EML 4905 Senior Design Project

A B.S. THESIS
PREPARED IN PARTIAL FULFILLMENT OF THE
REQUIREMENT FOR THE DEGREE OF
BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

Mining M.E.C. Panthers
NASA Lunar Robotics Senior Design Project
25% Report

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November 26, 2013

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 $\frac{g}{cm^3}$ when it is compacted and 0.75$\frac{g}{cm^3}$ 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-kilogram. Referencing the competition rules, 8 points are deducted for every kilogram of mass of the rover up to the 80-kilogram 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 kilobits/second 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 and habitats 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 kilograms. 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. [1]

1.3 Literature Survey

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. [2]

Wheeled vehicles "offer better fuel economy and reliability" [2] compared to tracked vehicles but only while on paved roads. It has been shown that for Army missions requiring "unrestricted terrian movement" [2] 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. [2] 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.

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 ELMS 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. [3]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. [3]

Another advantage the ELMS concept has over a rocker-bogie system is its simplicity. [3] The ELMS does not require the mechanical complexities needed by the rocker-bogie system and hence ends up being lighter. [3] 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. [3] 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. [3]

Table 1: Rocker-Bogie vs. ELMS

Subsystem	Rocker-Bogie	ELMS
Dimension	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
Total weight of Mobility System	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.)
Torque/wheel	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
Payload capacity	5 kg	5-8 kg

Soil

In the NASA rulebook [4] 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

Figure 1: Picture of embedded dirt on excavator tracks

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.

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 [5]. Due to the composition of the soil, it can be magnetic. [5] 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. [5] [4] NASA requires participants to wear a breathing apparatus and a suit while in the mining area. [4]

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.

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 2 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.

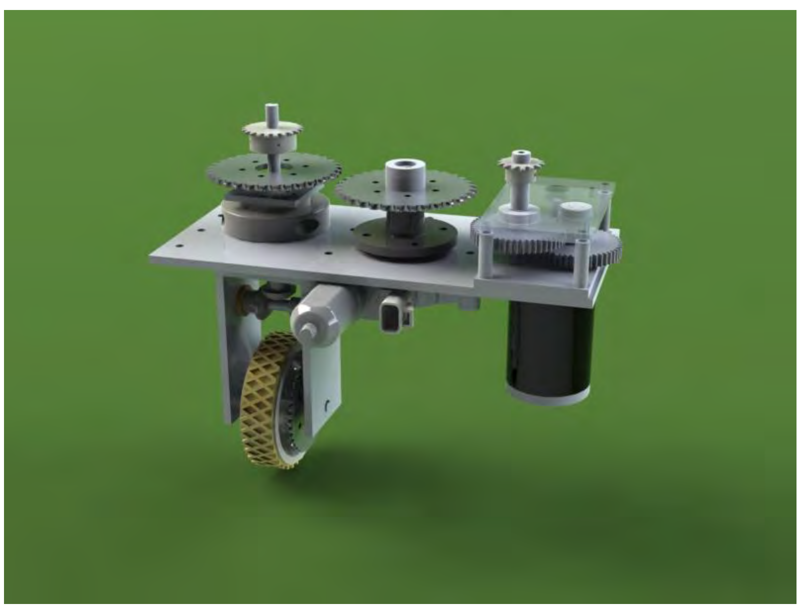

Figure 2: Swerve Drive System

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 3, courtesy of Predator. 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 to manufacture reasonably lighter tread links. Therefore, in spite of the redundancy that this system provides (Comparable to wheels), the weight and cost of implementation negate the benefits.

Figure 3: Predator Hybrid System

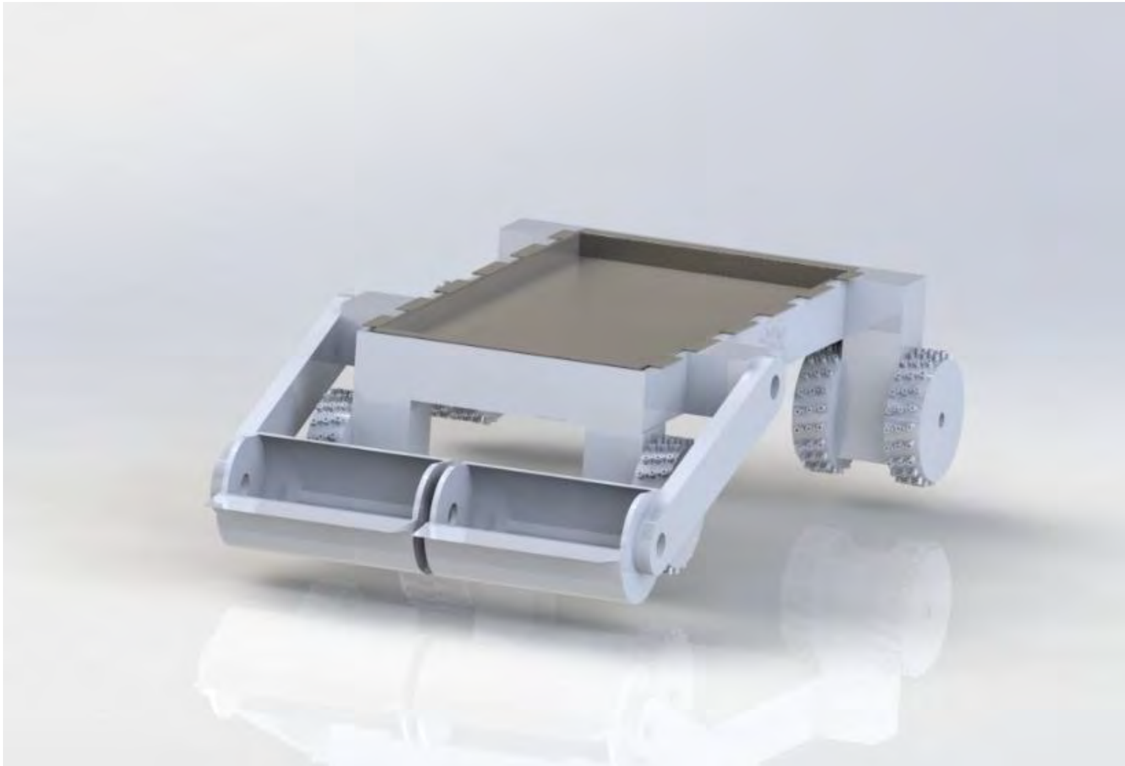

Figure 4: Conceptual Design 1

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.

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.

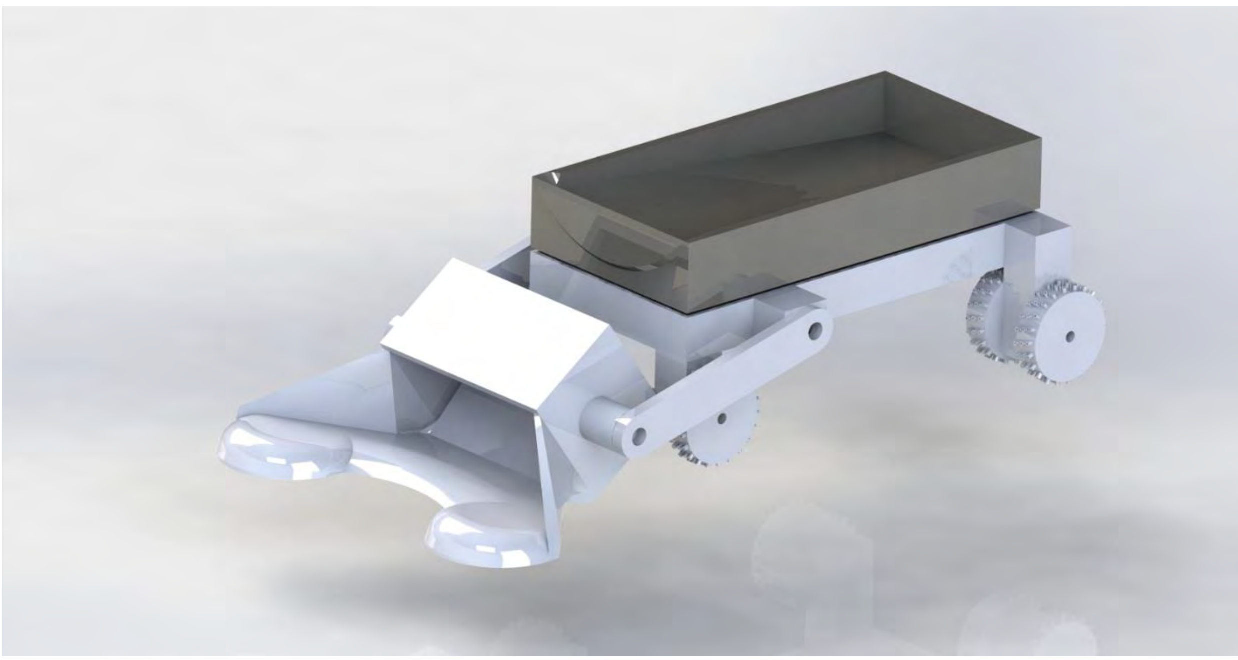

Figure 5: Conceptual Design 2

The initial method was the scoop mechanism, akin to a bulldozer, as in Figure 5. 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 collection bin fills. 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 drivetrain slippage as well as increased current draw from the drive motors.

Figure 6: 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 6. 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 7: Conveyer Belt

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 simple dumping mechanism like those found on garbage trucks. Since the bin where the soil is to be deposited is below the maximum height of the lunar rover, the dumping mechanism could be hinged at that point in, necessitating the use of only one or two linear actuators. 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 high placement dumping mechanism will be added to the design. The initial finalized design is pictured below in Figure 8.

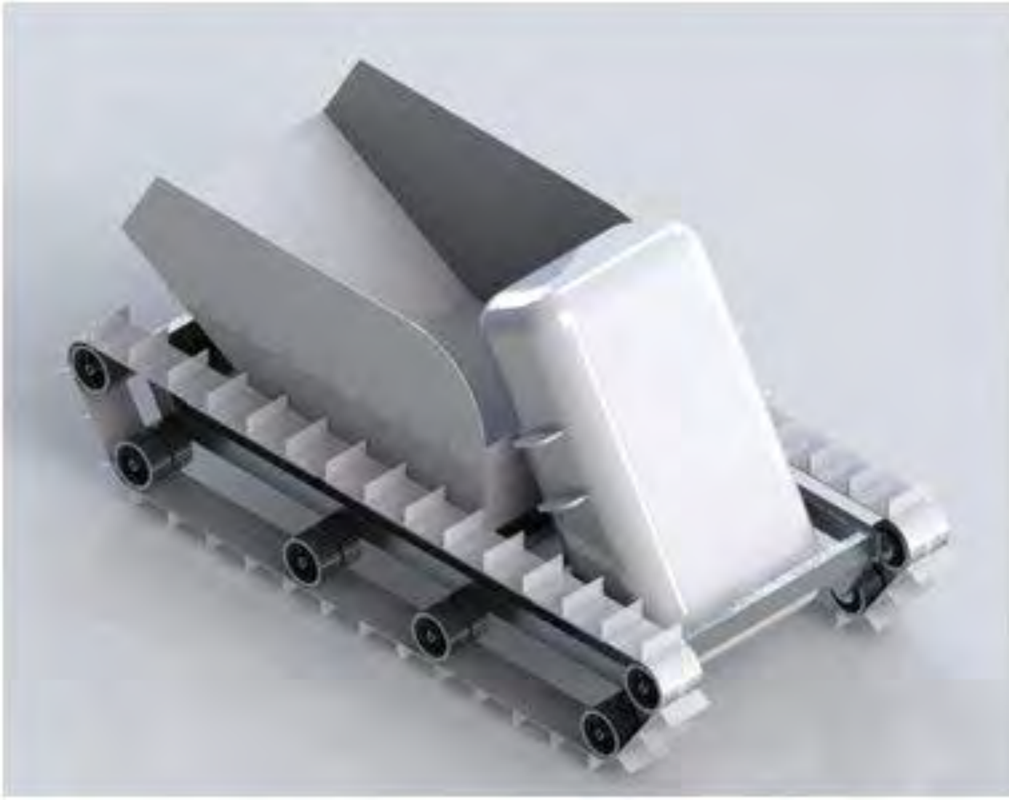

Figure 8: Initial Design

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 40mm. 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 will consist of two sprocket-driven treaded belts. The sprocket driven design was 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 will be custom engineered by us after receiving the treads. They will be machined out of UHMW (Ultra High Molecular Weight Polyethelyn), once the actual dimensions of the sprockets have been determined.

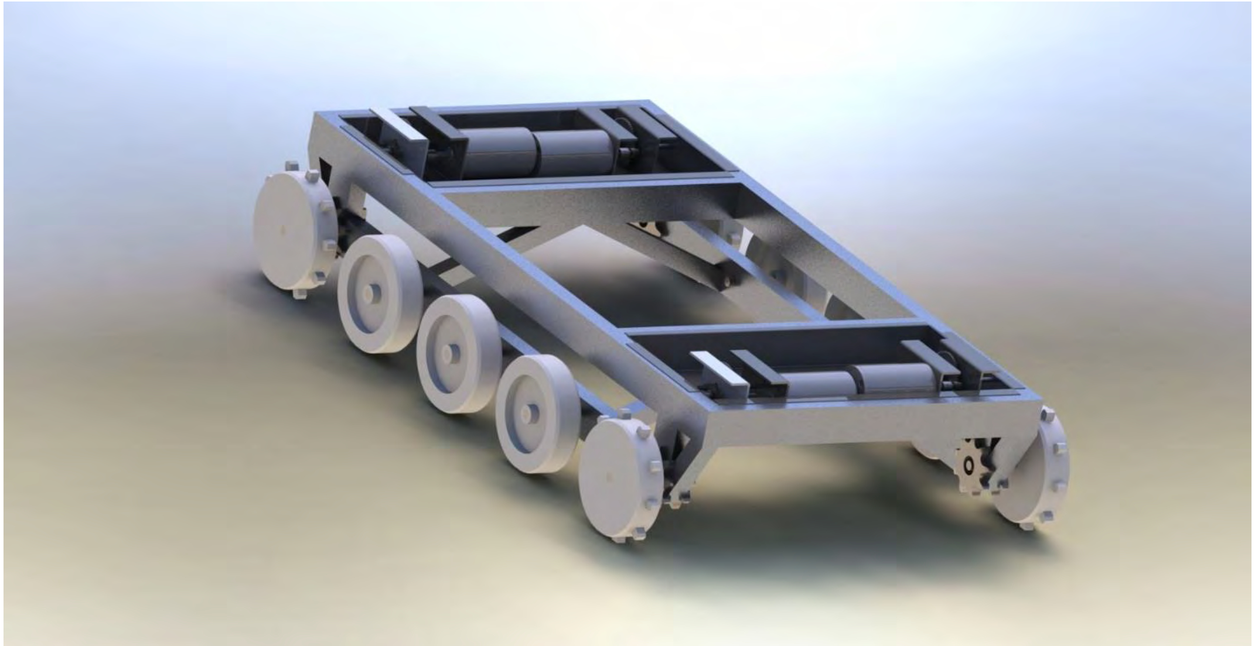

Figure 9: Frame with gearbox, idlers and pulleys

A four motor drivetrain will be 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 (CIM); 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, desired speed, 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 inches, a desired top speed of 3.5 feet per second 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 feet per second in mind. The maximum speed was determined by the amount of time necessary to traverse the entirety of the field at full speed.

Collection

The final collection method is to be designed in a fashion similar to Unitracks conveyor belts. These conveyor belts are used in high dust environments and are designed to be seamless, even while in operation. Seamless collection offers two major benefits, collection speed and minimal dust collection. By having a seamless 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. This allows for a more efficient collection of the soil and less time needed to reach the collection maximum load. The seamless design dust prevention is also a major benefit as there is a point deduction system for an overabundance of soil stuck in the rover. By preventing dust build up through design, we eliminate the possibility for point deductions.

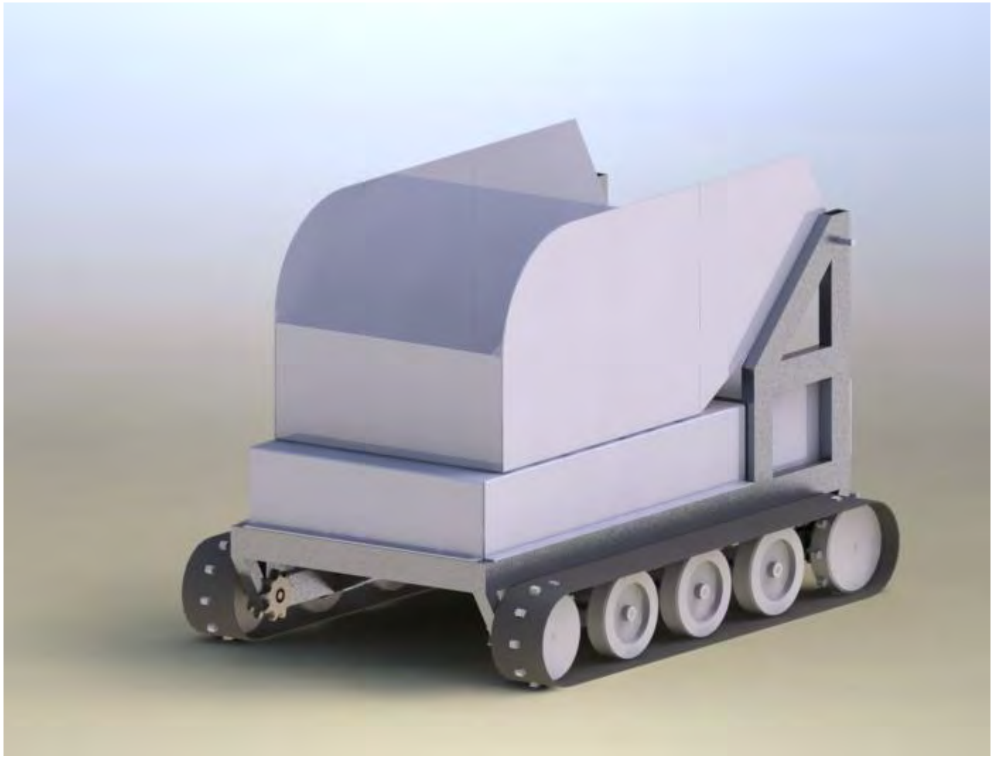

Figure 10: Improved Design

While the design of the collection buckets are not finalized, they will most likely be individually constructed of either ACM (Aluminum Composite Material) or stainless steel, bent to the required shapes and epoxied in the seams to prevent leaks. These buckets will be mounted to a timing belt via rivets or screws. The timing belt pulleys will need to be modified to allow the screws/rivets to pass without interference from the pulleys' teeth. This will be accomplished by machining slots into the pulleys' face with a lathe in the location of the mounting area. 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. This will be performed with lead screws driven by high RPM motors. The lead screws will allow the collection mechanism to rise for the depositing of the soil and lower for the collection. The motors have not been selected, as the final dimensions of the collection mechanism, including final weight, have not been determined.

Deposit

The dumping mechanism will be constructed from a single sheet of ACM or stainless steel bent into the necessary shape and bolted/welded together as well as epoxied to prevent leaks. A 30° angle bend will be incorporated on the backside of the dumping mechanism to prevent the soil from being stuck when depositing. The angle will also allow for the soil to smoothly slide out of the collection bin, preventing excessive dust aeration (another score penalty).

The collection bin will be driven around a hinge located below the soil exit point. The bin will be driven by a set of two linear actuators (one on each side to provide stability). The actuators have not been chosen since the necessary stroke and necessary driving force have not yet been determined. In order to assist with soil extraction, a vibration motor (high RPM motor with an off-center weight on the driveshaft) will be placed on the underside of the collection bin to agitate the soil should it get stuck during the depositing into the collection bin.

4. Project Management

4.1 Timeline

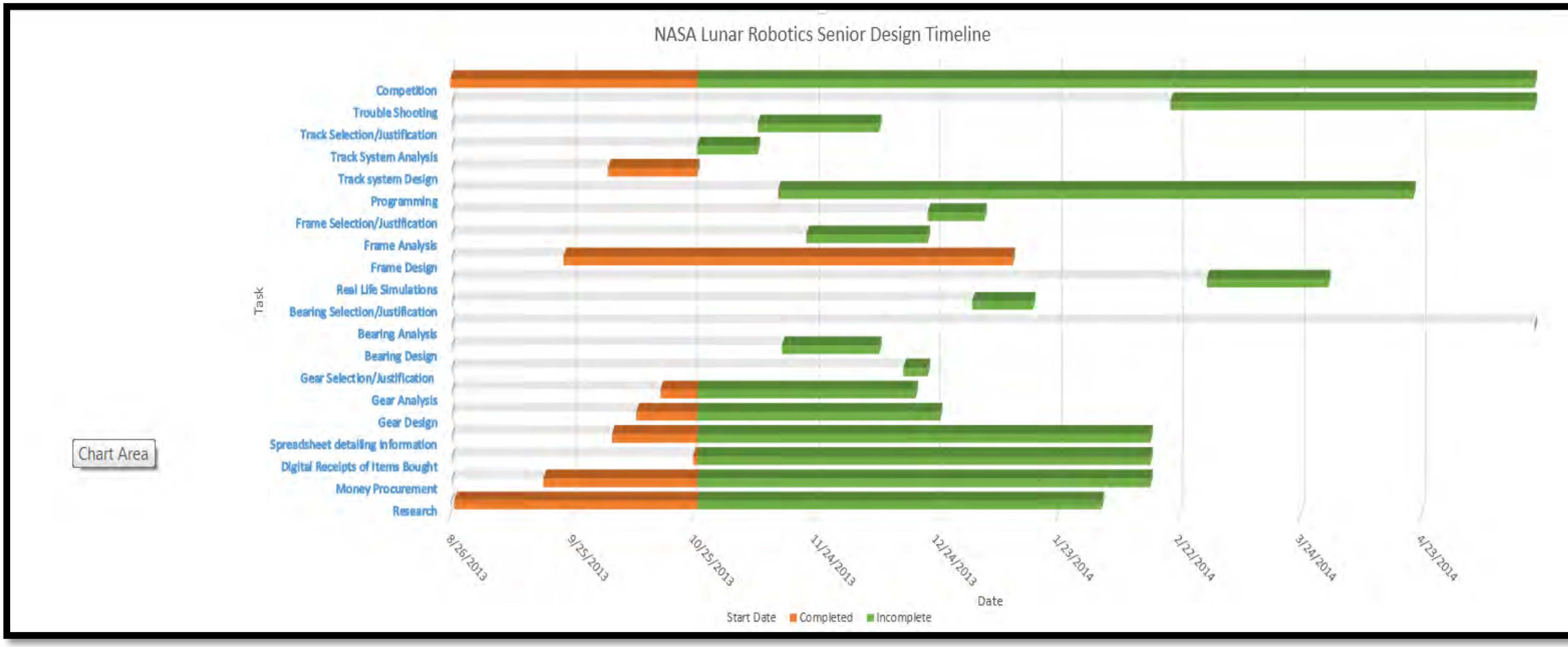

Figure 11: Timeline of Task for Project

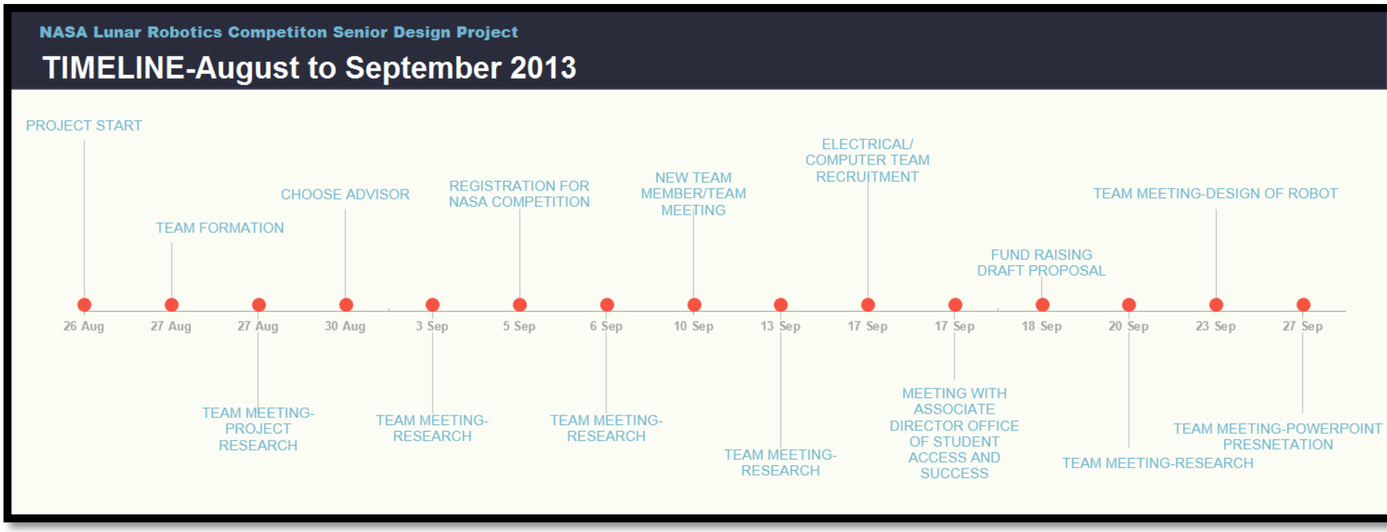

Figure 12: August to September 2013 Timeline

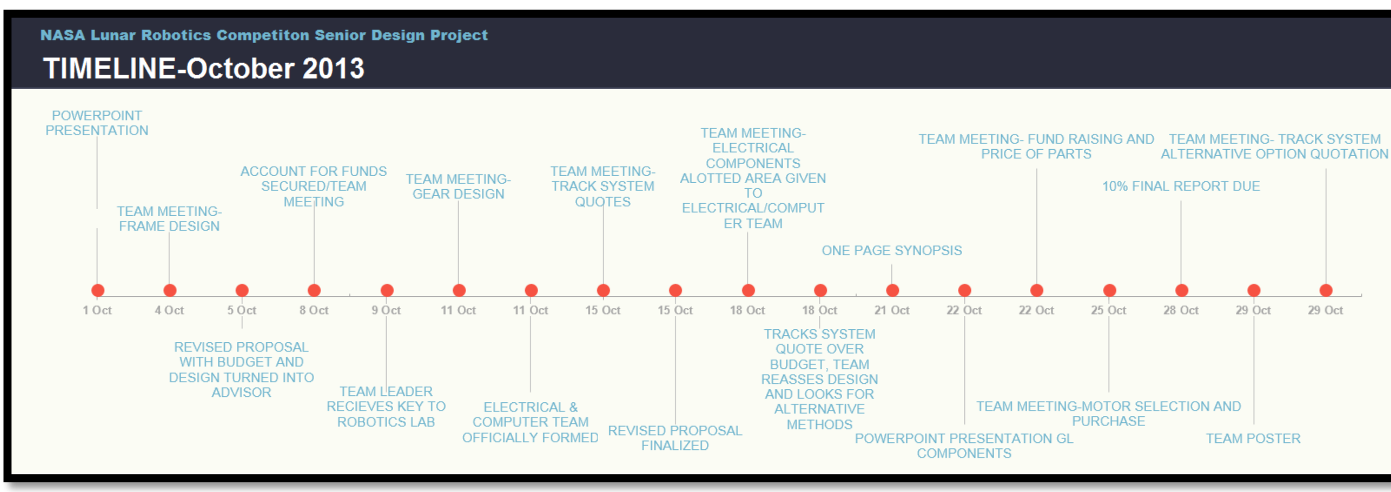

Figure 13: October 2013 Timeline

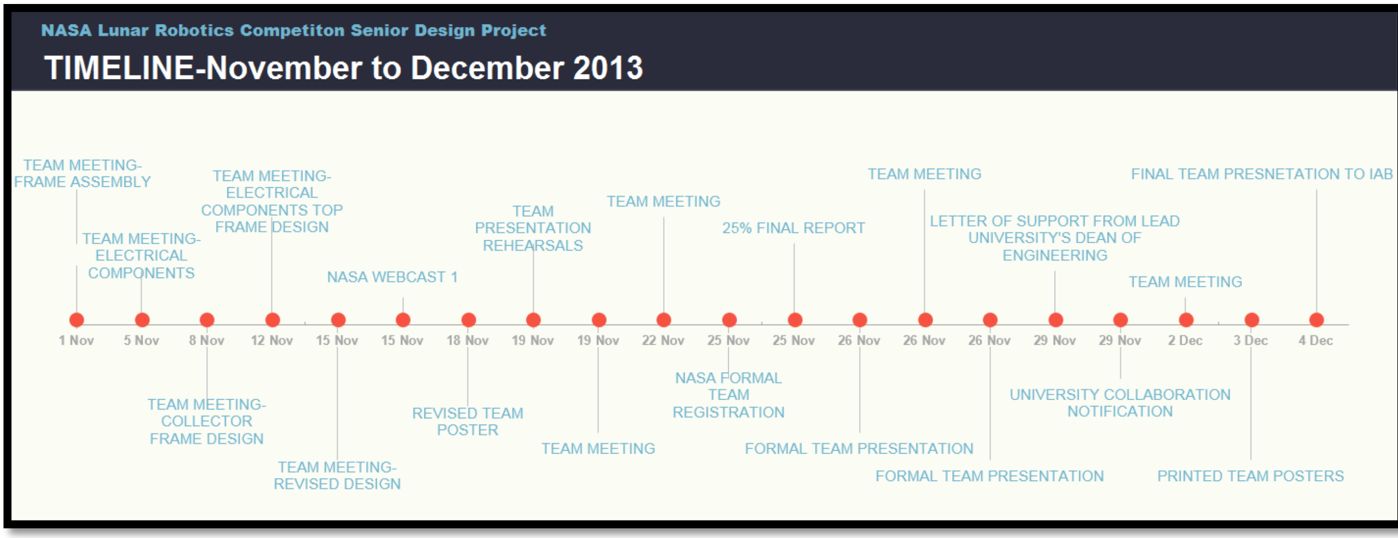

Figure 14: November to December 2013 Timeline

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 in Figure 11 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. Figure 12, 13, 14 shows the timeline of events for the months of August to December. 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.

Table 2: Senior Design Project Task Breakdown

Senior Design Project Task Breakdown				
	Hours Spent per Member			
Task	Allotted Days	Ronald Portorreal	Matthew Koza	Sean Di Pasquale
Research	160	55	55	55
Money Procurement	150	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	157	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	2	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 were 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 [4] therefore a sand dune surface [6] 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,

$$F_R = F_{Gross\ Weight} \times f_{Sand} \tag{1}$$

Next, the Gear Climb Force was calculated,

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

To add, the Acceleration Force was given by,

$$F_{Acceleration} = \frac{F_{Gross\ Weight} \times V_{desired\ speed}}{32.2\frac{ft}{s^2} \times s_{accleration\ time}} \tag{3}$$

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,

$$T_{Total\ wheel\ torque} = T_{\text{Total Tractive Effort}} \times RF_{Resistance\ Factor} \times R_{Radius\ of\ wheel} \tag{4}$$

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_{rr}
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 15: Contact Surface Breakdown [6]

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,

$$N_p = \frac{2k}{(1+2m)sin^2\emptyset}\left(m + \sqrt{m^2 + (1+2m)sin^2\emptyset}\,\right) \tag{5}$$

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 36). 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,

$$W_t = \frac{2T}{d} \tag{6}$$

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,

$$\sigma = \frac{W_t P}{FY} \tag{7}$$

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". [7] . 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. [8] [9] Additionally, the terms Y_N, K_T and K_T 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,

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

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	W	Torque		
2655	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	
σ Chosen Load (Bending Stress) (Lewis Bending Eq.)	15644.44	15644.44	psi
σ Max Load (Bending Stress)	24419.56	24419.56	psi

6. Major Components

The frame of the rover, Figure 16, is composed of 6061 aluminum tube with 1/8” 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 rectangular tubing while several of the smaller supports are made of 1x1 square tube. All of the aluminum in the frame has a T-6 temper rating, providing the highest maximum tensile strength within 6061 alloys.

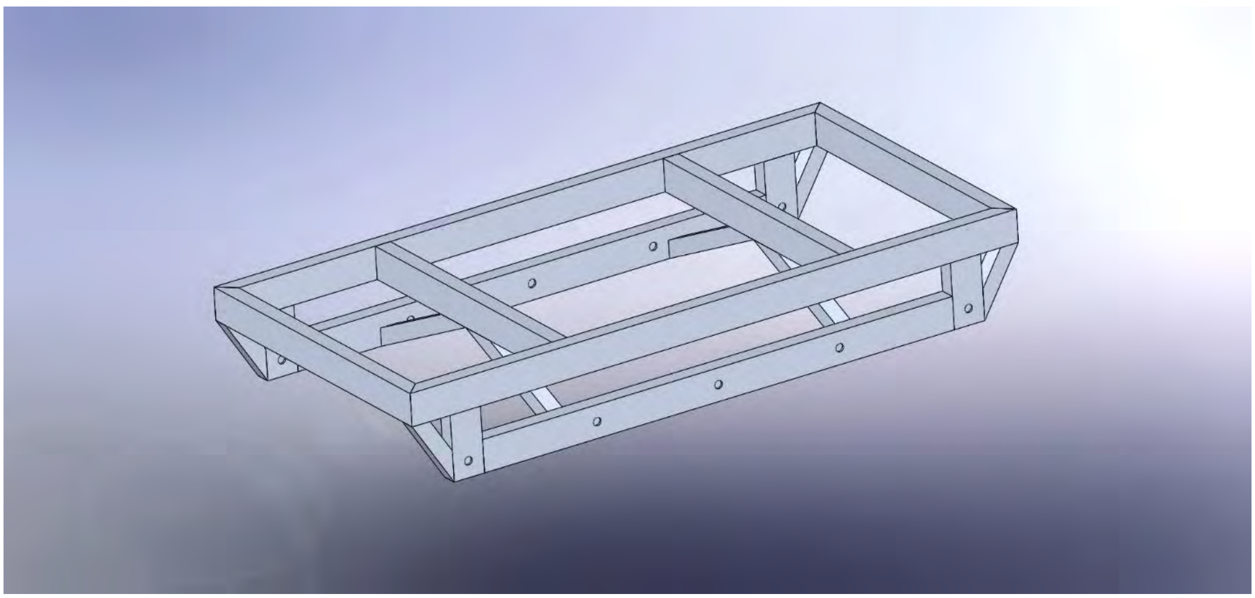

Figure 16: Frame

The drivetrain, Figure 17, is mounted directly to the bottom rails of the frame. The drivetrain 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 using ANSI #35 roller chain. 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 19.

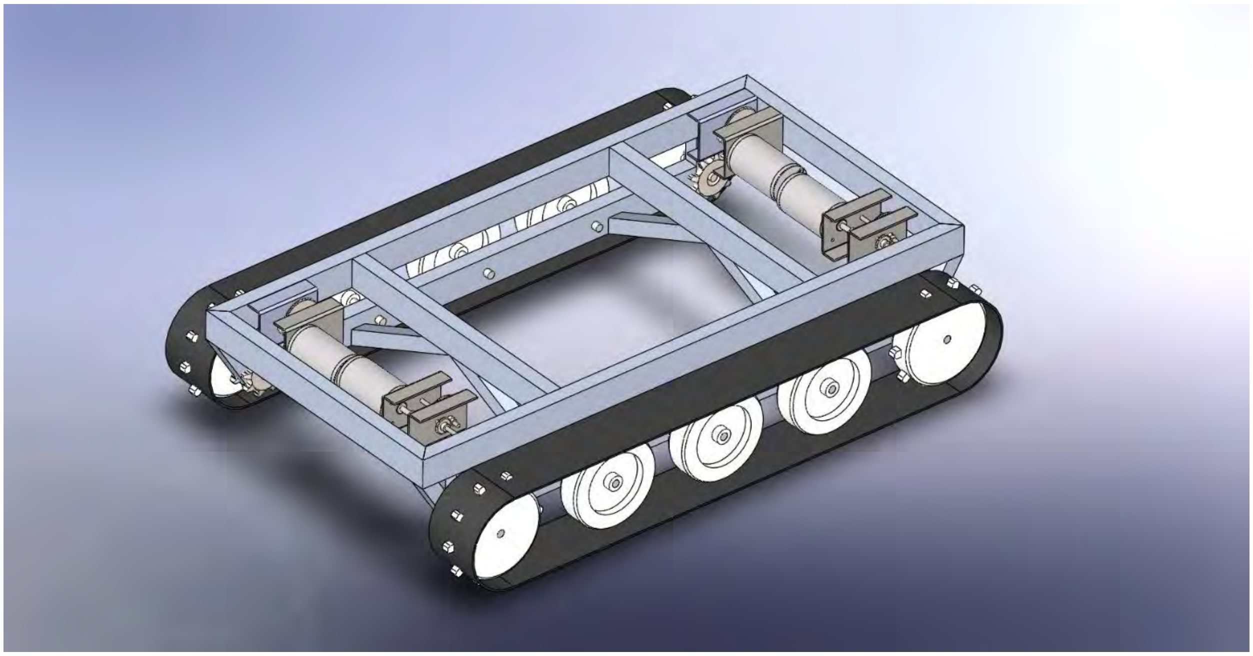

Figure 17: Frame, Drivetrain, idlers, pulleys and threads

Figure 18: CIM Motor

Figure 19: Threads

The collector bin, Figure 20, 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 1/8" thick sheet comprised of a 1/16" sheet of plastic sandwiched between two 1/32" 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.

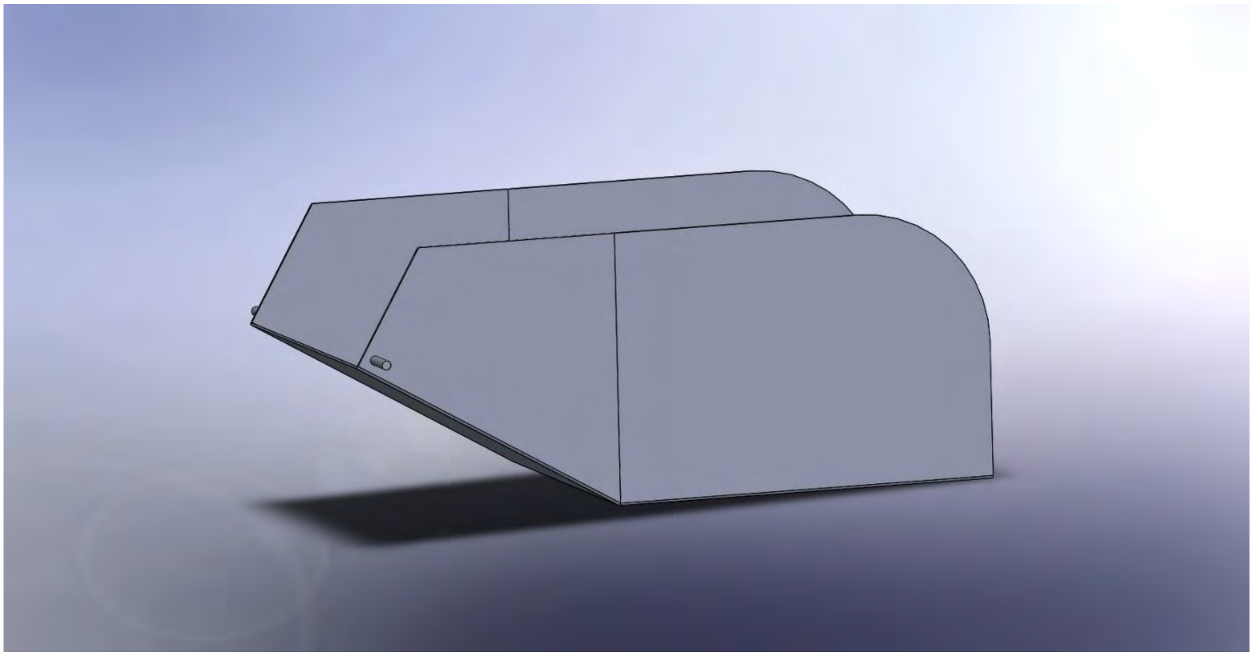

Figure 20: Collector Bin

The collection mechanism, Figure 21, is a continuously running conveyor bucket system used for collecting the regolith and placing it into the collector bin. The mechanism consists of 2 ANSI #35 roller chains with K1 connection links, Figure 22, spaced evenly along the chain. The buckets, comprised of 20 gauge stainless steel sheets formed into bucket shapes. These buckets are to be bolted to the connection links. 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.

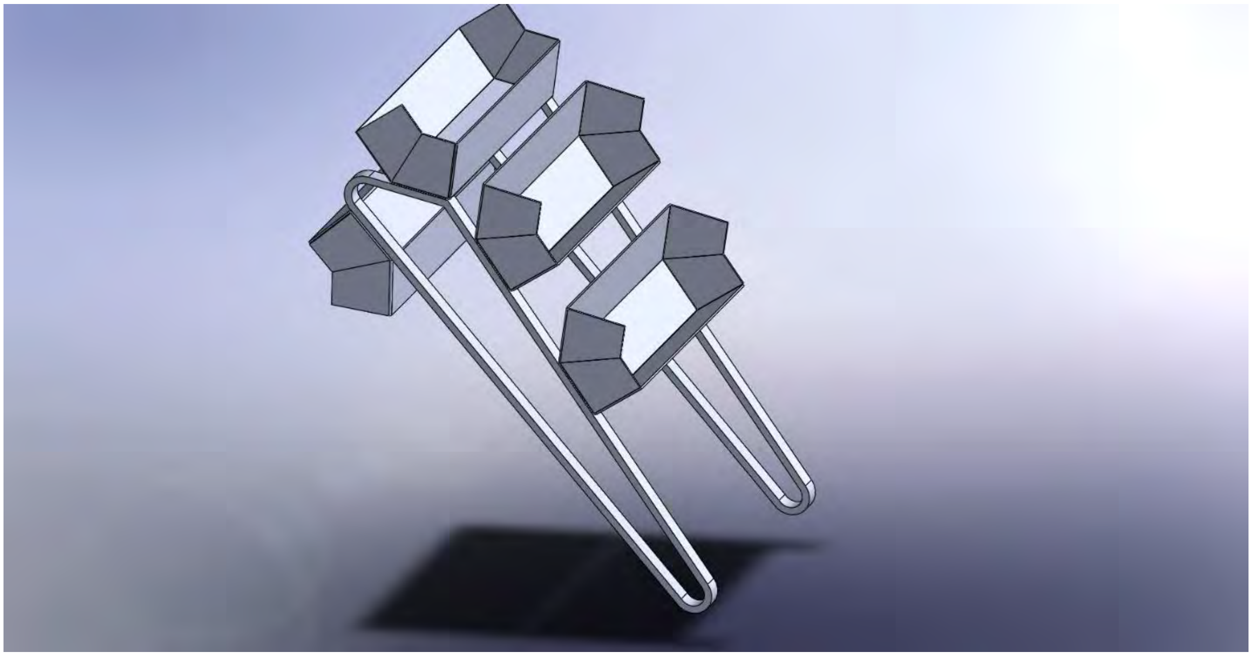

Figure 21: Collection Mechanism

Figure 22: ANSI #35 K1 Attachment Chain

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 1/8" 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.

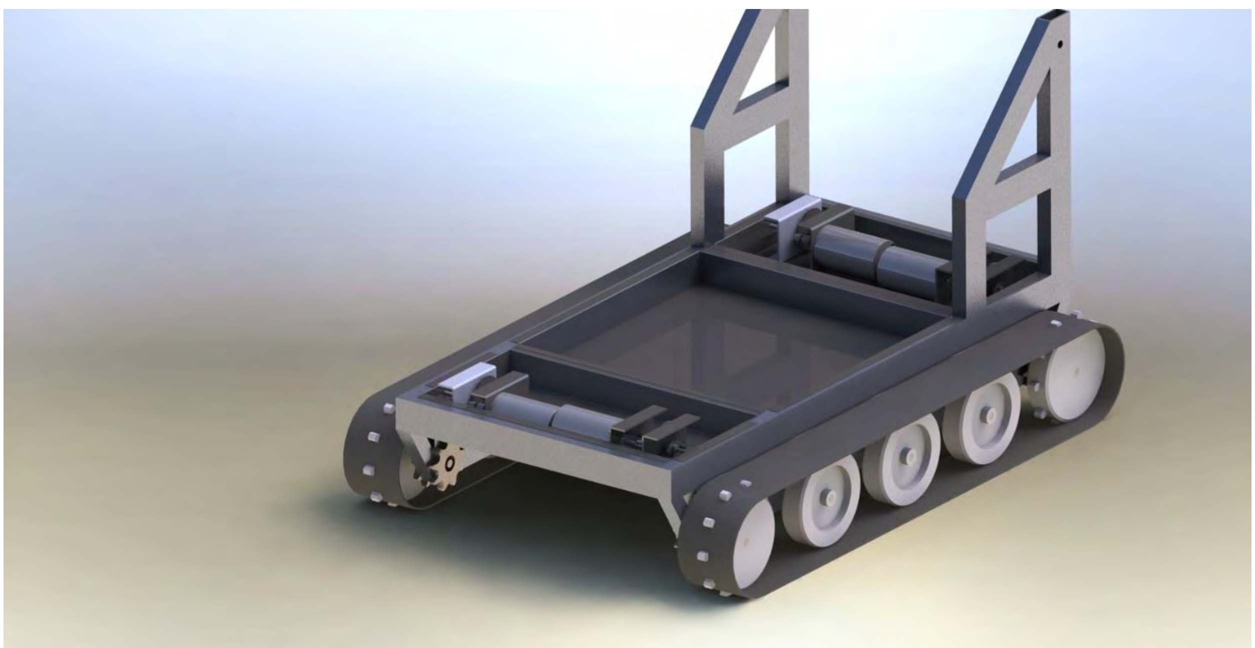

Figure 23: Structure of Rover

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 9 shows a list of parts and prices associated with them and if the item has been purchased. The total 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 27 & 28). 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 29, 30 & 31). A total of 37 shirts were sold yielding $455. Table 7 shows the cash flow in and cash flow out with a net difference of $445 in the negative. This shows that the project is being limited by the cost. An estimated cost of total hours spent was conducted using the national mean hourly wage for mechanical engineers. [10] The total cost was $46,863 with 1150 man hours used.

Table 7: Cash Flow In/ Cash Flow Out

Cash Flow In/ Cash Flow Out	
Expected Funds Raised	
Selling Shirts with Team Logo	$455.10
Personal funds spent	
Aluminum Frame (chassis only)	$122.09
Raspberry Pi Model B Revision2.0 512 MB	$42.88
Transcend 8GB 10 SDHC Flash Memory Card	$9.95
Idlers	$28.85
Tracks	$580.63
2.5inch CIM, Brushed DC Motor AM802-001A	$115.49
Total Cash In	$455.10
Total Cash Out	$899.89
Difference	-$444.79

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
Total Labor Cost	1150		$46,863

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

M.E.C. Panthers Lunar Mining Robot Budget					
Item	Price	Shipping	Quantity	Total Cost	Bought
Raspberry Pi Model B Revision2.0 512 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
Mocreo 5 in 1 Portable Wi-Fi 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 Version 2	$49.99	$0.00	1	$49.99	No
Arduino Uno microcontroller	$19.99	$0.00	2	$39.98	No
Threads and Pulleys	$500.00	$0.00	1	$500.00	No
Custom Chassis+ Conveyer Belt Frame+ Soil Container+ Soil Container frame + welding	$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, duck tape, sealant	$50.00	$0.00	1	$50.00	No
Heat sink, 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	$135.00	No
Hotel	$200.00	$0.00	1	$200.00	No
Machining Cost					
***Rough Estimate					Final Cost
					$4,970.06

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 five 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 on its own 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

Table 9 shows the estimated cost of the lunar rover parts. The estimated price is almost $5000. This is a rough estimate but currently 18% of the budget has been spent on the tracks, 4 motors, idler wheels, and frame for the chassis only, the micro-controller, and memory for the micro-controller. This totaled $900. The remaining two actuators and motor are expected to be donated from the previous team’s lunar rover. The motor controller will be built by the electrical team and once the two actuators and motors are donated to the team they can calculate the power the system will require.

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

Table 10: Savings Analysis

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

10. Testing

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.

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

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 Figures 24.

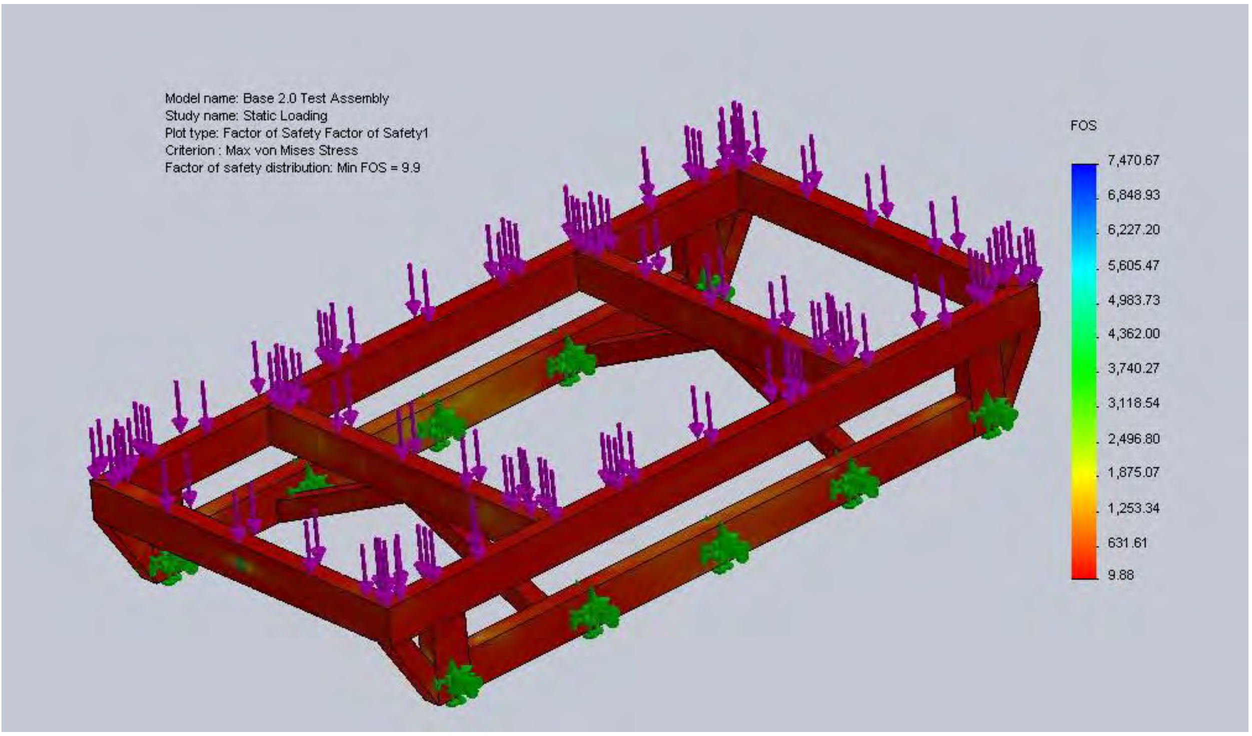

Figure 24: Frame Factor of Safety

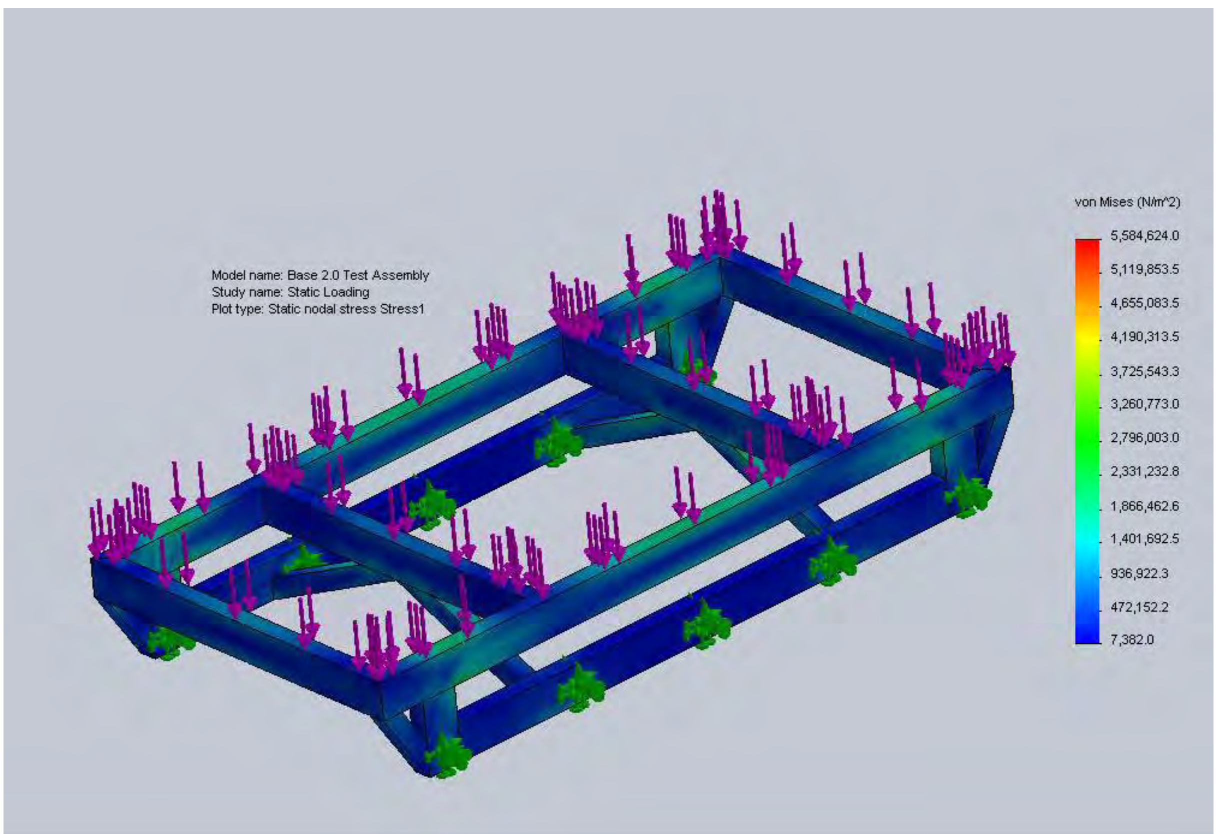

Figure 25: Von Mises Stress

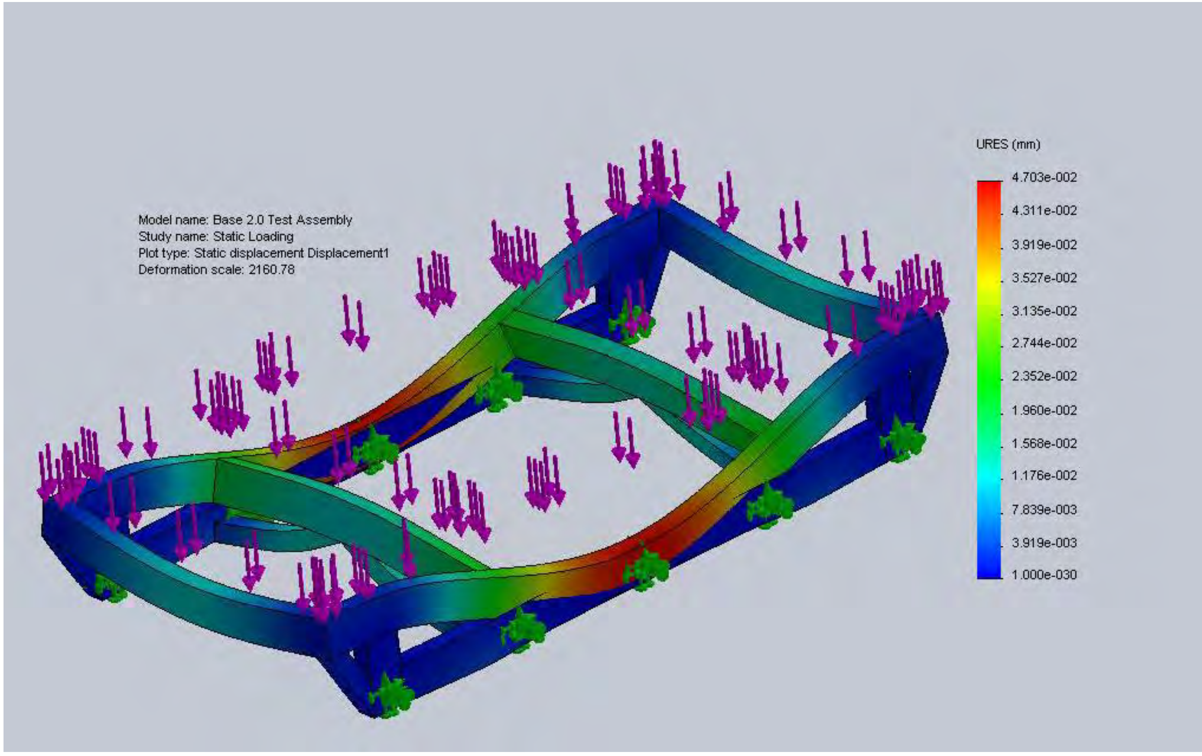

Figure 26: Frame Displacement

11. Conclusion and Future Works

This project has been a valuable tool and measure of the difficulties encountered by a product that does not exist. First, the team was informed that the school does not have a planned budget for senior design projects. This forced the team to look for funding. An account for potential funds to be deposited did not exist therefore, the ASME club graciously allowed our team to use their account in case funding was received. Next, asking for funding proved harder than it seems because a lot companies did not want to help or simply did not respond back. Then, some of the design ideas such as the track system simply are not available under the required budget. Other countries such as China and Russia had potential track systems but were not chosen due to the unreliability of ordering parts from an unknown website. Lastly, the design thickness of the frame is not available for the aluminum rectangular tube. This forced the team to increase the thickness and thus the overall weight of the design because a custom frame would go over budget.

The challenges that the Mining M.E.C Panthers will face are still on going. The frame, motors, and track system will be bought during this semester. They will be assembled and will provide a foundation for the remainder of the project. By focusing on the lower half of the robot the Electrical/Computer team can start wiring, installing electrical components and implement their programs. This should produce a functioning robot by the beginning of the next semester.

12. References

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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

Thank you,

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

Figure 27: Funding Proposal Page 1

Example of previous Success:

<https://www.dropbox.com/sh/cgp7x59t63s7tgt/IVOyoxa7XI/Final%20Video%20S.mp4>

Lunar Robotics Senior Design Budget					
Item	Price	Shipping	Quantity	Total Cost	Bought
Raspberry Pi Model B Revision2.0 512 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
Mocreo 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, ducktape, 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 28: Funding Proposal Page 2

Appendix: B-Shirt Funds

Figure 29: 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 30: Shirt Funding Website with Team information and picture

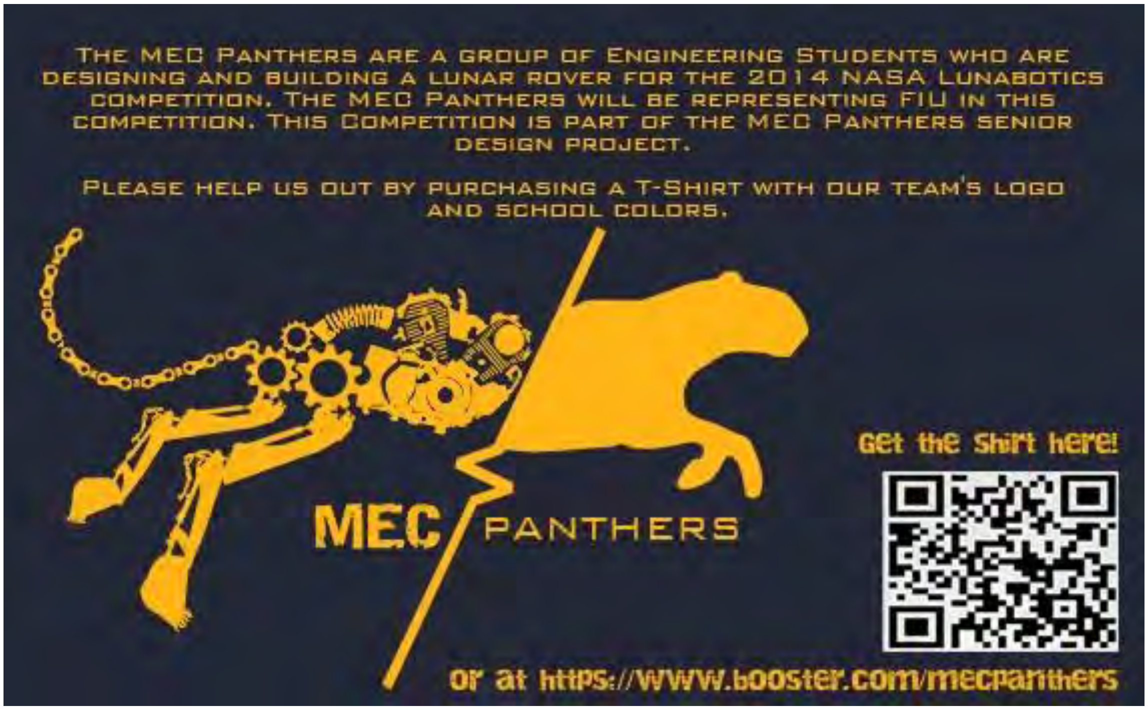


Figure 31: Flyer

Appendix: C-Receipts

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

11/11/2013 12:42:22
Merchant ID: 000000000794299
Terminal ID: 04502745
417520647997

CREDIT CARD
VISA SALE

CARD # XXXXXXXXXXXX4215
INVOICE 0012
Batch #: 000199
Approval Code: 06706B
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 2 PCS CUT TO 4 FT 2 PCS CUT TO 3 FT 4 PCS CUT TO 2 FT	22	0	22	3.70	81.40T
ALTSQ(6061)1.0...	Aluminum Tube - Square 6061 1.00" Sq x .125" wall x 24' R/L 6 PCS CUT TO 1 FT	6	0	6	2.97	17.82T
Freight	Freight Charge	1	0	1	15.92	15.92

PAID

Subtotal	$115.14
Sales Tax (7.0%)	$6.95
Total	$122.09
Payments/Credits	$0.00
Balance Due	$122.09

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

Figure 32: 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 Order: 39420
Invoice Number:	39420
Customer ID:	0

Billing Information	Shipping Information
Matthew Koza	Matthew Koza
33323	
	United States
kozam9707@gmail.com	
954	

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 33: Threads Receipt

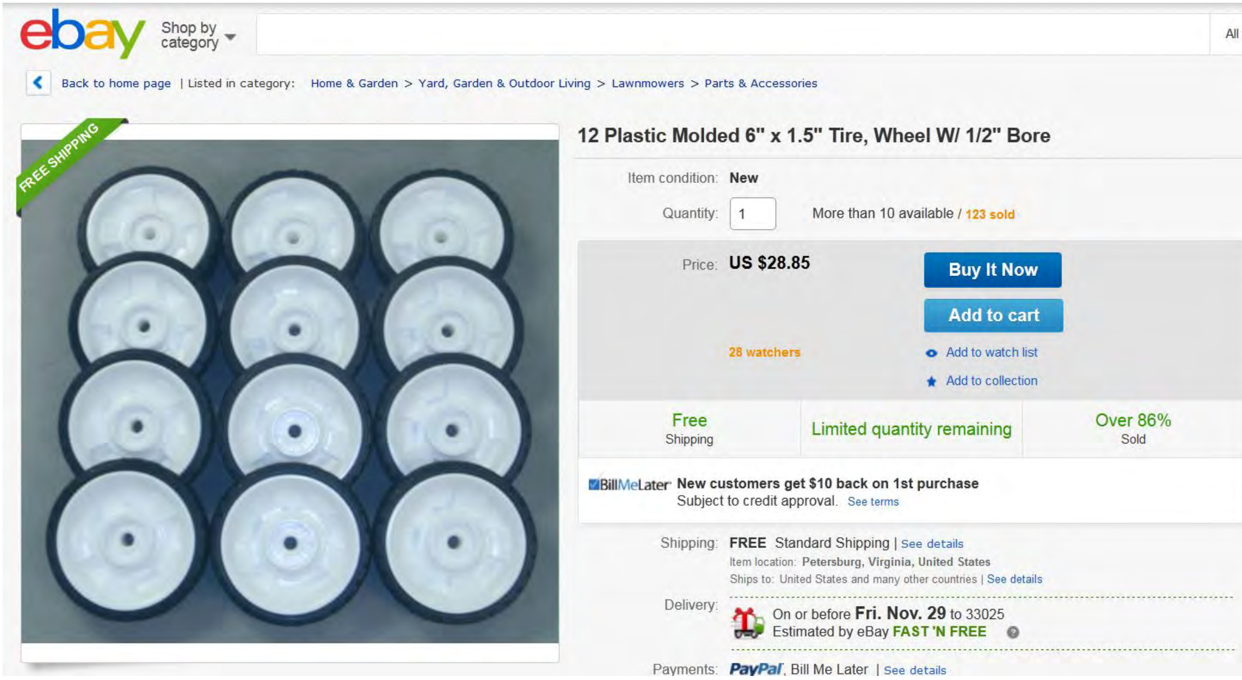
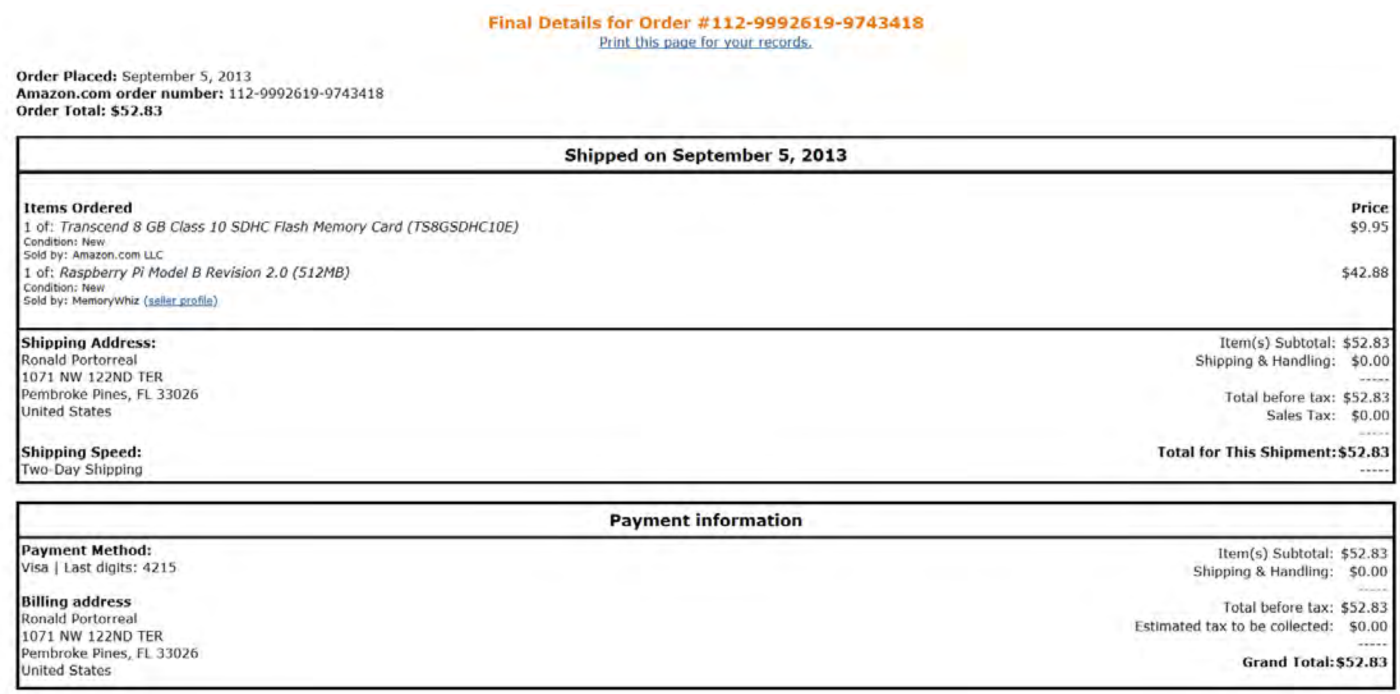


Figure 34: Idlers Bought



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

Items Ordered	Price
1 of: *Transcend 8 GB Class 10 SDHC Flash Memory Card (TS8GSDHC10E)* Condition: New Sold by: Amazon.com LLC	$9.95
1 of: *Raspberry Pi Model B Revision 2.0 (512MB)* Condition: New Sold by: MemoryWhiz (seller profile)	$42.88

Shipping Address:
Ronald Portorreal
1071 NW 122ND TER
Pembroke Pines, FL 33026
United States

Shipping Speed:
Two-Day Shipping

Item(s) Subtotal: $52.83
Shipping & Handling: $0.00

Total before tax: $52.83
Sales Tax: $0.00

Total for This Shipment: $52.83

Payment information

Payment Method:
Visa | Last digits: 4215

Billing address
Ronald Portorreal
1071 NW 122ND TER
Pembroke Pines, FL 33026
United States

Item(s) Subtotal: $52.83
Shipping & Handling: $0.00

Total before tax: $52.83
Estimated tax to be collected: $0.00

Grand Total: $52.83

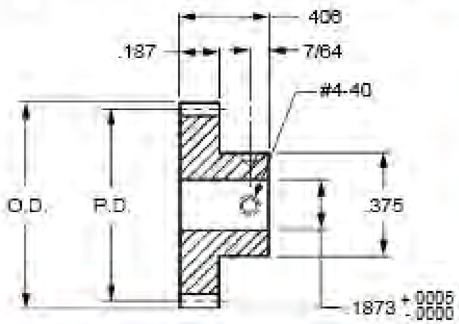
Figure 35: Receipt for Raspberry Pi and SD Card

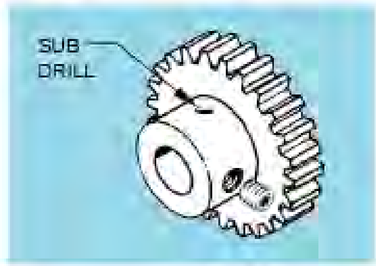
Appendix: Specification Sheet

Gear Product Finder

S INCH — **Spur Gears - 32 Pitch**

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





Precision Component

Catalog Number: 303 Stainless Steel	Catalog Number: 2024 Aluminum * Anodized	No. of Teeth	P.D.	O.D.
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 36: Gear Specification Sheet