (Hornback, 1998) tracked vehicles are the best choice because they have a lower ground pressure due to the increased surface area. This lower ground pressure allows these vehicles to go over terrain that would be impossible for a wheeled vehicle. The downside to this improvement is that they require more maintenance and are less reliable. (Hornback, 1998) Each type of mobility has a set advantage and disadvantage. The key to a successful project will be to design around the disadvantages while maintaining the advantages of track or wheeled vehicles.

### 1.3.2 Elastic Loop System versus Rocker-Bogie System

A recurring debate exists between the use of a conventional rocker-bogie system and a type of track system known as the elastic loop mobility system (EMLS). The EMLS concept was fortified through a joint effort between scientist Dr. Nicholas Costes of NASA’s Marshall Space Flight Center, W. Trautwein of Lockheed Missile and Space Company and Dr. Stein Sture of University of Colorado. (Nildeep Patel, 2002) The resulting design concept proved to be more

effective than a wheeled system through the distribution of the vehicle weight over a larger area providing the vehicle with better traction and a more compact size. (Nildeep Patel, 2002)

Another advantage the ELMS concept has over a rocker-bogie system is its simplicity. (Nildeep Patel, 2002) The ELMS does not require the mechanical complexities needed by the rocker-bogie system and hence ends up being lighter. (Nildeep Patel, 2002) Range of mobility through obstacles is also another category where the ELMS can prove to be more effective than the wheeled system. Where the wheeled system was only capable of climbing 18-degree slopes, the ELMS was able to climb a 35-degree slope. (Nildeep Patel, 2002) Table 1 shows a comparison between a rocker-bogie system and an ELMS system after a series of tests conducted at the U.S. Army Waterways Experiment Station. (Nildeep Patel, 2002)

**Table 1: Rocker-Bogie vs. ELMS**

<b>Subsystem</b>	<b>Rocker-Bogie</b>	<b>ELMS</b>
<b>Dimension</b>	60x40x30 cm	60x40x30 cm
No. of wheels	6	4
Wheel diameter	13 cm	6 cm
Wheel Width	7 cm	10 cm
Wheel rim thickness	1.5 cm	1.5 cm
Wheel weight	1.031 kg	0.576 kg
No of loops	0	2
Weight of each loop	0	1 kg
<b>Total weight of Mobility System</b>	6.2 kg	4.3 kg
Motors	Maxon REO –16	Maxon REO-16
No. of motors	6	4
Gearing	2000:1	2000:1
Stall Torque	13 Nm (110 in-lb.)	13 Nm (110 in-lb.)
<b>Torque/wheel</b>	1.2 Nm (10 in-lb.)	4 Nm (34 in-lb.)
Speed	0.4 m/min	0.4 m/min
Steering Rate	7 degrees/sec	Skid steering
Power/motor	14 v (normal operation)	14 v (normal operation)
Operating Range	100 m	1000 m
Slope Climbing	21 degrees max.	38 degrees max.
Obstacle Negotiation	20 cm max	Twice the linear dimension of loop
<b>Payload capacity</b>	5 kg	5-8 kg

### 1.3.3 Soil

In the NASA rulebook (NASA, 2014) it states that there is a dust tolerance design. The judges will evaluate the robot for operating in a clean manner, the amount of dust that is thrown into the atmosphere and how much soil gets into the electrical components. This issue is very important because most mining machines on earth have dust and dirt imbedded into them. Figure 1 shows the tracks of an excavator, a buildup of dirt can be seen on the interior of the track system. This image is common on earth, which means the soil on the moon, and mars must be different.



**Figure 1: Picture of embedded dirt on excavator tracks**

On the moon, dust that is disturbed can stay in a cloud due to the weaker gravitational forces and magnetic forces that can overcome this force (Taylor, 2007). Due to the composition of the soil, it can be magnetic. (Taylor, 2007) This means that a motor can easily be destroyed by the soil by creating a short circuit. Any electronic device that is not protected properly can be damaged by the lunar terrain. In addition to being harmful to electronics, the dust is also harmful to humans. (Taylor, 2007) (NASA, 2014) NASA requires participants to wear a breathing apparatus and a suit while in the mining area. (NASA, 2014)



### 1.3.4 Material-UHMW

UHMW (Ultra High Molecular Weight Polyethylene) is a thermoplastic polymer that has a high molecular weight (10 times greater than standard polyethylene resins) (Liaison Consulting, 2014). UHMW's high molecular weight leads it to having superior abrasion resistance, while it is self-lubricating with a low coefficient of friction (slightly less than Teflon). Along with its relatively light weight, its properties make UHMW ideal for the drive sprockets for our tread system. The high abrasion resistance ensures durability when coming into contact with the terrain and belt, the low coefficient of friction reduces sticking of the belt onto the sprocket and its light weight allows the weight to be kept low. (Goodfellow, 2014) (Liaison Consulting, 2014)

### 1.3.5 Material-ACM

ACM (Aluminum Composite Material) is a sheet metal like material that consists of two thin sheets of aluminum of varying thicknesses sandwiching a sheet of non-aluminum (polyethylene). This material was designed to allow for quick and easy fabrication as well as being lightweight and retaining strength. The main applications tend to be for false panels and quick set-up objects (such as temporary buildings). This material can be cut with a standard metal cutting tools (such as a jigsaw with metal blade) and can be formed by using a router to remove one later of aluminum and the non-aluminum core, this leaves the uncut layer aluminum to be hand-formed easily. After the shape has been formed, rivets or bolts can be used to hold the material in place. The ACM is to be cut and formed into the electronics box for the lunar rover

due to its lightweight properties as well as ease of manufacturing. (Alcoa, 2012) (John W. McDougal Company, 2014)



Figure 2: Composition of ACM material

### 1.3.6 Lithium Polymer Batteries

Lithium polymer (LiPo) batteries are rechargeable batteries, generally packs, that produce a high number of amp hours while maintaining a significantly lower weight than lead acid's with similar amp ratings as well as better amp ratings and charge capacities compared to lithium ion batteries. LiPo batteries are often used in RC applications, so their integration in the lunar rover should be easy. There are several issues present with lithium polymer batteries, many regarding their sensitivity to charging. When overcharged, lithium polymer batteries expand and overheat, which could lead to explosion. Lithium polymer batteries also require a specific charger to ensure an even charge; non-even charging can reduce cycle life and also lead to fire/explosion. (Battery University, 2014)

## 2. Project Formulation

### 2.1 Project Objectives

One of the motives of our design is to contribute evidence in favor of using a track system as opposed to the traditional wheel system. Theoretically, the track system would benefit many aspects of mobility including weight distribution, suspension and traction resulting in a more efficient overall system. Through the implementation of a track system in the design, the team hopes to further support the use of track system in future rover designs. Another aspect of designing an efficient rover involves the communication system. Autonomy is a difficult task that involves complex programming; however, the more the rover is able to perform on its own, the less amount of data transfer is needed to perform tasks, facilitating communication with the rover. By limiting the communication, weight, and increasing the lunar rover's overall efficiency the power system can be designed to last longer than the current design. This would make it possible for NASA to have more missions by reducing the cost or increasing the life cycle of the lunar rovers. The ultimate goal of the M.E.C Panthers is to meet all design specifications and pass the safety check during competition. This will allow the team to participate in the competition. Making it to competition is an accomplishment by its own right.

## 3. Design Alternatives

### 3.1 Conceptual Design

Several design variables were conceptualized for the lunar rover. The design was split between several different sections, mobility, collection and deposit. Each of the sections is to be designed separately in the order listed. The reason for designing the rover in chunks in that specific order is to allow fabrication of the initially completed sections while the design of the latter sections is still occurring. This allows us to further manage our limited time and put out a better end product.

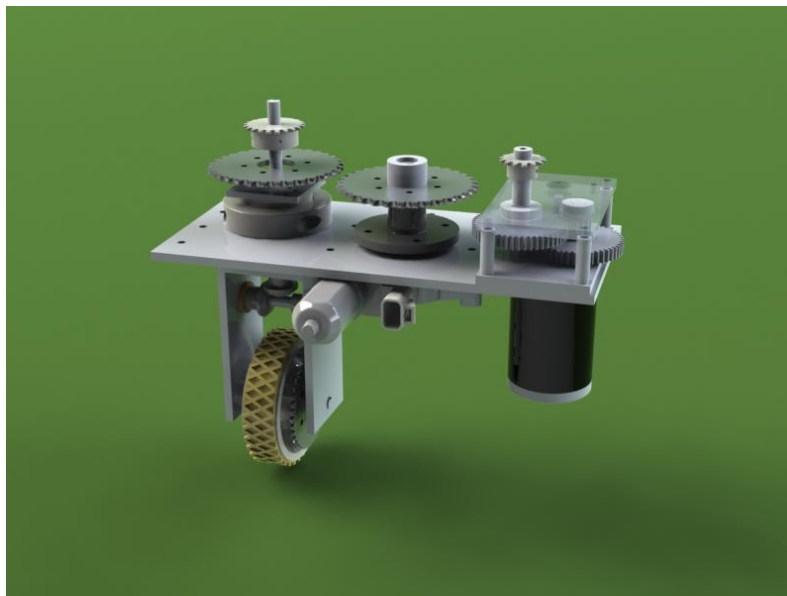
#### 3.1.1 Mobility

The first section designed was the mobility of the lunar rover. This section had the most variance between designs, ranging from quick, simple to complex, and precise. Some major design factors that were taken into account for the mobility of the rover are the terrain, precision and reliability.

The first option considered was wheels. One issue with wheels was that pneumatic wheels would not be allowed in the competition since they would not function properly in the lunar atmosphere. Therefore, only solid wheels were considered for the conceptual designs. Larger diameter wheels are preferred due to the greater ground clearance they provide as well as their higher rate of traction. In addition, wheels provide a cheap method for implementing mobility vs. other methods due to their simple design. Wheels also provide a high degree of reliability due to their simplistic design as well as the redundancy they provide. Redundancy was important for the design because only two runs are allowed at the competition and the

redundancy provided by wheels would ensure continued mobility even with the failure of part of the drive system.

A subdivision of wheels that was considered was the “swerve drive” setup. This setup requires an individual gearbox for each of the wheels as well as a separate gearbox that is tied into each of the wheels to allow for rotation around each of the wheels’ vertical Z-axis. A basic 3-D modeling of the swerve drive setup is shown in Figure 3 below. This design would allow an extremely high degree of drive precision by allowing the rover to be able to drive in any direction without having to turn along the frame’s central vertical Z-axis. While this design offers the highest degree of precision, it also provides the highest degree of difficulty to implement as well as highest cost and lowest reliability. By having not only each wheel individual driven, but also another driving motor for the wheel rotation, another failure point is added, reducing reliability of the rover. In the end, the negatives of this design far outweigh the positives and thus were not chosen.



**Figure 3: Swerve Drive System**

A hybrid wheel/tread system was evaluated next. The hybrid system uses wheels as the driven components, but supplements their traction by have a tread system loop around the wheel. The treads for this system are generally metal links joined together and wrapped around the wheels, as indicated in Figure 4. Using a metal tread system would drastically increase the weight of the lunar rover. Given the restrictions imposed upon the weight, a lighter option would have to be fabricated in order to reduce the weight. This method would still be the heaviest to implement, as well as significantly costlier than the wheels due to the custom machining required. Therefore, in spite of the redundancy that this system provides comparable to wheels, the weight and cost of implementation negate the benefits.



Figure 4: Predator Hybrid System, courtesy of Predator Inc.

The final mobility design conceptualized was “tank drive” or treads. This design provides the highest traction of any of the other designs. Treads allow for a higher “flotation” of the rover. Flotation is, by definition of Miriam Webster Dictionary, “The capacity to stay on the surface of a soft material, such as sand or snow”. Treads provide a high degree of flotation due to their ability to evenly distribute weight along their length, as opposed to wheels where the weight is distributed solely on the contact points of the wheels. Treads do not offer as high a degree of reliability as wheels do, but their reliability is still in an acceptable range. Treads also carry a

higher cost than wheels since they require pulleys for their drive implementation, but again, the cost associated with them was not enough to detract from their high degree of traction.

### 3.1.2 Collection

Several concepts for the collection mechanism were analyzed. After deliberation on preliminary research, two designs were selected for conceptualization, a scoop mechanism and a conveyor belt mechanism. These were looked at in reference to their cost, rate of collection, reliability and how they affect the drive system.

The initial methods was the scoop mechanism, akin to a bulldozer, as in Figure 5 and

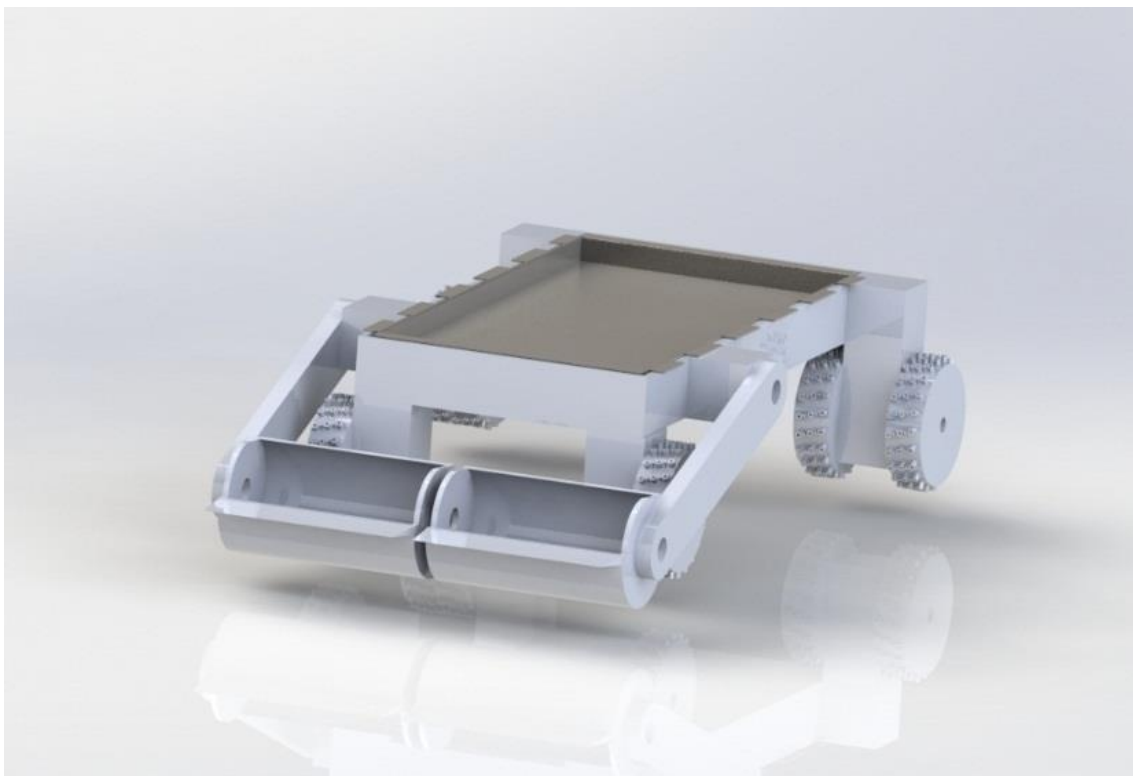
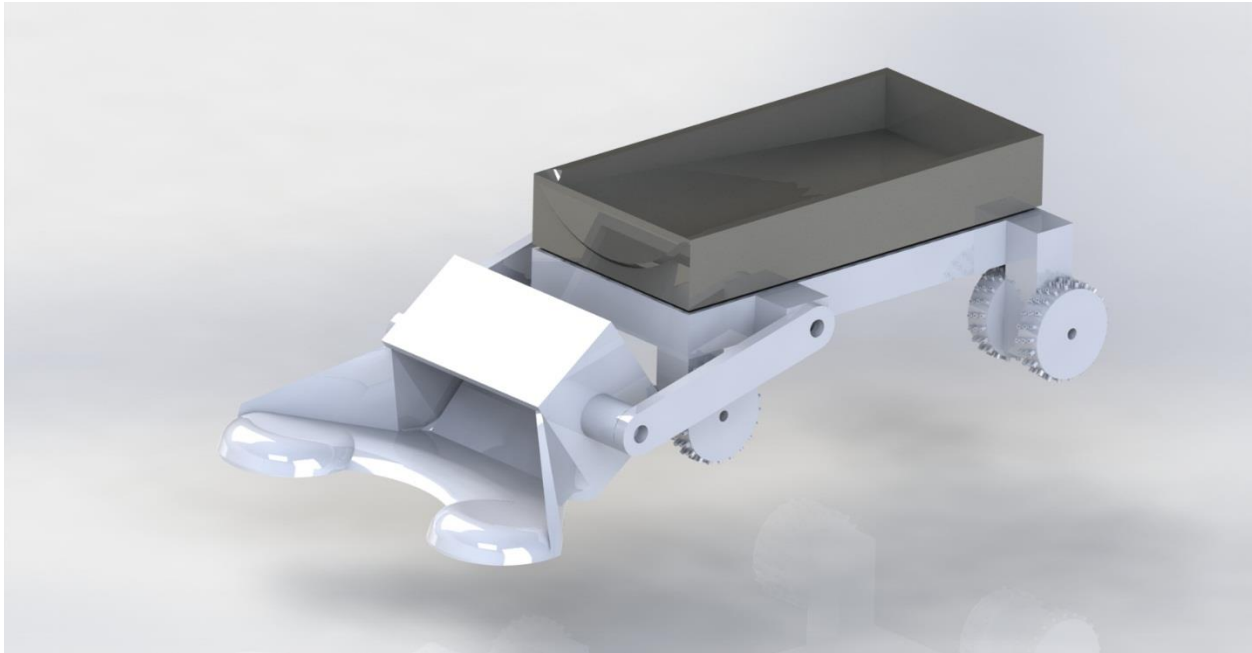


Figure 5: Conceptual Design 1

Figure 6. This method offers the lowest cost and highest simplicity of design. The implementation of this design is a scoop attached to a pivot arm. To drive this system, all that is needed is a single motor or linear actuator. However, while this method is simple to implement, it is highly inefficient in regards to collection as well as adversely affecting the mobility. The way bulldozers work is by lowering the bucket to below ground level and driving forward so the



**Figure 6: Conceptual Design 2**

collection bin fills. Figure 7 shows a typical bulldozer with a scoop and four large tires. There are several issues with this method, the first being the limited collection amount. This method requires single buckets to be collected at a time, limiting collection by the size of the bucket. However, increasing the size of the bucket drastically affects the moment it exerts on the arm it is mounted to. By increasing the moment, it increases the necessary force needing to be exerted by the motor/actuator, increasing cost and weight. The second major issue with this is how the collection would adversely affect the mobility. By needing to collect a large amount of soil at once, a large amount of resistance is going to act against the drive system and will have a higher



likelihood of inducing drive train slippage as well as increased current draw from the drive motors.



**Figure 7: Bulldozer**

The second collection method is the conveyor belt method. This is done by having a continuous belt driven from the surface of the soil to a collection bin, able to be lowered below the surface of the soil. On the belts is a series of collection bins that act as scoops, pictured in Figure 8. As the belt spins, the scoops pick up a small amount of soil, and upon reaching the vertical apex, deposit the soil into the collection bin. This method is significantly harder to implement, but will yield a much higher collection rate as well as low resistance against the drivetrain. By collecting a small amount of soil, but continuously, this method offers fast collection with minimal resistance. This method also allows for adjustable collection by allowing for faster/slow spinning of the collection belt. Ultimately, this method is costlier, but more effective for achieving the final design goal.



Figure 8: Conveyer Belt

### 3.1.3 Deposit

The design of the mechanism that will deposit the soil was conceptualized last, but had the least number of variables taken into account for the design. Overall reliability and simplicity were the two major factors desired for this mechanism and were heavily reflected on the final design chosen.

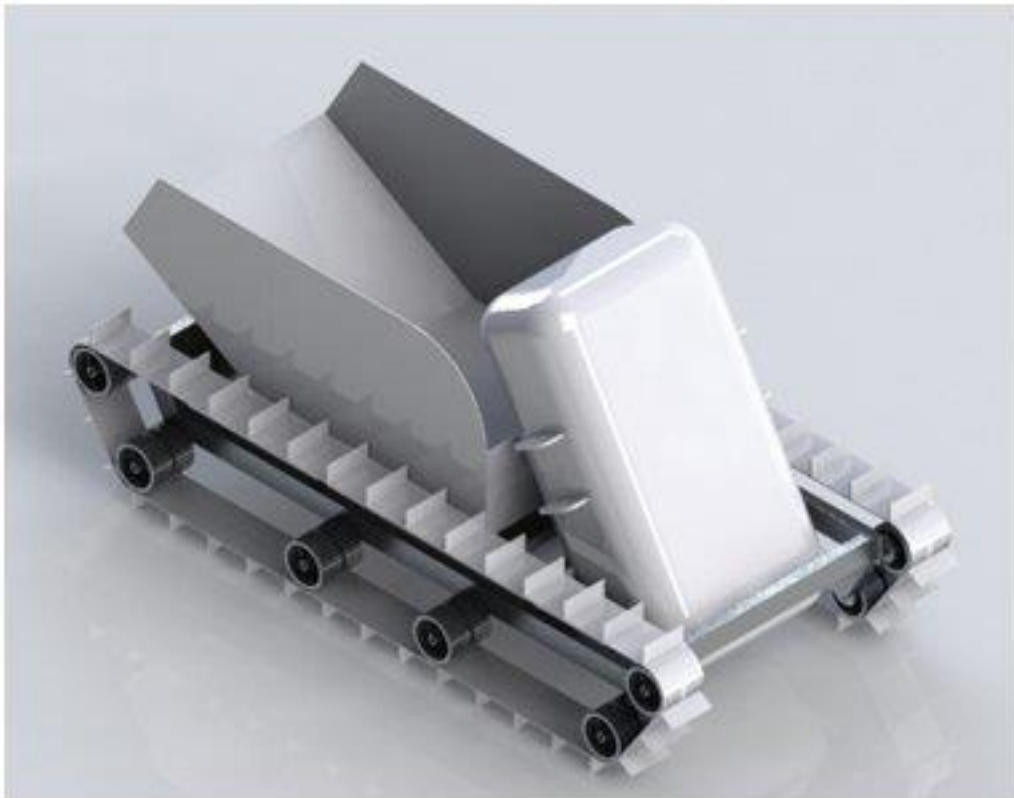
The first method conceptualized was having another conveyor belt to deposit the lunar soil into the collection bin in a similar fashion to how collection occurred. This method would have been costly, unreliable as well as complex. While it would allow the design to implement two similar features to reduce overall design time, there were virtually no benefits to this system. It would have been nearly impossible to ensure full soil extraction from the collection bin without adding a significantly higher degree of complexity to the design, as well as a high number of failure points. This method was deemed ineffective almost immediately.

The chosen method was a moveable dumping mechanism with a door. The soil collection will take place at the front of the robot while the dumping of the content will be at the back. The

dumping mechanism will sit on bearings that will be pulled by two motors via wire. This brings a high degree of simplicity to the design, as well as the ability to extract all of the soil from the collection bin. This method, being the most reliable, cheapest and easiest to implement, was chosen for the final design.

### 3.2 Proposed Design

The final proposed design used the most effective elements from the conceptual designs. The treads, conveyor collection and dump deposit system were all chosen to be implemented into the final design. For the final proposed design, a four motor drivetrain, variable speed collector and variable placement dumping mechanism will be added to the design. The initial finalized design is pictured below in Figure 9.



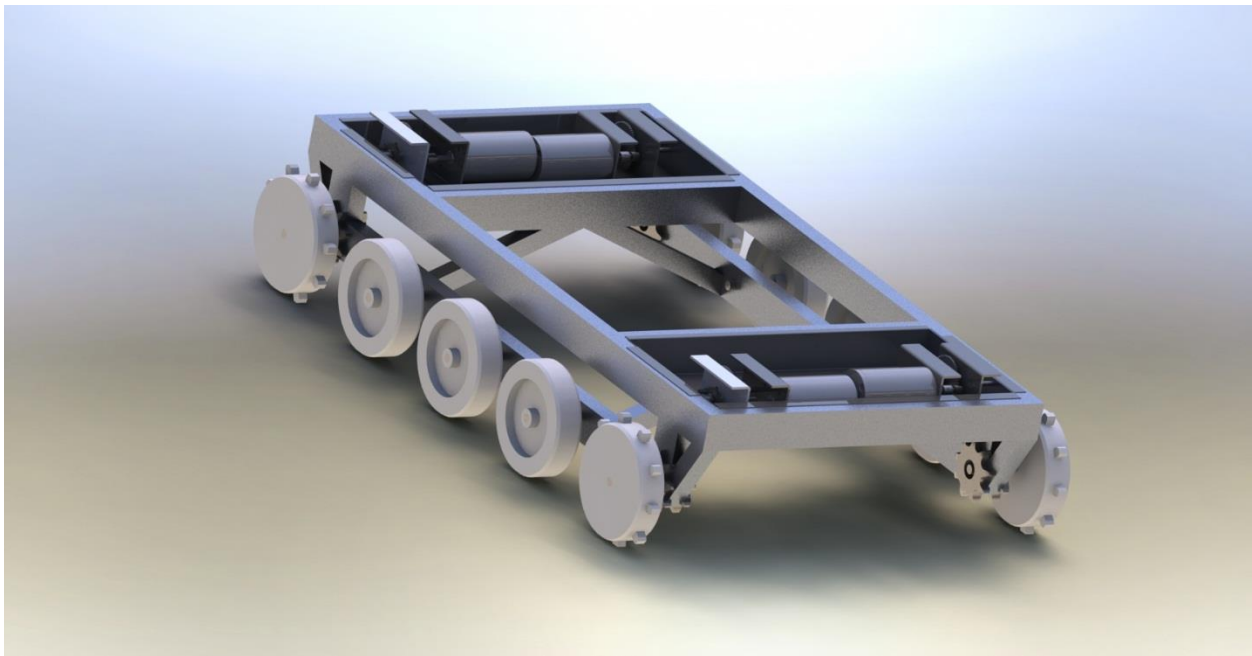
**Figure 9: Initial Design**

### 3.2.1 Drivetrain

The first iteration of the drivetrain utilized two pulley driven belts from Breccoflex. These belts were to be custom sized, weld-on profile and self-tracking. The custom sizing of the belts was due to the overall length of the frame. Due to this, pre-fabricated belts would be too short to implement in the design, requiring custom lengths. The weld-on profiles provided by Breccoflex were to be custom sized to the width of the treads (100mm), with a height of 40 mm. The self-tracking pulleys for the belts are designed with a center groove and curved tooth profile to prevent the belts from moving along the pulleys axially. The circular tooth pattern also provides a greater contact area per tooth, adding superior power transmission. There were several issues with these belts however, the first being the dust interference. Given that the regolith is extremely fine, it would have a high tendency of massing between the tread and pulley. This would have caused issues with the traction between the tread and pulley given enough of a buildup. The main issue with this design however, is cost. After contacting Breccoflex for pricing information, we were quoted \$1000 per pulley, given that our design used 4 drive pulleys and 6 idler pulleys, this would have entailed a cost of \$10,000 for just the pulleys, with additional cost being added for the treads itself. This would have taken us well beyond our budget, therefore this design was scrapped.

The finalized drivetrain consist of two sprocket-driven treaded belts. The sprocket driven design is implemented in order to decrease failure points due to the soil. Given the small size of the soil particles and their nature to get kicked up due to their low density, standard pulley driven belts run the risk of getting the soil caked between the pulley and belt, possibly causing a

derailing of the belt from the pulley and causing failure for half of the drive system. By using a sprocket driven tread, the drive sprocket physically pushes through the treads, allowing the soil to escape through the holes in the belts, eliminating a failure point. Sprocket driven treads also have a lower slippage rate, allowing for a higher reliability in the design. The treads were purchased from Superdroid Robots. While the treads themselves are priced within our budget, at \$560 for the pair, the drive sprockets were priced at \$300 apiece, taking the system out of the proposed budget. After contacting Superdroid Robots about a discounted price or engineering drawings of the drive sprockets so that they can be independently manufactured for a lower price, we were denied our request for both. The sprockets were custom engineered by us after receiving the treads. They are machined out of UHMW (Ultra High Molecular Weight Polyethylene).



**Figure 10: Frame with gearbox, idlers and pulleys**

A four motor drivetrain is implemented, consisting of each tread being driven by two motors. This design factor is used to add a form of redundancy to the drivetrain. If one motor were to fail for any reason, the other motor would still be able to drive that side of the rover. In addition, the four motor setup has a specific motor called CCL Industrial Motor Limited (CIM) motors; chosen for the drivetrain due to their high availability, large amount of relevant literature and familiarity.

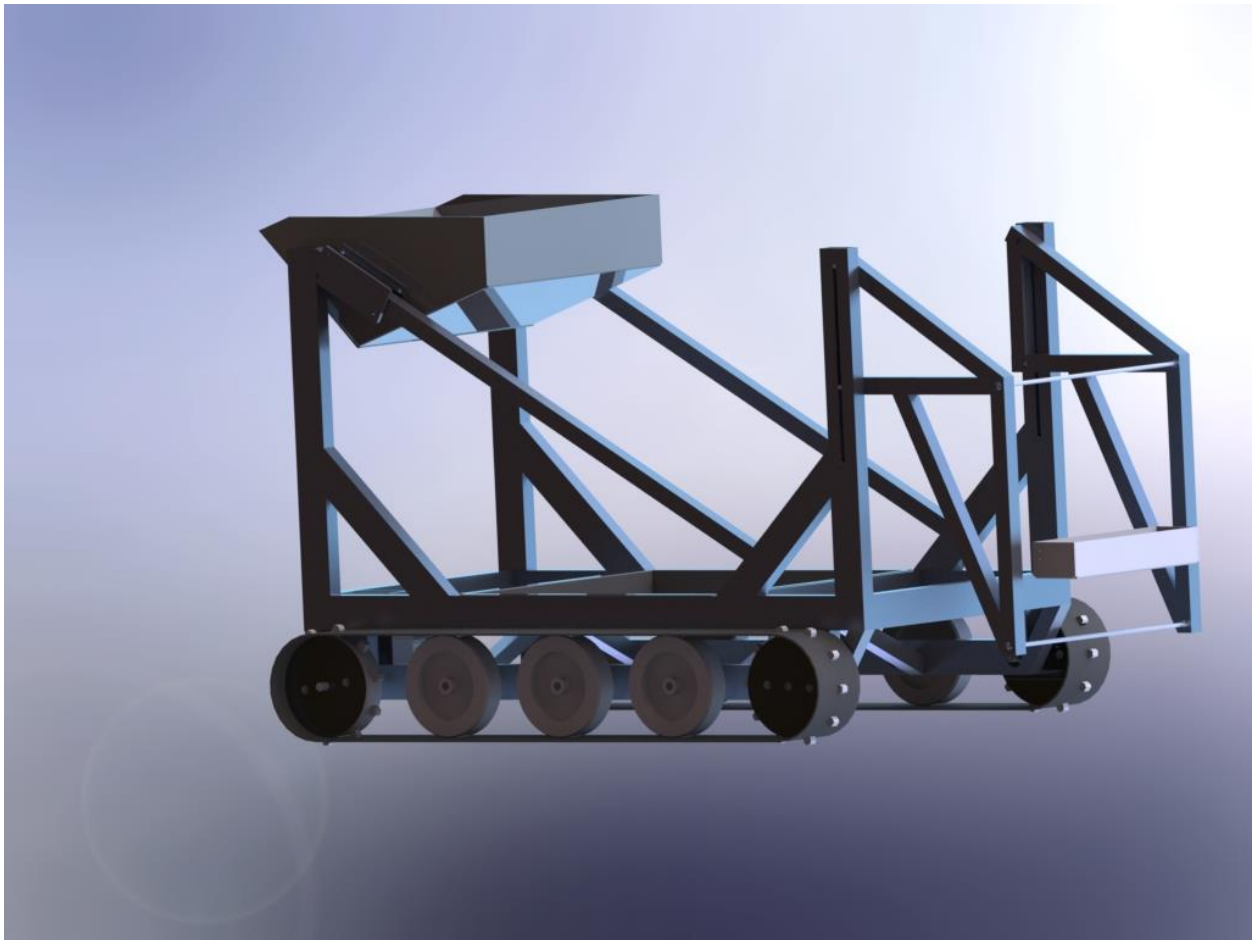
Torque calculations were performed using the “Drive Wheel Motor Torque Calculations” sheet from the University of Florida. This series of calculations take into account gross weight, number of wheels (pulleys), wheel radius, and desired speed, and acceleration, surface being traversed and maximum incline. The gross weight was determined by taking the maximum allowable weight and adding the maximum desired amount of regolith to be collected in a single pass. The pulley radius is 3 in, a desired top speed of 3.5 ft/s was chosen as well as a 2 second acceleration time. The incline chosen was 15°, given that was the estimated worst grade that might be traversed. Finally the calculation sheet provided a list of surfaces and their rolling resistances. Given the low density of the regolith, the surface with the highest rolling resistance (sand dune) was chosen from the table.

The two motors on each side will be combined together in a 15:1 custom gearbox. This ratio was determined with a final drive speed of 3.5 ft/s in mind. The maximum speed was determined by the amount of time necessary to traverse the entirety of the field at full speed.

### 3.2.2 Collection

The final collection method implements a chain drive on which buckets are attached. The chain collection offers two major benefits, collection speed and a reduced torque required to

power them. By having a chain collection system, more collection buckets can be placed on the belt, allowing a higher volume of soil to be collected with each revolution of the belt. A total of 10 collecting buckets are attached to the chain drive. This allows for a more efficient collection of the soil and less time needed to reach the collection maximum load.



**Figure 11: Improved Design**

The collection buckets are individually constructed out of ACM (Aluminum Composite Material), bent to the required shapes and epoxied in the seams to prevent leaks. These buckets are mounted to a #40 hollow chain belt via 8-32 screws. The entire system will be able to move vertically to allow the buckets to plunge into the surface of the soil to allow for the pickup. Two,

6 in stroke actuators will raise and lower the conveyer frame. One, gear motor will drive the conveyer belt. A total of six sprocket will be used and ten collecting buckets.

### 3.2.3 Deposit

The dumping mechanism is constructed from a single sheet of ACM bent into the necessary shape and riveted together as well as epoxied to prevent leaks. A 20° angle bend is incorporated on the bottom of the dumping mechanism to prevent the soil from being stuck when depositing. The angle allows for the soil to smoothly slide out of the collection bin, preventing excessive dust aeration (another score penalty). A door will prevent the soil from escaping until reaching the dump site.

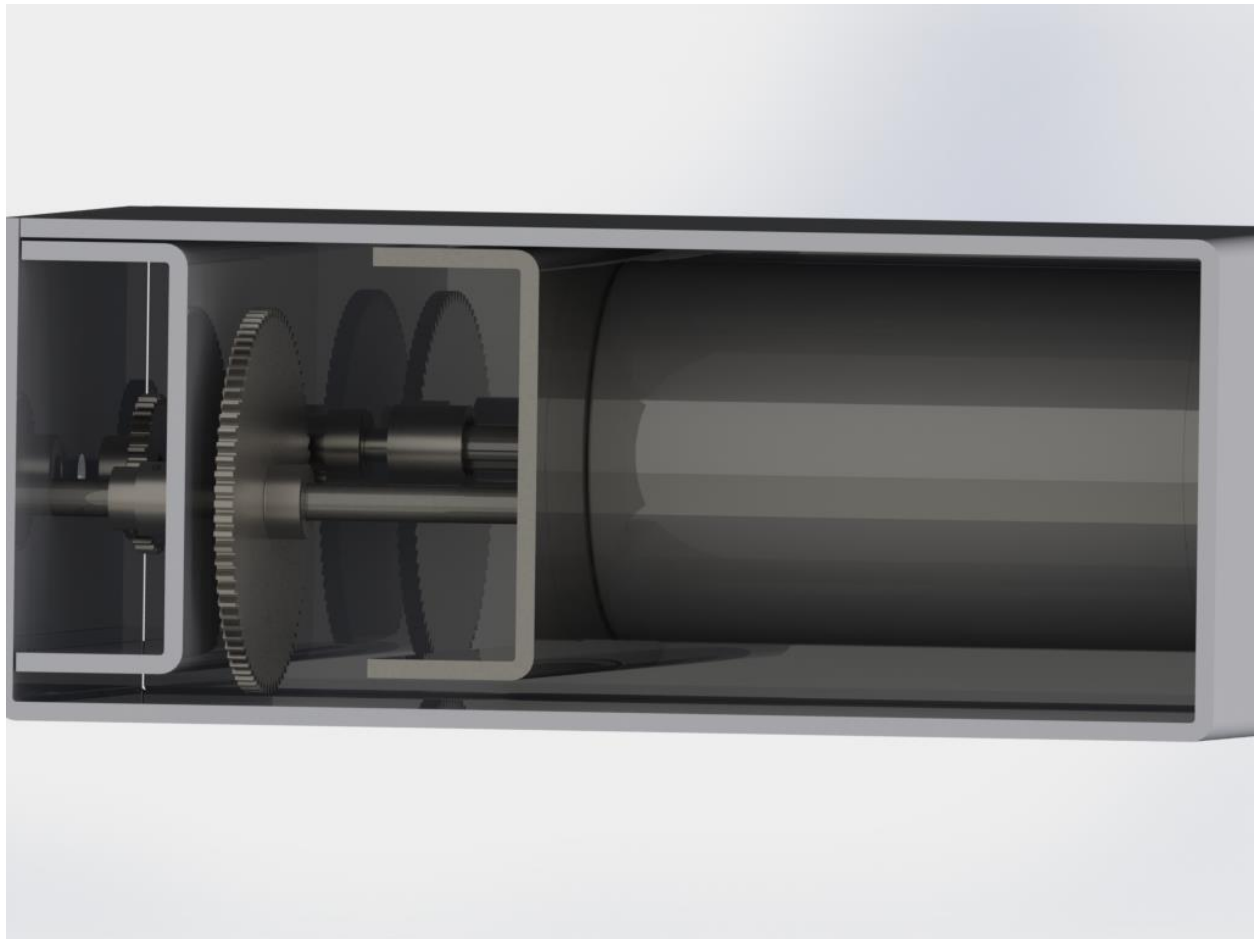
The collection bin is driven by two motors via wire. Two pieces of UHMV are used as sliding plates. The plates have four bolts on which bearings sit. One of the bolts is an eye hook onto which wire is attached. The wire follows a pulley located at the top-back part of the frame. Below this pulley a larger pulley is fixed to the motor.

## 3.3 Design Changes

One of the components that underwent the many changes was the gearbox. Throughout each design change the goal was simplicity, accessibility and a gear reduction as close as possible to 15:1. The original design had individually sealed gearboxes attached to the upper section of the base. The reduction obtained in this design from the motor to the output shaft was 12.25:1. Combinations of a 16 teeth and 56 teeth gears in two stages were to be used to achieve the reduction. The output shaft of the gearbox was to complete the power transfer as well as the



reduction desired to the sprocket drive shaft through a chain sprocket connection. Figure 12 below shows the positioning of the gearbox in the original design.



**Figure 12: Original Gearbox Design**

In order to improve the accessibility to the gears and motors in the presence of some failure during use, the second design maintained the same gear ratios and chain sprocket connection, but changed from a closed individually sealed unit to an open unit. The set of gears and motors for the rear drive sprockets would share a compartment attached in a similar manner to the electronics bin and covered with a removable lid allowing easy overhead access for

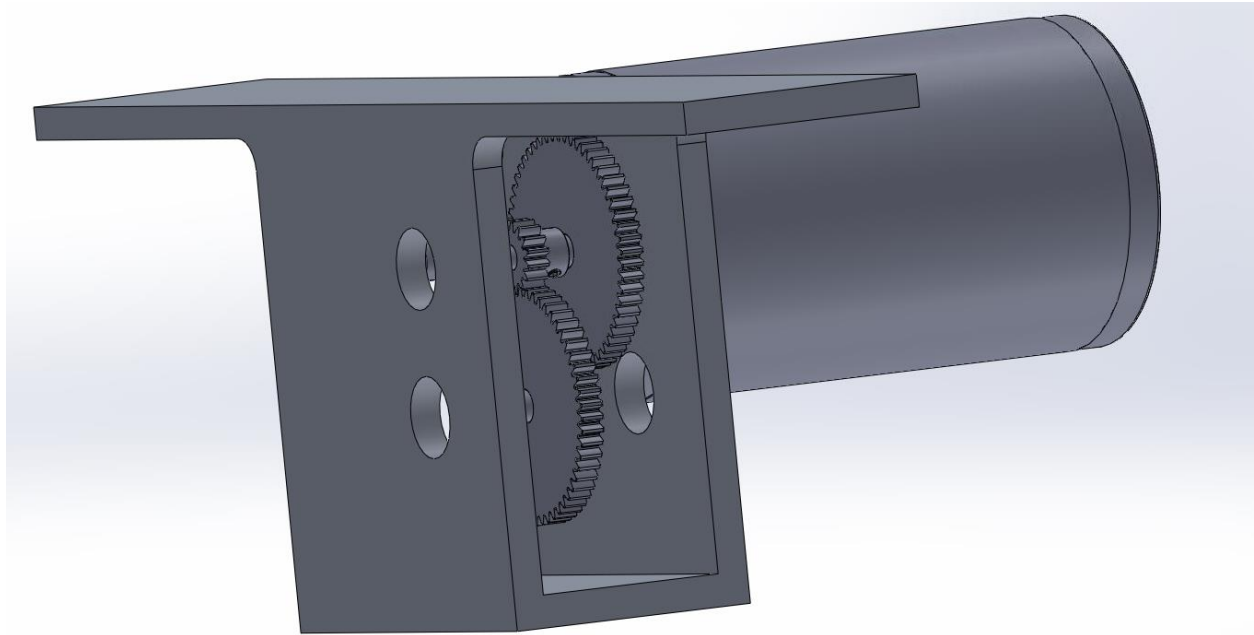
servicing. Figure 13 below shows the change in the housing units for the gears and motors proposed by the second gearbox design.



**Figure 13: Second Gearbox Design.**

Later the design was changed back to being an individually sealed unit with the gears being housed within 2x4, 0.25 in aluminum 6063 tubing and the motor being attached to the outside of the housing with its shaft entering the gearbox. The gear ratio and chain sprocket aspects of power transmission remained unchanged however the new housing would be cut to the needed size from a stock rectangular tube with a wing like extension that would span from one end of the frame to the following perpendicular support. This would allow the gear box to rest

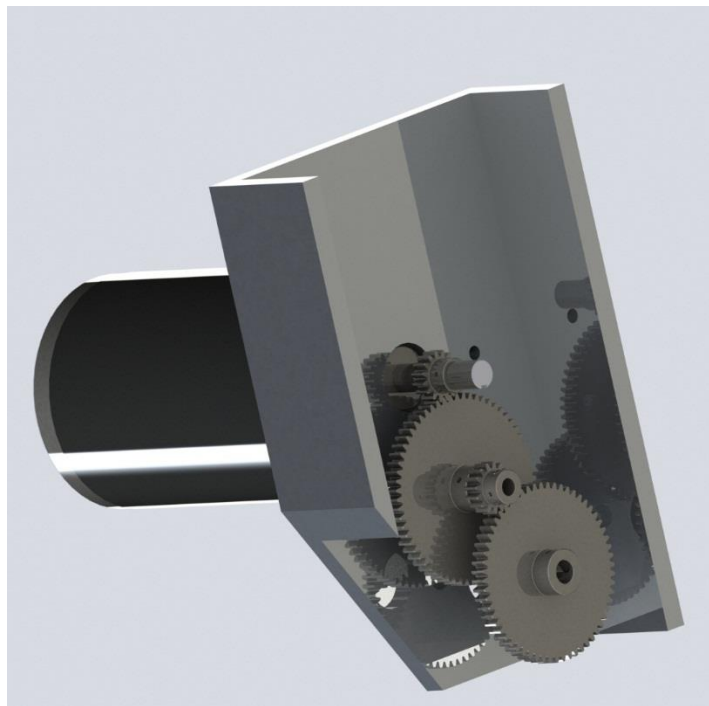
on top of the frame and be bolted on allowing for a quick removal of the entire unit should it need to be changed or repaired. Figure 14 below is a drawing of a design idea for the gearbox.



**Figure 14: Third Gearbox Design**

More changes in the design led to the fourth and final gearbox design. In this design the positioning of the gearbox was changed to a more vertical alignment of the gears aligning the output shaft of the gearbox with the shaft of the driving sprocket. This would allow the output shaft of the motor directly drive the sprocket eliminating the need for the chain sprocket connection. Performing this repositioning of the gearbox meant the last reduction needed from the chain and sprocket connection was lost. In order to compensate for the lack of final reduction a decision was made to redesign the gear sizes and ratio in order to complete the 15:1

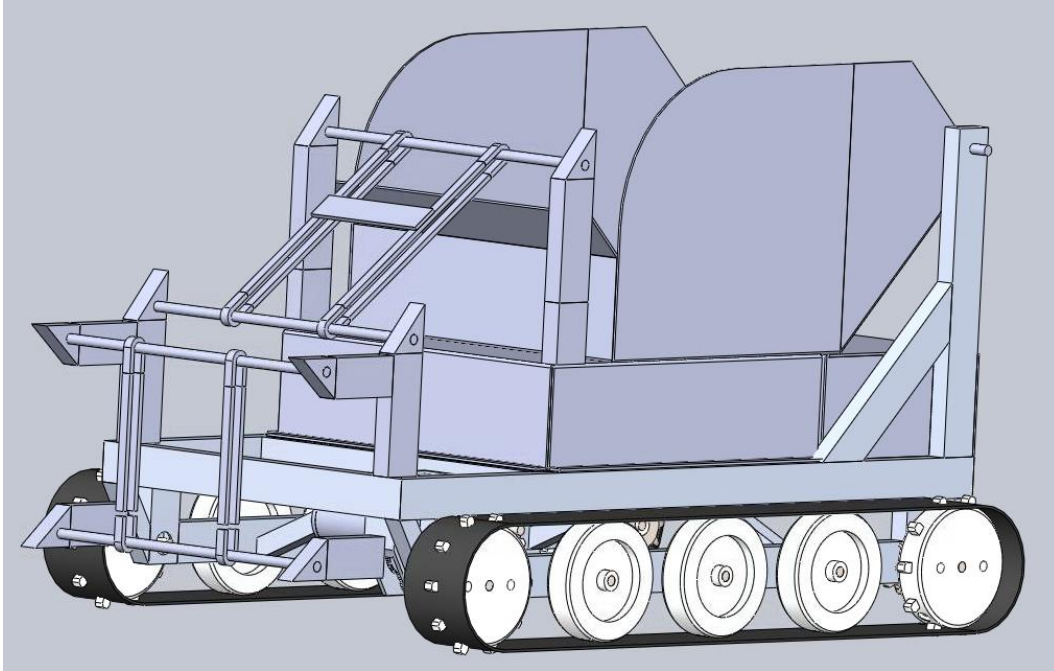
reduction within the gearbox. The reduction in all of the cases was to be done in two stages. A combination of a 16 teeth and 72 teeth gear in one stage while keeping the 56 to 16 teeth relation in the other stage gave a reduction slightly larger than 15:1 and was the first proposed combination. However an issue regarding interference between the gear of the first stage and the shaft of the second stage discarded this combination. To fix the issue, the team searched from the available gear sizes and selected a combination of 60 teeth with 16 teeth in the first stage followed by 64 teeth with a 16 teeth gear in the second stage. The resulting reduction between both stages was 15:1. A Solid works section view model of the final gear design is shown in Figure 15.



**Figure 15: Section view of Final Gearbox Design**

The collection mechanism, along with the dumping mechanism is two components that were essentially designed together. Similar to the design process undergone by the gearbox, the collecting/dumping mechanisms underwent many alterations and iterations regarding its final design. A continuous pick up system using buckets attached to a conveyer loop was the decided concept for the method of collecting regolith. At first it was to sit at an incline with the ability to travel down into the ground when needed to pick up regolith. Meanwhile the collecting bin was to sit above the electronics, run across the length of the base with an angled back side hinged at a point above 0.5 m to allow clearance of the bin where the regolith needs to be deposited. The bin would then pivot about the hinge, being lifted by an actuator to ultimately dump the collected regolith.

Certain obstacles encountered with the first design forced a rethinking of both the collector and dumping mechanism. For the collector, the mechanism setup required to have the collector at an angle with the ability to be lowered into the ground proved to be too complex. Also, the buckets on the conveyer would have encountered issues clearing the collection bin on the robot, especially when lowered. Hence, for the second design, rather than be at an angle, the collector would be positioned vertically and be lowered as needed by actuators. Then as the buckets reached the peak of the collector, the regolith would fall onto a moving conveyer belt angled to provide more space between the moving buckets and the bin. The bin in this design remained unchanged. The second design is shown in Figure 16 below.



**Figure 16: Second Design of Collecting/Dumping Components**

Eventually it was determined that the process of using a conveyor belt to catch the falling regolith from the bucket and transfer it to the bin might not be the most efficient collection system. Also, there were some doubts as to whether the buckets would clear the conveyor belt with the space needed for the falling regolith to land on the belt. This led to the consideration of an L-shaped collector. This shape would allow the buckets to have ample clearance from the bin even when lowered. Regarding the lowering of the collector, the second design simplified the process by only requiring vertical displacement driven by actuators. The bin was also redesigned around efficiency. In the previous designs, a practically square bin was to be lifted, or rotated about a pivot point to dump the regolith. This process would require two actuators with a significant stroke length and had a higher possibility of having some regolith get trapped in the corners of the bin. The fix to these issues was making the entire length of the bin a downward slope. By doing so, the idea was that as the regolith was collected in the bin it would accumulate

towards the rear. Then when it needed to dump the regolith it would simply open a rear gate and the weight of the regolith would carry it down the incline and out the back of the robot. To be certain the regolith slid out, a small actuator would lift the bin slightly to increase the incline. Figure 17 below shows the thought process that went into this design. As can be seen the collector wraps around in an L shape over where the bin would be placed. On the upper right corner of the figure is a modified version of the bin were rather than a straight slope along the length of the robot, the slope ends earlier and for the remainder of the length the bin is more square. Doing so allowed nearly double the capacity of the completely inclined bin. On the same day many alternate designs were discussed, therefore, this design never left the white board.

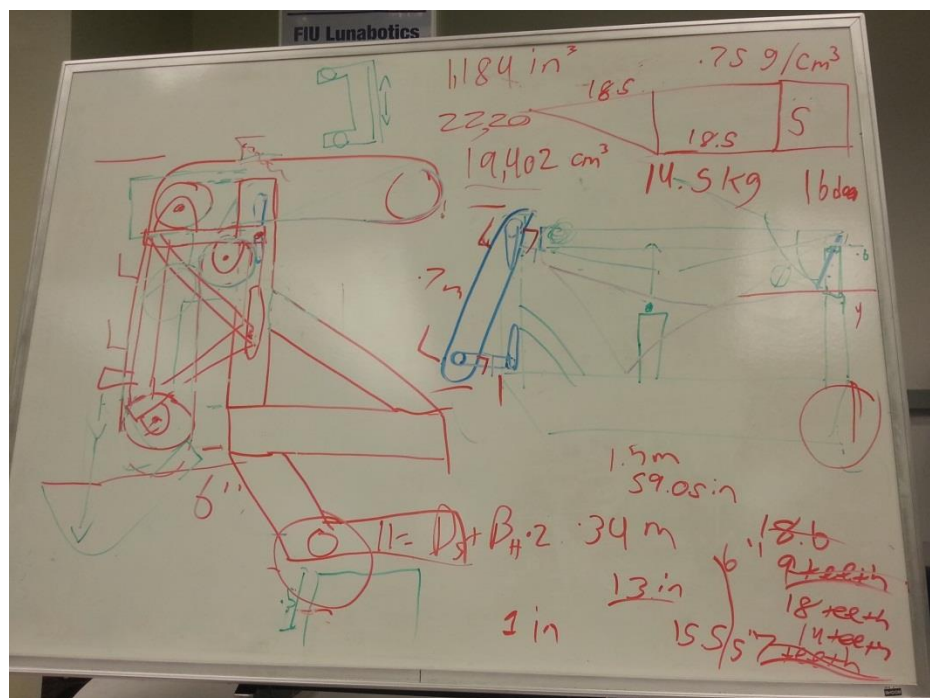
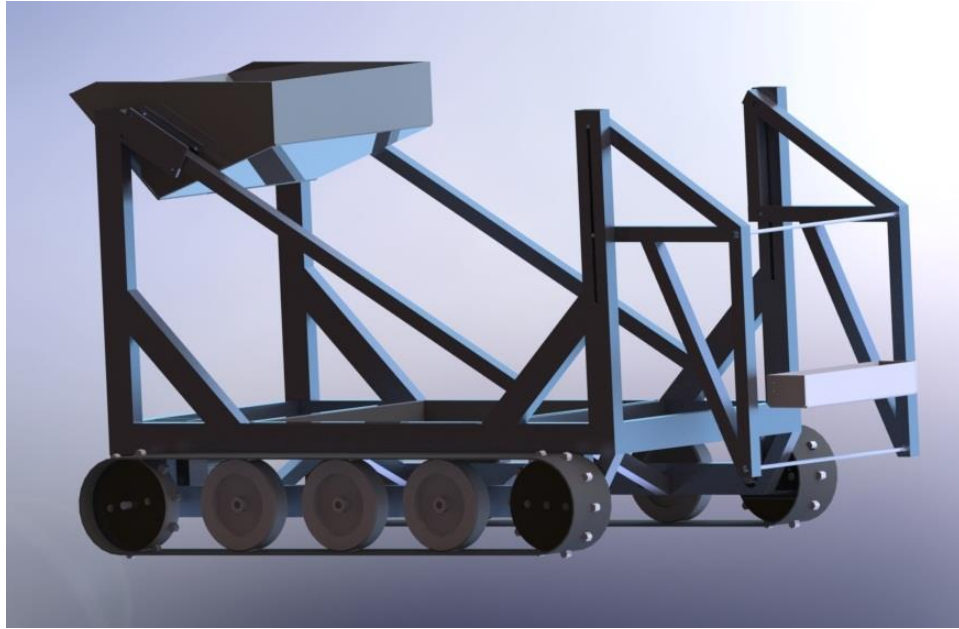


Figure 17: Fresh Ideas and Calculations

The second design ended up being too complex in the sense of making the loop return to make an L-shape; this required too many parts and possibly too much weight. Another issue that

caused some concern was whether the regolith in the bucket would fall out during the horizontal section and fall either into the returning buckets below, or just not in the bin. These issues were addressed in the final design. The collector was modified so that the buckets do not travel horizontally. Following the vertical segment of the collector is an inclined section. At the peak of the inclination the buckets turn and begin descending at an incline. It is during this turn that the buckets would release the regolith into a bin below. The collector would be attached to two actuators and guided by two vertical supports fixed to the base. Vertical travel would be controlled by the actuators with guided support from the supports. The collector should be able to dig 4 inches below ground level, therefore, that was the height used to determine the size of the bin possible with the buckets clearing the bin. The bin design is quite different from the previous designs; however, it incorporates some of the ideas. A Solidworks rendering of the design can be seen in Figure 18. The bin is sitting on the front of the base, below the descending buckets. The sides of the bin are attached to a diagonal rail using a combination of aluminum plates and roller bearings both above and below the rail. At the end of the rail a motored device will pull the bin up along the rails once it has been filled and is ready to dump. Once it reaches its final position at the top, the inclined back door of the bin will be opened to release the regolith. The height of the bin will be such that when the door is opened downwards, it will rest on the collection bin on the field and ensure the regolith travels into the large bin at the same angle as the floor of the bin on the robot.





**Figure 18: Final Collecting/Dumping Design**

## 4. Project Management

The task of the mining rover has been broken down by the various components that make up the robot. In addition, it has been further divided to account for design, analysis and justification for each component. The design and analysis tasks are separated because the team must verify that the ideas can work through calculations. The justification is the pricing of the component and is meant to prevent unnecessary spending and overspending. Implementing this type of role breakdown allows the project to be divided into mini-task. The Gantt chart shown in Figure 19 shows the completed and uncompleted task from the beginning to the day of competition with these mini-tasks in mind. The goal of the group was to meet up every Tuesday and Friday and take care of the mini-task that was assigned. The focus of the task assigned for this semester deal with the frame, the motor, the gearbox and the track system. Focusing on these components would ensure a prototype to be built by the end of the semester.

Table 2 shows how each member has been assigned his or her respective task and the breakdown of hours estimated to take to complete each task. Each member is required to do research and attend the meetings. The team meetings last on average two to three hours. Below Figure 20, Figure 21, Figure 22, and Figure 23 shows the timeline of events for the months of August to May. This timeline reflects the pace of the group and shows the progress and setbacks that the team faces. The days allotted allow the team to verify that the calculations work with the design and obtain a price that is within budget. If this were not met then the team would have to redesign and recalculate the analysis.

## 4.1 Timeline

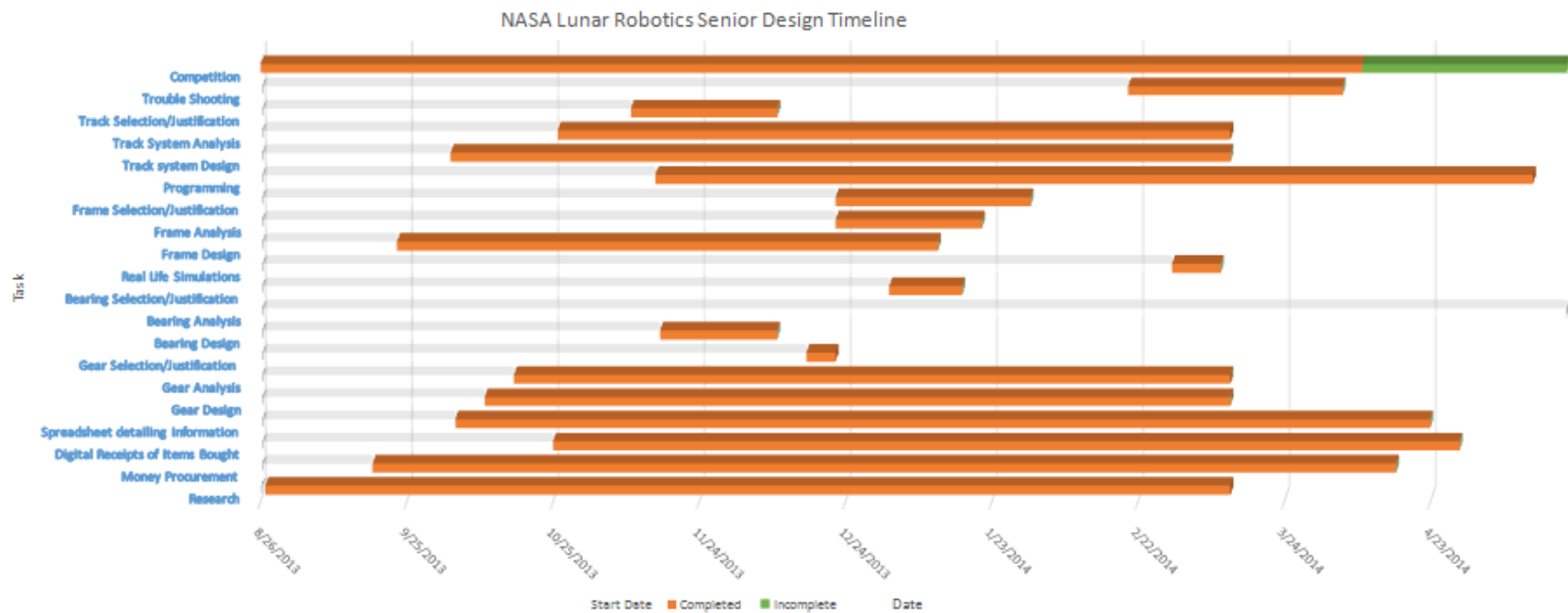


Figure 19: Timeline of Task for Project

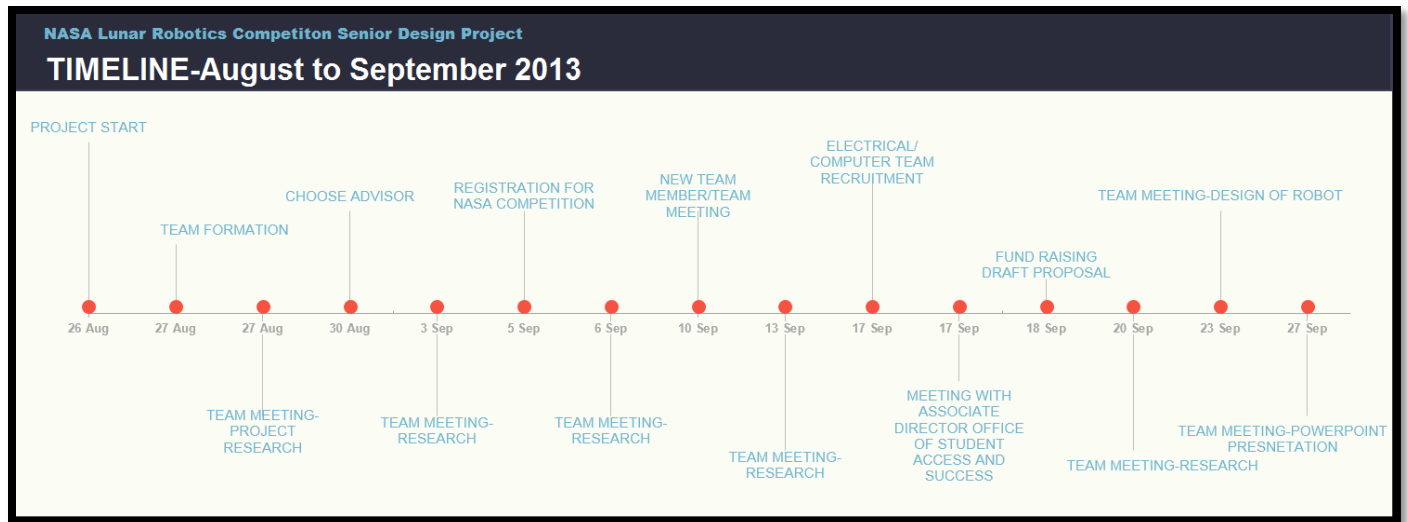


Figure 20: August to September 2013 Timeline

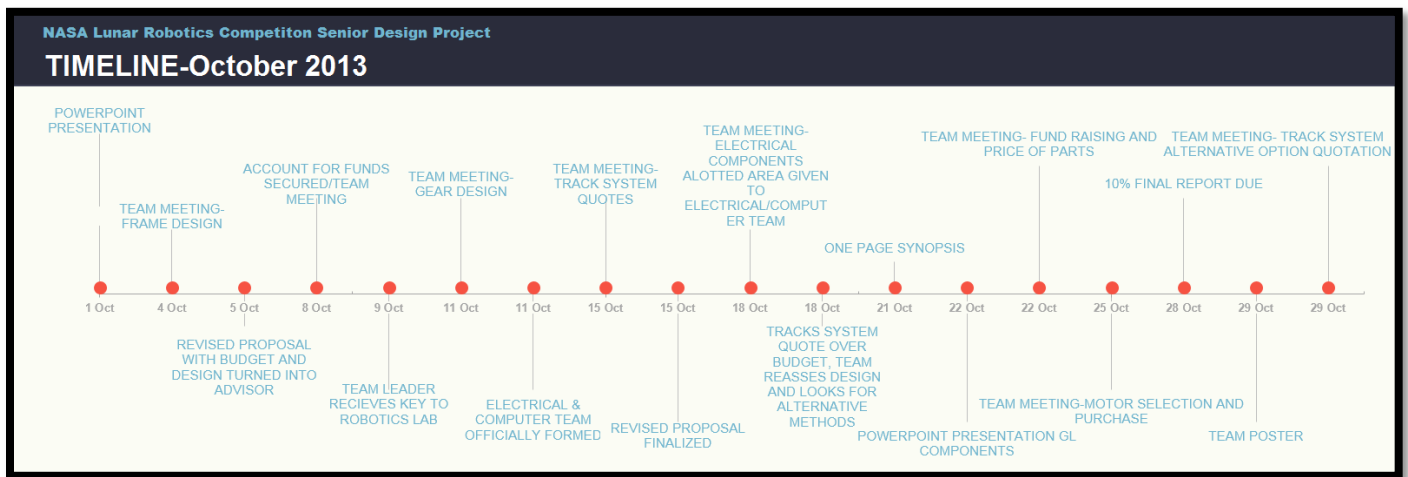


Figure 21: October 2013 Timeline



Figure 22: November to December 2013 Timeline

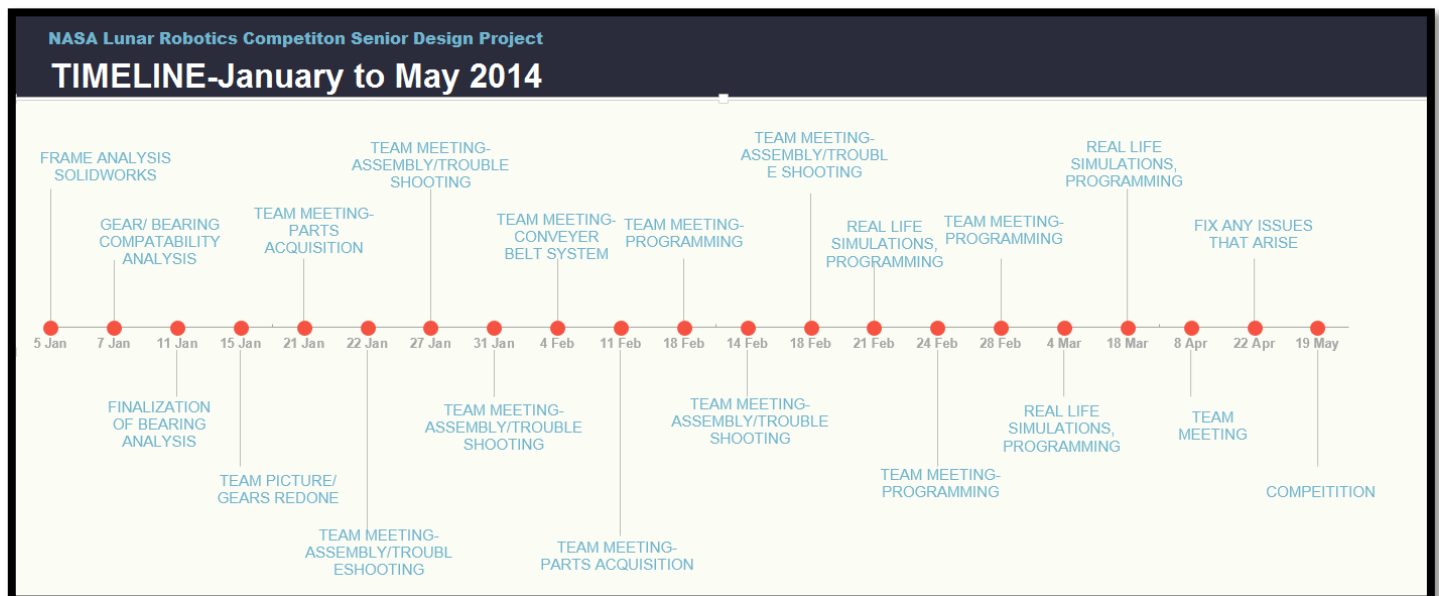


Figure 23: January to May 2014 Timeline

Table 2: Senior Design Project Task Breakdown

Senior Design Project Task Breakdown				
Task	Hours Spent per Member			
	Allotted Days	Ronald Portorreal	Matthew Koza	Sean Di Pasquale
Research	110	55	55	55
Money Procurement	111	50	5	5
Digital Receipts of Items Bought	113	5	5	5
Spreadsheet detailing information	133	5	5	10
Gear Design	75	15	5	5
Gear Analysis	63	10	5	5
Gear Selection/Justification	6	5	5	5
Bearing Design	24	5	5	15
Bearing Analysis	15	5	5	10
Bearing Selection/Justification	15	5	5	5
Real Life Simulations	30	30	30	30
Frame Design	111	5	15	5
Frame Analysis	30	5	5	10
Frame Selection/Justification	14	5	5	5
Programming	110	60	60	60
Track system Design	22	5	20	5
Track System Analysis	15	5	10	5
Track Selection/Justification	30	15	20	10
Trouble Shooting	90	90	90	90
Competition	7	25	25	25
Total time (hours)		405	380	365

## 5. Analytical Analysis

The design limitation of the lunar rover is the starting point for the analysis. There is a weight limit of 176 lbs. (80kg). In addition, it was estimated that 24 lbs. of regolith would be the max capacity of the lunar rover. Therefore, the maximum weight that needs to be designed for is 200 lbs. The diameter of the wheels was chosen to be 6 inches and the chosen desired speed was 3 feet per second. NASA did not provide any friction factor for the regolith (NASA, 2014) therefore a sand dune surface (MJB, 2013) was chosen to closely approximate the regolith. An angle of 15 degrees was chosen to be the maximum incline the lunar rover would experience. The Rolling Resistance Force was calculated with,

$$F_R = F_{Gross\ Weight} \times f_{Sand} \quad (1)$$

Next, the Gear Climb Force was calculated,

$$F_{Gear\ Climb} = F_{Gross\ Weight} \times \sin \theta_{Max\ Incline} \quad (2)$$

To add, the Acceleration Force was given by,

$$F_{Acceleration} = \frac{F_{Gross\ Weight} \times V_{desired\ speed}}{32.2 \frac{ft}{s^2} \times s_{acceleration\ time}} \quad (3)$$

This then allows the Total Tractive Effort to be computed by adding equations 1, 2, and 3. The total wheel torque can then be calculated under the worst possible conditions,

$$T_{Total\ wheel\ torque} = T_{Total\ Tractive\ Effort} \times RF_{Resistance\ Factor} \times R_{Radius\ of\ wheel} \quad (4)$$

Finally, dividing the Total Wheel Torque by 4 gives the torque required for each motor. A motor torque of 6.875 in-lb. was chosen and this resulted in a required 15-to-1 gear reduction ratio. Table 3 shows the results of these calculations.

**Table 3: Torque and Gear Ratio Calculations**

Gross Weight (lb)		Wheel Radius (in)	Desired Speed (ft/s)	Weight on Each Wheel (lb)	
200		3	3	50	
Total Tractive Effort (lb-ft)		Grade Climb Force	Acceleration Force	Rolling Resistance Force	
121.08		51.76	9.32	60.00	
Total Wheel Torque (in-lb)		Max Incline (Degrees)	Acceleration Time (s)	Individual Wheel Torque	
417.73		15	2	104.43	in-lb.
Motor Torque		Resistance Factor	Surface	Required Minimum Gear Ratio	
110	oz-in	1.15	0.3	15.19	
6.875	in-lb				

Contact Surface	C <sub>rr</sub>
Concrete (good / fair / poor)	.010 / .015 / .020
Asphalt (good / fair / poor)	.012 / .017 / .022
Macadam (good/fair/poor)	.015 / .022 / .037
Snow (2 inch / 4 inch)	.025 / .037
Dirt (smooth / sandy)	.025 / .037
Mud (firm / medium / soft)	.037 / .090 / .150
Grass (firm / soft)	.055 / .075
Sand (firm / soft / dune)	.060 / .150 / .300

**Figure 24: Contact Surface Breakdown (MJB, 2013)**



Once the gear reduction ratio was calculated at 15 to 1 then the gear analysis can be performed. Due to space limitations a 32 pitch gearing system was chosen because it provides a flexible gearing setup with a 20 degree pressure angle which is standard. The gear reduction was divided into two parts, a 5 to 1 then a 3 to 1 reduction. This would require four gears total. The first calculation performed was the interference of the gears using,

$$N_p = \frac{2k}{(1+2m)\sin^2\phi} (m + \sqrt{m^2 + (1 + 2m)\sin^2\phi}) \quad (5)$$

This gave the minimum teeth of 16 shown in Figure 4 with different ratio calculations. The largest gear that can be used is 101 teeth. The SDP/SI Company was used to acquire the gears. They came in 16, 48 and 80 teeth (see Appendix C Figure 78). The start of the gear analysis will focus on the pinion because it is the gear that is most likely to fail first due to its size and the fact that it is directly attached to the motor. The first thing that must be done is to calculate the Transmitted load for the normal load and max load,

$$W_t = \frac{2T}{d} \quad (6)$$

The SDP/SI Company will provide the d, P, F, Pressure angle, and material of gear. To calculate the Lewis Bending Equation we need to obtain the Lewis Form Factor  $Y_N$  from Table 14-2 of Shigley's Mechanical Engineering Design Book. The Lewis Bending Equation can then be used for normal and max loads,

$$\sigma = \frac{W_t P}{F Y} \quad (7)$$

The next part of the analysis involves the calculation of the Factor of Safety, but before we can perform the calculation we must first find some information pertinent to the equation. The Factor of Safety equation requires the allowable strength to be known but not enough

information is provided by the manufacturer to obtain this. Therefore, “it is reasonable to estimate an allowable strength as ..., one third of the material’s ultimate tensile strength”. (Dornfeld, 2004). The ultimate tensile strength is not known but can be easily found. The 303 Stainless Steel has an ultimate strength 89900 psi, while the 2024 Aluminum anodized is 57300 psi. (MatWeb, 2013) (MatWeb, 2013) Additionally, the terms  $Y_N$ ,  $K_T$  and  $K_R$  must be obtained. They are found in Shigley’s Mechanical Engineering Design Book pages 762-764. With this information the Factor of Safety can finally be computed with,

$$S_F = \frac{S_t Y_N / (K_T K_R)}{\sigma} \quad (9)$$

Table 6 shows that both materials pass the Factor of Safety at the normal load but at max load the 2024 Aluminum anodized fails. This can be resolved by reducing the cycle of  $Y_N$  from  $10^7$  to  $10^4$ . The cycle for  $Y_N$  chosen is the standard therefore it will not be changed. The gear analysis is yet to be completed but it must stop at this point because there is insufficient data to continue with the gear contact stress. The reason for this is because very little is known about the materials.

**Table 4: Interference**

Interference				
m	k	1		
	Np1	Np1	Ng1	Ng1
1	12.32313	13	16.45061	16
2	14.16077	15	45.48881	45
3	14.98089	15	45.48881	45
4	15.4436	16	101.0707	101
5	15.74047	16	101.0707	101

Table 5: Motor Power

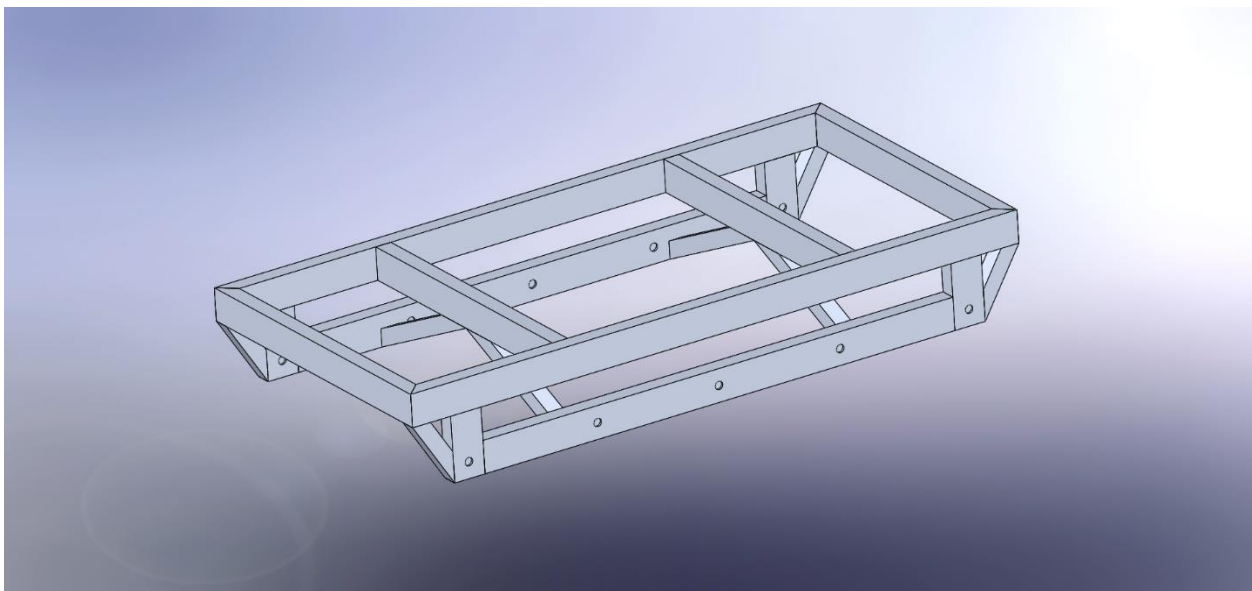
Motor Power				
337 2655	W	Torque		
	rpm	Normal Load	Max Power	
		110	171.7	in.-oz.
		6.875	10.73125	in-lb.
		3500	2655	rpm
	Wt.	27.5	42.925	lb.

Table 6: Gear Analysis

Gear Analysis			Units
N	16	16	
Gear Material	303 Stainless Steel	2024 Aluminum Anodized	
Pressure Angle	20	20	degrees
P	32	32	
F	0.1875	0.1875	in
dp	0.5	0.5	in
Y	0.3	0.3	
Wt. Chosen Load	27.5	27.5	lb.
Wt. Max Load	42.925	42.925	lb.
V	347.54	347.54	ft./min
H	0.45	0.45	Hp.
SF at Chosen load	1.92	1.22	
SF at max load	1.23	0.78	
$\sigma$ Chosen Load (Bending Stress) (Lewis Bending Eq.)	15644.44	15644.44	psi
$\sigma$ Max Load (Bending Stress)	24419.56	24419.56	psi

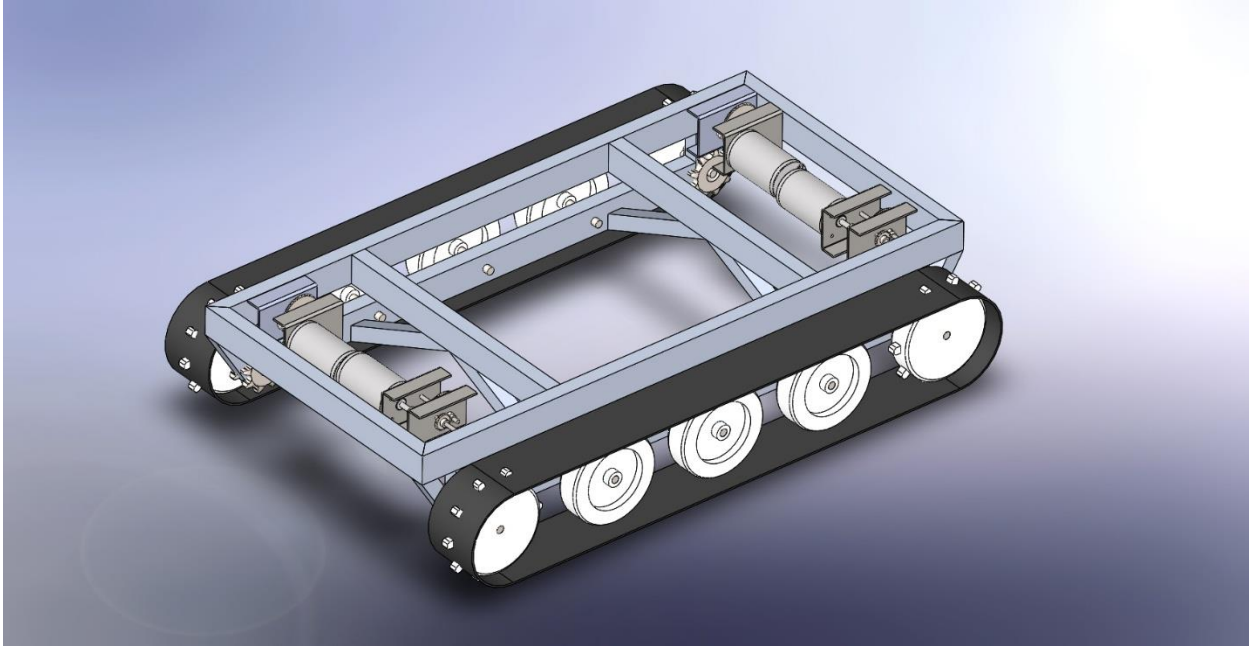
## 6. Major Components

The frame of the rover, Figure 25 , is composed of 6061 aluminum tube with 0.125 in wall. Aluminum tube was chosen due to its high strength to weight ratio, while taking cost into factor. The major portions of the frame are made of 2x1 in rectangular tubing while several of the smaller supports are made of 1x1 in square tubes. All of the aluminum in the frame has a T-6 temper rating, providing the highest maximum tensile strength within 6061 alloys.



**Figure 25: Frame**

The drive train, Figure 26, is mounted directly to the bottom rails of the frame. The drive train consists of 4 CIM motors, Figure 18. These motors are then put into individual speed reduction gearboxes containing a 15:1 ratio. The output shafts of the gearboxes then drive the tread system. The tread system is driven by 4 custom machined drive sprockets. These drive sprockets are made of UHMW and are engineered specifically to work with the hole pattern in the treads provided by Superdroid Robots, Figure 28.



**Figure 26: Frame, Drive train, idlers, pulleys and threads**



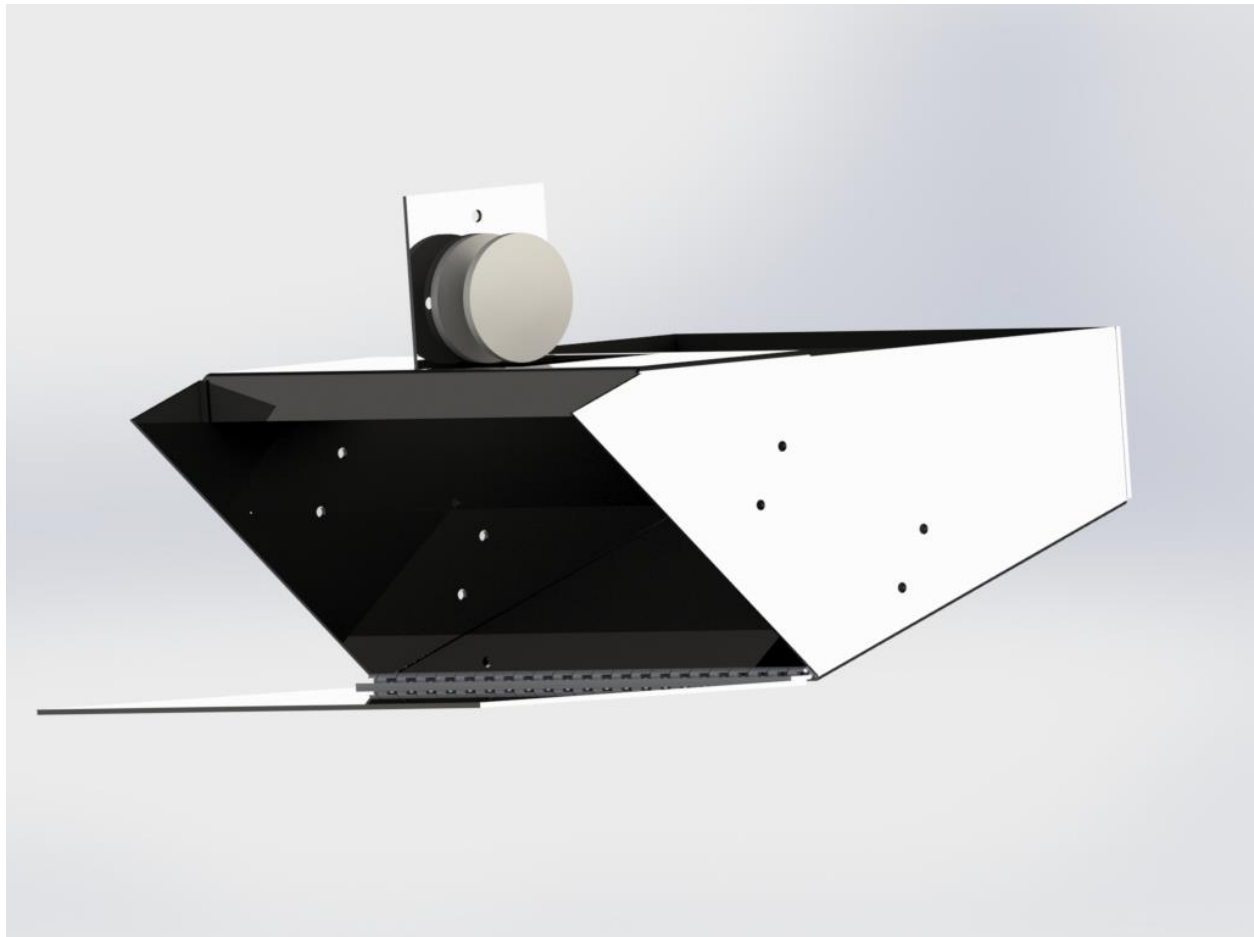
**Figure 27: CIM Motor**



Figure 28: Threads

The collector bin, Figure 29, was designed to hold a volume of regolith roughly double the maximum amount of the desired load. The collector bin is located at the rear of the rover and is set on a frame with a hinge located at the top of the bin. This hinge allows the collection bin to pivot at a point slightly higher than the height of the bin required to deposit the regolith. This allows the design to eliminate a point of mobility (moving the collection bin higher for depositing the regolith). The collector bin itself is composed of a single bent sheet of ACM (Aluminum Composite Material). ACM is a 0.125 in thick sheet comprised of a 0.0625 in sheet of plastic sandwiched between two 0.03125 in sheets of aluminum. This material is designed to

be easily bent into shape using just a router to remove the surface layer of aluminum. After a final shape has been achieved, it can be fastened together to form a rigid body.



**Figure 29: Collector Bin**

The collection mechanism, Figure 30, is a continuously running conveyor bucket system used for collecting the regolith and placing it into the collector bin. The mechanism consists of two ANSI #40 hollow pin roller chains and one ANSI #40 roller chain, Figure 31, spaced evenly along the chain. The buckets comprised of ACM formed into bucket shapes. These buckets are to be bolted to the connection links using 8-32 screws at 1.25 in length. The mechanism has an angled return at the top to ensure that the regolith falls squarely into the collection bin when the bucket is flipped and no regolith is accidently deposited outside of the bin's footprint.



**Figure 30: Collection Mechanism**



**Figure 31: ANSI #40 Hollow Pin Chain (Left) and ANSI #40 Chain (Right)**



## 6.1 Electrical Components

### 6.1.1 Microcontroller

The first objective of the electrical/computer team was to identify a computer processor that will handle part or all the computations needed by the mining robot. Before the electrical /computer team joined the MEC Panthers, the mechanical group chose the Raspberry Pi as a possible computer processing unit (CPU). This CPU operates at 700 MHz (Mega Hertz) with 512 Mb of RAM (Random Access Memory). (Raspberry Pi, 2014) That made it an ideal choice for the project and additionally it came equipped with a USB hub, pins outs for any sensors, and runs on the Linux operating systems. The major fault of the CPU was later noticed when the mechanical and electrical/computer group were programming to do some basic test. During this time, the Raspberry Pi was found to be very unstable and it was then decided to change to another CPU.

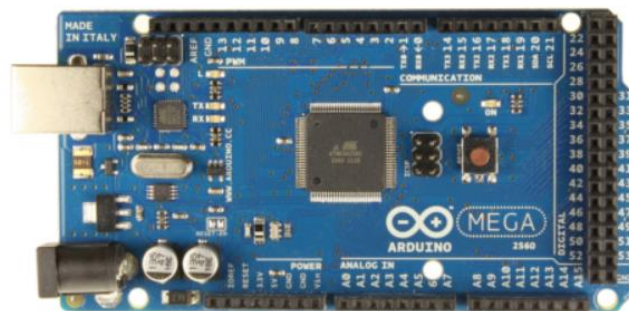


Figure 32: Raspberry Pi

The team has looked at many CPU and microcontrollers. Table 7 shows a list of the top three choices the group has looked at. Figure 33, Figure 34, and Figure 35 show the different boards that are being considered. (Amazon, 2014) (Arduino, 2014) (GE tech wiki, 2013). Ultimately, the Arduino Mega 2560 and the Arduino Uno (a smaller version of the mega) was used in conjunction to do the programming.

**Table 7: Microcontroller Comparison**

Microcontroller Comparison								
CPU/Microcontroller	Clock Speed	Pin IO	UART(serial ports)	Analog Pin	USB	Pin Output Voltage	Expandable	Price
Arduino Mega 2560	16 MHz	54	4	16	Yes-1	5V	Yes	\$33.99
Intel Galileo	400 MHz	14	2	6	Yes-1 micro	5V or 3.3V	Yes	\$59.99
Iduino DUE	84 MHz	54	4	12	Yes-1	3.3V	Yes	\$45.00



**Figure 33: Arduino MEGA**

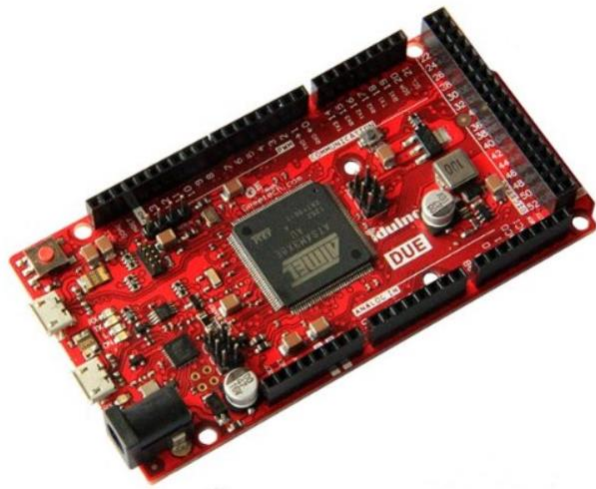


Figure 34: Iduino DUE



Figure 35: Intel Galileo

### 6.1.2 Sensors

The sensors that will be used are infrared sensors that can detect distances. They will be paired into long and short range and will surround the robot. These sensors will help tell distances and keep the robot from crashing into obstacles. The figure below shows the sensors. The long-range sensors have a range of about 8 to 60 in while the short-range sensors have a range of about 4 to 31 in. (Sharp, 2013) (Sharp, 2001)



Figure 36: Infrared Sensor

### 6.1.3 Camera

The camera used will be the CMUcam4 and it is open source and re-programmable. This allows the team to make the necessary changes needed. Additionally the camera has a built in servo control. The cameras main function is to detect a predetermined color. This will be the key component to achieving the full autonomy.(Cmucam, 2012)

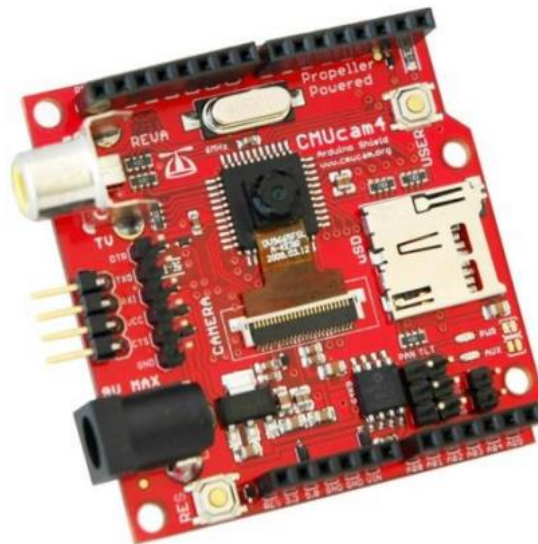


Figure 37: CMUcam4 (camera)

#### 6.1.4 Battery

The batteries that will be used are Thunder power 14.8 V 8-amp hour batteries. They will be mounted close to the motor controllers as suggested by Orion robotics, makers of the motor controllers. The batteries belong to the 2012 Pantera team. Figure 38 shows one of the two batteries that will be used in the robot. (Thunder Power, 2014)



Figure 38: 8Ah 14.8V Battery

### 6.1.5 Motor Controller

The first motor controller chosen to run the four track motors will be Roboclaw 2X60 Amp motor controllers. Figure 39 shows the motor controller that will be used. (Orionrobotics, 2014). The second motor controller chosen by the mechanical team to run the same motors are the Vex Victor 888 motor controllers shown below. They are capable of handling the voltage spike of the motors unlike the Roboclaw chosen by the electrical team. More information about this can be found in Section 11. Testing.

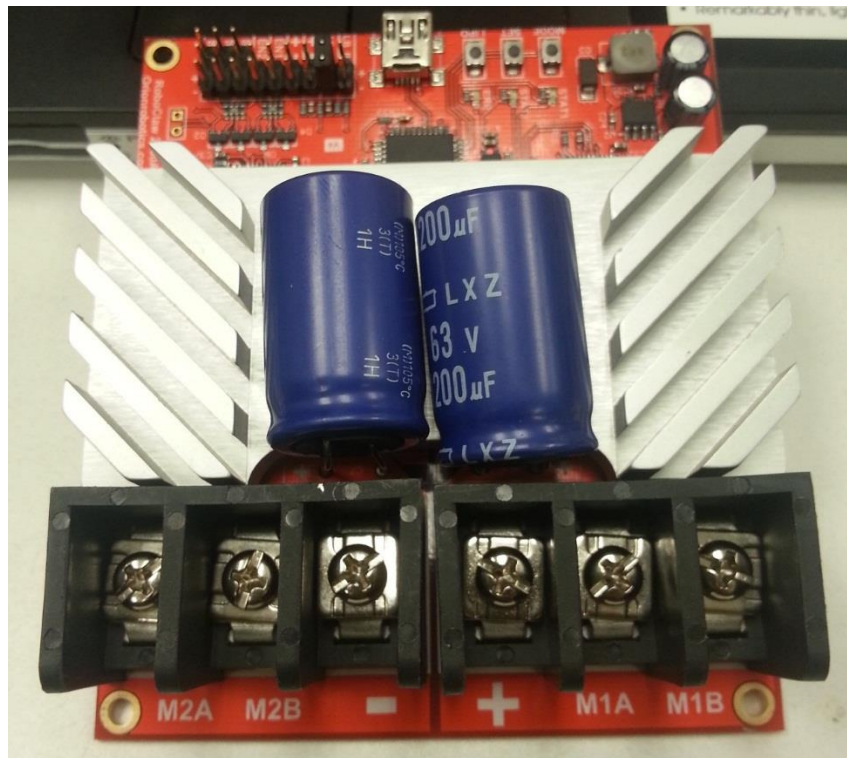


Figure 39: Roboclaw 2X60A Motor controller





Figure 40: Vex Victor 888 Motor controllers

### 6.1.6 Router

The router to be used will be a Linksys router common in many households. It conforms to the NASA requirement of USA IEEE 802.11 b/g standard (NASA, 2014). Figure 41 shows the router and the two antennae that will be placed on the highest points of the robot to ensure signal is never lost during normal operations. (Linksys, 2014)



Figure 41: Linksys Router

### 6.1.7 Electrical Wiring Diagram

The lunar rover will employ 4 vex motor controller that will handle the drive train.

The electrical team created an electrical diagram for the rest of the moving components including the Arduino mega and the CMUCAM 4, Figure 42 shows that diagram. The top portion of the rover has simple moving parts. Therefore, the electrical team decided to use simple relays that turn power off and on with the Arduino mega deciding when that happens.



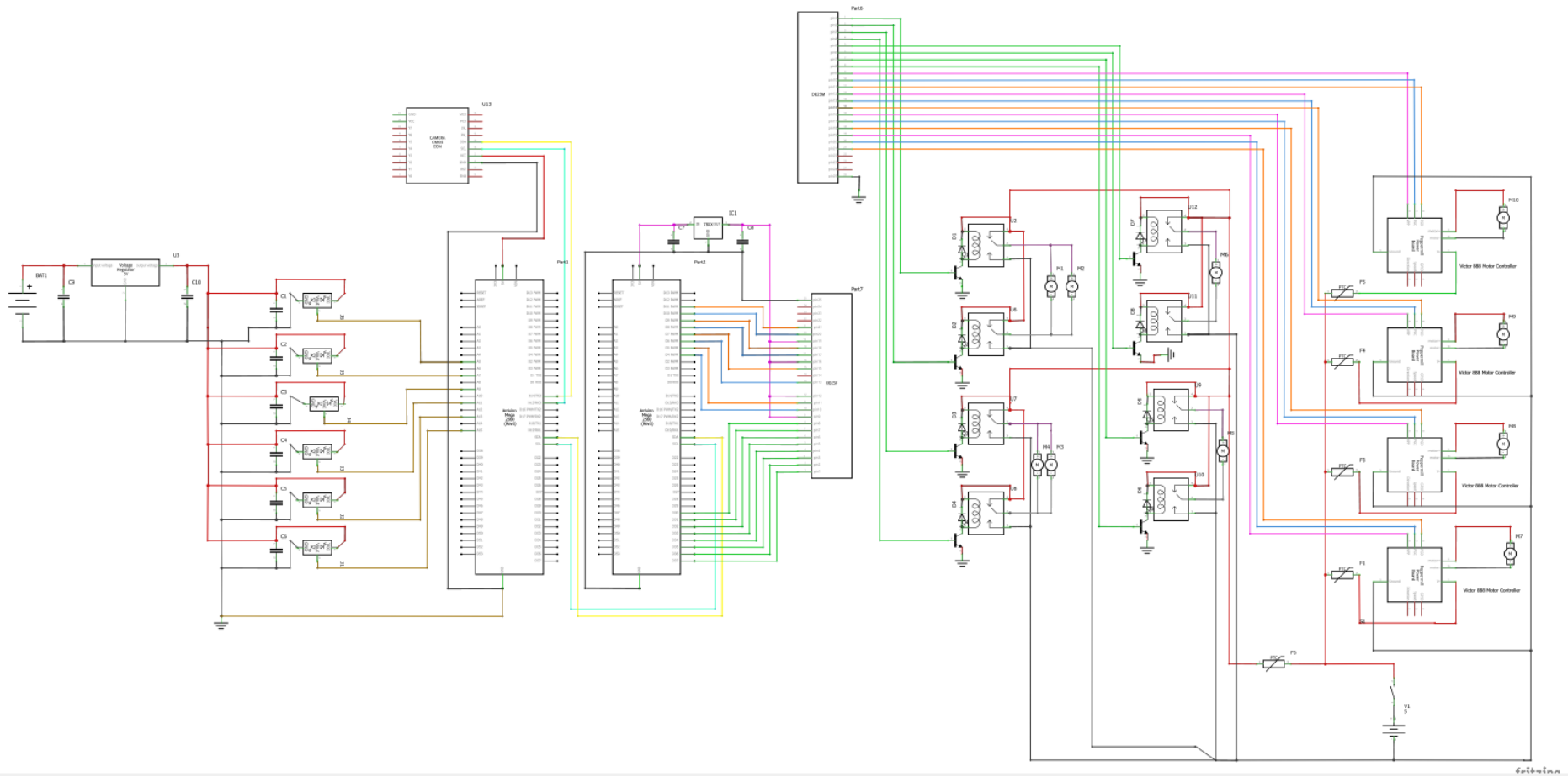
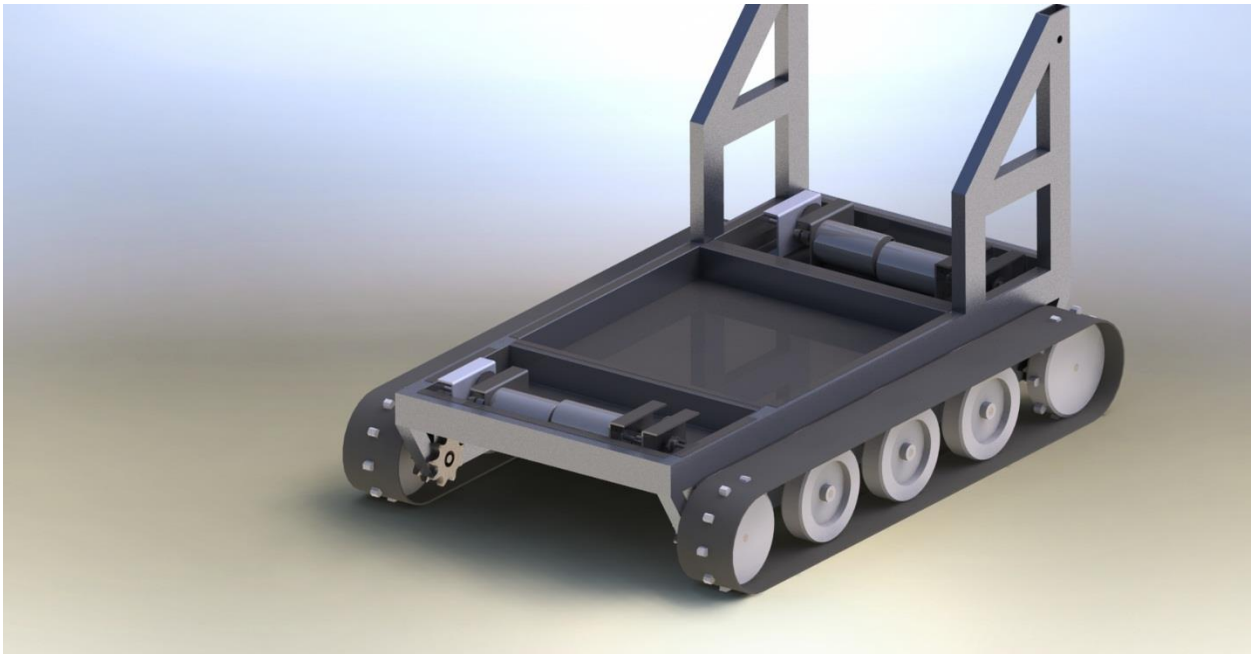


Figure 42: By Adelkis Rodriguez, Electrical Team Leader

## 7. Structural Design

An important aspect of creating an effective rover is optimizing as much of the design as possible. The structure of the rover is an area of the design where the framework layout, material and volume can be optimized to meet goals and standards. The base of the frame was constructed of 6061 aluminum 0.125 thick tubing. In order to lower the total weight of the frame significantly, aluminum tubing rather than solid aluminum was used. This decision was made due to the fact that the aluminum tubing would be strong enough to withstand the operating conditions of the rover. The aluminum frame will be welded together giving a simple, clean, sealed form of bonding.



**Figure 43: Structure of Rover**

As a result of limitations regarding the size of the track treads, the frame had to be slightly sized down from the original desired length of 1.5 m to 1.016 m and a width of 0.508 m. Supports were placed at two locations evenly spaced at the top of the base. Also, two angled

supports connect the top supports with the bottom longitudinal tubes at the bottom of the base. The implementation of the supports allows the base to remain rigid as well as support the loading of the components and collected regolith. In between the top supports are cavities that will serve as compartments in which the computer and electrical components will be housed as well as the motors and gearboxes for each driving pulley. Utilizing the open spaces left in the base of the frame, the components are maintained within the base of the frame keeping the frame balanced. Another advantage is that the bulk of the weight of the frame will be kept at the base lowering the center of gravity. Implementing these minor revisions, the structural design of the rover contributes to the ultimate goal of an efficiently functioning rover.

## 8. Cost Analysis

At the beginning of the project a budget was formed that tried to estimate the cost of the lunar rover. Table 10 shows a list of parts and prices associated with them and if the item has been purchased. At the beginning of the project, the initial estimated cost of the lunar rover was \$4970 . This number is half of what the previous team had spent. A letter of proposal was made to attract potential sponsors for the competition (see Appendix A: Figure 69 and Figure 70). This type of fund raising was unsuccessful and therefore other means of funding was sought.

The next type of funding sought was to more direct by selling shirts. We employed the help of Dr. Benjamin Boesl to give the M.E.C. Panthers access to a tax exempt account. This allowed the group to create a shirt on booster.com. A goal of 100 shirts was set and through social media advertisement of our team shirt began. In addition, flyers were made and distributed locally (see Appendix B: Figure 71, Figure 72, Figure 73). A total of 55 shirts were sold yielding \$600. An estimated cost of total hours spent was conducted using the national mean hourly wage for mechanical engineers. (Bureau of Labor Statistics, 2012) The total cost was \$46,863 with 1150 man hours used.

The final cost of this project is estimated to be \$6,110.08. A total of \$800 was raised for funding not including funding that will come from NASA at the end of April. Although, the budget is at 6110.08, 1005.22 was donated or borrowed, \$800 was fund raised and only \$4,554.86 was actually spent by the group. There was also machine work done that was done free or at a huge discount than normal. This work if actually calculated could put the budget well over \$8000.

Table 8: Labor Cost

Engineers	Hours Spent	Hourly Mean Wage	
Ronald Portorreal	405	\$41	\$16,504
Matthew Koza	380	\$41	\$15,485
Sean Di Pasquale	365	\$41	\$14,874
<b>Total Labor Cost</b>	1150		\$46,863

Table 9: M.E.C. Panthers Lunar Mining Robot Budget

M.E.C. Panthers Senior Design Project Budget						
Item	Price	Ship	Qty	Total Cost	Bought	Purchaser
2.5inch CIM, Brushed DC Motor AM802-001A	\$25.00	\$15.49	4	\$115.49	Yes	Matthew
Threads	\$580.63	\$0.00	1	\$580.63	Yes	Matthew
Chassis aluminum 6061 2X1X0.125	\$122.09	\$0.00	1	\$122.09	Yes	Ronald
Linksys Router	\$49.99	\$0.00	1	\$49.99	Yes	Juan
Poster Board	\$142.03	\$0.00	1	\$142.03	Yes	Ronald
Gearbox Housing	\$11.78	\$18.84	4	\$65.96	Yes	Matthew
Gears (32 Pitch 16T,60T,64T)	\$378.04	\$12.74	16	\$390.78	Yes	Ronald
Welding and Cutting of frame	\$120.00	\$0.00	1	\$120.00	Yes	Sean
Pixy CmuCam4	\$99.95	\$0.00	1	\$99.95	Yes	Adelkis
Wristbands	\$177.92	\$0.00	300	\$177.92	Yes	Group
Idlers	\$28.85	\$0.00	1	\$28.85	Yes	Matthew
Motor Controllers	\$169.99	\$0.00	2	\$339.98	Yes	Raul & Jorge

2XSharp GP2Y0A41SK0F Analog Distance Sensor 4-30cm & 6X3-Pin Female JST PH-Style Cable (30 cm) with Male Pins for 0.1" Housings	\$27.40	\$5.95	8	\$33.35	Yes	Virgil
4XSharp GP2Y0A21YK0F Analog Distance Sensor 10-80cm	\$39.80	\$4.95	4	\$44.75	Yes	Virgil
4XSharp GP2Y0A02YK0F Infrared IR Range Sensor (20-150cm)	\$45.04	\$0.00	4	\$45.04	Yes	Virgil
0.25 inch drill bit and fasteners	\$18.40	\$0.00	1	\$18.40	Yes	Sean
Round Rod , Rivets, Hex bolt, spacer nylon, wire rope, eye bolt	\$28.60	\$0.00	1	\$28.60	Yes	Sean
Bearings .5" and .25"	\$141.84	\$5.00	36	\$146.84	Yes	Juan
WJB WZ 1/2 72 L Linear Shaft, Carbon Steel, Inch, 1/2" Diameter, 0.4995" Diameter Tolerance, 72" Length	\$38.90	\$0.00	1	\$38.90	Yes	Sean
WJB WZ 1/4 36 L Linear Shaft, Carbon Steel, Inch, 1/4" Diameter, 0.2495" Diameter Tolerance, 36" Length	\$19.49	\$0.00	1	\$19.49	Yes	Sean
Arduino Mega	\$39.95	\$0.00	1	\$39.95	Yes	Adelkis
45' #18 Solid UL	\$8.55	\$0.00	1	\$8.55	Yes	Adelkis
6 inch stroke Linear Actuators	\$219.99	\$24.81	2	\$244.80	Yes	Ronald
Aluminum plate, round shaft, and steel round shaft	\$23.95	\$0.00	4	\$23.95	Yes	Ronald
.125 Wall 6061-T6 8ft	\$30.50	\$0.00	1	\$32.64	Yes	Ronald
Custom Conveyer Belt Frame & Bucket frame	\$85.98	\$24.87	16	\$110.85	Yes	Ronald
Welding of Conveyer Belt Frame & Bucket frame	\$120.00	\$0.00	1	\$120.00	Yes	Sean
10 Ball Bearing R188-2RS RS .25 inch x .5 inch x.1875	\$23.94	\$0.00	2	\$47.88	Yes	Matthew
Lot 20 Flanged Bearing FR8RS .5 inch x 1.125 inch	\$55.55	\$0.00	1	\$55.55	Yes	Matthew
10 Flanged FR4ZZ .25 inch x .625 inch FR4Z inch Miniature Ball Radius Bearing	\$37.00	\$0.00	2	\$74.00	Yes	Matthew
UHMW Plastic Sheet Jig Stock .25 x 4 x 48 inch	\$15.00	\$11.90	1	\$26.90	Yes	Matthew
AME 214 series Gear motor	\$39.39	\$22.17	2	\$100.95	Yes	Matthew
AME 210 series 12V 88 in-lb RH&LH gear motor	\$39.49	\$41.67	2	\$120.65	Yes	Matthew
Fasteners, threaded rod and hinge continuous	\$24.63	\$0.00	1	\$24.63	Yes	Matthew
ANSI 40B15 & ANSI 40B12 Steel Sprocket	\$137.80	\$0.00	8	\$137.80	Yes	Ronald
Seed Ethernet Shield	\$19.25	\$0.00	1	\$19.25	Yes	Raul
100CT BLK 8 inch 50lb screw mount, .125 drill bit, fasteners	\$36.72	\$0.00	1	\$36.72	Yes	Matthew

#40 Hollow Pin Roller Chain, #40 Connecting Link	\$57.46	\$7.99	1	\$65.45	Yes	Sean
Fasteners, Grease, Split lock washers	\$17.52	\$0.00	116	\$17.52	Yes	Matthew
UHMV Plastic Sheet Jig Stock .25X4x48 inch	\$15.00	\$11.90	1	\$26.90	Yes	Matthew
Chip-Clearing Cobalt Steel Jobbers Drill Bit	\$9.56	\$5.30	2	\$14.86	Yes	Ronald
Hex Key, 0.375 rod, angle aluminum, eye w/nut, fasteners	\$57.45	\$0.00	1	\$57.45	Yes	Matthew
Miniature TTL JPEG Camera with NTSC Video	\$35.95	\$12.38	1	\$48.33	Yes	Sean
40A Circuit Breaker , 150A Circuit Breaker	\$47.03	\$0.00	5	\$47.03	Yes	Adelkis
Solder Plug, Perfboard, 125VAC15A relay, Solder jack	\$20.24	\$0.00	6	\$20.24	Yes	Adelkis
SUBD Socket, SUBD Plug	\$5.86	\$0.00	2	\$5.86	Yes	Adelkis
Adjustable Reamer, 39/64 Drill	\$28.11	\$0.00	2	\$28.11	Yes	Ronald
10ft 40 Chain, Roller	\$51.75	\$0.00	0	\$55.38	Yes	Ronald
Vex 888 Motor Controller	\$59.99	\$12.17	4	\$252.13	Yes	Sean
WS Deans	\$16.03	\$0.00	2	\$16.03	Yes	Virgil
eye bolt, 12 solid thin black 1ft, Machine screw, AA battery	\$17.45	\$0.00	4	\$17.45	Yes	Virgil
Fasteners	\$13.36	\$0.00	49	\$13.36	Yes	Ronald
2X11/64 Drill bit, 100X #8-32 screw, 100X nylon lock nut, punch prick, offset screwdriver, 8X #6-32 set screws	\$34.65	\$0.00	1	\$34.65	Yes	Ronald
Thunderpower 14.8V 8AH batteries	\$367.05	\$0.00	2	\$734.10	Yes	Lent by Janet
Gearbox 2-Left, 2-Right	\$30.00	\$0.00	4	\$120.00	Yes	Funds Raised
Shaft Adapter(gearbox)	\$8.75	\$0.00	4	\$35.00	Yes	Funds Raised
Gears(bore and press bushings)	\$140.00	\$0.00	4	\$140.00	Yes	Funds Raised
Shaft Adapter(pulley)	\$90.00	\$0.00	3	\$90.00	Yes	Funds Raised
Gear (bore ID)	\$20.00	\$0.00	1	\$20.00	Yes	Funds Raised
Pulley	\$29.00	\$0.00	5	\$145.00	Yes	Funds Raised
UHMW 6.5 inch diameter	\$101.00	\$0.00	1	\$101.00	Yes	Donated
UHMW 2 & 5 inch diameter	\$8.76	\$0.00	1	\$8.76	Yes	Donated
UHMW 5 inch diameter	\$46.36	\$0.00	1	\$46.36	Yes	Donated
ACM (Aluminum Composite Material 17.8 ft^2)	\$115.00	\$0.00	1	\$115.00	Yes	Donated
<b>Funds Spent</b>	<b>Final Cost</b>		<b>Personal Funds Spent</b>	<b>Funds Raised</b>	<b>Donated or Lent</b>	
<b>\$5,104.86</b>	<b>\$6,110.08</b>		<b>\$4,554.86</b>	<b>\$794.00</b>	<b>\$1,005.22</b>	

## 9. Prototype Construction

### 9.1 Description of Prototype

The M.E.C. Panthers Lunar Mining Robot is a rover that can collect regolith and return it to a specified location. It uses six motors and two actuators to perform its duties. The four motors are used to run the tracks and one motor is used for the conveyer bucket system. The two actuators move the conveyer bucket system and the collector bin. The collector bin is placed on top of the frame on which it rotates about a point above 0.5 meters. The conveyer bucket system is placed in front of the rover. The conveyer bucket system works by moving buckets in a closed loop. The buckets are designed to pick up regolith and hold onto it until they reach the apex, from which the regolith is deposited into the collector bin. The frame is aluminum 6061 and the internal components are protected by a plastic sheet and sealed. The internal components include motors, circuit boards, router, motor controllers, micro-controller, wires, fans, heat sinks, a router, and batteries. The rover will be able to perform functions autonomously or by remote control. The rover also has a camera that can detect colors, track objects and determine distance through pixels with advanced programming.

### 9.2 Prototype Cost analysis

The estimated price of the project is \$6110. Currently an extra 23% of the budget has been spent. The initial budget was, for all purposes a guess at what the project should take to build, taking into account the previous team's budget and what was felt to be the right price. Some parts of the project could not be given a dollar value but if it was would exceed \$8000 due to the fact that the welding, machine work done was greatly discounted or free.



Table 10 shows the price for the track system from highest to lowest and shows the savings by changing the manufacturer. By using Superdroid threads and building our own pulleys we bring down the cost to something that we can manage. Our first choice was to go with Brecoflex but the price determined the outcome of our choices.

**Table 10: Savings Analysis**

Savings Analysis			
<b>1</b>	Brecoflex Pulleys & threads	\$10,000.00	2 versus 1 Savings
			568%
<b>2</b>	Superdroid Robots pulleys and threads	\$1,760.00	3 versus 1 savings
			1316%
<b>3</b>	Superdroid Robots threads only	\$560.00	3 versus 2 savings
	Pulleys custom built	\$200.00	232%
	Total	\$760.00	

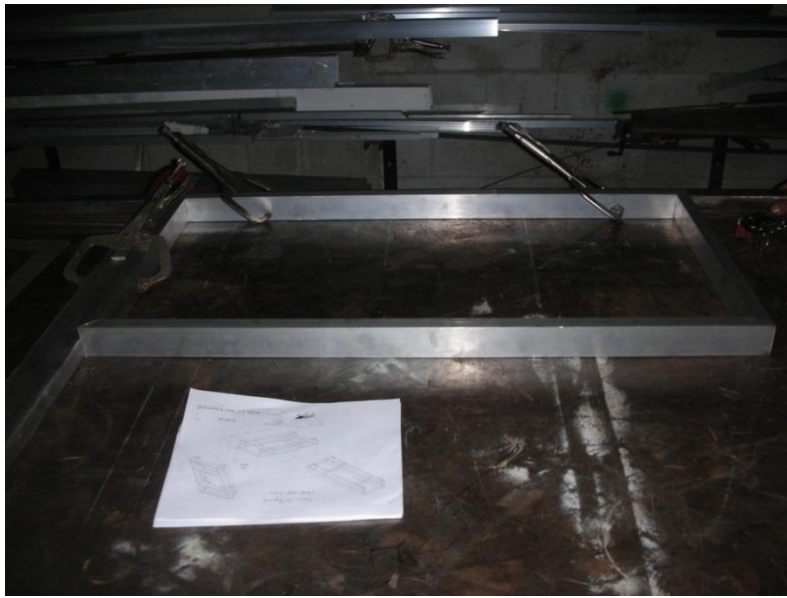
### 9.3 Prototype Fabrication

Once the decision was made regarding the final component design of the M.E.C. Panther rover, the purchasing of materials and construction of the prototype was underway. The constructions of the mechanical aspects of the rover were assembled starting from the bottom and progressing to the upper components. The material for the base of the frame, the gearbox, the drive sprockets, the threads

The threads and idle rollers were stock items that did not need to be modified after purchase. Therefore the first component requiring fabrication was the base frame of the rover. As previously discussed, 1x2x0.125 in aluminum 6061 and 1x1x0.125 in aluminum 6061 tubing was used to construct the base. Due to the fact that most of the rover's weight and components

would be resting on the base, welding was chosen as the fastening process. Welding the base together would provide the strength and rigidity desired to withstand the both the static and dynamic loads the rover might experience. The size and angles needed for the aluminum tubing were cut using a miter saw. The cutting and welding of the base frame of the rover was performed by G&F General Welding under the instruction and supervision of the M.E.C. Panther team.

The first section of the frame assembled was the top section. The length and angles of the tubing were cut using a miter saw then tack welded together. Figure 44 and Figure 45 show the result of the tack welding process. Following the layout of the top section, the remaining aluminum tubes were cut to size and provided with the necessary angle. A drill press was used to drill the bearing holes through the horizontal bottom tube and the short vertical tube at the ends. Figure 44, Figure 45, and Figure 46, show the cuts and positioning of the different sections of the base including the holes drilled through the bottom rail of the frame. Figure 47 shows the base put together and temporarily fastened with tack welds.



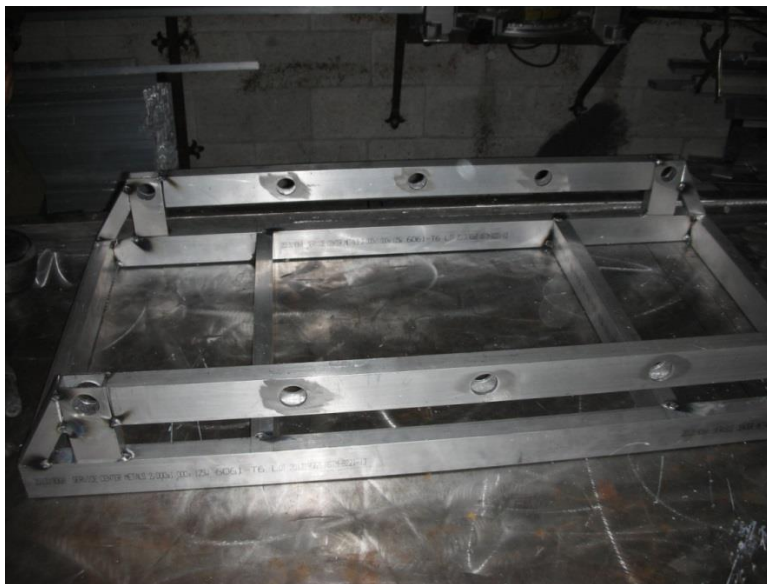
**Figure 44: Top Rectangle of base**



**Figure 45: Top Section of base**



**Figure 46: Pieces of base cut to size and drilled out**



**Figure 47: Base tack welded together**

After tack welding the base and checking to make sure the base was in the proper configuration, the addition of filler metal was done. The welds were completed with 4043 aluminum filler using a Hobart MIG welding unit. Once the welds were completed, they were smoothed out as much as possible with a handheld grinder. Later a hand file was used to refine

some of the areas that were not accessible with the grinder. In addition to filing it, the base was smoothed out using a sand block, giving the base a smooth surface.



**Figure 48: Addition of filler material to weld**



**Figure 49: Completed welding of the base**





**Figure 50: Completed base before deburring.**



**Figure 51: Completed base after deburring.**



**Figure 52: Different views of completed base.**

As the base of the rover was completed, construction of the gearbox began. The gearbox was designed to be an independently sealed unit for each motor. The housing of the gearbox is 2x4x0.25 in aluminum 6063 tubing. The output shaft of the gearbox is also the driving shaft of the sprocket. Construction of the gearbox housing was done using a vertical band saw to cut the stock pieces to size as well as provide the designed angular edge that would allow the gearbox to hide behind the base frame of the rover.

Part of the drive system of the rover is the four drive sprockets that will drive the threads. The sprocket material is UHMW, a very strong thermoplastic polyethylene. In order to ensure a

reliable and efficient transfer of power to the threads the drive sprockets must be fitted to the dimensions of the purchased threads. Using a CNC machine the sprocket was machined out of a stock piece of UHMW plastic to provide accurate dimensions to ensure a snug fit with the threads diminishing chances of the threads popping out of the sprockets.

The bin that would house the electronic equipment including the batteries was constructed together with the gearbox. The bin needed to be strong in order to firmly hold all the electronics without deforming or allowing the equipment to shift. However it also needed to be light to keep the overall rover weight down. To achieve the desired quality for the bin, an aluminum composite material (ACM) was used. ACM is made up of a plastic layer sandwiched between two thin sheets of aluminum. The composite material is extremely versatile because of its strength and lightweight properties. Despite its strength it can be bent into a desired shape. Therefore to create the bin in the dimensions needed to fit in the rover, squares on each corner were cut out with a jigsaw leaving what would be the side panels extended on each side. After cutting the corners, all four extended panels were bent 90 degrees to complete the bin.

Once the base of the frame was completed along with the components that are attached to it, the design of the upper section of the frame was finalized and constructed. Before approaching a welder to complete the fabrication of the frame, using the university's student machine shop an 11.25 in long slot was milled out on a rectangular 2x1x0.125 in aluminum tube. Then following the same procedure as for the bottom section of the frame, the top section was first tack welded together. First the vertical supports were cut with a miter saw to the exact measurement desired and tacked perpendicular to the surface of the bottom section. A square tube was temporarily tacked across each pair of supports to keep the spacing between them at the top. The 45 degree angled supports were then also cut using a miter saw to the designed



measurements and tacked into place. After inspecting and confirming the positioning of the supports, the welder proceeded to completing the process by adding the filler material to affix the upper section to the lower section of the frame. Upon cooling of the frame the welder then deburred the frame using a handheld grinder. The figures below show the progression of the welding process.



**Figure 53: Upper Section of frame tack welded**



Figure 54: Completed frame before deburring.

Along with the upper section of the frame, the welding job also included the fabrication of the frame of collection mechanism. The collection mechanism had two arms that each consisted of five square 0.125 in aluminum tubes with angled cuts that were welded together. Exact lengths and angles of each piece can be found in the part drawings in the appendix. Just as the previous jobs, the arms were assembled and tacked into position. Then after verification of the position, was welded together. The placement and drilling of holes into the arms of the collection mechanism was done by the MEC Panther mechanical team using the university's student machine shop. As well, all of the welding needed for the fabrication of the frame was performed using the facility of G&F General Welding by Jenry Ramos.

## 9.4 Prototype Assembly

### 9.4.1 Gearbox

Following the fabrication of the prototype components was the process of assembling the components to obtain the final functioning prototype. The first assembly completed was that of the gearbox. Its components included the motor, 0.25 in shafts, the gears, bearings, shaft adapter and shaft collars. The motor had an 8 mm output shaft, while the designed gearbox ran using 0.25 in shafts. Hence the need for the shaft adapters; to bring the motor shaft down from 0.315 in (8mm) to 0.25 inch shaft. Figure 55 shows the gears used in the gearbox.

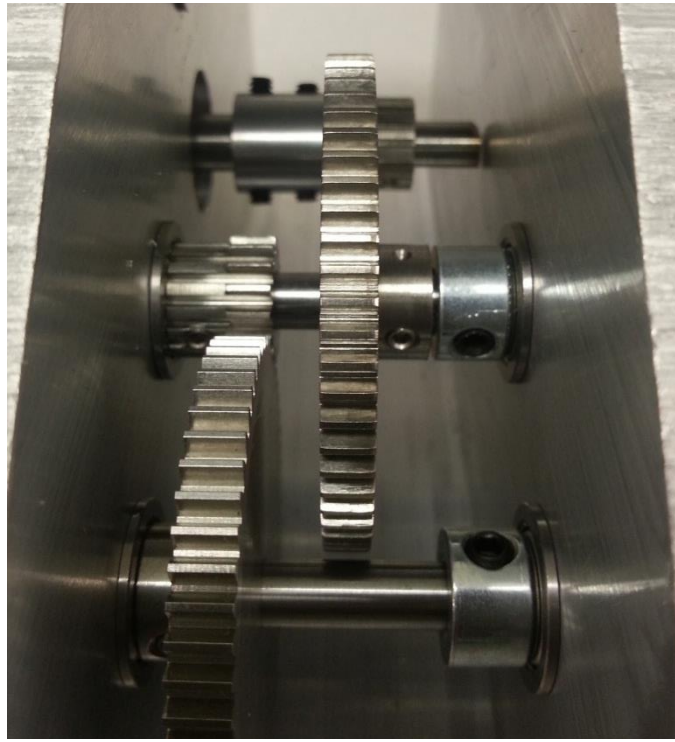


Figure 55: 16, 60 and 64 teeth gears from left to right

#### 9.4.1.1 Gearbox Assembly

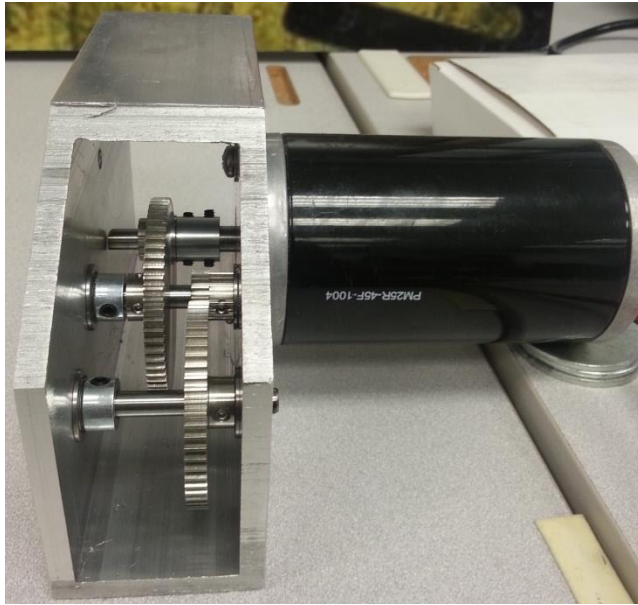
In order to assemble the gearbox, the bearings were first pressed into the machined holes using the tool in Figure 58. The bearings were pressed into the gearbox to provide it with a tight fit and the tool allowed the bearing to be easily and evenly pressed. After pressing the bearings, the shaft, gears and shaft collars needed to be put together simultaneously by passing the shaft through one bearing then through the gear and collar, then out through the other bearing. This same process was followed for each stage within the gearbox. Unlike the gear stages, the motor shaft was mounted to the gearbox by two screws. Since the motor was fixed onto the gearbox, the shaft did not need a bearing to hold it in place. Attached to the motor shaft is the shaft adapter, followed by the 0.25 inch shaft, to which the 16 teeth pinion gear is affixed. Once the

gears were aligned with the necessary clearances they were fastened to the shafts using set screws. In each stage of reduction the shaft passing through the bearings are held in place using a shaft collar which also used set screws to hold it in place. The purpose of the shaft collars is to prevent the shaft from sliding in an axial direction. A completed gearbox is available in Figure 57, where all the components are visible.



**Figure 56: Inside View of Completed Gearbox**





**Figure 57: Completed Assembly of Gearbox**

Figure 57 shows the completed assembly on the left side and the functioning gearbox on the right side. Figure 58 shows the tool used to press the bearings into the gearbox.



**Figure 58: Pressing tool for bearings**

## 9.4.2 Conveyer Scoop System

### 9.4.2.1 Scoop

The scoops were pre-cut and bent to shape, and all that was required was to rivet them together at four points. These scoops attached to the chain by four 8-32 screws and 4 nylon washers. These scoops are attached to the ANSI #40 hollow pin chains. The screws are held in place by nylon locking nuts.

### 9.4.2.2 ANSI #40 Chain and ANSI #40 Hollow pin chains

The chains are first attached to the sprockets. The chains come in 10 ft. sections and must be cut by grinding off one of the link connection. Then when appropriate length is measured it is closed by a master link. The master link is fixed by a clip. There are two different chains, one for the scoop mechanism which has the hollow pin and the other is for the driving sprocket attached to the motor. There are two different chains because there was not enough of the hollow pin chain. The regular chain was procured locally.

### 9.4.2.3 Sprockets

The sprockets were machine by Professor Zicarelli. The sprockets that act as idlers, required two bearings each. These idler sprockets fit on a 0.25 in shaft. The drive sprocket required a special shaft adapter to fit on the motor. The two sprockets connecting to the drive sprocket required a special shaft size with a size of 0.375 in and 0.25 at the last 1.125 in of both sides of the shaft. 8-32 set screws hold the driving sprockets in place; the idler sprockets just spin freely.

#### 9.4.2.4 Conveyer Scoop System Assembly

These components were attached to conveyer frame and are held together by screws. The conveyer frame is attached to two actuators and held in between the main rover frame holds both together.

### 9.4.3 Dumper Bin System

#### 9.4.3.1 Dumper

The dumper bin is made out of ACM and is riveted together to form the shape. It was pre-cut and routed and later assembled by the mechanical team. The dumper is held together with a bin brace shown in (Appendix: Parts Drawings Figure 98). This holds the motor on top and is bolted to the dumper. The motor is bolted to the bin brace and a pulley is press fitted to the shaft. The wire is fixed to the pulley and connected to an eyebolt at the door of the dumper. The dumper door is a piano hinge, letting it open and close. The dumper is aided by glides onto which bearings sit. The glides (Appendix: Parts Drawing Figure 96) are UHMW plates and they are held together by long screws and one eyebolt on each set.

#### 9.4.3.2 Pulley

Five pulleys make up the Dumper bin system. Two are small idler pulleys that guide the wire, one we mentioned in the dumper and it retains the wire for opening and closing the door. The last two are fixed on the motors that drive the dumper up and down the track. There is a shaft adapter (Appendix: Parts Drawing Figure 92) that fits between the motors and the driving pulleys.

#### 9.4.3.3 Dumper bin system assembly

The dumper bin is set on top of the frame and the glides are screwed in. This lets the dumper bin move up and down freely. Wire is guided from the driving pulleys to the idler pulley to the eyebolts on the glides. Then two elastic tubes are used to tension the dumper bin through the same eyebolts. The dumper door also has wire that is fixed to the driving pulley on top of the bin brace. Below is a picture of this mechanism.

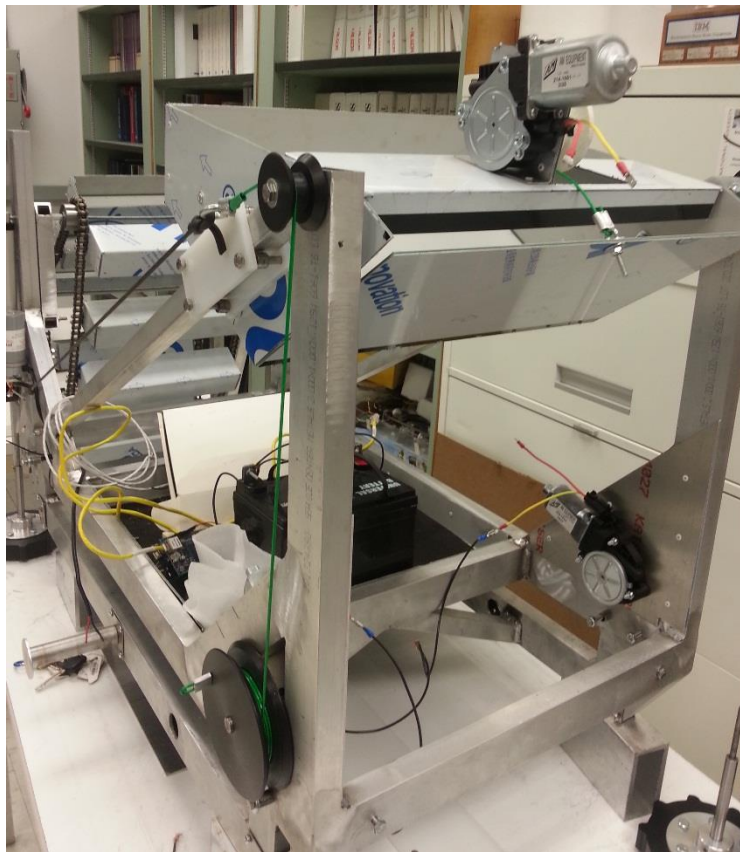


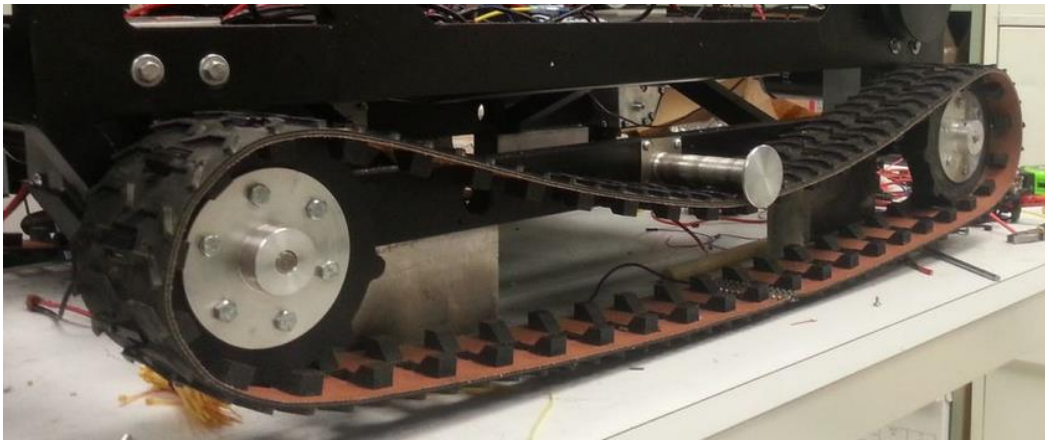
Figure 59: Dumper Bin Assembly

#### 9.4.4 Track System

The track system for the rover is compromised out of the four gearboxes with the four motors attached, an idler tensioner, four UHMW pulleys, two tracks and a hub. The gearboxes



are bolted to the frame. The drive shaft (Appendix: Parts Drawing Figure 84) go through the frame and sit on two bearing each. The bearing are held in place by two plates with 8-32 screws. The wheel pulleys (Appendix: Parts Drawing Figure 82) were made by Professor Zicarelli and fit onto the drive shaft. A hub (Appendix: Parts Drawing Figure 97) is then placed in front of the drive pulley and bolted together. Then a setscrew fixes the shaft from freely spinning. The figure below shows the track system assembled.



**Figure 60: Track System**

#### 9.4.5 Electronic System

The electrical part of the project has been left to the electrical/computer team. They have created the circuit for the relay system but have yet to assemble the components.

## 10. Programming

### 10.1 Mechanical Program

The mechanical team created a chat server between the Arduino microcontroller and the host computer using a sample program that is provided by the Arduino programming language. The Arduino is connected to an Ethernet shield that allows it to connect to the Linksys router. This allows the host computer to connect to the Arduino. Using telnet, an old Microsoft program to connect to an internet address, the host computer is able to make a connection with the Arduino. After the chat server was complete it was then possible to send commands to the Arduino, using keyboard commands.

The next task of the manual control was getting the Arduino to interpret the keyboard commands sent to it. Using the typical “wasd” keys to control movement, the Arduino was set to perform a task when it received any of those key functions. The “v” key was set to stop the robot. The program worked by listening to the telnet program and by using “if statements” and “else if statements”. The Arduino then would execute a subroutine for the different possible ways to move. The manual control program is very simple and takes a low amount of bandwidth, making it an ideal tool for controlling the rover. Below, (Appendix: Mechanical Team Manual Control Program), is a sample of the program. Testing was performed on the full forward, full backward, half forward, and half backward part of the program. More testing is required for the turning portion, therefore parts of the program are left commented out. In addition, an IP camera will be used to allow the team to see during the competition.

### 10.2 Electrical Program

The electrical team has gone through the steps of trying to make the lunar rover built by the mechanical team into a more robust platform, which can perform autonomous functions. Below is a Breakdown of Autonomy created by: Adelskis Rodriguez, Electrical Team leader.

# Adelskis Rodriguez

## MEC Panther Mining Robot

### Breakdown of Autonomy

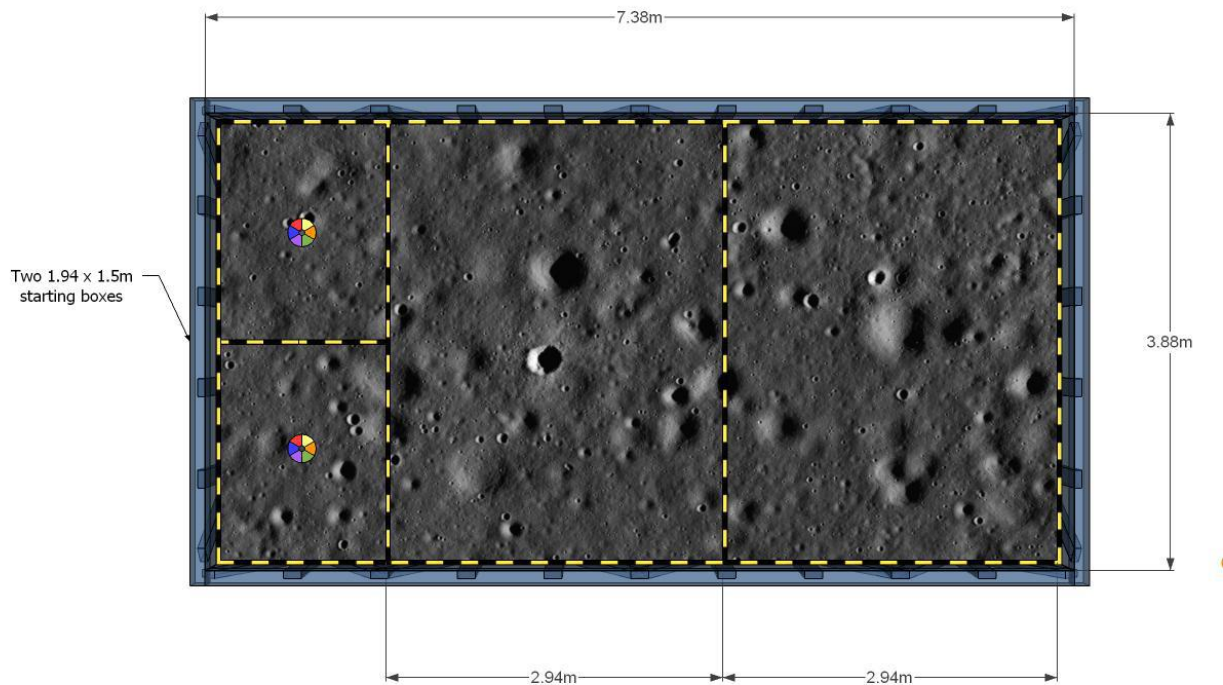


Figure 61: NASA Lunar Competition Stage layout (NASA, 2014)

**Note:**

1. The rover will start at any position in the starting boxes.
2. There will be three trips.

The purpose for the CMUCAM4 it is used to detect the color marker on the bin that will be placed by MEC Panthers. The CMUCAM4 will then send the data back to the microcontroller and steer the robot to “Zero Point”. The camera will pan and tilt on the base with a pair of stepper motors that will be mounted to a post on the robot.

#### Traveling the bin as “zero point”:

Order of events:

1. The camera will sweep the around on the pan and tilt component to detect the color marker on the bin.
2. The pan and tilt assembly will stop once the color marker is found
3. Rotate the robot to match the camera orientation
4. Move the robot towards the color marker center spot.
5. Stop robot if a rear infrared sensor reads 10cm from object
  - a. If the second infrared sensor reads a difference of 5cm; correct the course till the second infrared sensor reads the same
6. Check the infrared sensor, if both reads 10cm initiate the dump sequence.

#### Traveling from the bin to the collection area:

Order of Operation

1. Zero point
2. Initiate forward movement
3. Stop when one of the front infrared sensors reads object at 140cm
  - a. If the other sensor has difference of 10cm correct the angle to equal 140cm
4. Initiate collection of regolith
  - a. Drops the conveyer to the soil
5. Move forward as the robot is collecting soil
  - a. Stops if the pressure reaches a set pressure on the pressure sensor or stops when one of the front sensors read 40cm
6. Initiate return trip
  - a. Picks up the conveyer
  - b. Follow the path taken forward in reverse.
7. When the CMUCAM4 reads a particular set of pixels from the color marker
  - a. Then have the camera guide the robot back to the color marker
  - b. The first infrared sensor reads 10cm the robot stops.
    - i. If the second infrared sensor reads a difference of 5cm; correct the course till the second infrared sensor reads the same
  - c. Check the infrared sensor, if both reads 10cm initiate the dump sequence.
8. Zero point
9. Initiate 45 degree angle till the forward right sensor reads 30cm from wall
10. Rotate the right side of the robot till the first and secondary sensor on right side is equal.
  - a. Record the value

- b. Set the required distance away from the wall to the recorded value.
  - 11. Move forward as the robot is collecting soil
    - a. Stops if the pressure reaches a set pressure on the pressure sensor or stops when one of the front sensors read 40cm
  - 12. Initiate return trip
    - a. Picks up the conveyer
    - b. Follow the path taken forward in reverse.
  - 13. When the CMUCAM4 reads a particular set of pixels from the color marker
    - a. Then have the camera guide the robot back to the color marker
    - b. The first infrared sensor reads 10cm the robot stops.
      - i. If the second infrared sensor reads a difference of 5cm; correct the course till the second infrared sensor reads the same
    - c. Check the infrared sensor, if both reads 10cm initiate the dump sequence.
  - 14. Zero point
  - 15. Initiate 45 degree angle till the forward left sensor reads 30cm from wall
  - 16. Rotate the left side of the robot till the first and secondary sensor on left side is equal.
    - a. Record the value
    - b. Set the required distance away from the wall to the recorded value.
  - 17. Move forward as the robot is collecting soil
    - a. Stops if the pressure reaches a set pressure on the pressure sensor or stops when one of the front sensors read 40cm
  - 18. Initiate return trip
-

- a. Picks up the conveyer
  - b. Follow the path taken forward in reverse.
19. When the CMUCAM4 reads a particular set of pixels from the color marker
- a. Then have the camera guide the robot back to the color marker
  - b. The first infrared sensor reads 10cm the robot stops.
    - i. If the second infrared sensor reads a difference of 5cm; correct the course till  
the second infrared sensor reads the same
20. Check the infrared sensor, if both reads 10cm initiate the dump sequence.

## 11. Testing

### 11.1 Simulation

During the selection of the frame material and layout the two main concerns were the structural strength and weight while not exceeding the dimension constraint. The dimensions of the frame are 1.016 m in length and 0.508 m wide. Figure 16 shows the design of the base of the frame. The components of the rover will be contained in the compartments visible between the two support members. The bottom longitudinal members on each side have dual purposes, to hold the idlers of the track system and to provide ground clearance to avoid contact with any possible obstacles. The material selected for the frame was 6061 aluminum. The aluminum pieces are square and rectangular tubes with a thickness of 0.125 inches; by doing so the weight of the frame was lowered significantly while maintaining the structural strength needed to carry the desired load. This desired load was determined by the team considering the weight of the design without collected regolith and then adding the amount of regolith to be transferred in one trip. The completed design must weigh no more than 80 kg and the goal for amount of regolith transferred per trip is 40 kg. The total weight used to determine the loading that the base of the frame will be experiencing is 120 kg and the load is shown below.

$$F_{total} = W * g = 120 * 9.81 = 1177.2 \text{ N}$$

Once the load was set, CAD software was used to see how the base of the frame would react to the load it will bear in the future. For the simulation, the loading was rounded up to 1200 N and distributed along the entire upper surface of the frame. The results returned from the software showed the base of the frame to have the lowest safety of factor equal 9.9. The safety



of factor analysis was performed using the maximum von Mises Stress criterion. The simulation results are available in Figure 62.

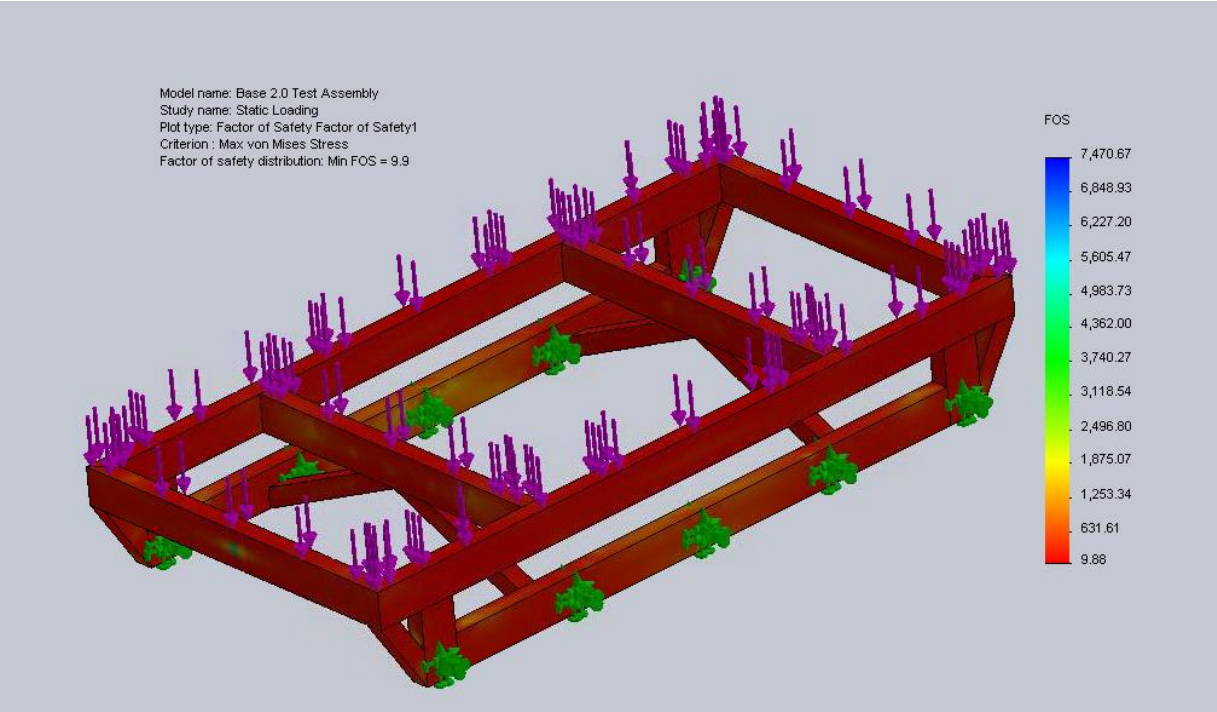


Figure 62: Frame Factor of Safety

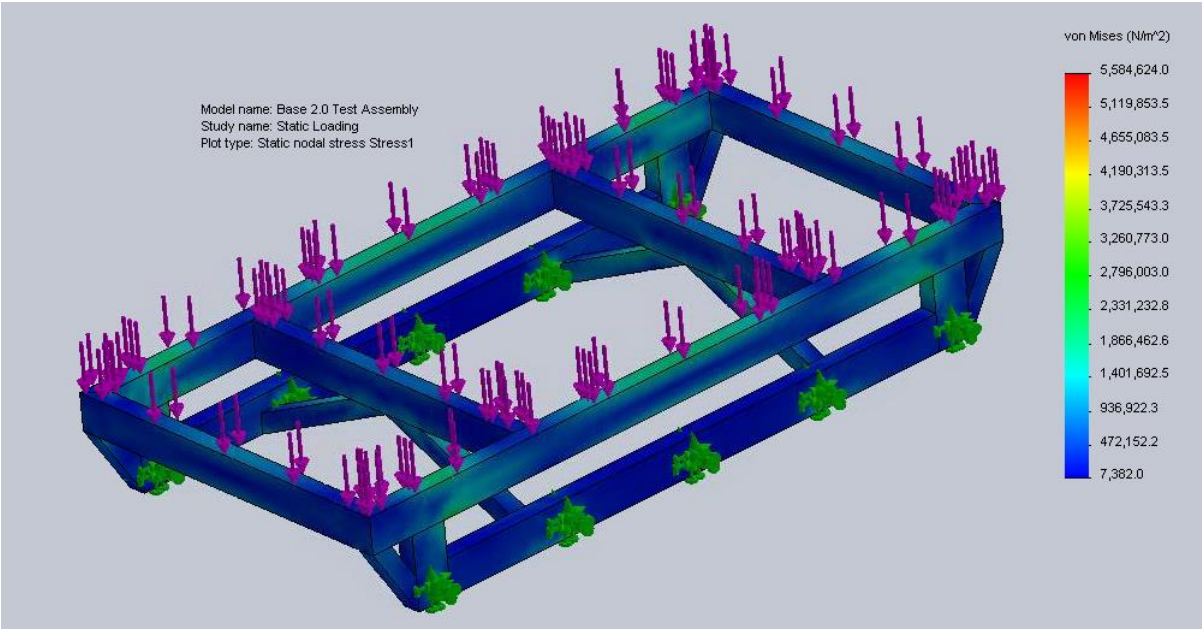


Figure 63: Von Mises Stress

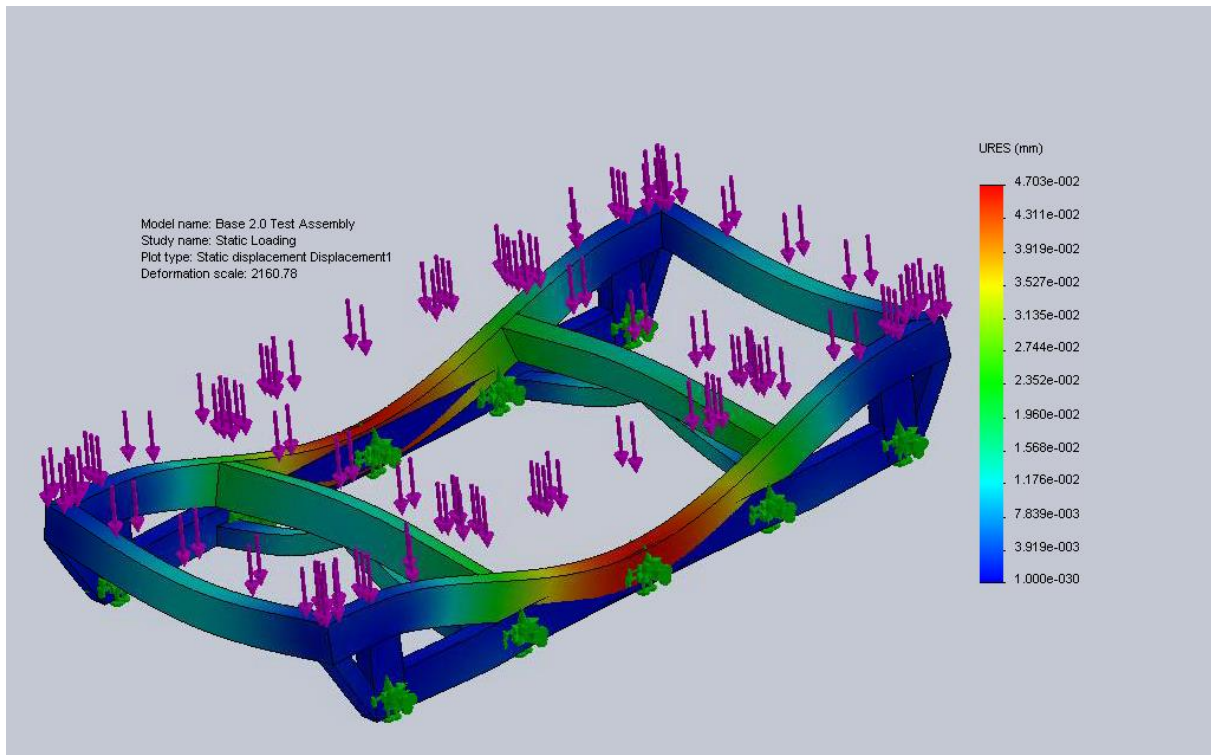
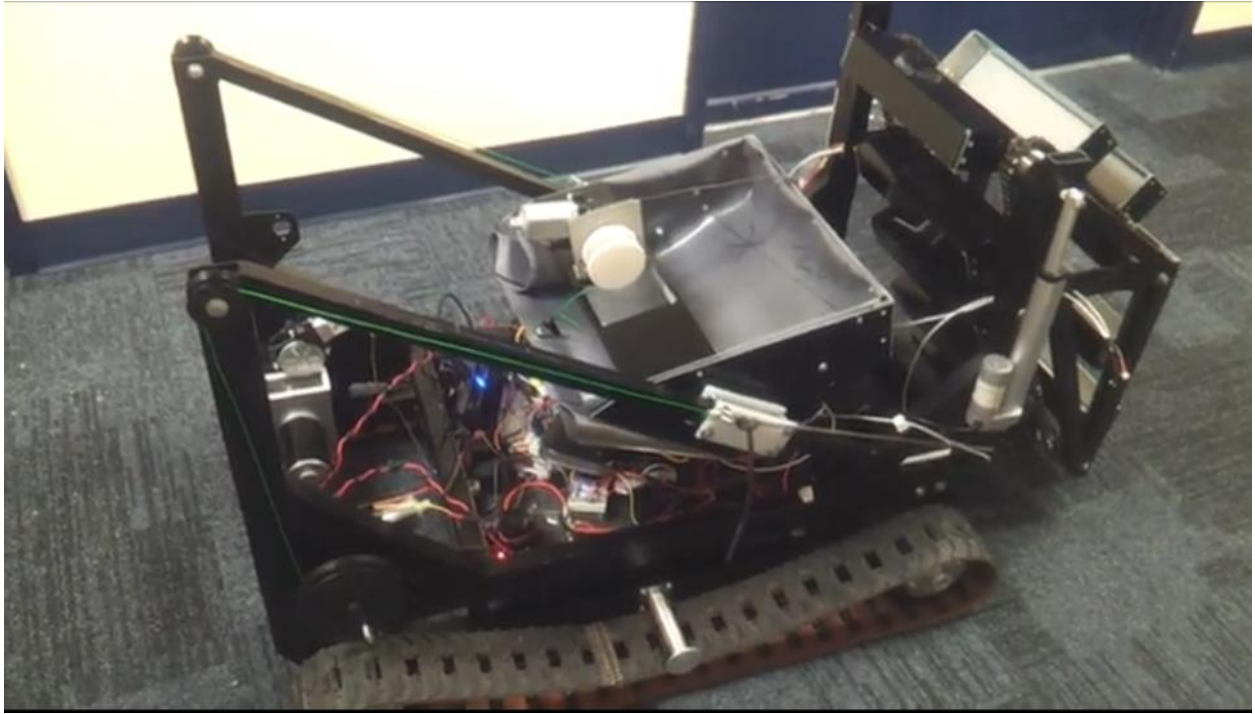


Figure 64: Frame Displacement

## 11.2 Actual

### 11.2.1 Frame

One of the first components tested was the frame. We had a person that weighed over a 120 pounds stand on it and it did not fail. Additionally, the frame was tested with all the components attached in the figure below.



**Figure 65: Fully Assembled Robot**

### 11.2.2 Gearbox

The next item that was tested was the gearboxes. After, they were assembled we attached the motor and starting testing it. We immediately noticed that some of the gearboxes sounded quiet while others sounded louder. We quickly determined that something must be loose. We discussed with Professor Zicarelli this issue. First, the shaft adapter that went on the motor was too loose and he offered to remake it for us. Second he suggested we increase the size of the

holes where the motor attached. This would allow us to reposition the motor to the optimal spot, given that we did not mess up on our calculations for the gears the problem should rely on the motor. After, extensive running of the gearboxes, it was noticed that several things happened, some of the set screws holding the gears were coming out, some of the gears had teeth damage. We quickly decided to take apart the whole gearbox which took more effort than first intended. Since we used Loctite a chemical compound that acts like glue, we had to drill out the set screws. This took a long time since we were trying to be careful not to break the sensitive components. We re-tapped all the set screw holes on the gears and used an 8-32 set screw tap instead of the 6-32 because it would offer more surface area to hold the gear. Additionally, we decided to machine a better flat on the shafts that went out to the pulley and hub.

### 11.2.3 Drive Shafts

Re-facing the shafts shown in (Appendix: Parts Drawings, Figure 84) showed a major flaw in the material. These shafts were case hardened and the interior was softer than the outside. We had intentionally made the shaft diameter smaller but when we faced one of those shafts, the part broke. This failure was most likely due to a couple things: material quality, the hard shoulder from the 0.5 in to the 0.25 in change in diameter. A simple fillet would have prevented this failure but since all the shafts have it we are planning on using a different material that can get us to the competition.

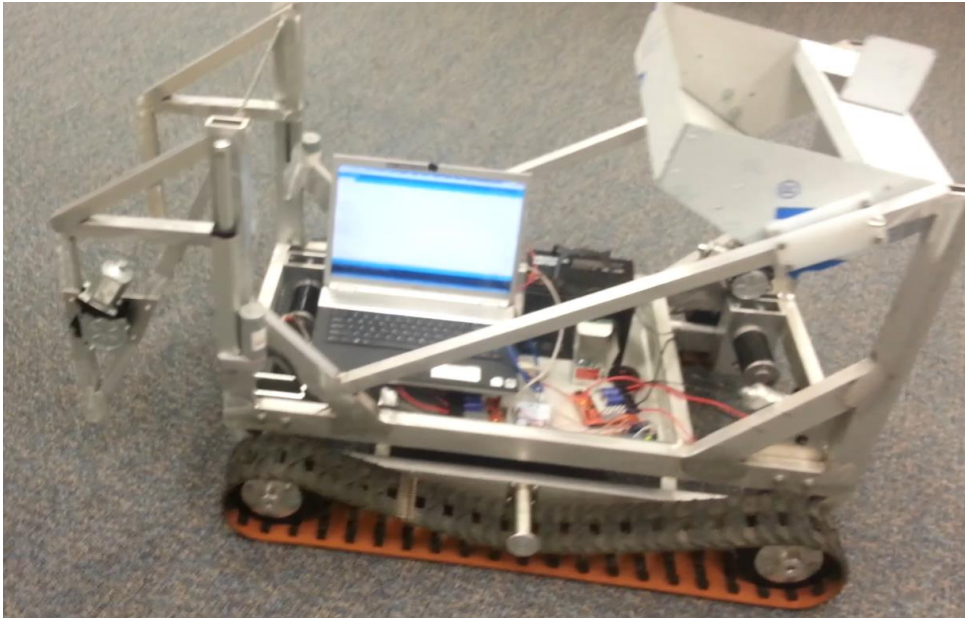
### 11.2.4 Motor Controllers

We were able to test the robot on the floor with all four Roboclaw motor controllers. The figure below shows the first test run we attempted on the floor. This part of the project is the most dangerous in regards to failure and possible injury. The test went well at half speed but when full speed was initiated, we later found out the motor controller was damaged. The team leader contacted the makers of the motor controller and it was determined that the motor controllers could not handle the voltage spike the motors produce. The motors we have can output 266 Amps at stall current combined and the Roboclaw motor controller could only handle 180 Amps. A solution was suggested by the manufacturer and that is to use a ramp function which would in essence smooth out the voltage spikes produced by the motors. The mechanical team then decided to buy four Vex Victor 888 motor controllers that could handle spikes for several reasons. First, even with the ramp function any external force could result in a voltage spike from the motors. Second, the time required to send and repair the Roboclaw would set the team back and possibly not being able to finish. The electrical team did not want to do this because it was extra money and they were committed to using those motor controllers. A compromise was determined by having the electrical team continue to use their motor controller and the mechanical would use the new ones chosen.

The new Vex 888 motor controllers were tested but not on the ground. These motor controllers required calibration and some research to get the wiring correct. The calibration was dependent on the values given in the program. We chose 1500 for neutral, 1000 for full backward and 2000 for full forward. When we tested them they performed as expected but there is a slight delay in the commands. The delay is inherent of the motor controller itself and may be reduced but not eliminated. In our initial test, all four motor controllers were not tested, only two



because of the problem encountered with the gearboxes. Our second test with the finished product had all components working with the manual control option shown in



**Figure 66: First Test Run using Orion motor controller**



**Figure 67: Assembled Robot**

### 11.2.5 Conveyer System

The conveyer system was tested out and gave many problems from the chain to the scoops. First, one belt would not fit properly. We had to drill out larger holes where the sprockets are located in the middle. This allowed us to fit the belt on. Differences in the manufacturing of the left and right side is the reason why the belts didn't fit. The next, problem encountered where in the scoops themselves. At the time we were not aware of it and ran the motor and it bent the top shaft and the belts slipped out of alignment. Our advisor told us that if it still works don't change the shaft, so we kept it on there. We tried to figure out why this was happening. We made sure all the buckets were aligned correctly to each other. Later, we measured the scoop length and determined this was the cause of the problem. When the scoops were made two of the buckets were smaller than that prescribed length of 12 inches in (Appendix: Parts Drawings Figure 101). This was quickly solved by adding spacers in between the smaller scoops. This produced a uniform length across and resulted in a properly functioning conveyer system. The relay system is still has not been assembled by the electrical group therefore we could only test it by giving power to the motor.



**Figure 68: Conveyer Belt System**



### 11.2.6 Dumper System

The dumper system was another system dependent on the relay system that can't be fully tested until it is completed by the electrical team. Either way, a simple test was performed by giving power to both motors. This resulted in good feedback on the way up but sloppy feedback on the way down. A bungee cord was then attached to the eye hook on the glides and secured to the bottom. This gave consistent movement up and down.

## 12. Conclusion and Future Works

The M.E.C Panthers has had a challenging time building a lunar rover for the NASA 2014 competition. Many things have gone wrong and adding a large multi-disciplinary team did not help. Either way, the team manage to fund raise \$800 and is expected to receive some funding from NASA. The most challenging part of this project has been the gearboxes because the way they were designed left little margin for error. If we could do this project again that would be the first thing that would be changed. The logistics of acquiring a product was the next most challenging task encountered during the project. Many things could not come together until the very end because parts were not in or took too long. Many of the estimates made for the project were inaccurate by a month because of time delays. Working with the electrical/computer team was also another challenge because they did not live up to their potential.

The mechanical team built the robot with manual control as its main function. It is hoped that the electrical/computer team create a fully autonomous program to maximize the rovers potential. The team also presented its project during the FIU Engineering Expo which it plans to visit two schools that showed interest in the project. During the short test runs that the team manage to record, the rover performed well and it is planned to be so, during the future weeks before the NASA competition.

## 13. References

- Alcoa. (2012, December 14). *Reynobond Architecture*. Retrieved January 29, 2014, from Alcoa: [http://www.alcoa.com/aap/north\\_america/catalog/pdf/brochures/Reynobond\\_Brochure.pdf](http://www.alcoa.com/aap/north_america/catalog/pdf/brochures/Reynobond_Brochure.pdf)
- Amazon. (2014, January 29). *Arduino Mega 2560 R3*. Retrieved January 29, 2014, from Amazon: [http://www.amazon.com/Arduino-MEGA-2560-R3/dp/B006H0DWZW/ref=sr\\_1\\_1?s=electronics&ie=UTF8&qid=1390774577&sr=1-1&keywords=arduino+mega+2560+r3](http://www.amazon.com/Arduino-MEGA-2560-R3/dp/B006H0DWZW/ref=sr_1_1?s=electronics&ie=UTF8&qid=1390774577&sr=1-1&keywords=arduino+mega+2560+r3)
- Arduino. (2014, January 29). *Intel Galileo*. Retrieved January 29, 2014, from Arduino: <http://arduino.cc/en/ArduinoCertified/IntelGalileo>
- Battery University. (2014, January 29). *Is Lithium-ion the Ideal Battery?* Retrieved January 29, 2014, from Battery University: [http://batteryuniversity.com/learn/article/is\\_lithium\\_ion\\_the\\_ideal\\_battery](http://batteryuniversity.com/learn/article/is_lithium_ion_the_ideal_battery)
- Bureau of Labor Statistics. (2012). *17-2141 Mechanical Engineers*. Washington: United States Department of Labor.
- Cmucam. (2012, May 14). *CMUcam4*. Retrieved January 29, 2014, from cmucam.org: <http://www.cmucam.org/projects/cmucam4/>
- Dornfeld, W. (2004). *Gear Tooth Strength Analysis*.
- GE tech wiki. (2013, May 22). *Iduino DUE*. Retrieved January 2014, from DE tech wiki.
- Goodfellow. (2014, January 29). *Polyethylene-U.H.M.V (UHMW PE) Material Information*. Retrieved January 29, 2014, from <http://www.goodfellow.com/E/Polyethylene-UHMW.html>: <http://www.goodfellow.com/E/Polyethylene-UHMW.html>
- Hornback, P. (1998). *The Wheel Versus Track Dilemma*. Fort Knox: Armor .
- John W. McDougal Company. (2014, January 29). *Aluminum Composite Material*. Retrieved January 29, 2014, from John W. McDougal Company: <http://www.jwmcd.com/index.php?id=22>
- Liaison Consulting. (2014, January 29). *Materials*. Retrieved January 29, 2014, from <http://www.crownplastics.com/polymersprocesses/materials>: <http://www.crownplastics.com/polymersprocesses/materials>
- Linksys. (2014, January 29). *Linksys Support*. Retrieved January 29, 2014, from Linksys: <http://support.linksys.com/en-us/support/routers/WRT54GL>
- MatWeb. (2013, November 24). *303 Stainless Steel, annealed* . (MatWeb LLC) Retrieved November 24, 2013, from <http://www.matweb.com/search/DataSheet.aspx?MatGUID=61bd8c4763af44ab82793f78c89c9c77&ckck=1>
- MatWeb. (2013, November 24). *Aluminum 2024-T4; 2024-T351* . (MatWeb LLC) Retrieved November 24, 2013, from <http://www.matweb.com/search/DataSheet.aspx?MatGUID=67d8cd7c00a04ba29b618484f7ff7524>

MJB. (2013). *EML2322L – MAE Design and Manufacturing Laboratory*. Gainesville: University of Florida.

NASA. (2014). NASA's Fifth Annual Robotic Mining Competition Rules & Rubrics 2014. Kennedy Space Center: NASA.

Nildeep Patel, A. E. (2002). *Elastic Loop Mobility System: The Concept and Future Prospects for Rover Mobility on Mars*. Noordwijk: 7th ESA Workshop on Advanced Space Technologies for Robotics and Automation ESTEC.

Orionrobotics. (2014, January 29). *RoboClaw 2x60A Motor Controller with USB*. Retrieved January 29, 2014, from Orionrobotics: [http://www.orionrobotics.com/RoboClaw-2x60A-Motor-Controller-with-USB\\_p\\_333.html](http://www.orionrobotics.com/RoboClaw-2x60A-Motor-Controller-with-USB_p_333.html)

Popular Mechanics. (2013). *Mining The Moon*. New York: Popular Mechanics.

Raspberry Pi. (2014, January 29). *FAQs*. Retrieved January 29, 2014, from Raspberry Pi: <http://www.raspberrypi.org/faqs#performanceSpeed>

Sharp. (2013, August 1). Retrieved January 29, 2014, from [http://www.sharp-world.com/products/device/lineup/data/pdf/datasheet/gp2y0a41sk\\_e.pdf](http://www.sharp-world.com/products/device/lineup/data/pdf/datasheet/gp2y0a41sk_e.pdf)

Sharp. (2001, September 6). *General Purpose Type Distance Measuring Sensors*. Retrieved January 6, 2014, from Sparkfun: <https://www.sparkfun.com/datasheets/Components/GP2Y0A21YK.pdf>

Taylor, L. A.-H. (2007). *Unique Properties of Lunar Soil Lead to Unexpected ISRU Discoveries*. Knoxville: Planetary Geosciences Institute, Dept. of Earth & Planetary Sciences.

Thunder Power. (2014, January 29). *Tp8000-4s4pl*. Retrieved January 29, 2014, from Thunder Power: [http://www.thunderpowerrc.com/8000-mAh\\_2/TP8000-4S4PL](http://www.thunderpowerrc.com/8000-mAh_2/TP8000-4S4PL)

Trautwein, N. C. (1973). *Elastic Loop Mobility System- A New Concept for Planetary Exploration*. Great Britain: Journal of Terramechanics.

# Appendix

## Appendix: A-Company Proposal

November 24, 2013

Dear Company X,

I am serving as team captain of my Senior Design project at Florida International University. This project is focused on the international Lunar Robotics Competition sponsored by NASA. I am writing in regards to ask for your financial support in this endeavor. Your contribution would enhance the success rate of this project and would provide a footprint for the FIU Engineering Center& at the NASA Competition. After the project is completed, it will stay on display at the University and be shown to the youths that visit the school to encourage them to pursue careers in math, science and engineering. It is highly beneficial to invest in our project because you would be helping out the community and exposing your company to an international event.



I do not expect you to just invest blindly in our project. The link below is a small example of what some teammates have previously accomplished together. The picture below shows our initial robot design. In addition, there has been one previous successful Lunar Robot that went to competition from FIU. One of our members competed in the First National Competition and won the regionals in 2006, 2007 and 2008. The team that will work on this project spans three engineering disciplines; Mechanical, Computer and Electrical Engineering.

By helping us in this endeavor, we plan on recognizing your organization. We will acknowledge any donation or discount on our Facebook page and in our public presentations. If you donate \$500 we will put a decal for your company on our Lunabotics robot. If you donate \$1000, we will put your logo on the robot and the shirts we wear at the competition. A YouTube video will also be made for the robot with acknowledgment to your organization. We plan on building on our past failures and success to accomplish this challenge. We hope that you will choose to share in this success by your financial support. Attached, please find a letter of support from our faculty advisor at FIU as well as our budget. If you have any questions please email me at [rport009@fiu.edu](mailto:rport009@fiu.edu)

Thank you,

Ronald Portorreal  
Florida International University  
10555 West Flagler Street  
Miami FL, 33174

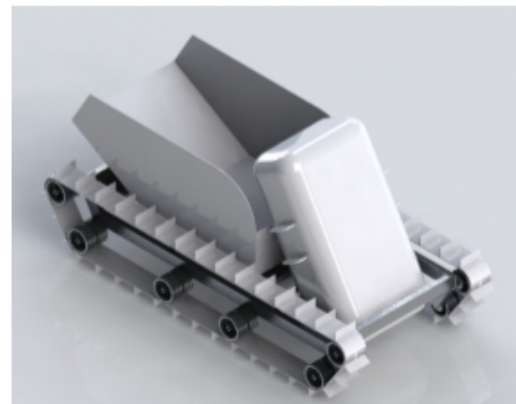


Figure 69: Funding Proposal Page 1

Example of previous Success:

<https://www.dropbox.com/sh/cgp7x59t63s7tgt/IV0yoxa7XI/Final%20Video%20S.mp4?>

Lunar Robotics Senior Design Budget					
Item	Price	Shipping	Quantity	Total Cost	Bought
Raspberry Pi Model B Revision 2.0 512 MB	\$42.87	\$0.00	1	\$42.87	Yes
Phantom YoYo 100mm Ultra Large Circular Micro Switch Button	\$9.99	\$6.84	1	\$16.83	No
Transcend 8GB 10 SDHC Flash Memory Card	\$8.99	\$0.00	1	\$8.99	Yes
2.5inch CIM, Brushed DC Motor AM802-001A	\$25.00	\$15.49	4	\$115.49	Yes
Macroe 5 in 1 Portable Wifi 802.11 b/g/n Hotspot Router w/4000mAh Power Bank	\$29.99	\$0.00	1	\$29.99	No
Watt's Up RC Watt Meter & Power Analyzer WU100 Verion 2	\$49.99	\$0.00	1	\$49.99	No
Arduino uno microcontroller	\$19.99	\$0.00	2	\$39.98	No
Motor Controller 2x60A	\$199.99	\$0.00	3	\$599.97	
Threads and Pulleys	\$500.00	\$0.00	1	\$500.00	No
Custom Chasis+Frame+Conveyer Belt Frame+Soil Container	\$1,500.00	\$0.00	1	\$1,500.00	No
Custom Gearbox	\$100.00	\$0.00	6	\$600.00	No
Conveyer belt	\$500.00	\$0.00	1	\$500.00	No
Conveyer Belt Motor	\$25.00	\$0.00	1	\$25.00	No
Conveyer Belt Frame Motor	\$25.00	\$0.00	1	\$25.00	No
Sensors	\$175.00	\$0.00	1	\$175.00	No
Camera	\$100.00	\$0.00	2	\$200.00	No
Power Unit	\$150.00	\$0.00	1	\$150.00	No
Wires, resistors, potentiometers, breadboard, cable shielding	\$100.00	\$0.00	1	\$100.00	No
Screws, bolts, zip ties, ducttape, sealant	\$50.00	\$0.00	1	\$50.00	No
Heatsink, fan	\$30.00	\$0.00	4	\$120.00	No
Shipping 10% of Cost		\$385.92		\$385.92	N/A
Transportation	\$135.00	\$0.00	1	\$200.00	No
Hotel	\$200.00	\$0.00	1	\$0.00	No
Machining Cost					No
				Final Cost	
				\$5,435.03	
**Rough Estimates					

Figure 70: Funding Proposal Page 2

## Appendix: B-Shirt Funds

### MEC Panthers



Gildan Ultra Cotton T-shirt | Sizes: YXS - 4XL | [View Sizing Line-Up](#)

Help us raise money to build a Lunar Rover for a NASA competition!

The MEC Panthers are an engineering team at Florida International University. We're raising funds to allow us to build a Lunar Rover for the 2014 NASA Lunabotics Competition.

Shirts will be delivered approximately 2 weeks after the close date.



All funds raised will go directly to *FIU ASME Student Section*.

55 shirts | \$600 raised

Thanks to our supporters!

Figure 71: Shirt Funding Website

## More about this campaign



The MEC Panthers are an interdisciplinary group consisting of mechanical, electrical, and computer engineers from Florida International University. The MEC Panthers are designing and building a lunar rover for the 2014 NASA Lunabotics competition. This is an international competition between 50 different universities, with the MEC Panthers representing FIU. The MEC Panther engineering students are using this competition as a platform for their senior design project, a culmination of their engineering curriculum. One of the biggest hurdles left for the MEC Panthers to overcome before the competition is fundraising! Please help us out by purchasing a T-Shirt with our team's logo and school colors.

Organized by  
**Matthew Koza**  
[Contact](#)

Help us make this campaign a success!

- ☒ [View Our Campaign](#)
- ☐ [Share this on Facebook](#)
- ☐ [Buy a T-shirt](#)

**Figure 72: Shirt Funding Website with Team information and picture**



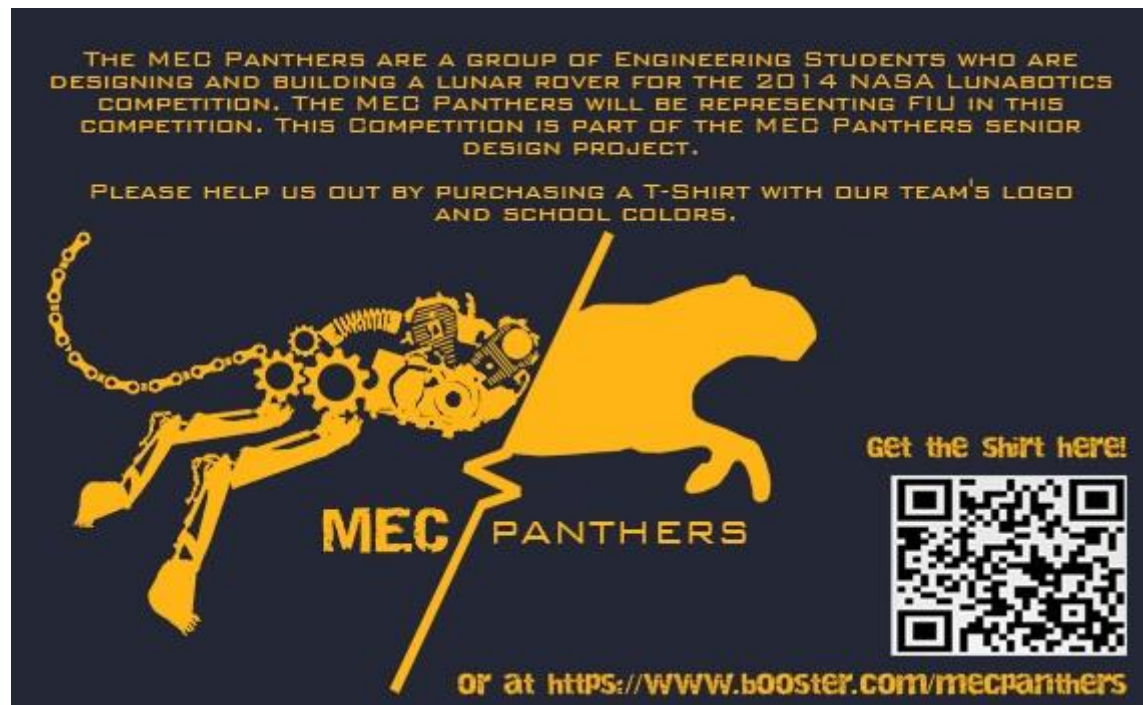


Figure 73: Flyer

## Appendix: C-Receipts

**STOCK CAR STEEL**  
801-A PERFORMANCE RD  
MOORESVILLE, NC 28115

11/11/2013 12:42:22  
Merchant ID: 00000000794299  
Terminal ID: 04502745  
417520647997

CREDIT CARD  
VISA SALE

CARD # XXXXXXXXXXXX  
INVOICE 0012  
Batch #: 000199  
Approval Code: 067068  
Entry Method: Manual  
Mode: Online

**SALE AMOUNT** \$122.09

### Invoice

Date	Invoice #
11/11/2013	339599

Ship To  
Ronald Porporreal

S.O. No.	P.O. No.	Terms	Rep	Ship Via
154258	Ronald	C.O.D.	SB	UPS

Item	Description	Ordered	Prev. Inv...	Invoiced	Rate	Amount										
ALTRC(6061)2x1...	Aluminum Tube - Rectangle 6061 2.00" x 1.00" x .125" wall x 24' R/L	22	0	22	3.70	81.40										
ALTSQ(6061)1.0...	2 PCS CUT TO 4 FT 2 PCS CUT TO 3 FT 4 PCS CUT TO 2 FT Aluminum Tube - Square 6061 1.00" Sq x .125" wall x 24' R/L	6	0	6	2.97	17.82										
Freight	Freight Charge	1	0	1	15.92	15.92										
				<table border="1" style="width: 100%;"> <tr> <td><b>Subtotal</b></td> <td>\$115.14</td> </tr> <tr> <td><b>Sales Tax (7.0%)</b></td> <td>\$6.95</td> </tr> <tr> <td><b>Total</b></td> <td>\$122.09</td> </tr> <tr> <td><b>Payments/Credits</b></td> <td>\$0.00</td> </tr> <tr> <td><b>Balance Due</b></td> <td>\$122.09</td> </tr> </table>			<b>Subtotal</b>	\$115.14	<b>Sales Tax (7.0%)</b>	\$6.95	<b>Total</b>	\$122.09	<b>Payments/Credits</b>	\$0.00	<b>Balance Due</b>	\$122.09
<b>Subtotal</b>	\$115.14															
<b>Sales Tax (7.0%)</b>	\$6.95															
<b>Total</b>	\$122.09															
<b>Payments/Credits</b>	\$0.00															
<b>Balance Due</b>	\$122.09															

Phone #	Fax #	Web Site
704-664-3044	704-664-2647	www.stockcarsteel.com

Figure 74: Aluminum Receipt for chassis only



SuperDroid Robots <orders@sdrobots.com>

to me ▾

Thank you for your business.

### Thank you for your order!

#### Order Information

Merchant: **SUPERDROID ROBOTS INC**  
Description: [www.superdroidrobots.com](http://www.superdroidrobots.com) Order: 39420  
Invoice Number: 39420  
Customer ID: 0

#### Billing Information

Matthew Koza

#### Shipping Information

Matthew Koza

United States

Shipping: US \$0.00

Tax: US \$0.00

**Total: US \$580.63**

#### American Express

Date/Time: 16-Nov-2013 14:30:12 EST

Transaction ID: 5697202567

<http://www.superdroidrobots.com>

Figure 75: Threads Receipt

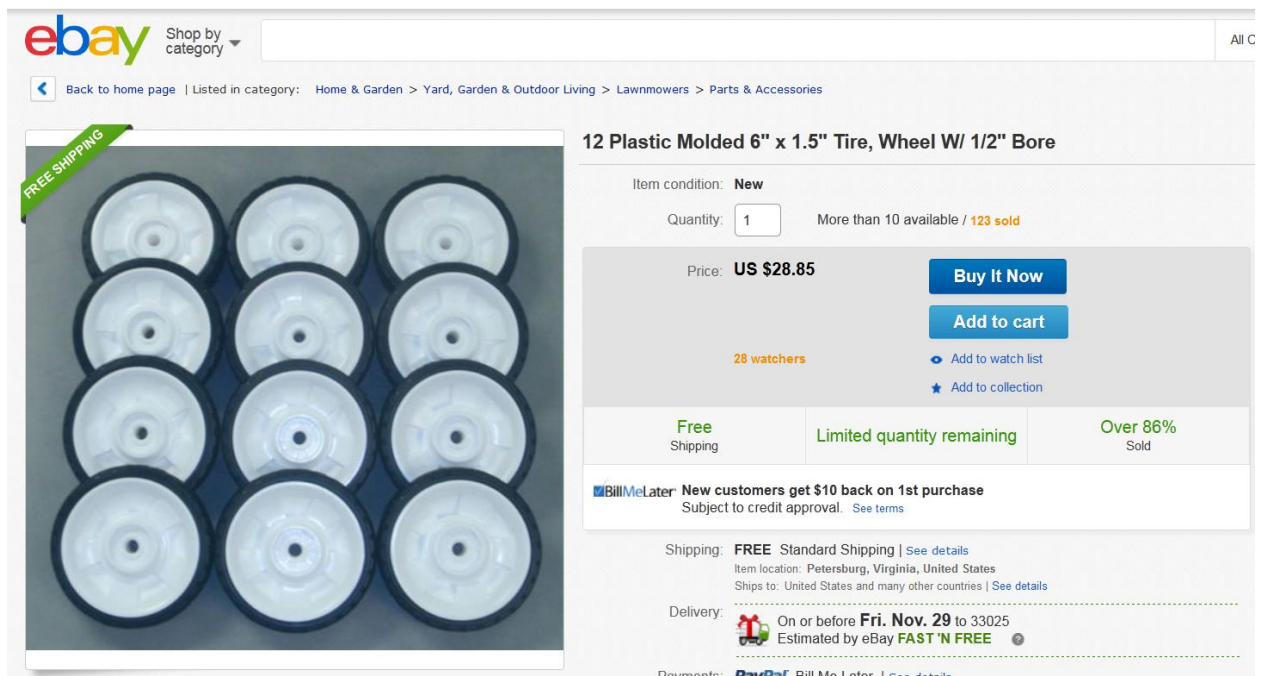


Figure 76: Idlers Bought

**Final Details for Order #112-9992619-9743418**

[Print this page for your records.](#)

Order Placed: September 5, 2013  
 Amazon.com order number: 112-9992619-9743418  
 Order Total: \$52.83

Shipped on September 5, 2013	
<b>Items Ordered</b> 1 of: <i>Transcend 8 GB Class 10 SDHC Flash Memory Card (TS8GSDHC10E)</i> Condition: New Sold by: Amazon.com LLC 1 of: <i>Raspberry Pi Model B Revision 2.0 (512MB)</i> Condition: New Sold by: MemoryWhiz ( <a href="#">seller profile</a> )	<b>Price</b> \$9.95 \$42.88
<b>Shipping Address:</b> Ronald Portorreal 10000 1st Avenue San Diego, CA 92123 United States <b>Shipping Speed:</b> Two-Day Shipping	Item(s) Subtotal: \$52.83 Shipping & Handling: \$0.00 ----- Total before tax: \$52.83 Sales Tax: \$0.00 ----- <b>Total for This Shipment: \$52.83</b> -----
Payment information	
<b>Payment Method:</b> Visa   Last digits: <b>Billing address</b> 10000 1st Avenue San Diego, CA 92123 United States	Item(s) Subtotal: \$52.83 Shipping & Handling: \$0.00 ----- Total before tax: \$52.83 Estimated tax to be collected: \$0.00 ----- <b>Grand Total: \$52.83</b>

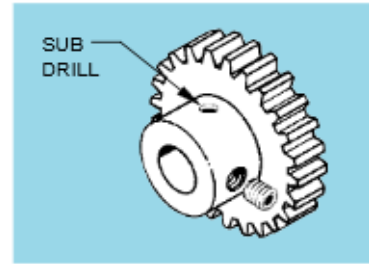
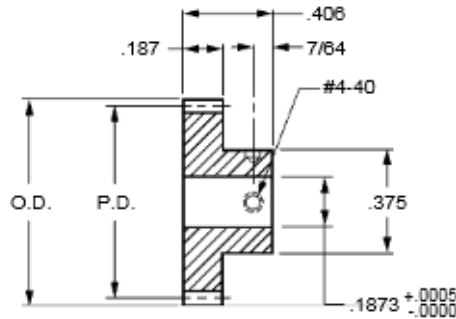
To view the status of your order, return to [Order Summary](#).

Figure 77: Receipt for Raspberry Pi and SD Card

## Gear Product Finder

**S INCH****Spur Gears - 32 Pitch**

■ AGMA Q10    ■ 20° PRESSURE ANGLE    ■ 3/16 FACE    ■ 3/16 BORE



**S** Precision  
Component

Catalog Number		No. of Teeth	P.D.	O.D.
303 Stainless Steel	2024 Aluminum * Anodized			
S1084Z-032S012	S1084Z-032A012	12	0.3750	0.438
S1084Z-032S016	S1084Z-032A016	16	0.5000	0.563
S1084Z-032S018	S1084Z-032A018	18	0.5625	0.625
S1084Z-032S020	S1084Z-032A020	20	0.6250	0.688
S1084Z-032S022	S1084Z-032A022	22	0.6875	0.750
S1084Z-032S024	S1084Z-032A024	24	0.7500	0.813
S1084Z-032S026	S1084Z-032A026	26	0.8125	0.875
S1084Z-032S028	S1084Z-032A028	28	0.8750	0.938
S1084Z-032S030	S1084Z-032A030	30	0.9375	1.000
S1084Z-032S032	S1084Z-032A032	32	1.0000	1.063
S1084Z-032S036	S1084Z-032A036	36	1.1250	1.188
S1084Z-032S040	S1084Z-032A040	40	1.2500	1.313
S1084Z-032S048	S1084Z-032A048	48	1.5000	1.563
S1084Z-032S056	S1084Z-032A056	56	1.7500	1.813
S1084Z-032S060	S1084Z-032A060	60	1.8750	1.938
S1084Z-032S064	S1084Z-032A064	64	2.0000	2.063
S1084Z-032S068	S1084Z-032A068	68	2.1250	2.188
S1084Z-032S072	S1084Z-032A072	72	2.2500	2.313
S1084Z-032S080	S1084Z-032A080	80	2.5000	2.563
S1084Z-032S084	S1084Z-032A084	84	2.6250	2.688
S1084Z-032S088	S1084Z-032A088	88	2.7500	2.813
S1084Z-032S092	S1084Z-032A092	92	2.8750	2.938
S1084Z-032S096	S1084Z-032A096	96	3.0000	3.063
S1084Z-032S100	S1084Z-032A100	100	3.1250	3.188
S1084Z-032S108	S1084Z-032A108	108	3.3750	3.438
S1084Z-032S112	S1084Z-032A112	112	3.5000	3.563
S1084Z-032S116	S1084Z-032A116	116	3.6250	3.688
S1084Z-032S120	S1084Z-032A120	120	3.7500	3.813
S1084Z-032S128	S1084Z-032A128	128	4.0000	4.063
S1084Z-032S130	S1084Z-032A130	130	4.0625	4.125

\* T4 or T351 Aluminum Alloy, anodized before cutting.

Available on special order: 14-1/2° P.A., teeth not listed, different bore size and/or material.

Figure 78: Gear Specification Sheet

Appendix: Parts Drawings

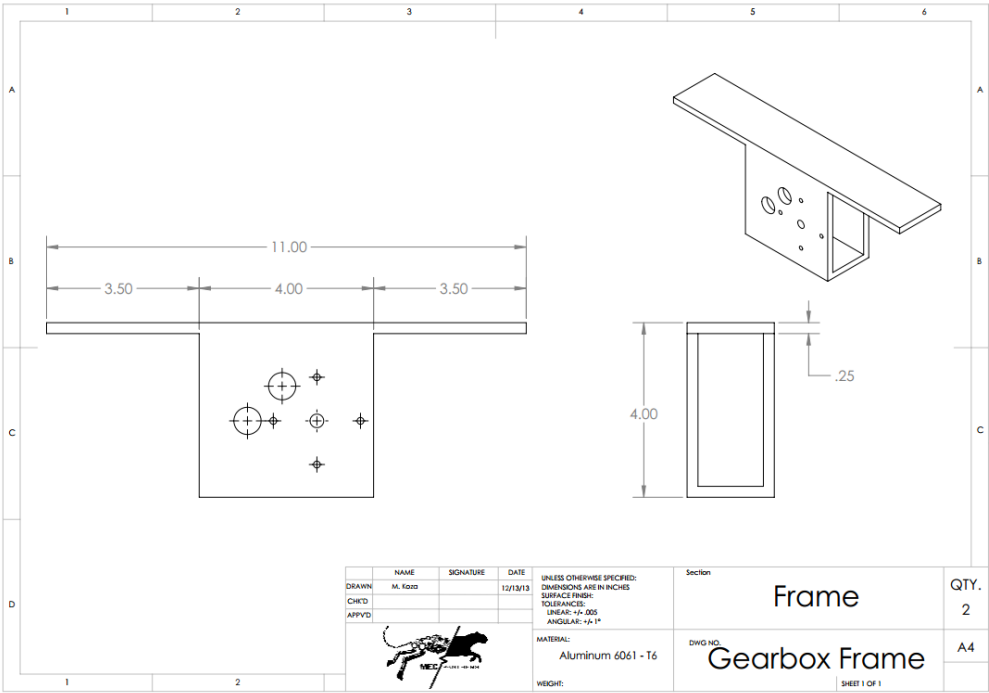


Figure 79: Third Gear Box Design Drawing

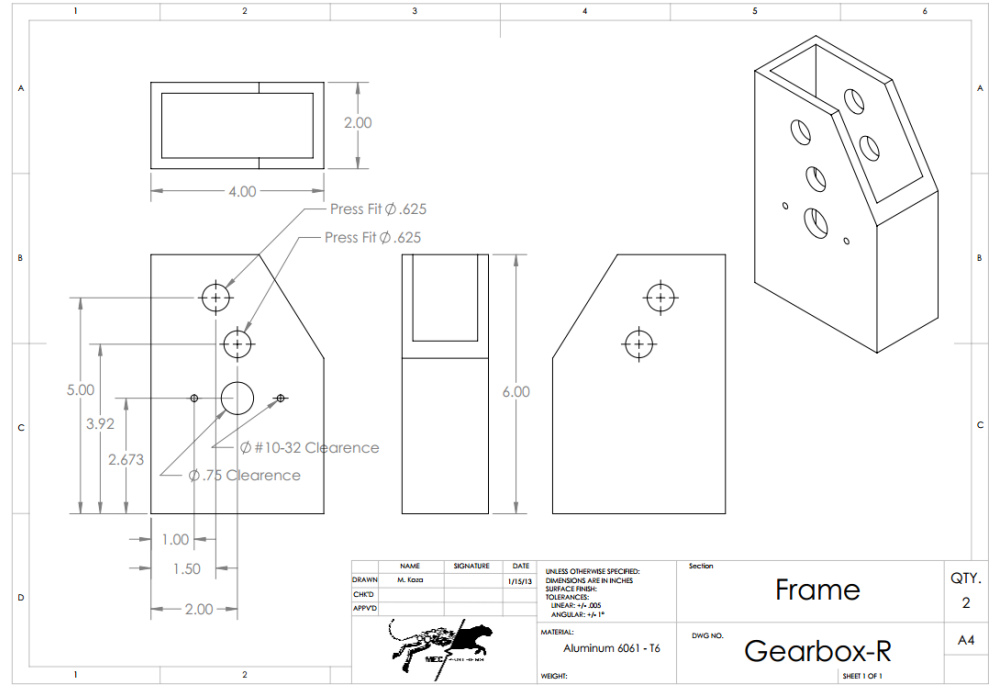


Figure 80: Final Gearbox Right Side Drawing

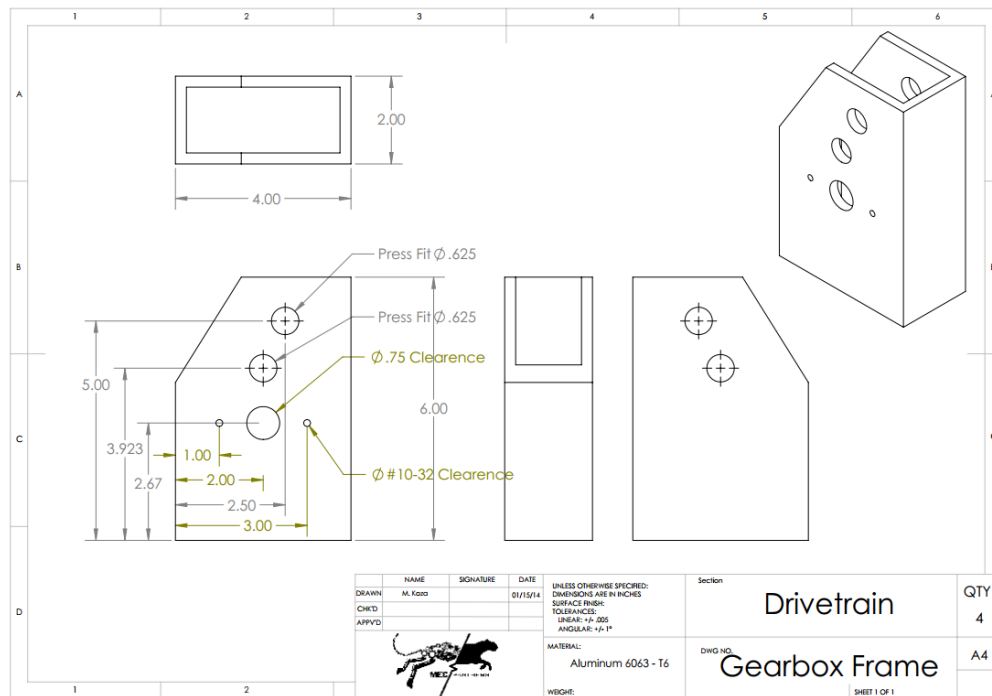


Figure 81: Final Gearbox Left Side Drawing

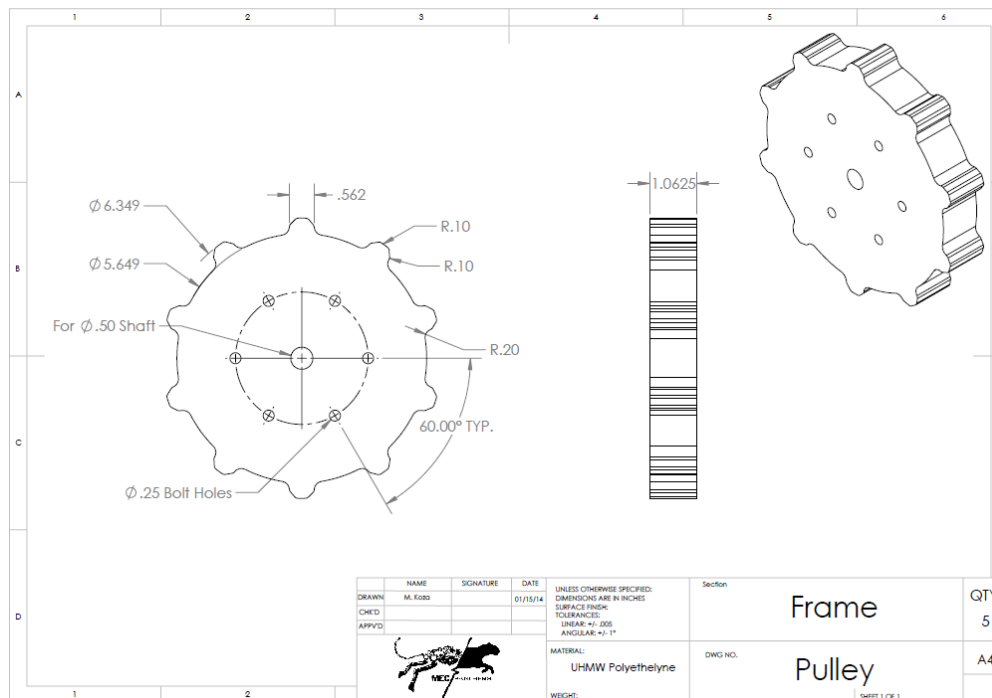


Figure 82: Driving Pulley Part Drawing

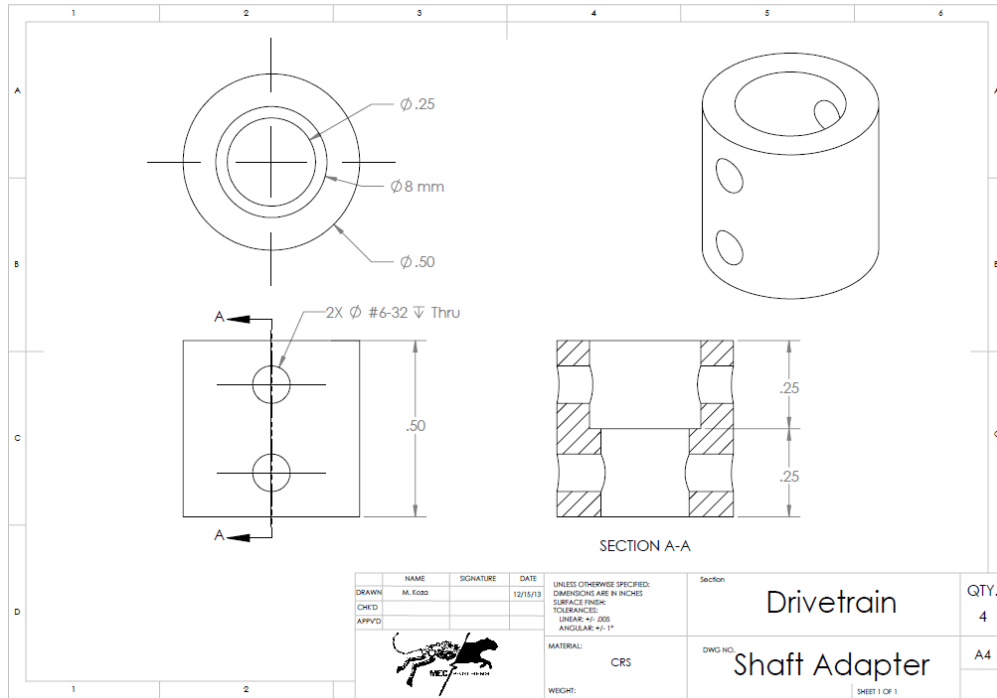


Figure 83: Custom Shaft Adapter Part Drawing

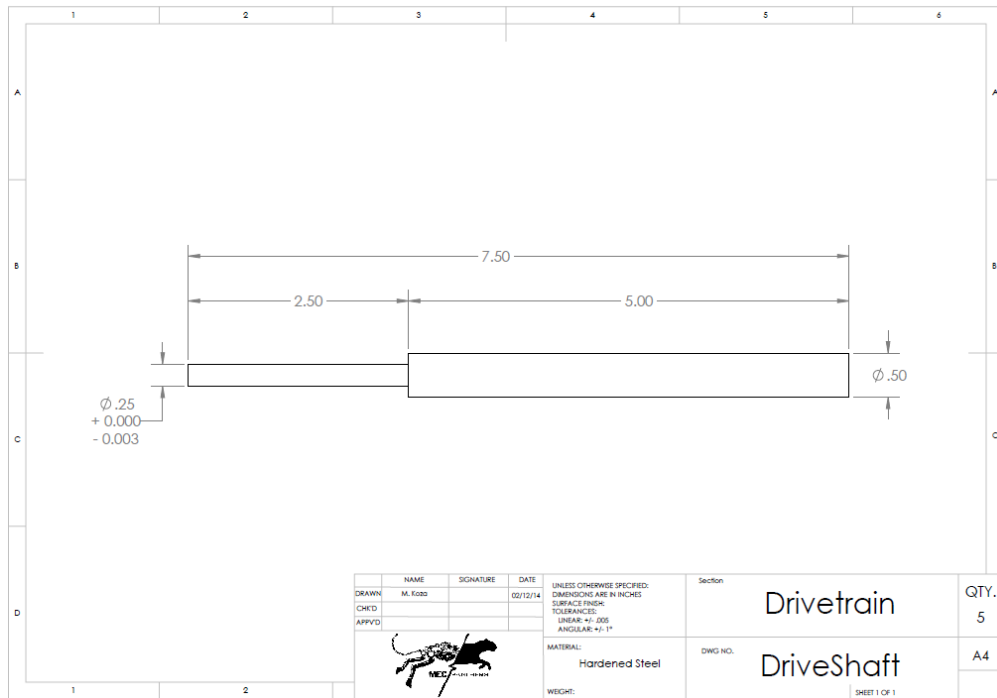


Figure 84: Driveshaft Part Drawing



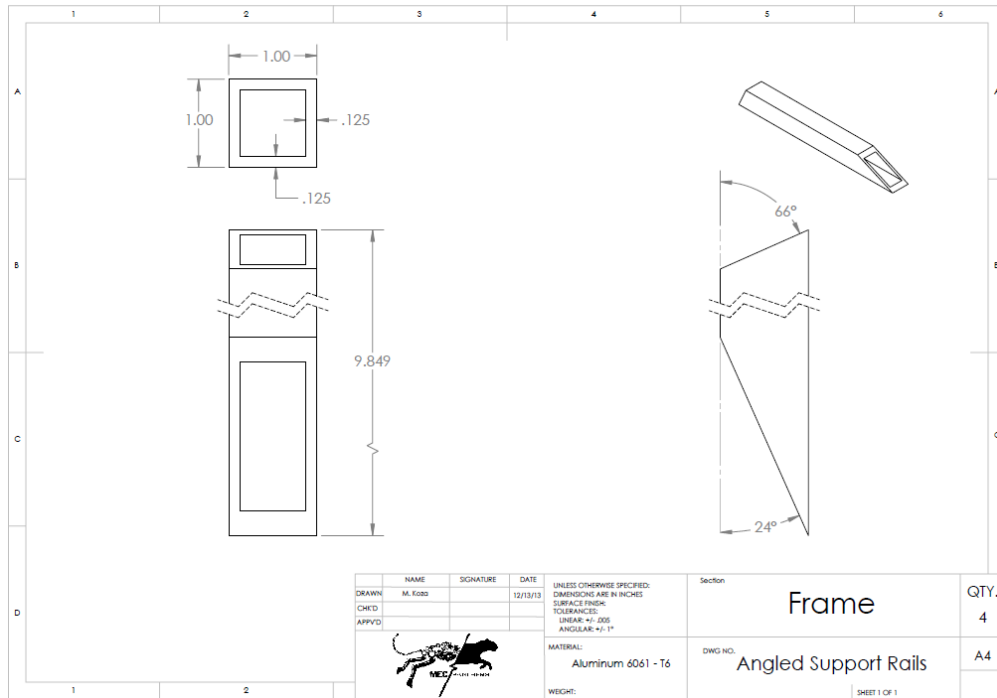


Figure 85: Angled Support Rails Drawing

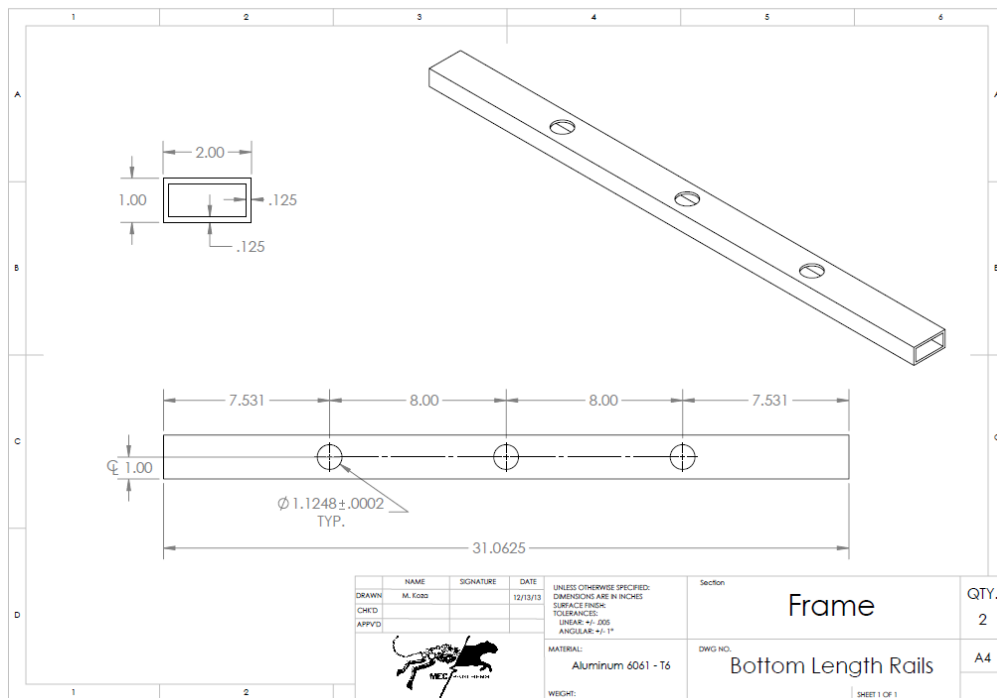


Figure 86: Bottom Length Rail Drawing

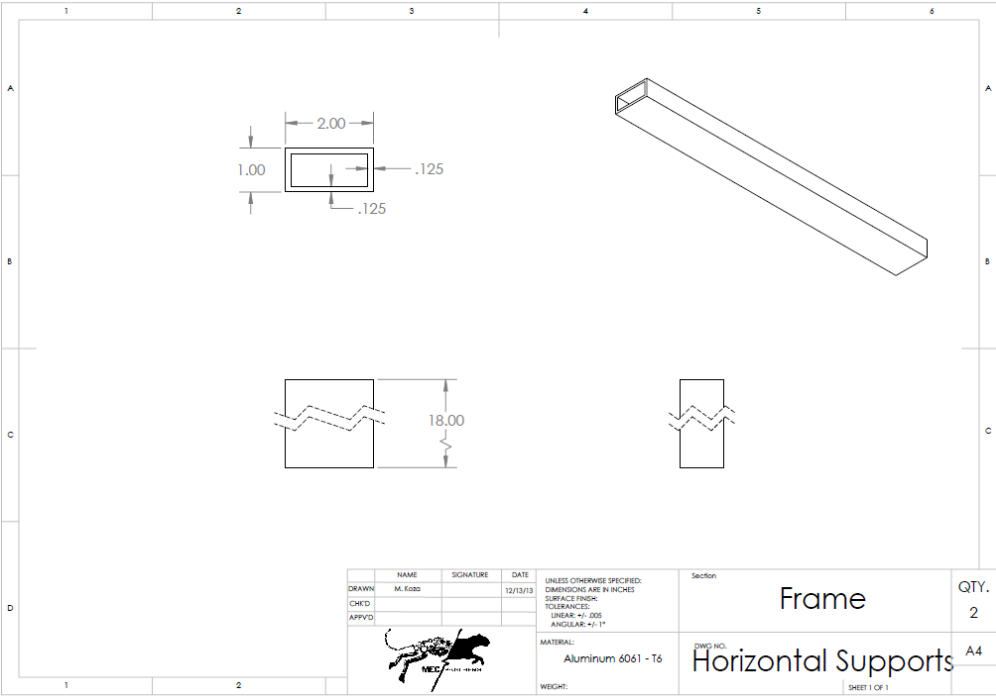


Figure 87: Horizontal Supports Drawing

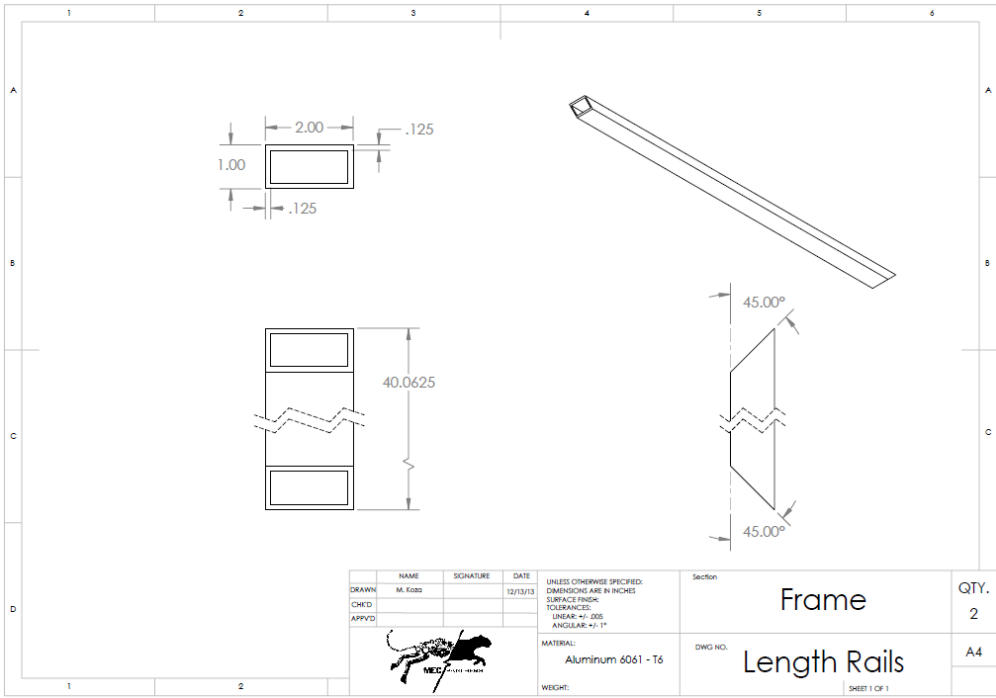


Figure 88: Length Rail Drawing

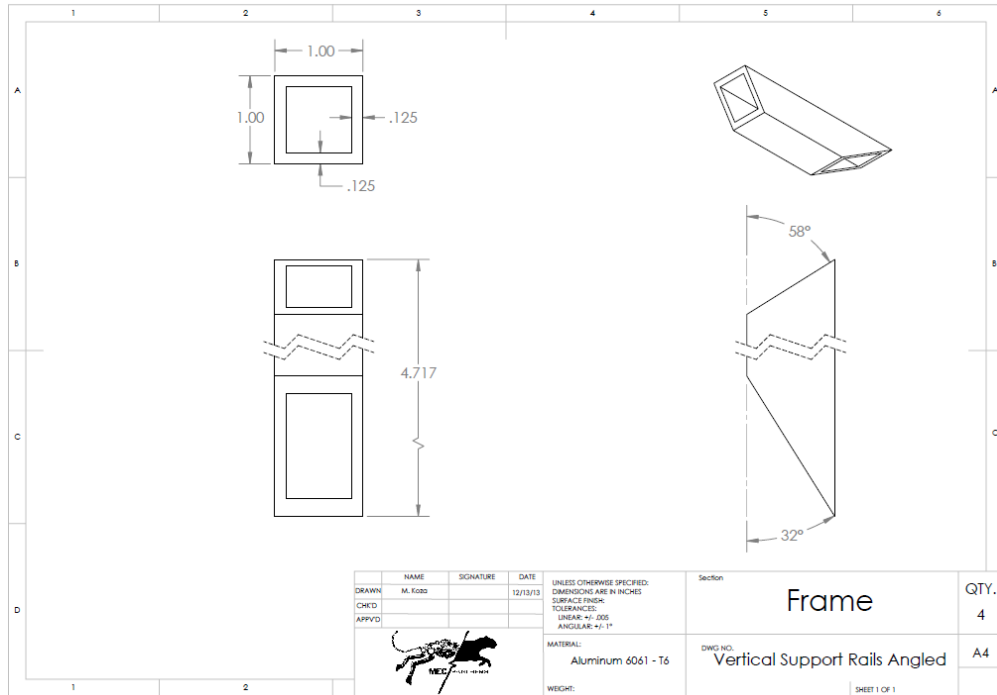


Figure 89: Vertical Support Rails Angled Drawing

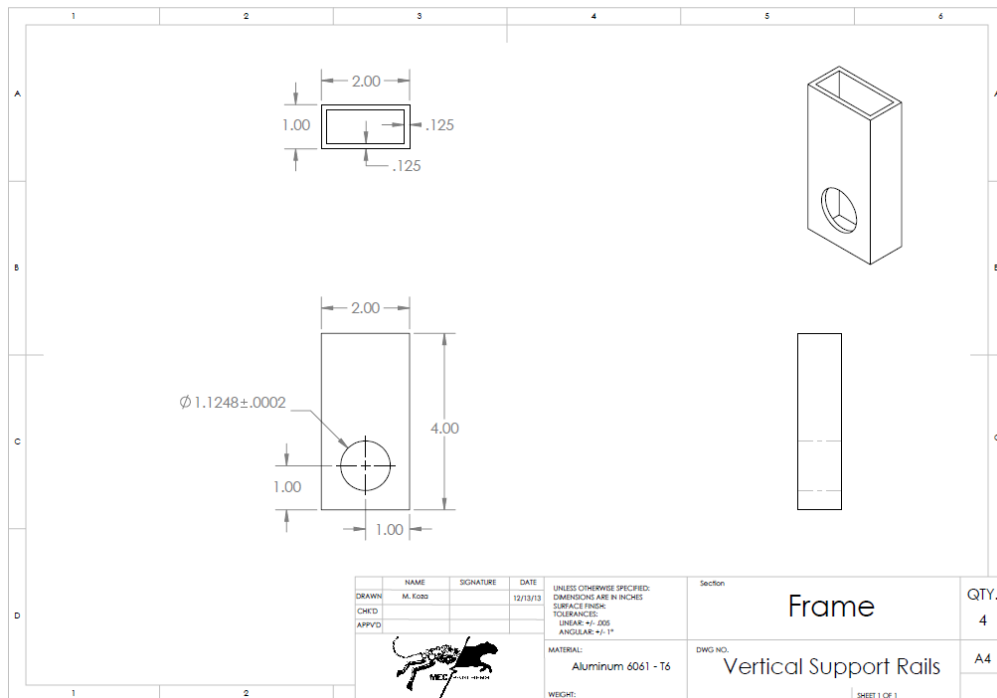


Figure 90: Vertical Support Rails Drawing

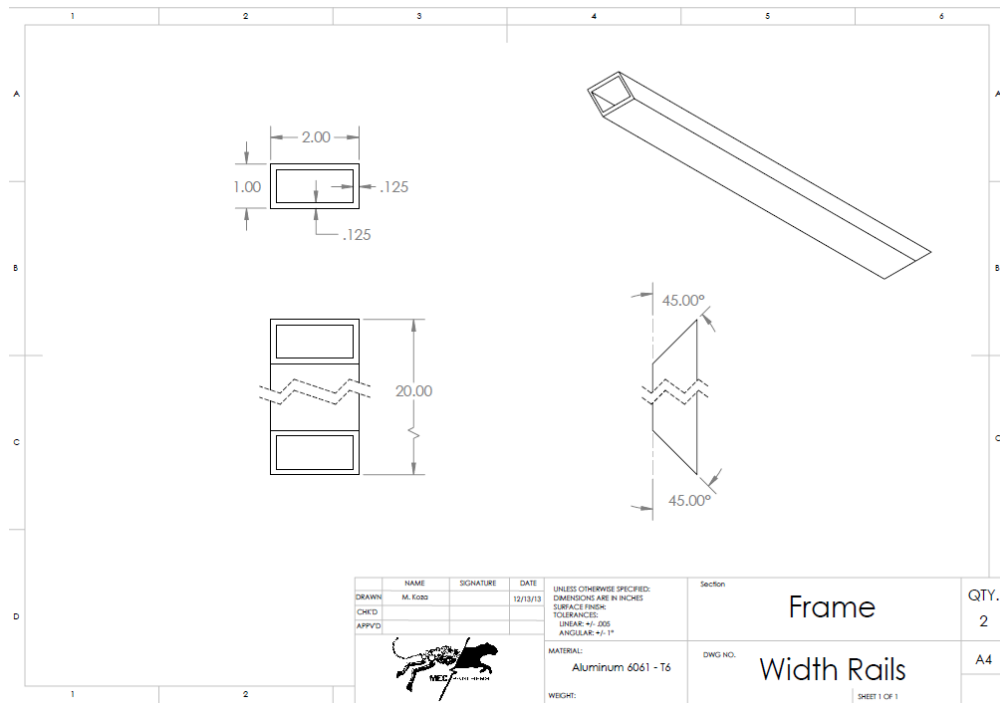


Figure 91: Width Rails Drawing

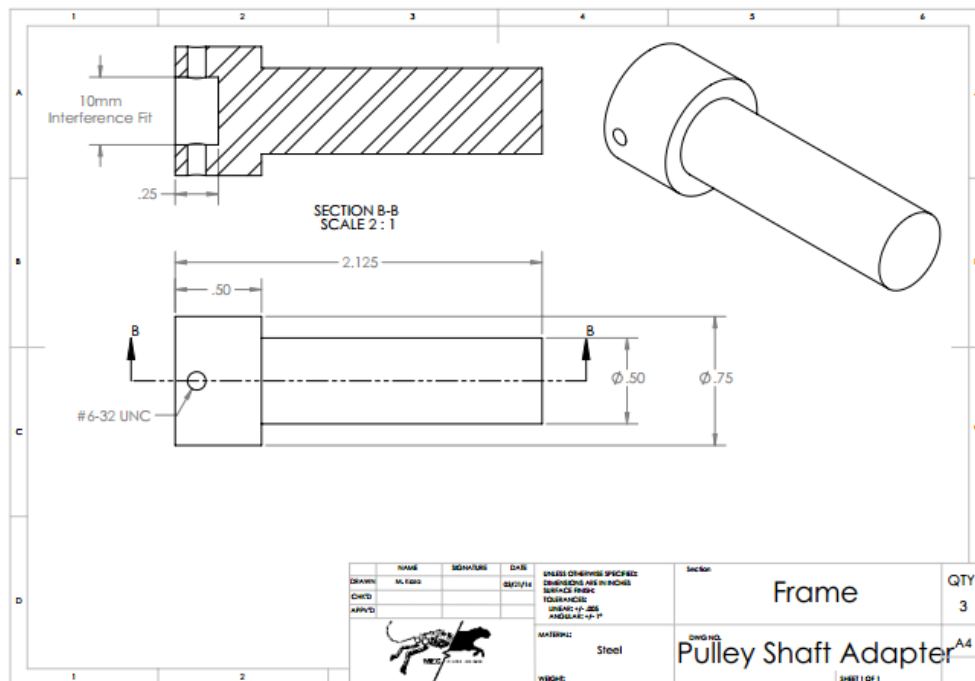


Figure 92: Pulley Shaft Adapter

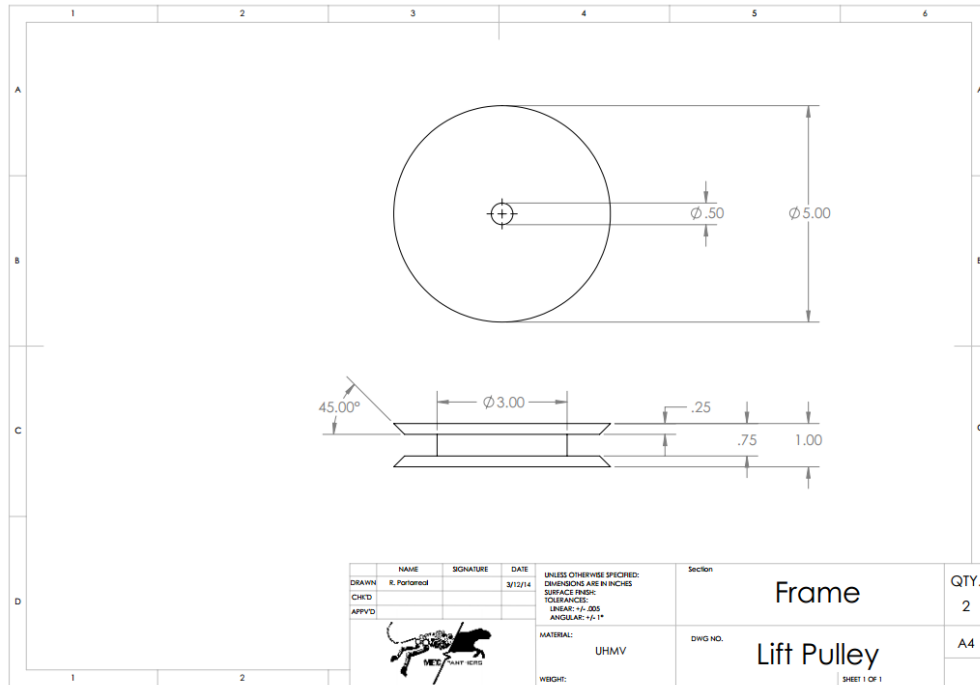


Figure 93: Lift Pulley

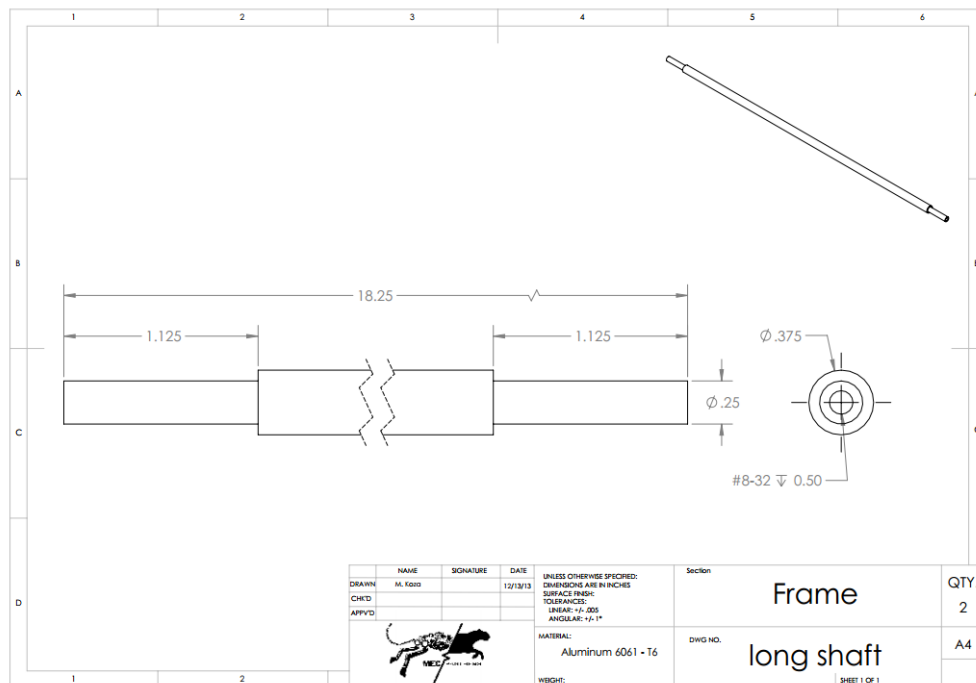


Figure 94: Long Shaft

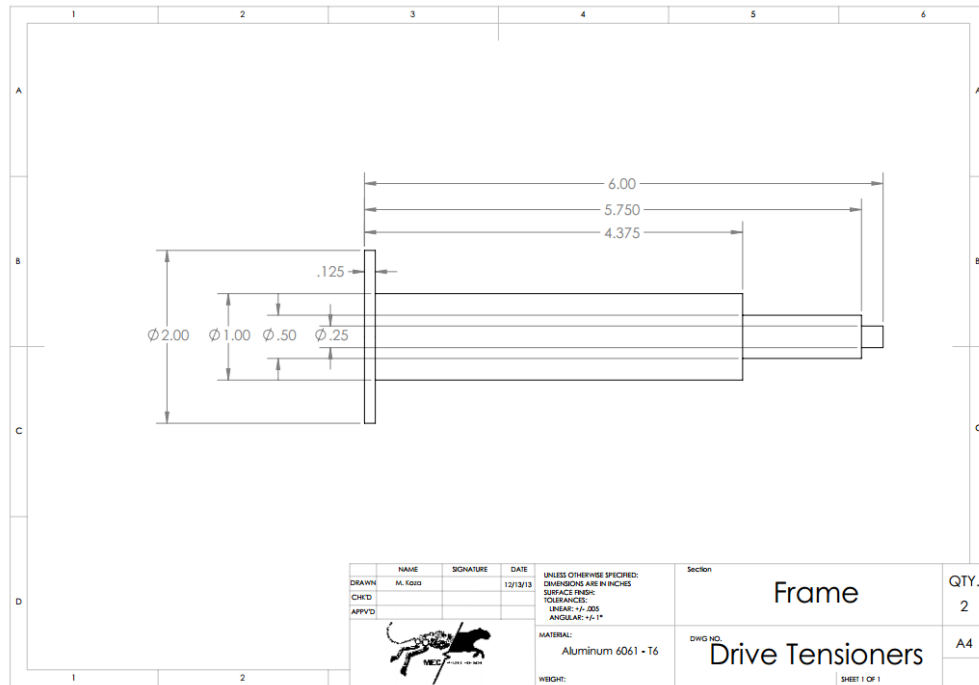


Figure 95: Drive Tensioners

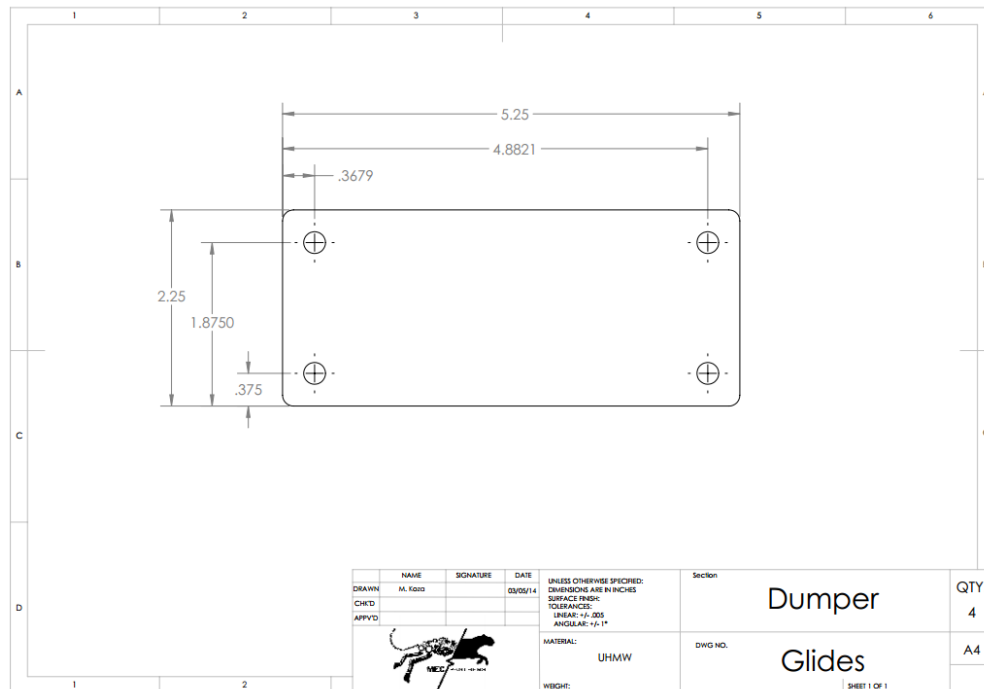


Figure 96: Glides

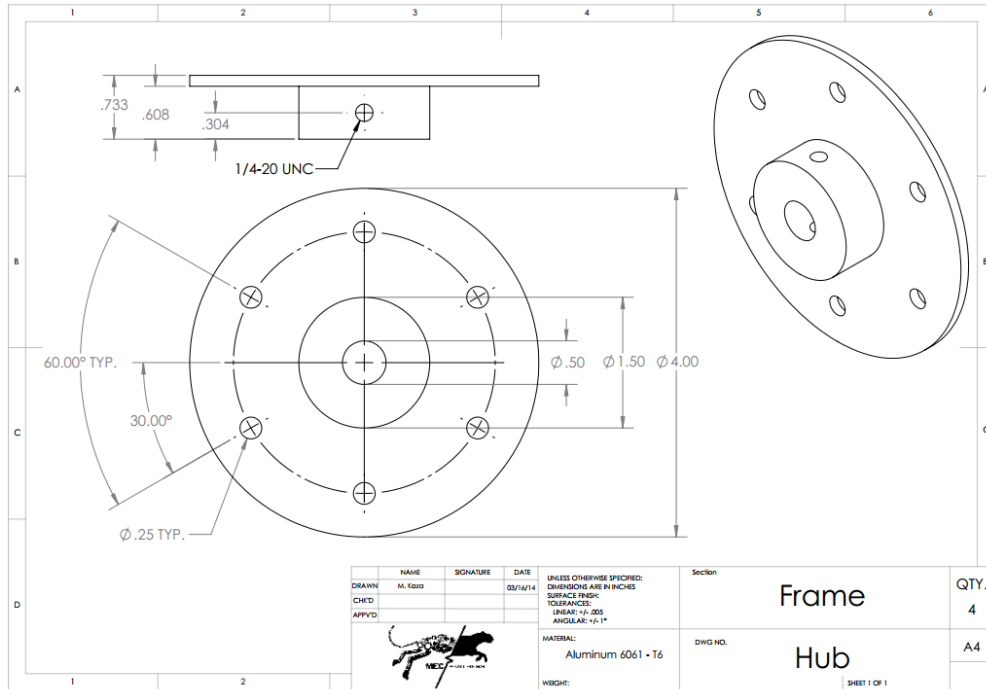


Figure 97: Hub

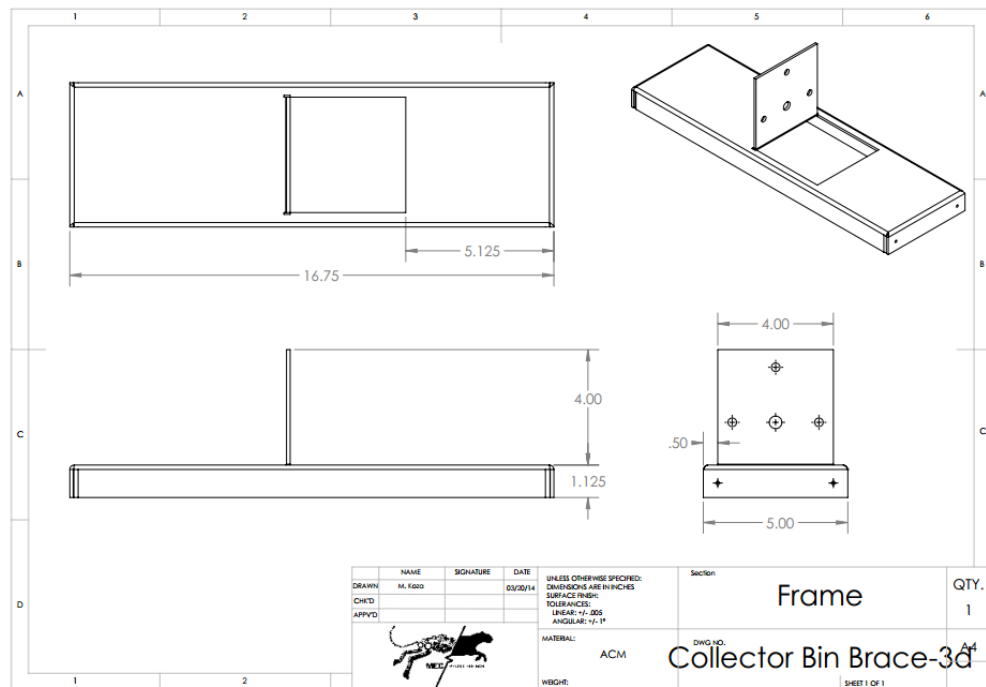


Figure 98: Collector Bin Brace-3D

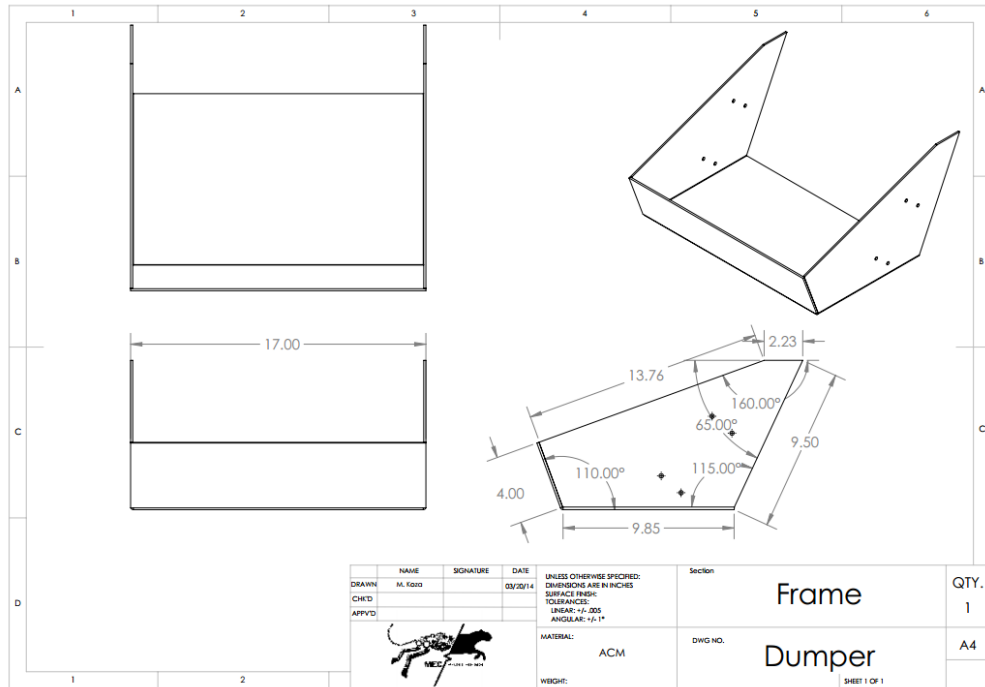


Figure 99: Dumper

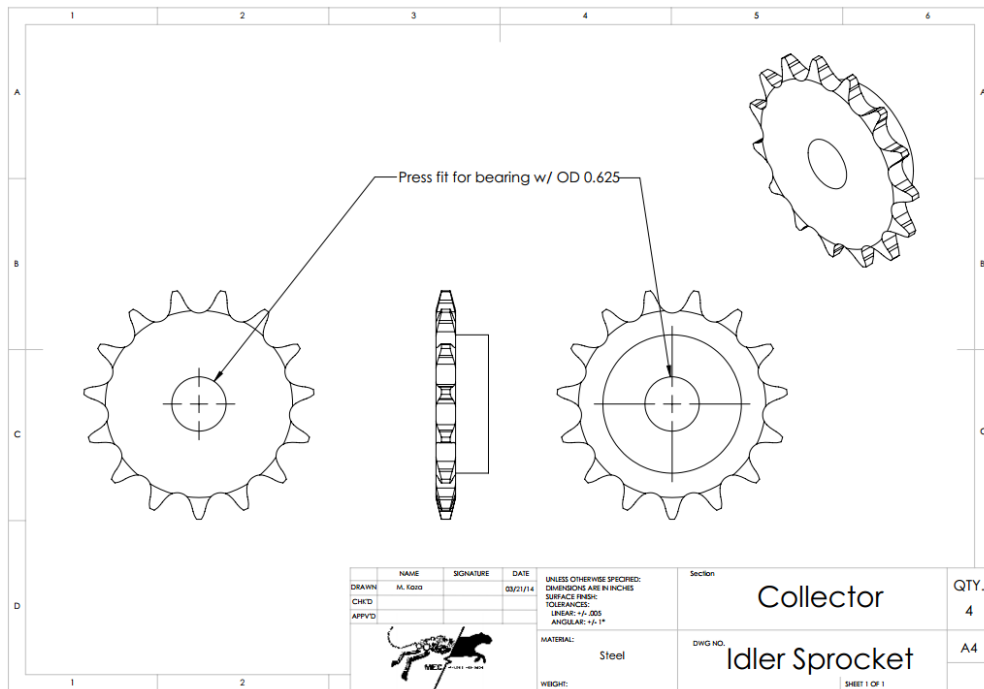


Figure 100: Idler Sprocket



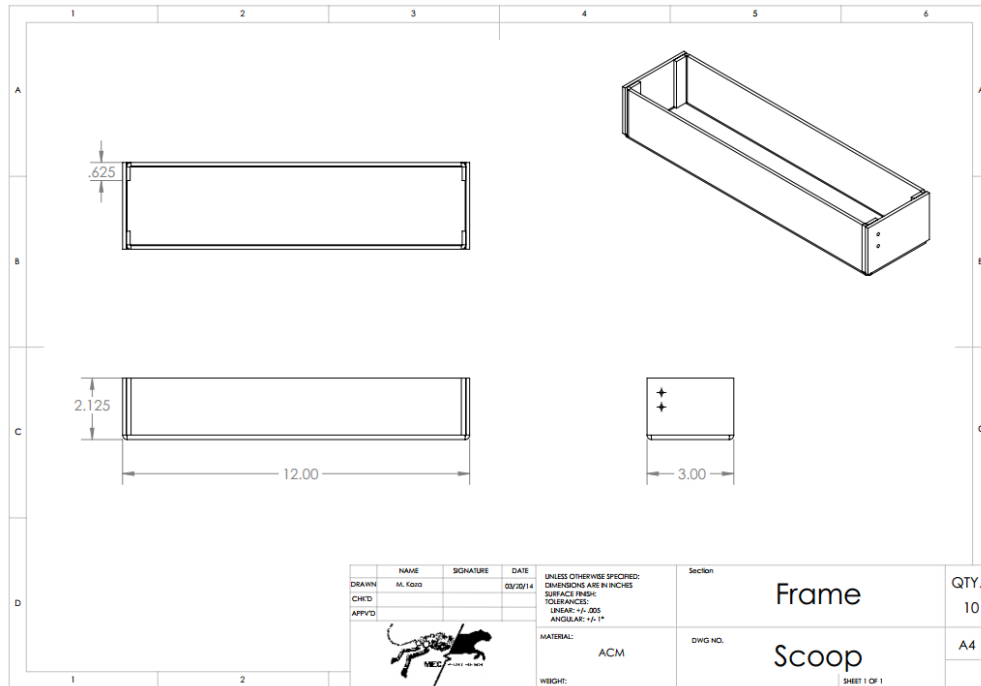


Figure 101: Scoop

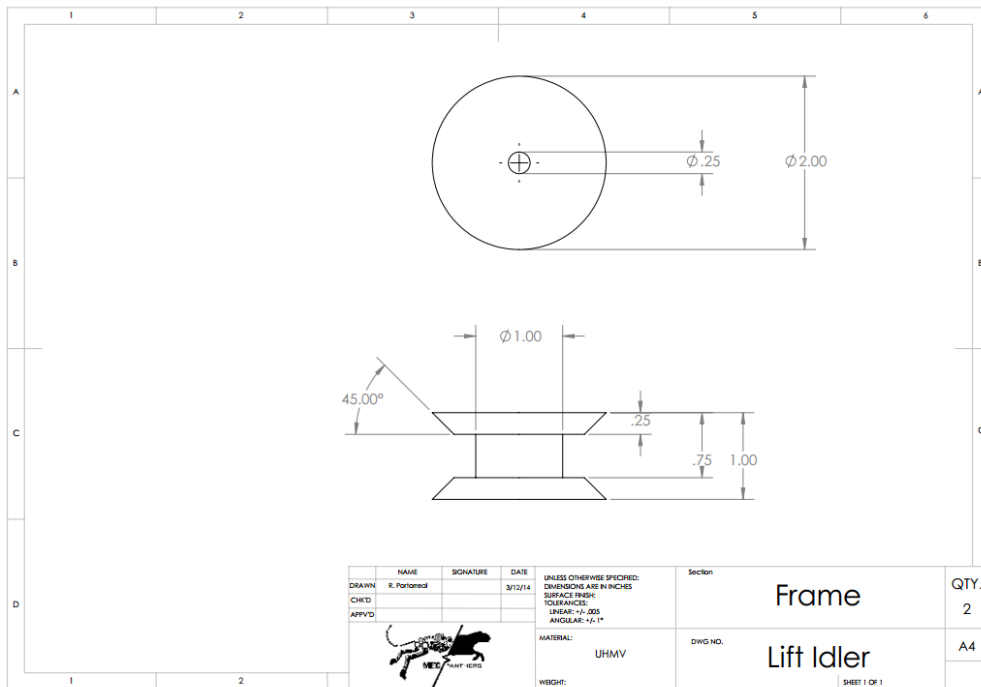


Figure 102: Lift Idler

## Appendix: Mechanical Team Manual Control Program

/\*

MEC PANTHERS WIFI Control for LUNAR Robot. Uses telnet server to connect to IP address.

Takes computer keyboard input as command signals for movement control.

Using VEX 888 motor controller and calibrating them to a range of 1000-2000.

1000-Full Speed backward

2000-Full Speed forward

1500-Neutral Speed

Circuit:

\* Ethernet shield attached to pins 10, 11, 12, 13

\* Analog inputs attached to pins A0 through A5 (optional)

\*/

```
#include <Arduino.h>
```

```
#include <Servo.h>
```

```
#include <SPI.h>
```

```
#include <Ethernet.h>
```

```
#include <Servo.h>
```

```
int forwardr;
```

```
int backwardr;
```

```
int stop12;
```

```
int i;
```

```
// Enter a MAC address and IP address for your controller below.
```

```
// The IP address will be dependent on your local network.
```

```
// gateway and subnet are optional:
```

```
byte mac[] = {
```

```
    0xDE, 0xAD, 0xBE, 0xEF, 0xFE, 0xED };
```

```
IPAddress ip(192,168,1, 149);
```

```
IPAddress gateway(192,168,1, 1);
```

```
IPAddress subnet(255, 255, 255, 0);
```

```

Servo myservoRight, myservoLeft,myservoBLeft,myservoBRight, myservoLift;

// telnet defaults to port 23

EthernetServer server(23);

boolean alreadyConnected = false; // whether or not the client was connected previously


void setup() {
  // initialize the ethernet device

  myservoLeft.attach(5);
  myservoRight.attach(6);
  myservoBLeft.attach(8);
  myservoBRight.attach(7);


  Ethernet.begin(mac, ip, gateway, subnet);
  // start listening for clients
  server.begin();
  // Open serial communications and wait for port to open:
  Serial.begin(9600);
  while (!Serial) {
    ; // wait for serial port to connect. Needed for Leonardo only
  }
  Serial.print("Chat server address:");
  Serial.println(Ethernet.localIP());
}


void loop() {
  // wait for a new client:
  EthernetClient client = server.available();
  if (client) {
    if (!alreadyConnected) {
      // clead out the input buffer:

```

```

// when the client sends the first byte, say hello:
client.flush();
Serial.println("Welcome Panther");
client.println("Hello, MEC Panther!");
client.println("Enter at your own risk!");
alreadyConnected = true;
}
if (client.available() > 0) {
    // read the bytes incoming from the client:
    char thisChar = client.read();
    // echo the bytes back to the client:
    //server.write( thisChar);
    // echo the bytes to the server as well:
    if (thisChar=='w')
    {
        forward();
        // server.write(thisChar);
        client.print("half speed forward");
        //Serial.print(thisChar);
    }
    else if (thisChar== 's')
    {
        backward();
        //server.write(thisChar);
        client.print("half speed backward");
    }
    else if (thisChar== 'W')
    {
        forward1();
        // server.write(thisChar);

```

```

    client.print("full speed forward");
}
else if (thisChar== 'S')
{
    backward1();
    // server.write(thisChar);
    client.print("full speed backward");
}
else if(thisChar=='v')
{
    stop1();
    Serial.print(thisChar);
    client.print("Stop");
}
else if(thisChar=='a')
{
    // left();
    Serial.print(thisChar);
    client.print("Left");
}
else if(thisChar=='d')
{
    //right();
    Serial.print(thisChar);
    client.print("Right");
}
else
{
    stop1();
}

```

```

    }
}

void forward()
{
    //Half Speed
    forwardr=1750;
    backwardr=1250;
    myservoLeft.writeMicroseconds(backwardr);
    Serial.println("forward");
    myservoRight.writeMicroseconds(forwardr);
    Serial.println("forward1");
    myservoBLeft.writeMicroseconds(forwardr);
    Serial.println("forward2");
    myservoBRight.writeMicroseconds(backwardr);
    Serial.println("forward3");
    delay(1);
}

void backward()//
{
    //Half Speed
    forwardr=1750;
    backwardr=1250;
    myservoLeft.writeMicroseconds(forwardr);
    Serial.println("backward");
    myservoRight.writeMicroseconds(backwardr);
    Serial.println("backward1");
    myservoBLeft.writeMicroseconds(backwardr);
    Serial.println("backward2");
}

```

```

myservoBRight.writeMicroseconds(forwardr);
Serial.println("backward3");

delay(1);
}
void forward1()
{
  //Full speed
  forwardr=2000;
  backwardr=1000;
  myservoLeft.writeMicroseconds(backwardr);
  Serial.println("forward");
  myservoRight.writeMicroseconds(forwardr);
  Serial.println("forward1");
  myservoBLeft.writeMicroseconds(forwardr);
  Serial.println("forward2");
  myservoBRight.writeMicroseconds(backwardr);
  Serial.println("forward3");
  delay(1);
}
void backward1()
{
  //Full speed
  forwardr=2000;
  backwardr=1000;
  myservoLeft.writeMicroseconds(forwardr);
  Serial.println("backward");
  myservoRight.writeMicroseconds(backwardr);
  Serial.println("backward1");
  myservoBLeft.writeMicroseconds(backwardr);

```

```

Serial.println("backward2");
myservoBRight.writeMicroseconds(forwardr);
Serial.println("backward3");
delay(1);
}
void left()
{
//This part of the code requires testing
forwardr=stop12+i;
backwardr=stop12-1;
stop12=1500;
for(int i=0;i<100;i++){
myservoLeft.writeMicroseconds(backwardr);
myservoRight.writeMicroseconds(backwardr);
myservoBLeft.writeMicroseconds(forwardr);
myservoBRight.writeMicroseconds(forwardr);
delay(1);
}
}
void right()
{
//This part of the code requires testing
forwardr=stop12+i;
backwardr=stop12-1;
stop12=1500;
for(int i=0;i<100;i++){
myservoLeft.writeMicroseconds(forwardr);
myservoRight.writeMicroseconds(forwardr);
myservoBLeft.writeMicroseconds(backwardr);
myservoBRight.writeMicroseconds(backwardr);

```



```

    delay(1);
}
}

void stop1()
{
    myservoLeft.writeMicroseconds(1500);
    Serial.println("stop");
    myservoRight.writeMicroseconds(1500);
    Serial.println("stop");
    myservoBLeft.writeMicroseconds(1500);
    Serial.println("stop");
    myservoBRight.writeMicroseconds(1500);
    Serial.println("stop");

    delay(1);
}

void rotateR() {
    //This part of the code requires testing
    forwardr=stop12+i;
    backwardr=stop12-i;
    stop12=1500;
    for(int i=0;i<100; i++){
        myservoLeft.writeMicroseconds(forwardr);
        myservoRight.writeMicroseconds(forwardr);
        myservoBLeft.writeMicroseconds(forwardr);
        myservoBRight.writeMicroseconds(forwardr);
    }
}

void rotateL(){

```

```
//This part of the code requires testing  
forwardr=stop12+i;  
backwardr=stop12-i;  
stop12=1500;  
for(int i=0;i<100; i++){  
    myservoLeft.writeMicroseconds(backwardr);  
    myservoRight.writeMicroseconds(backwardr);  
    myservoBLeft.writeMicroseconds(backwardr);  
    myservoBRight.writeMicroseconds(backwardr);  
}  
}
```