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

Team Unknown: Lunar Excavation Robot
100% Report

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Fall 2013

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Michael Sewar, Mark Tuazon, and Zhen-hua Wang 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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Table of Contents

List of Figures

List of Tables

Abstract

NASA's Lunabotics competition is held annually with participants worldwide competing for both the winning position which offers scholarship money, as well as possible retainability by NASA to further robot design and implement the ideas exhibited throughout the course of the competition. We were to design a robot capable of traversing an obstacle course to reach a specified location in order to mine moon "material," reaching a minimum of 10 kilograms of mined material within 10 minutes. Other rules and regulations applied such as size and weight limitations to the robot. Additional features may have included being able to operate completely autonomously, with a low energy-consumption operation that allows the robot to operate for extended amounts of time. The robot also needed to operate at certain bandwidths in order to reduce the possibility of radio-interference between other sensitive electronics and communication devices that would be present should an excavation expedition ever make it to the moon. Dust-free operation and structural integrity both served as important qualifications for robot design in order to improve the overall functionality of the robot.

Introduction

Problem Statement

The purpose of this project was to build a robot worthy of NASA's Lunabotics competition which consists of excavating regolith or, rather, simulant known as Black-Point 1 (BP-1) and then transport the excavated material to a collection bin. The robot was encouraged to be fully autonomous or semi-autonomous and traverse through terrain similar to that found on the moon such as craters and large rocks which would hinder the robot's journey.

Motivation

The nature of this project was to design and build a robot that met NASA's Lunabotics competition criteria in order to test our capabilities in robot building, to improve the standing of our ABET accredited engineering programs at FIU, and to further our own understandings and expertise within the field of robotics and the encompassing mechanical engineering spectrum.

Literature Survey

The NASA Lunabotics Mining Competition seeks to promote interest in space and STEM (science, technology, engineering, and mathematics). The objective was to build a robotic excavator to navigate an obstacle course to a designated area, collect an amount of moon dirt simulant called regolith and carry it back to a collection bin. The purpose was to simulate the conditions of moon excavation and exploration while operating semi- or fully autonomous. Using research done on space robots and fully autonomous robots and companies that specialize in mining such as Caterpillar and Rio Tinto, the attempted build operated under such conditions.

Surface Mining

Defined by the Society for Mining, Metallurgy, and Exploration as "the initial exploitation of a deposit involved rudimentary scratching at outcrops and picking up pieces of ore from the surface." [5] In other words, it is used to clear away the surface of an area in order to prep and area for mining out a covered resource. In this case, the machine used for surface mining must have an ability to navigate throughout unknown terrain in order to clear away the surface; with this in mind, a part of our focus is to develop a substantial means of locomotion.

Mining is an important industry as various materials such as aluminum, copper, gold, iron, silica, and sodium carbonate, just to name a few [7]. Without such materials, items such as computer chips and glass would be near impossible to manufacture. Even further, high rise buildings would be incredibly hard to build. With that said, mining has its place, even looking further and beyond to the moon. The moon may have material which may not be discovered or found purpose here, but the limit is continuously being pushed.

Autonomy

Autonomy is explained as a "system capable of operating in the real-world environment without any form of external control for extent periods of time" by George A. Bekey [2]. Full autonomy was sought after because of the fact that in space there is very little room for error in communication. So if the Lunabot could achieve a set task automatically, it would cut down on the components needed for remote control. If there was a break in communication, a task may still be accomplished without assistance from an outside source. If autonomy was achieved then the Lunabot may be viewed as a robot, defined as a machine that senses, thinks, and acts. When dealing with autonomy there are also set rules that must be dealt with in order to keep high-level control which is defined by Asimov's laws:

1. A robot should never harm a human being.
2. A robot should obey a human being, unless this contradicts the first law.
3. A robot should not harm another robot, unless this contradicts the first or second law.

Figure 1: Arduino Duo board

To insure the safety of all personnel operating the Lunabot, a kill switch was installed into the design as well. Microcontrollers were used as the source for controlling motors and sensors. Arduino is an open-source prototyping platform used by designers and hobbyist with a lot of help on programming.

BASIC stamp is a very user-friendly interface and debugging method.

Frame and Locomotion

When designing a frame, NASA usually has specific dimensions set in place to fit into a space on the rocket for travel. The smaller and lighter the weight, the better and easier for travel. The competitions rules limit a four person team to a maximum mass of 92 kg, while for a three person team the maximum mass of 69 kg. With this limitation in mind, the build needed to fit more components within a confined space. The slight trade-off, though, is that in turn, the weight is reduced. The frames built by FIU in past years have done well in regards to weight upon talking with the previous designers. After such discussions and circumstances, the conclusion was to use a frame offered by the previous 2012-2013 Lunabotics team.

Locomotion was either made up of tracks, which do very well on sand and hazardous road conditions; and wheels, which are used primarily because they are specialized to grip and maneuver through dirt, sand, or grass and hold no air to cope with the conditions of space (airless tires).

Regolith Collection

The collection bin was positioned at the center of the Lunabot which prevented the motors from having to compensate for a shift in center of gravity. This would work well in competition and has been employed by numerous previous teams.

Figure 2: Collection bin idea

Previous designs have tried to acquire regolith by means of shoveling such as that seen in most mining applications. The flaw in this design is that the acceleration of gravity is different than that of the moon. On the moon you are working with an acceleration of 1.622 m/s^2 as opposed to 9.81 m/s^2 on Earth. When coupled with the light weight and power needed to push the shovel, the robot will often be entrenched in the dirt rendering it useless. Designated motors for the collection method while the Lunabot remains stationary would be an ideal strategy and much more efficient given the conditions prescribed.

Conceptual Design

Design 1

A load bin would be positioned on actuators which rise and drop as well as tilt once at a certain height to drop the load using a gear mechanism. Tracks would be used to guide the Lunabot through the dirt and rocky terrain. The rising and lowering of the bin would improve the trek by being able to avoid larger obstacles at variable heights. Once the Lunabot would reach the mining site, the bin would lower to the floor opening a front panel as well as lower an attached rotary shoveling mechanism and scoop in regolith. Once the bin would fill sufficiently, actuators would raise the bin to traveling position and travel to dump site and dump load.

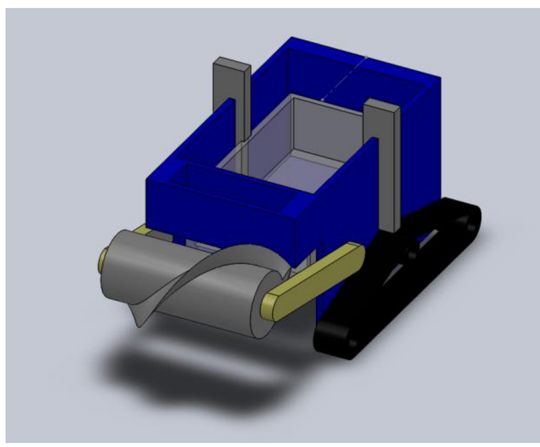


Figure 3: Design 1 conceptual idea

Design 2

This design had a wheeled base locomotion using two conveyor belts with attached shovel. The drop and dig mechanism and motors that tilt the load bin force the regolith back onto rear conveyor belt. Additional motors would tilt both conveyor belts in order to travel through course once the collection bin is full. At the dumping location, the rear conveyor belt would deposit the regolith collected.

Figure 4: Laurentian University's 2011-2012 Lunabot

Design 3

Focused on being light and mobile, the Lunabot would keep all components simple and light. Most of the resources would be placed on powerful motors and large wheels capable of overcoming uneven terrain. At the dig site, a shovel positioned opposite to the direction of traveled would drop down. The Lunabot would travel in reverse in order to collect regolith thus reducing the chance of friction overcoming the light weight. Once regolith is collected, a shovel would be raised and dumped into the collection bin on top of the Lunabot.

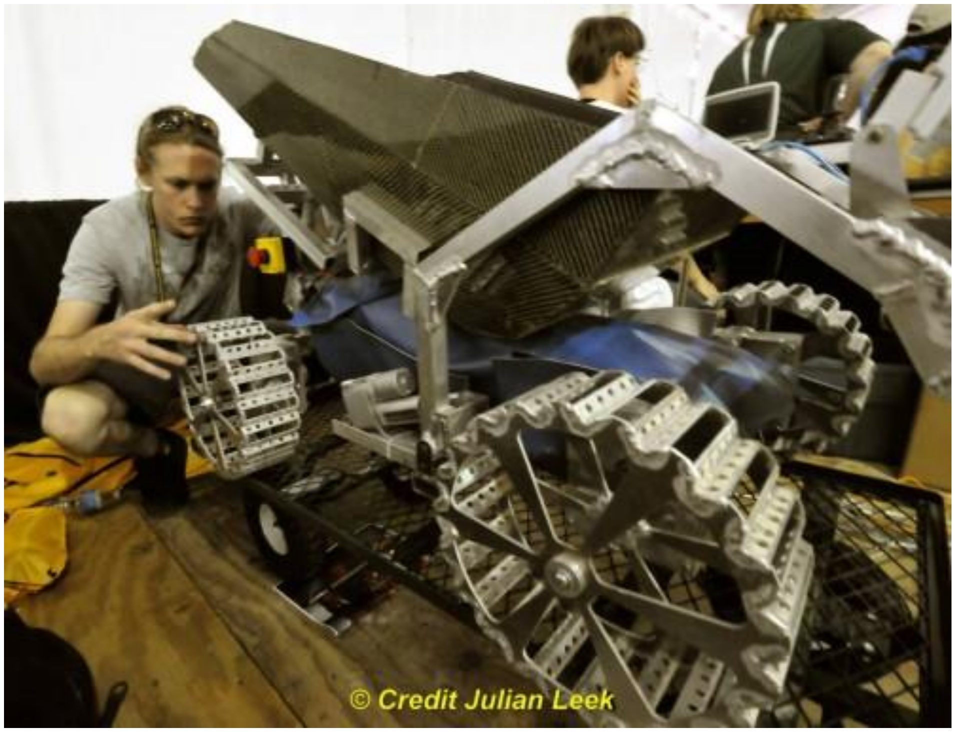


Figure 5: Design 3 loosely based on the University of North Florida 2011-2012 Lunabot

Design 4

The design in mind utilized caterpillar tracks in order to provide optimal contact with the lunar soil simulant, BP-1, providing the stability and grip needed to traverse the obstacle course area effectively. This reduced possibly flipping over or becoming trapped in the BP-1 material.

The tracks and the motors driving them would have reversible rotary directions and the software would be coded accordingly in order to provide the Lunabot with turning capability akin to other track-driven vehicles such as tanks and construction vehicles. Tracked wheels are implemented in the design of the Lunabot because of traction needed due to the surface terrain faced during competition. The type of terrain is that similar to flour, in that it is mostly fine and compacted. Tracked wheels give the advantage of providing continuous traction and stability. Mobility is key yet not necessarily nimble mobility. Stability is of much more priority than quickness which may cause the Lunabot to turn over, as seen from previous competitors. Also the wheels will turn due to them being connected through the use of a sprocket and chain. The sprocket will be fixed and not freewheeling; that is, as the wheels are moving the sprocket and chain will always be moving at the same speed.

In the front of the Lunabot, a rotary auger dredge would be placed in order to dig into the BP-1 and propel the material inwards and into a collection bin. The auger design was based primarily on those of auger dredges. It is comprised of two augers in opposite directions that push dirt towards a center point at which the soil is picked up by a vacuum. The two augers converge towards a center point, but not in such a way that the two create a sharp, acute angle but instead create a type of horizontal flap that "catches" the dirt.

The means by which the regolith would be transported into the collection bin was that of a vacuum. The pump of a vacuum cleaner would work much like how it does normally; it will draw the sifted soil, due to the auger, into the bin. The auger itself would be raised during the robots transitory stage, and lowered when needed to engage with the BP-1.

The collection bin would be designed similar to those in construction or waste management, with the capability of being lowered during the mining process and raised during transportation in order to provide ground clearance while traversing the obstacle course. Finally, the collection bin would be raised when the robot has reached the dumping station, lifting the bin and depositing the collected BP-1 into the competition bins. The bin would be tilted via a mechanism as opposed to an individually regulated motor to cut back on power consumption and weight. This is because the mechanism would function only to tilt the bin in order to deliver the payload into the reception bins. The collector bin itself will be lifted in order to have clearance for the competition bins. Linear actuators will be on the sides of the collector bin, lifting it vertically straight. On the rear will be hooks that are guided by vertically straight bars. These hooks will catch at the end of the bar thus causing the collector bin to pivot and dump the soil. The actuators will then descend and cause the collector bin to return to its normal position. A visual of this can be seen in Figure 6 and 7.

This design focused on the concepts of keeping the robot at a low center of gravity in order to provide operational stability, as well as keep the overall weight of the robot light in order to both reduce energy consumption, allow ease of handling, and possible transportation to the moon itself. The issue of bandwidth was relatively low when compared to how much dust would be generated during operation as well as make the Lunabot itself dust-free and having longer operational life without a possible need for maintenance. Seals were considered to reduce the contamination of components with BP-1 as well as other mechanical modifications to improve structural integrity and reduce unnecessary stresses; ball bearings and the like would be used on an as needed basis.

To develop a fully autonomous machine a number of sensors, microchips and microcontrollers would be used in order to detect distances, depth perceptions, actuator control as well as power usage and output depending on situation. The ideal microcontroller for running the Lunabot may be an Arduino board or BASIC stamp board due to its simplicity and open source coding. This would help the programming stage go smoother.

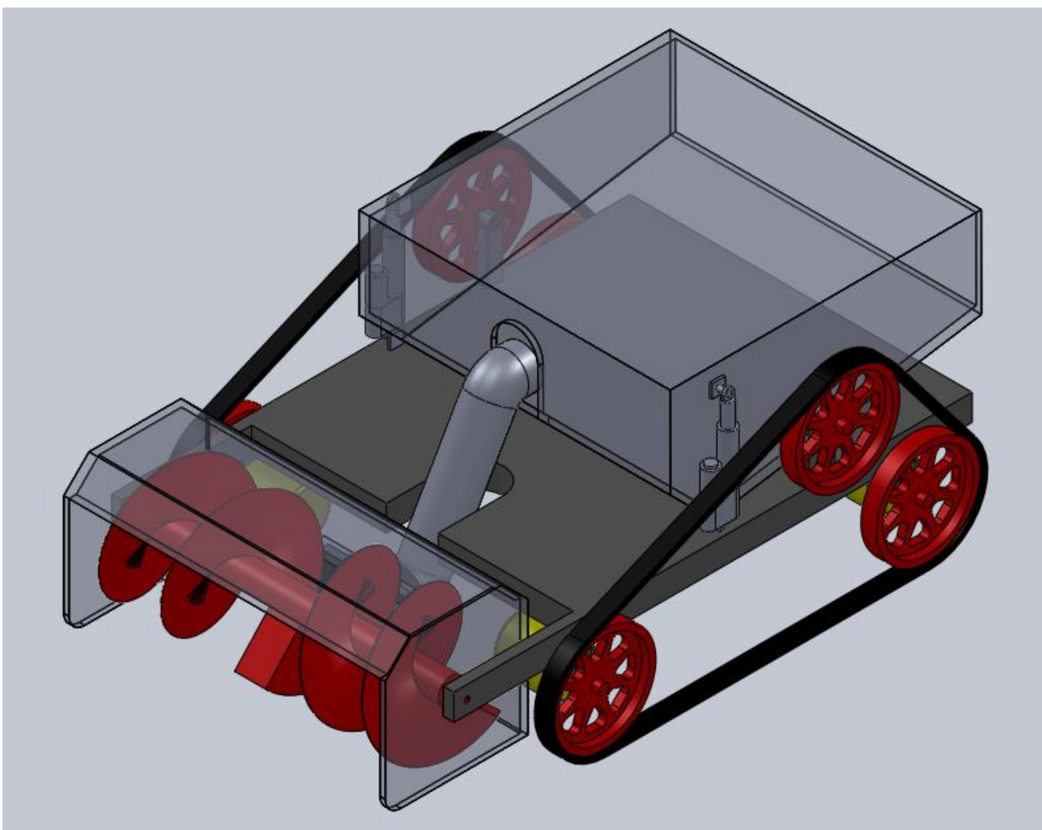


Figure 6: Proposed design

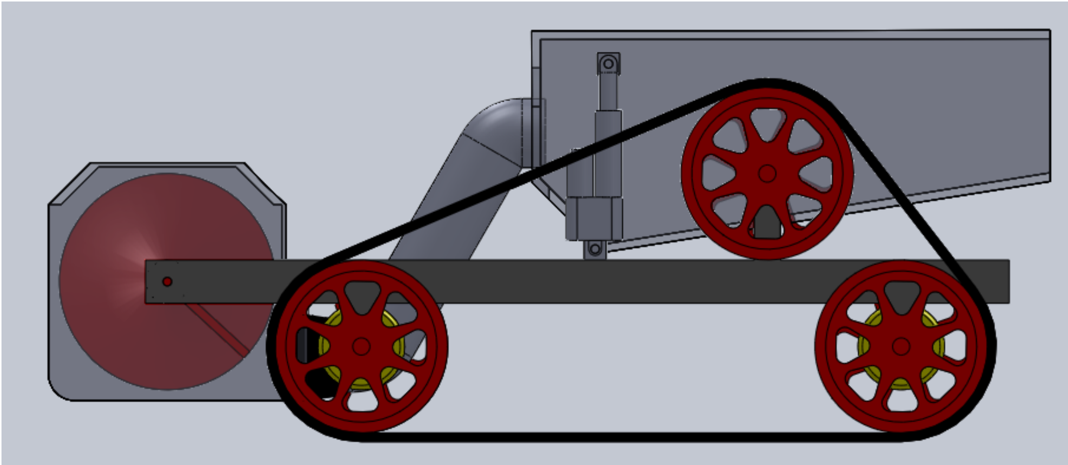


Figure 7: Side view

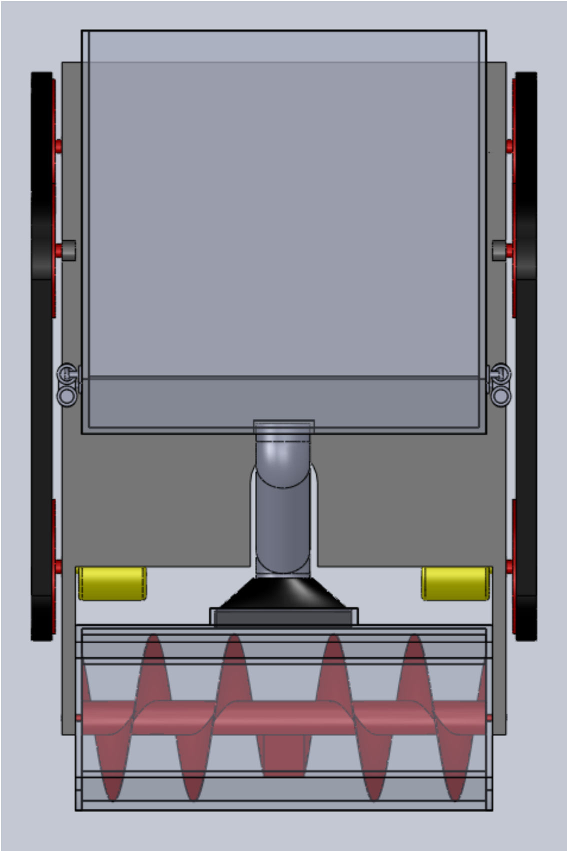


Figure 8: Top view

Design 5

Since the time the design 4 was proposed, changes were made, mostly due to advice from the IAB as well as considering realistic application. These changes were reflected in the frame of the Lunabot, the application of the auger, and the method by which regolith will be emptied.

Regarding the frame of the Lunabot, it was changed to work in two stages: driving and collection. In doing so, the frame reflected this as well with the frame consisting of an outer and inner frame. The outer frame would hold the wheels and act as a main body; a foundation for the Lunabot to work from. The inner frame works inside of the outer, rotating at a pivot. This inner frame pivots downward and upward with the point of rotation near the rear of the robot. The inner frame houses the auger as well as the bin. As stated briefly, the system would work in stages. While driving and travelling, the Lunabot's inner frame would be raised by actuators, enough to clear any rocks waiting underneath. When the Lunabot would arrive at the mining location, the inner frame rotates downward. Simultaneously the auger would engage, digging and penetrating into the regolith. Once the inner frame would reach its limit below the surface, the Lunabot would travel forward. Once the Lunabot had collected its share of regolith, it would raise the inner frame by the actuators and returns to the competition bins (driving backwards – this is key as explained later).

A very key feature that was removed from the other designs was the vacuum. As described, a vacuum was to be placed towards the bottom behind the auger in order to pick up the collected dirt. It was concluded by determining how the dirt would be transported from collection to holding. The Lunabot would need a means of doing so and was concluded that a vacuum attachment would achieve what was needed. The vacuum would need to be particularly powerful in order to keep up with the demand of the soil being collected. But considering the future applications of the design, the idea of using a vacuum in a vacuum (space) would be inconceivable. The way a vacuum cleaner works would not be able to do so in a minimal atmospheric environment, such as the moon. Because of this oversight, the final design of the Lunabot was changed accordingly. Essentially the vacuum portion has been nixed.

The auger had also been modified slightly. Previously the design called for a solid auger dredge similar to those found on old snow thrower accessories for tractors. The proposed design would have used one of those (although very heavy) or would have fabricated its own. These two considerations helped motivate the altering of the auger to that of a modern snow blower. This design would seem to be able to pick up more regolith without having to drive the snow blower too hard (as some snow blowers can reach up to 2500 rpm).

As for the method by which regolith will be deposited, this has been changed from the raising bin, similar to that of a dump truck. This change was made due to the consideration of the amount of regolith collected, the strength of the bin, as well as the amount of force the actuators raising the bin could generate (while considering cost). So instead of raising the bin and dumping all of the collected regolith, the deposition of material will be done by a conveyor-type mechanism. The conveyor-belt will extend over the edge of the bin, high and long enough to extend over the competition bins once the Lunabot reaches the edge. This conveyor-belt sits inside of the collection bin in the inner frame. As mentioned, the auger and collection bin are basically always along the same plane, rotating in the inner frame. This change would also alleviate any excessive stresses on the actuators that would have been raising the bin should the design have proceeded as previously conceived. One other advantage is that system is durable so long as the driving system for the conveyor-belt is somewhat decent. Even crude parts should be able to stand up to the environment. This would help to reduce the cost of the overall build.

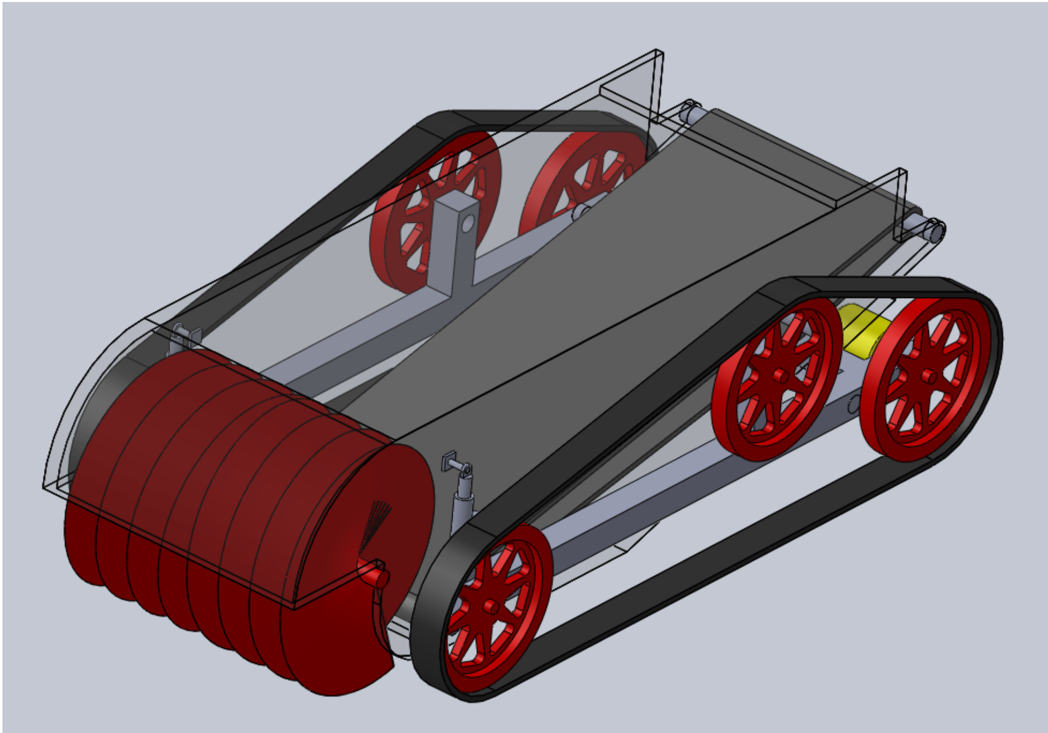


Figure 9: New Proposed Design

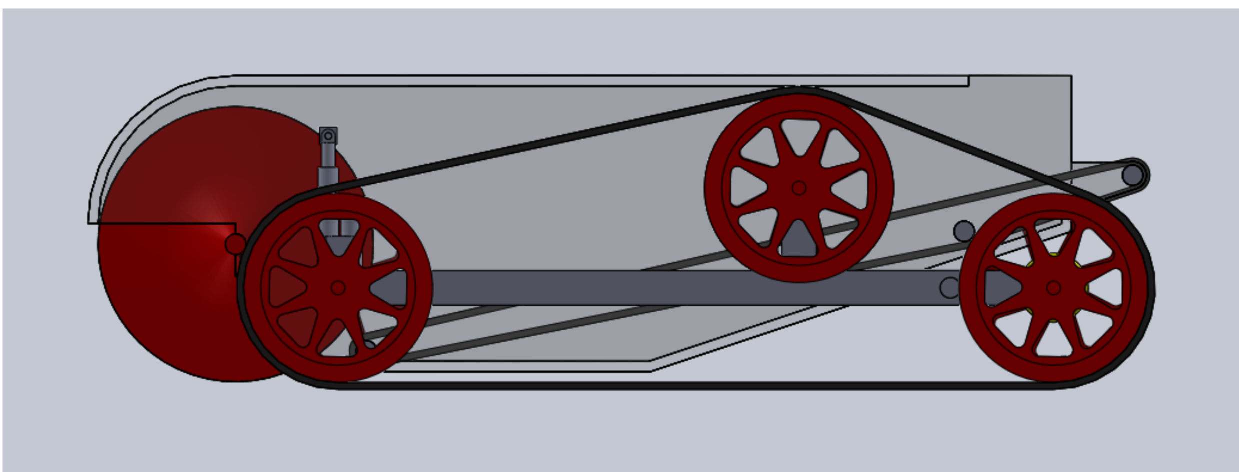


Figure 10: Side view (new)

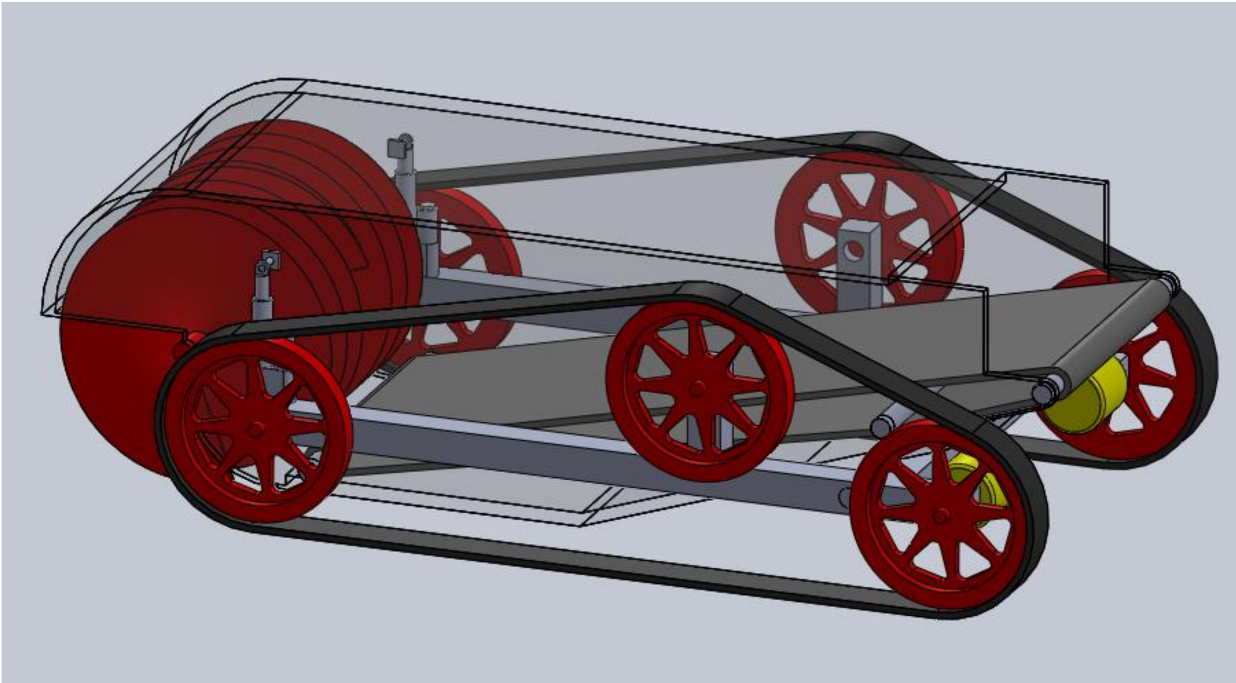


Figure 11: Side-rear view

Final Design

The second design is based mainly on winning design for the 2012 Lunabotics Mining Competition. The focus was mostly on acquiring regolith at a rapid pace as well as dumping it at an equally quick pace. The design had too many motors which would possibly increase the chance of a malfunction. Another reason this design was not chosen was because of the weight limitations. The design with all its components and motors would yield a hefty Lunabot. The third design was more focused on low cost and lighter weight. But on the other hand, because of the light weight, the Lunabot would not be able to retrieve a sufficient amount of regolith each run. Because of this, more runs to and from the dump site would increase the chances of malfunction. With the help of pivoting linkages, the amount of motors needed is reduced while still providing the functionality needed to accomplish the tasks. From this it was concluded that the final design be based off design 5 but with slight modifications, one being that the new frame be modelled after the salvaged frame.

A frame which had already been built previously would be repurposed. Because of this, the drawings and design had to be slightly modified but the overall functioning components of the project remained the same. Fortunately, the newly acquired frame had roughly the same geometry compared to what was sought after; a triangle based frame with the center offset towards the back.

Although the circumstances could not have been foreseen, what could be done needed to be done with what was received. The frame may not have been the ideal choice, with the heavier aluminum and slightly thinner and taller footprint, but as engineers, working with what is given is imperative and it also provided an opportunity for us to showcase the adaptability of acquired learnings throughout the undergraduate career. Modifications to the proposed design were necessary, but do not limit the design by any means.

In the following figures is the redesigned Lunabot model. One can note that the frame itself, while a far departure from previous iterations of our project, still retains the track-driven mobility implementation, as well as the rear-centered 3rd auxiliary wheel to hold tension in the tracks. This wheel had been included in the design model but by no means was guaranteed to make it onto the finalized product considering it can be simply replaced with a rod or bearing assembly to keep tension within the tracks. The actuators received shall be placed towards the front of the bin in order to allow the whole mechanism to pivot, and motors driving the track will be placed in the rear, nested beneath the rotating bin pivot bar.

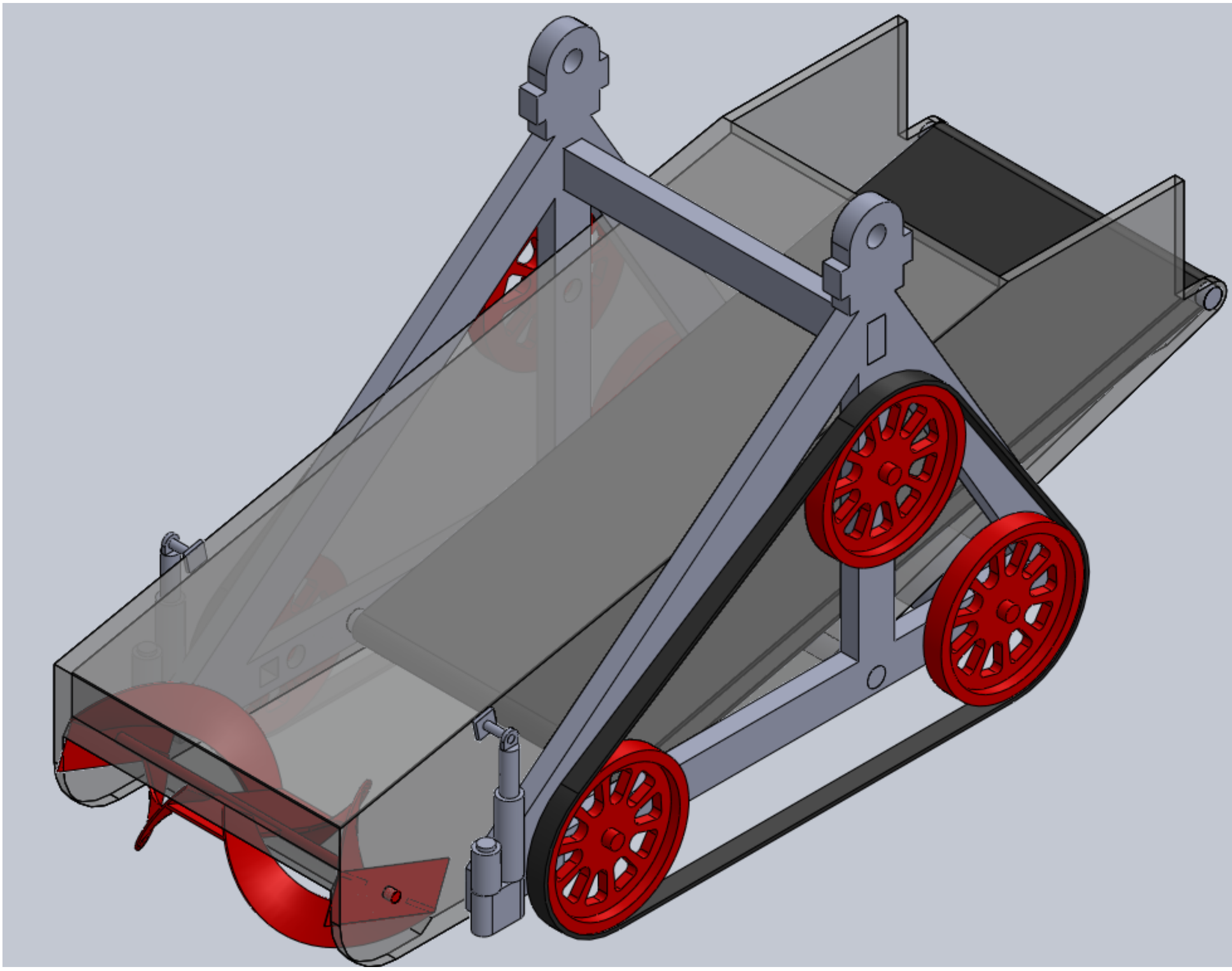


Figure 12: Final Design - Isometric View

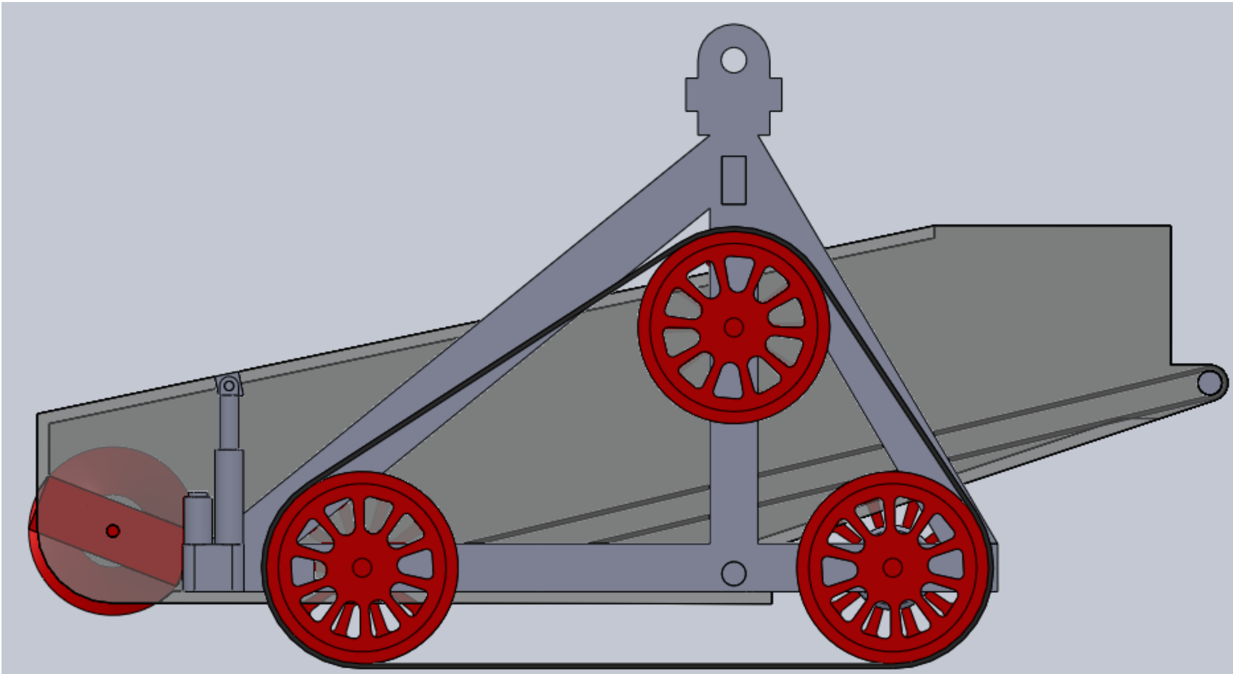


Figure 13: final Design - Right View

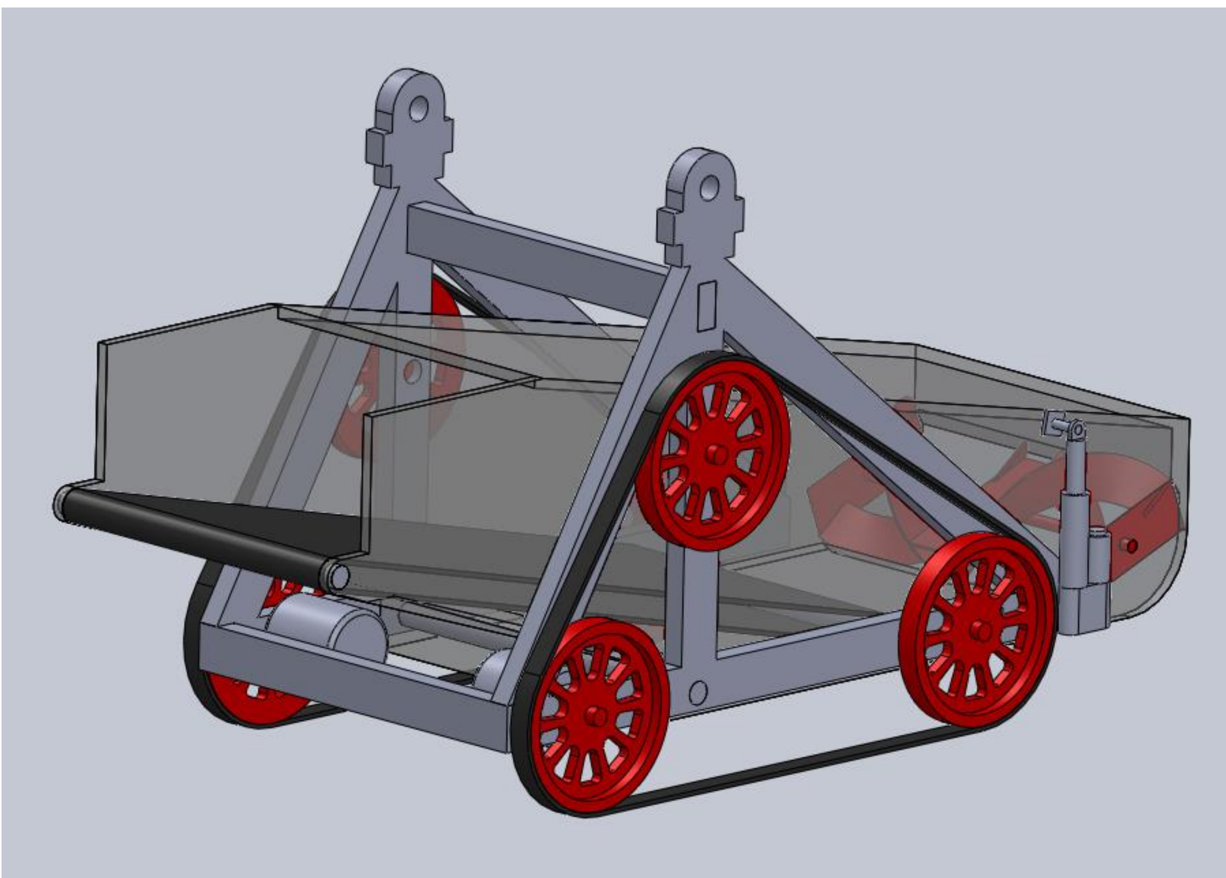
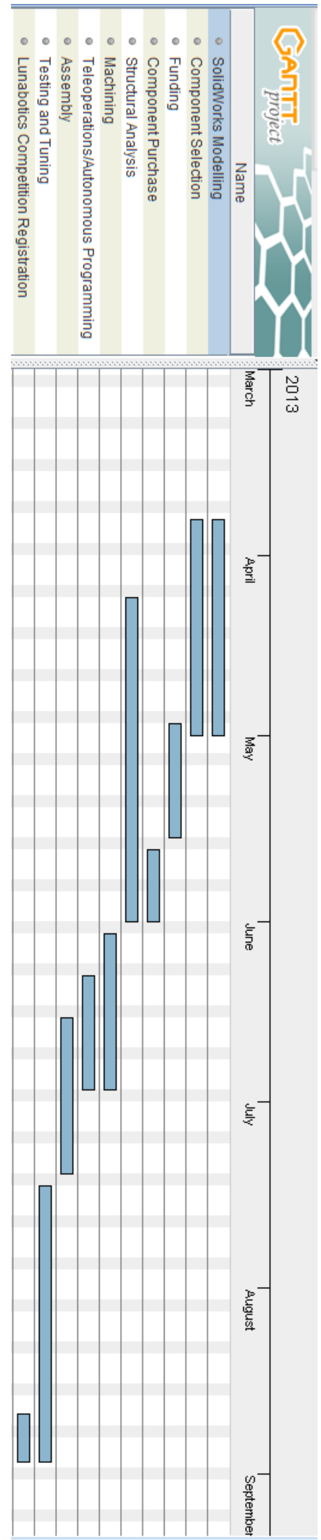
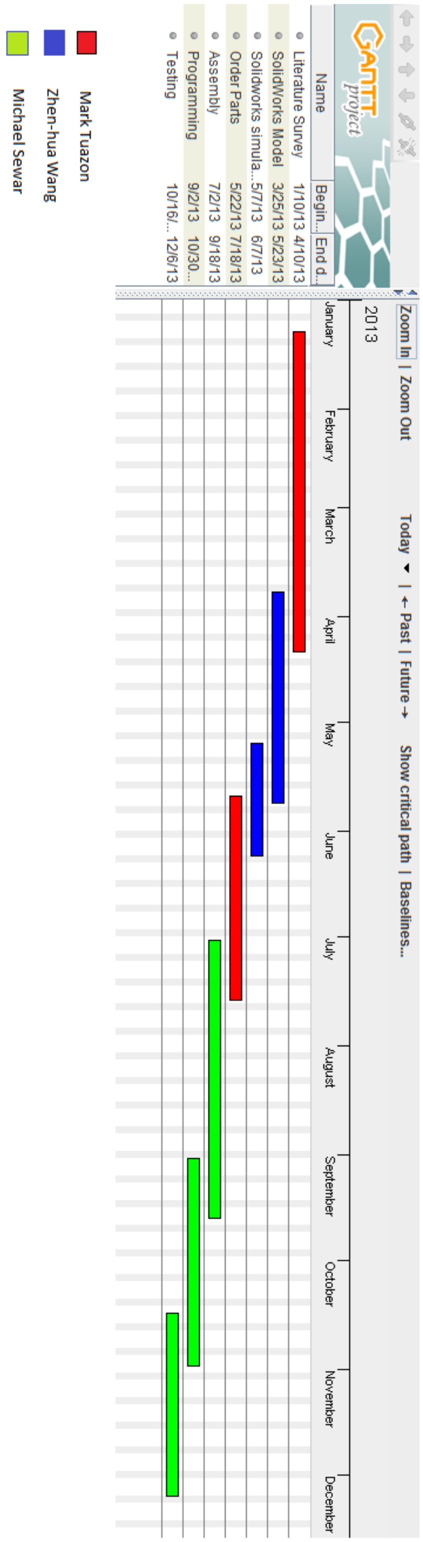


Figure 14: Final Design - Back-Rear View

Project Management

Timeline





Roles and Responsibilities

Roles and responsibilities have been broken down into equal parts based on personal experience and are chosen by each individual. The responsibilities are given to ensure that the task is completed but every member has a hand in the project as a whole. This will ensure that the transitions are smooth with full communication on expectations and opinions in order to come up with the best reasonable decisions. The three main members of the project are Michael Sewar, Mark Tuazon and Zhen-hua Wang, all Mechanical Engineering majors. An electrical engineer will be brought in during the assembly and testing phase to double check, run and oversee the electrical components and wiring so that the Lunabot runs smoothly.

Mark Tuazon

As team leader, Mark will oversee the overall progress of the project, keep track of deadlines, and find issues that may escalate. He is doing most of the research and collection a lot of concepts which will provide the basis for the design. He is also in charge of data analysis during testing which will be put into our records as well as be used for the calculations.

Zhen-hua Wang

As the lead designer of the Lunar Excavation Robot, Zhen will oversee the modeling and simulation portion of the project. This includes the initial design concepts, simulation of the design and component analysis of material and build using SolidWorks. Zhen will also provide a bill of materials, set of drawings and diagram parts and assembly. He will also take the lead in the testing phase of the project due to the design may have to be modified based on real world interaction.

Michael Sewar

Michael is in charge of building and programming the Lunabot. Using the SolidWorks models and diagram as a base, he will find parts that match the specifications drawn in order to develop a physical model of the Lunabot. Once built, he will work hand in hand with, if possible, an electrical engineer and a programmer to develop the electrical components and programming of the Lunabot with the goal of creating a fully autonomous system.

Projected Hours

Projected amounts of hours put into the Lunabot from Spring 2013 semester through Fall 2013. These hours include work being over the summer. Work over the summer will decrease slightly due to summer internships but work will be non-stop through Fall 2013.

Table 1: Projected hours

Estimated Man Hours			
	Mark Tuazon	Zhen-hua Wang	Michael Sewar
Research	120	70	70
SolidWorks Model	30	70	50
SolidWorks Simulation	30	90	30
Component Selection	110	60	70
Parts Purchase	100	70	80
Fabrication	80	90	120
Assembly	80	70	100
Programming	70	70	100
Testing	80	110	80
Total:	700	700	700

Engineering Design

Major Components

Figure 15: *Snow Demon* snow thrower

Figure 16: Auger dredge

Auger

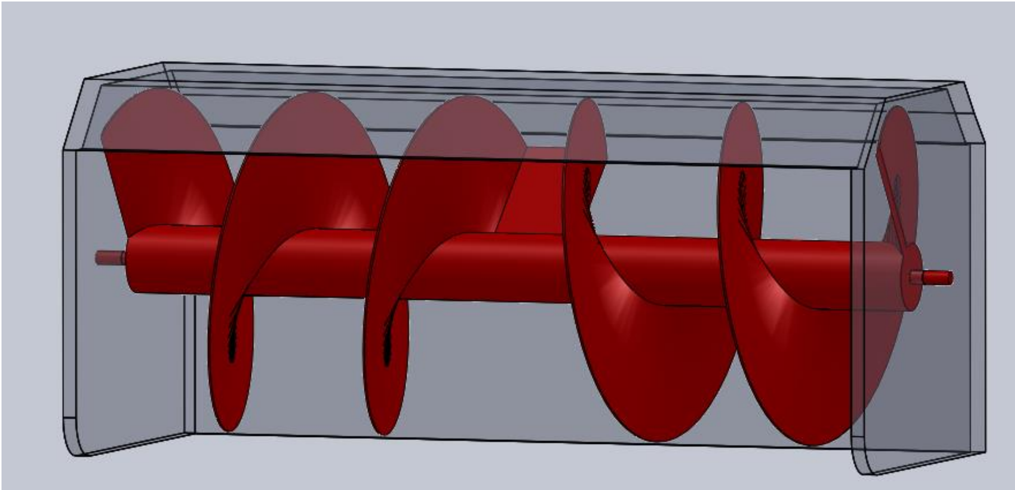


Figure 17: Auger design

Unfortunately as stated before, the design shifted towards a more lightweight snow blower rather than a typical auger dredge (which are very similar to old tractor-drive snow throwers). Weight considerations as well fabrication issues were considered. As seen in Figure 18, the auger is designed with a more open design. This would be suitable with snow as snow tends to clump together and hold its shape better (thus snow blowers tend to break down the snow with an impeller in a two-stage design). Considering our application and time table, the auger was used as it was.

Figure 18: Auger of previous team, Pantera

In regards to the auger-bit, as shown in the preceding figure, we would like to take this time to acknowledge Team Pantera for being kind enough to supply our Lunabot with their surplus back-up auger-bit. They were kind enough to supply us with their auxiliary auger for no charge, saving our team both time and money, and we are ever so grateful to have them as part sponsors.

A radiator fan motor was salvaged for the purpose of driving the auger bit. The motor rotated fast enough with decent torque, suitable enough to rotate the auger. Timing components were fitted onto the auger as well as the motor, and driven by a belt. As mentioned previously, the rotation of the auger need not be excessively fast.

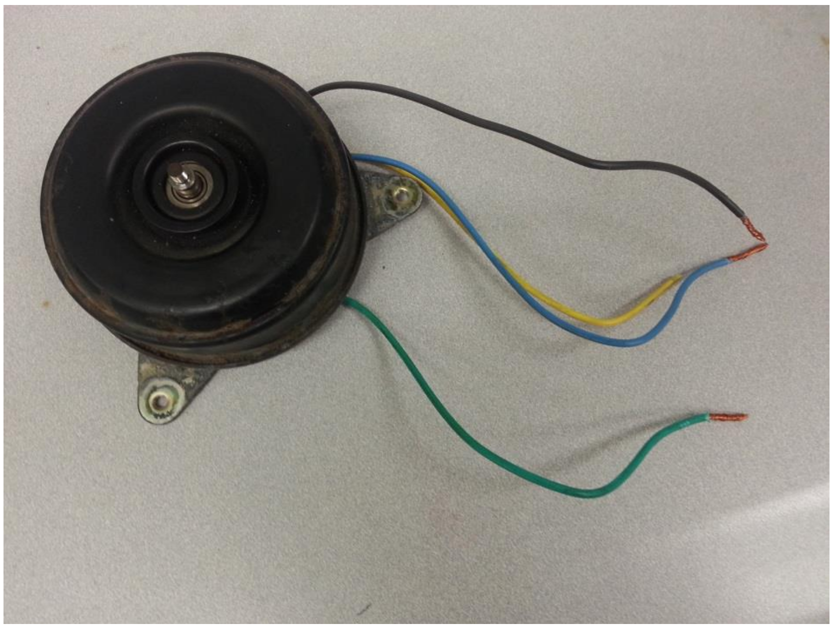


Figure 19: Radiator Fan Motor

Collector Bin

The collector bin was designed to 1) hold the collected dirt and 2) deliver the payload to the competition bins. They are meant to be kept light weight yet durable. Prior teams have done so by using Plexiglas to keep things lightweight. Plexiglas had its applications early on such as “periscope ports on submarines and for windshields, canopies, and gun turrets on airplanes [6]”. Durability and saving weight was solved by using such material.

Figure 20: Linear actuator

The design consists of a conveyor-type mechanism. This change was due to weight limitations with lifting the collector bin once it had collected regolith. More powerful actuators would have had to be purchased but due to limited funding, actuators were reused from previous projects (thus not as powerful for a rising bin). As mentioned, the body consists of an inner and outer frame. The inner frame holds the auger and collector bin (which includes the conveyor-belt mechanism) and rotates about a fixed point. Actuators used were strong enough to support the weight of the inner frame as well as the additional weight from the collected regolith during competition. Using two actuators in this fashion instead of four or six in the previous design yields just about, if not more, efficiency. The reason is that with the two actuators located at the front of the Lunabot, it takes less torque than with the four or six actuators. This concept follows that of a door and hinge. As far as the construction of the conveyor-belt, it is composed of a simple rubberized surface with protrusions; to scoop the regolith. The raised surfaces were simply that of aluminum brackets; basically anything strong enough and durable enough to the abrasion against the regolith and collector bin. This is similar to that which is utilized in Design 2. The conveyor-belt has its own motor which will work while the Lunabot reaches the competition bins and is not driving.

Drive System

Figure 21: Possible solution for sprocket and chain

Figure 22: Second possible solution to sprocket and chain

As originally designed, the Lunabot would utilize a tracked wheel system. However, for the sake of modularity, the drive system was designed to support both a tracked wheel system as well as a prototypical 4-wheeled system. The traditional design of a 4-wheeled machine would be best for travel and transportation. The tracked system was designed and hoped to be best for the Lunarena and environment similar to the Moon's surface. This is because a tracked wheel system would have better traction and little vibration and much more stable center of gravity. Whether tracked or traditional wheels, the open design of the Lunabot allows for such a feature. In place of the ideal tracked wheels, lawnmower wheels served as a somewhat suitable substitute.

Figure 23: Lawn Mower Wheel

Electronics

The wireless controls were done using the Digi XBee kit found on sparkfun.com. This module is completely independent from a network using only two modules to communicate wirelessly over a given area. This is done by one connected to the computer controlling the microcontroller and the other to the microcontroller of the device. The XBee module acts the same as if there was a wired connection with ranges of up to 300 feet, as long as there is no interference. The modules will be run using an Arduino Mega 2560 due to the amount of output peripherals needed for controlling all motors and actuators. A shield will cut down on the amount of wiring as well as provide sensor input and outputs to be used with parts such as ultrasonic sensors to sense distance preventing collision and cameras for real time surveillance.

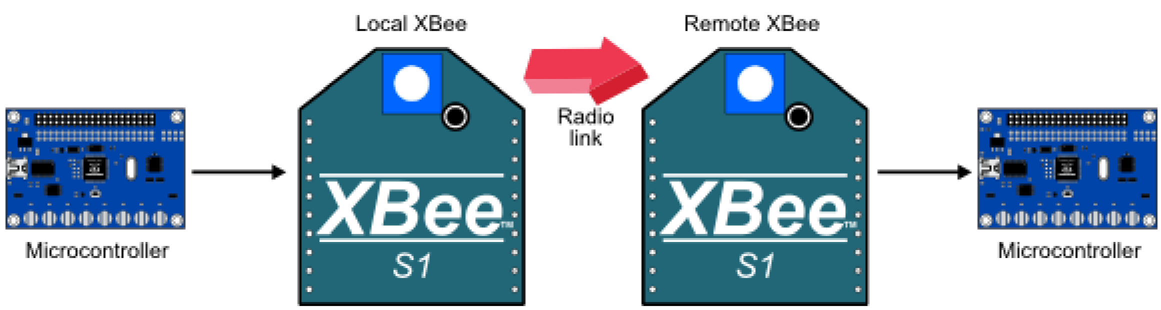


Figure 24: Xbee Wireless System

Motor drivers will be used to drive the motors for both driving the chassis as well as driving the conveyor-belt mounted inside the collector bin. The ideal motor driver is a 4-channel motor driver from sparkfun.com which is a piece to their Rover 5 vehicle. This motor driver can not only drive four 12 volt DC motors but can also run encoders for each motor sending real time feedback of position to the user. This motor driver will also control the direction of rotation by switch the polarities of the power and control the speeds of the motors by means of pulse with modulation (PWM). To power the motors it uses external power from the high power battery to power the 12 volt DC motors while using a 5 volt power source to control the logic pins which is taken from the Arduino board. To drive all the components of the robot a 12 volt lead acid battery will be used coupled with a voltage regulator to ensure the correct amount of current to power all the electronics of the robot; it will be sealed inside the bin in a fabricated compartment to try and make use of as much space as possible and minimize the size of the total robot. Once the electronics are all measured and fitted to the compartment, a series of channels will guide all the wiring throughout the robot keeping all wiring sealed and protected from the sample in the collector bin.

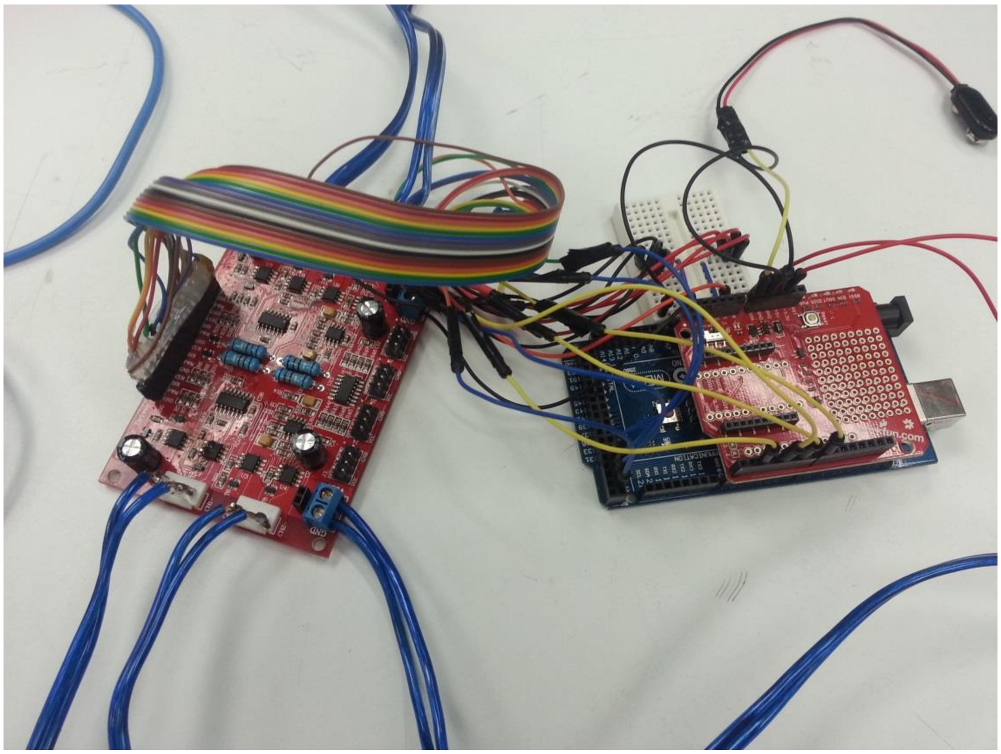


Figure 25: Assembled board

Salvaging parts from a previous Lunabot, with their permission, the frame served as a good starting point to fit the electronics, motors, and gearing. Upon researching the numerous methods for digging and dumping, the fabrication included two 12-volt Denso brand DC motors as well as 2 linear actuators rated at 200 pounds each. This was well over the previously expected operating strength. The design used the four channel motor driver to operate the auger, and 2 actuators. The Denso DC motors are high torque motor which will be ideal for propulsion of the robot. A high revolution motor will be needed to drive the auger at the speed needed to operate correctly. For this, the motor from a radiator was used. The conveyor-belt requires little speed nor torque to rotate because it breaks down and empties the collected material. To rotate the conveyor belt, a power window motor was used from a 1994 Toyota Corolla.

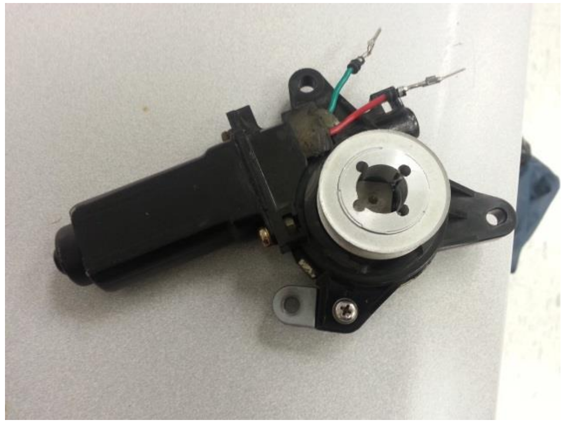


Figure 26: Power Window Motor - Front View

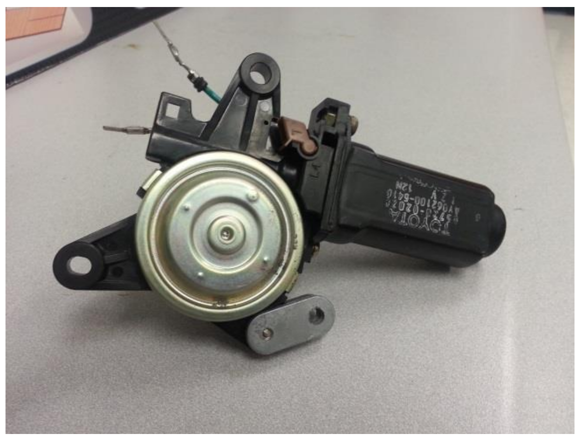


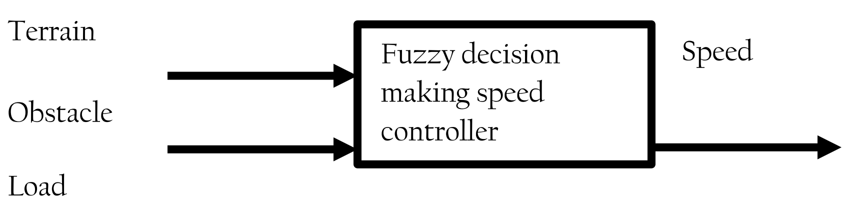
Figure 27: Power Window Motor - Rear View

Power consumption was the looming drawback to the modified Lunabot. The motors used not only drew a lot of current and power to operate but also add greatly to the weight of the entire machine. The power source had to be of sufficient power. Increased weight in turn increased the weight applied on the wheels. To compensate this, a 12V 7A lead-acid car battery was used as the main power source.

Figure 28: Denso Wiper Motor

Automation

The automation section consisted of using a series of ultrasonic sonars in order to detect obstacles and control the speed of both wheels. Using MATLAB's built in fuzzy logic function to model the automation section of the robot; a series of simple rules developed a 3-D surface to model all cases of the inputs, resulting in an ultimate output. This speed controller determined the correct speed of the Lunabot based on the weight of the load, distance an obstacle is, and the status of the terrain being traveled on. The following system was created:



The following surface was developed with no inconsistencies:

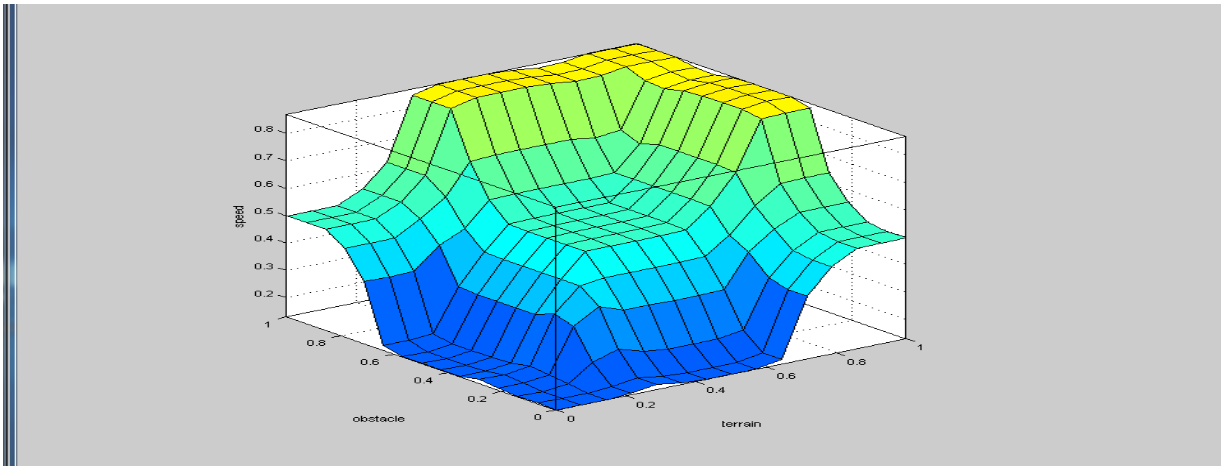


Figure 29: 3D surface of obstacle, terrain, and speed

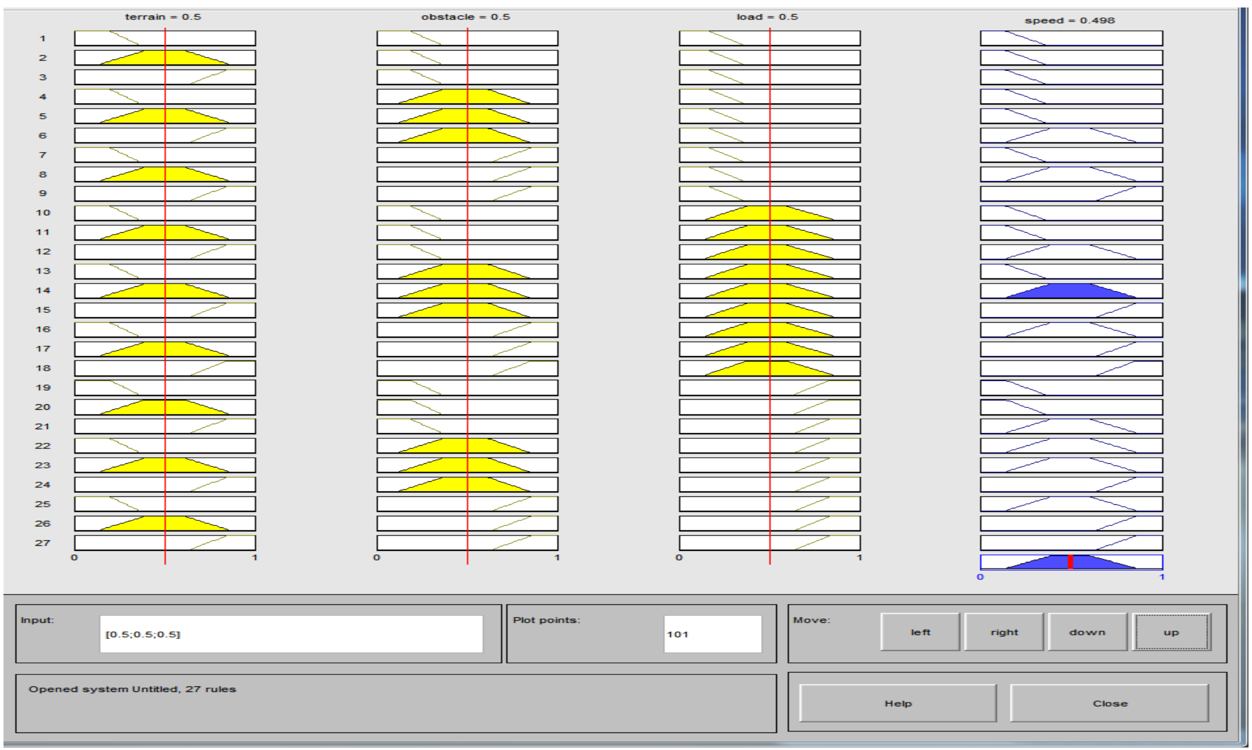


Figure 30: Speed rate calculations

1. If (terrain is rugged) and (obstacle is close) and (load is full) then (speed is slow) (1)
2. If (terrain is intermediate) and (obstacle is close) and (load is full) then (speed is slow) (1)
3. If (terrain is smooth) and (obstacle is close) and (load is full) then (speed is slow) (1)
4. If (terrain is rugged) and (obstacle is med) and (load is full) then (speed is slow) (1)
5. If (terrain is intermediate) and (obstacle is med) and (load is full) then (speed is slow) (1)
6. If (terrain is smooth) and (obstacle is med) and (load is full) then (speed is medium) (1)
7. If (terrain is rugged) and (obstacle is far) and (load is full) then (speed is slow) (1)
8. If (terrain is intermediate) and (obstacle is far) and (load is full) then (speed is medium) (1)
9. If (terrain is smooth) and (obstacle is far) and (load is full) then (speed is fast) (1)
10. If (terrain is rugged) and (obstacle is close) and (load is half) then (speed is slow) (1)
11. If (terrain is intermediate) and (obstacle is close) and (load is half) then (speed is slow) (1)
12. If (terrain is smooth) and (obstacle is close) and (load is half) then (speed is medium) (1)
13. If (terrain is rugged) and (obstacle is med) and (load is half) then (speed is slow) (1)
14. If (terrain is intermediate) and (obstacle is med) and (load is half) then (speed is medium) (1)
15. If (terrain is smooth) and (obstacle is med) and (load is half) then (speed is fast) (1)
16. If (terrain is rugged) and (obstacle is far) and (load is half) then (speed is medium) (1)
17. If (terrain is intermediate) and (obstacle is far) and (load is half) then (speed is fast) (1)
18. If (terrain is smooth) and (obstacle is far) and (load is half) then (speed is fast) (1)
19. If (terrain is rugged) and (obstacle is close) and (load is empty) then (speed is slow) (1)
20. If (terrain is intermediate) and (obstacle is close) and (load is empty) then (speed is slow) (1)
21. If (terrain is smooth) and (obstacle is close) and (load is empty) then (speed is medium) (1)
22. If (terrain is rugged) and (obstacle is med) and (load is empty) then (speed is medium) (1)
23. If (terrain is intermediate) and (obstacle is med) and (load is empty) then (speed is medium) (1)
24. If (terrain is smooth) and (obstacle is med) and (load is empty) then (speed is fast) (1)
25. If (terrain is rugged) and (obstacle is far) and (load is empty) then (speed is medium) (1)

Figure 31: List of rules for all cases to develop the surface

The graph above derived a MATLAB code which could be modified in order to develop a C++ code to be used with Arduino. Since all cases use percentage, 0% to 100%, on a 0-1 scale, the code would modify the ultrasonic sonar and PWM of the DC motors to compensate 0% to 100% of the speed.

Structural Design

The frame was constructed out of aluminum by the previous Lunabotics team. Minimalism with regards to the frame was predominantly the driving factor. Because minimalism was valued, limiting weight was a priority as well as rigidity. Smaller components, remote parts, and the power source will be housed within the robot.

The frame was also divided into two sections: an inner and outer frame. The inner frame lied within the outer frame. It held the auger and collector bin and rotated about a fixed point (located near the rear) through the use of actuators (located near the front). The outer frame was basically the body which held the electronics, motors, and wheels. This design also helped the auger “cut” into the ground as it rotated downward – while the inner frame rotates downward, the auger begins rotating. With the rotation about a fixed point, this helped the Lunabot traverse the terrain by raising the inner frame enough to pass over obstacles.

As noted, a frame has been salvaged and as such has decreased the overall budget as well as saved time. Additionally, because of its similar design, finding a point of rotation for the collector bin was simple enough. The actuators were fitted near the front, but because of the length brackets were fitted securely to the bin. This allowed for the actuator to rise while the brackets were able to rotate slightly, all the while the bin rotated about the point of rotation. The upside to the foot long actuators was that each actuator could support a load of up to 200 lb. Because of this, concern of whether they would be strong enough to lift the bin assembly including collected regolith had been "lifted".

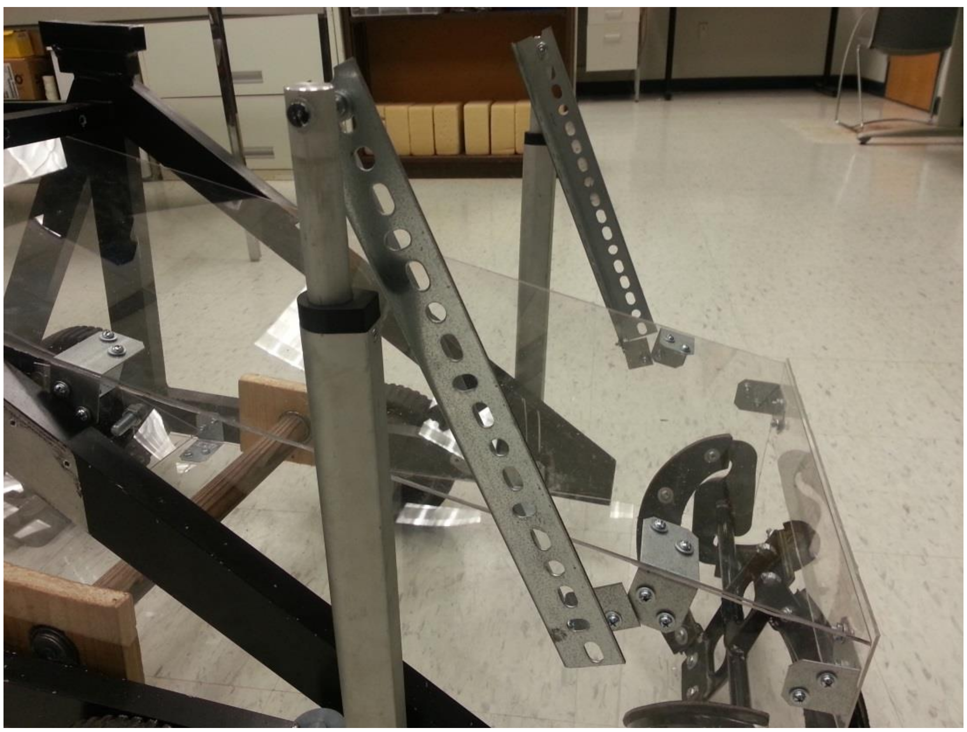


Figure 32: Brackets fitted onto Actuators and Collector Bin

Provided below are pictures of the salvaged frame and snow-blower auger-bit. The following figures show the salvaged frame. We would once again like to take this time to thank Team Pantera for their generosity in offering our team their auxiliary auger-bit from their parts bin.

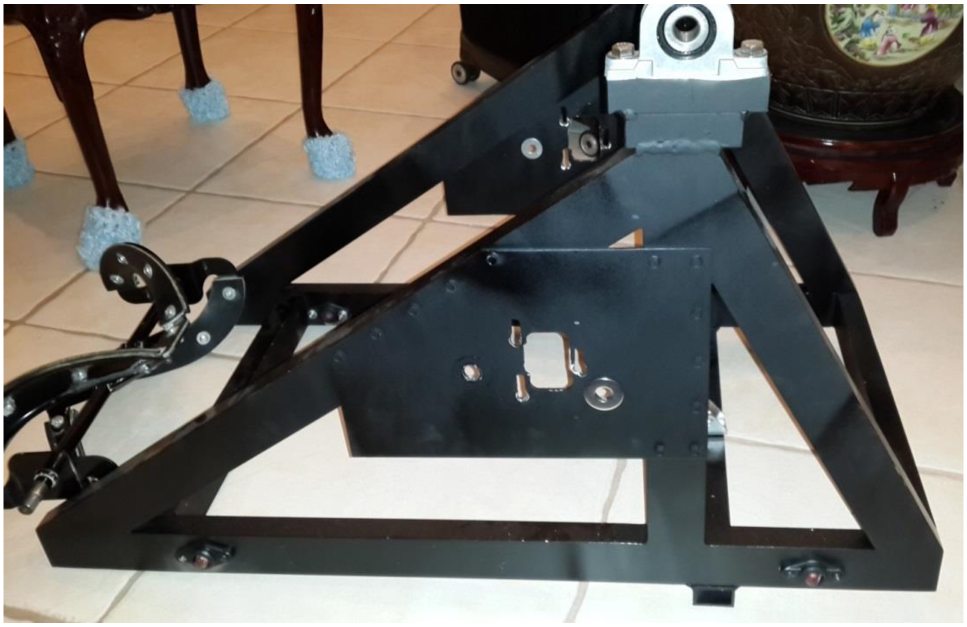


Figure 33 Salvaged Frame Right View (With Auger-bit)

Figure 34 Salvaged Frame Top View (With Auger-bit)

Prototyping

Prototype Cost Analysis

As stated, there a several major components that have been repurposed for this project. These components include the frame, motors, and actuators. Because of this, the original predicted cost of the

Lunabot had decreased drastically. Parts that were salvaged were not done blindly but were accepted because of the ability to adapt them to the final design. The components had proven useful and worked well where used. Speaking of cost, below is the table of project expenses, also noting the multiple items that were salvaged for little to no cost.

Table 2: Cost Analysis Approximation

Component	No.	Part	Price
Electronics	1	Arduino Mega 2560	$28.85
	1	Wi-Fi Shield	$94.95
	5	Ultrasonic Sonars	$15.99
	4	Kill Switch	$14.99
	1	Gear head Webcam	$10.99
	1	XBee Wireless Kit	$95.95
	1	4-Channel Motor Controller	$24.95
Auger Dredge	1	Spare Auger Bit	$0
Power source	1	Powerhouse Battery	$21.95
	1	Battery Charger	$35.00
Drive System	4	Lawnmower Wheels	$0
	2	Denso DC Motor	$0
	1	Toyota Power Window Motor	$0
	1	Radiator Fan Motor	$0
Conveyor Belt	1	Wood Dowel	$2
Frame	1	Salvaged Frame	$0
Collector Bin	3	.125” 36” x 72” Plexiglas Sheets	$160
Misc.		Screws, washers, nuts, bearings	$30
Total			$535.61

Prototype Build

The following pictures highlight the construction of the Lunabot. The initial frame that was salvaged had to be reduced, simplified in order to house what was designed. The journal bearings mounted atop the frame were removed as well as the front and middle bars located at the bottom. The bottom was cleared in order to allow for the inner frame (which houses the collector bin, auger, and conveyor belt) to rotate about a point.

Figure 35: Initial Salvaged Frame

2 sheets of Plexiglas were utilized to prepare the collector bin. Dimensions were drawn up from Solidworks and drawn on the sheets. The pieces were cut to size and fitted together using aluminum brackets. The brackets allow for rigidity as well as the silicone, which was also used in order to fill the gaps).

Figure 36: Cut collector bin fitted in frame

Figure 37: Collector Bin fitted

Figure 38: Final Collector Bin

Figure 39: Auger fitted in Frame

Figure 40: Auger fitted - Side View

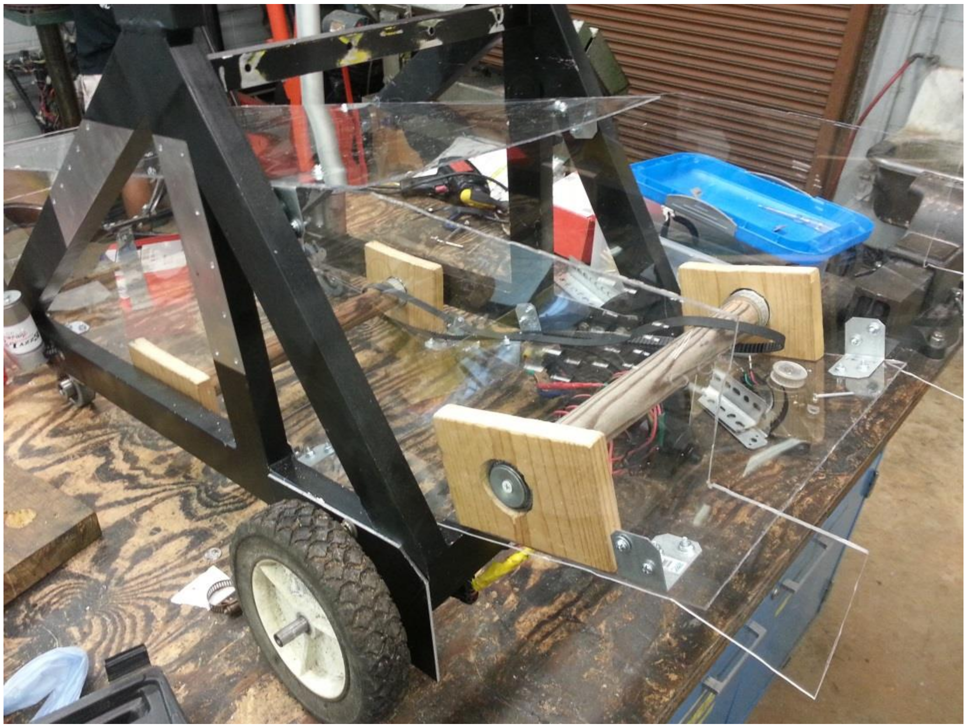


Figure 41: Conveyor Belt System modifications and alterations

Figure 42: Prototype without Conveyor Belt

Figure 43: Prototype without Conveyor Belt – Side View

Figure 44: Prototype without Conveyor Belt – Front View

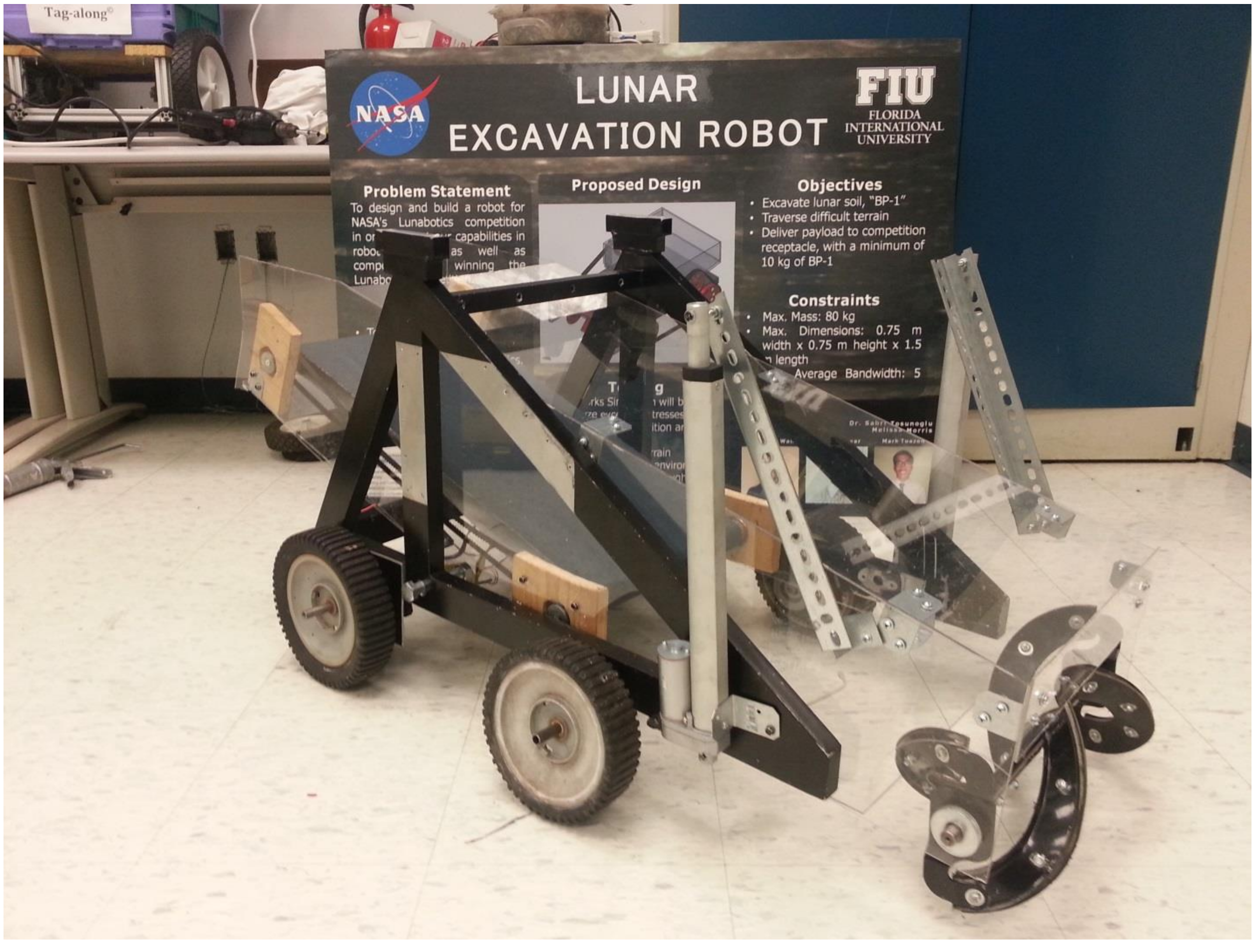


Figure 45: Final Prototype assembly of Lunabot

Simulation

CAD simulations were run to give an idea of the kind of stresses that take place throughout the frame, collector bin, and auger. As stated, the results give a range of suitable data to work with. The parts primarily analyzed included are the frame of the Lunabot itself which shall hold the entire robot together, the collection bin because of the material it is made of and the varying roles it will serve, and the auger because it will be the major working component in collecting the lunar-soil simulant.

Frame

For the following images, the frame was simulated with the fixtures located at the points in which the wheels sit. Forces were then applied to where the actuators would be and at the point of rotation. And as seen, the frame was suitable enough, with the highest point of deformation located at the front. In assuming variables, the resulting factor of safety for the frame was 350.

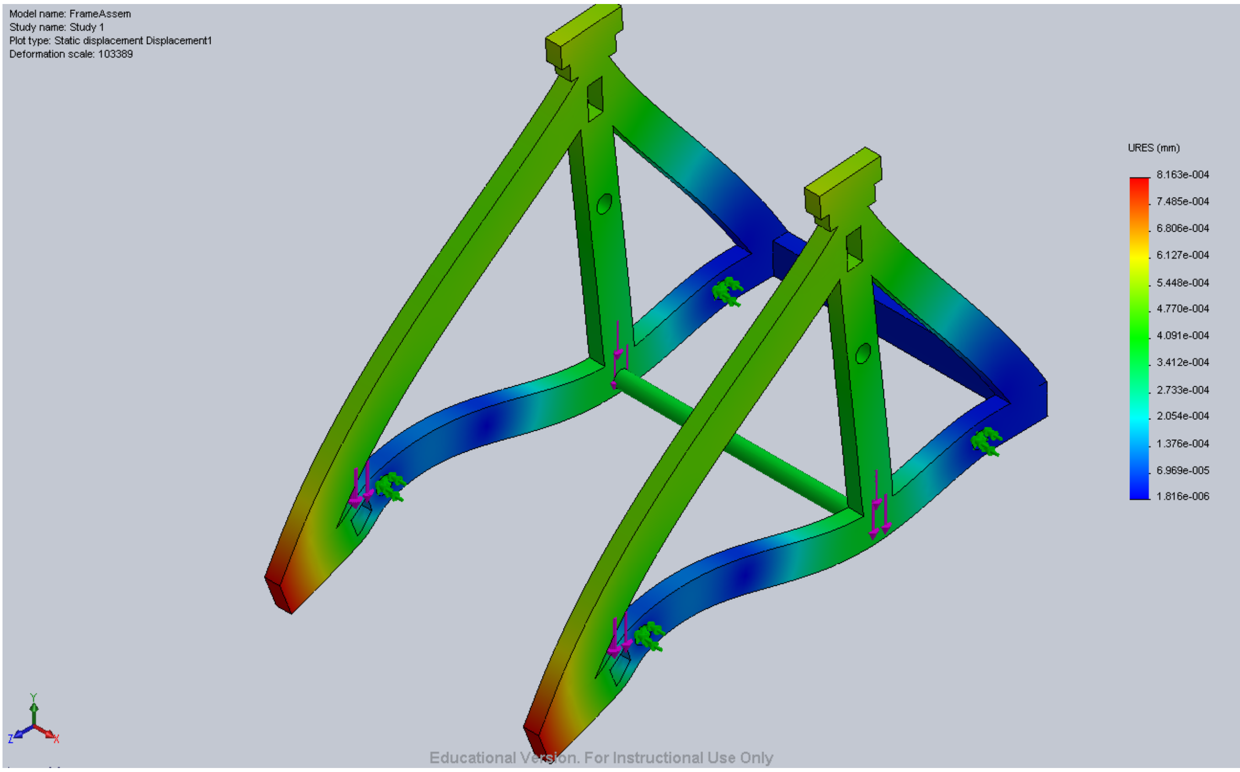


Figure 46: Frame – displacement

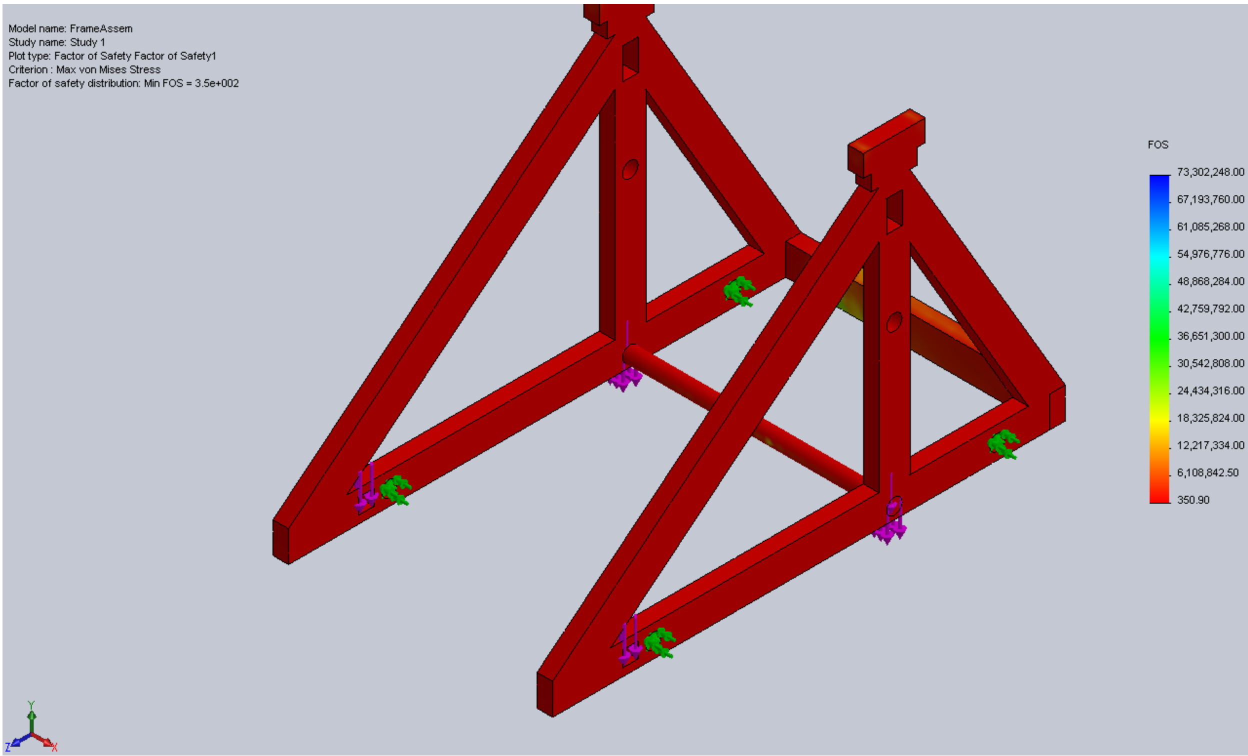


Figure 47: Frame - FOS

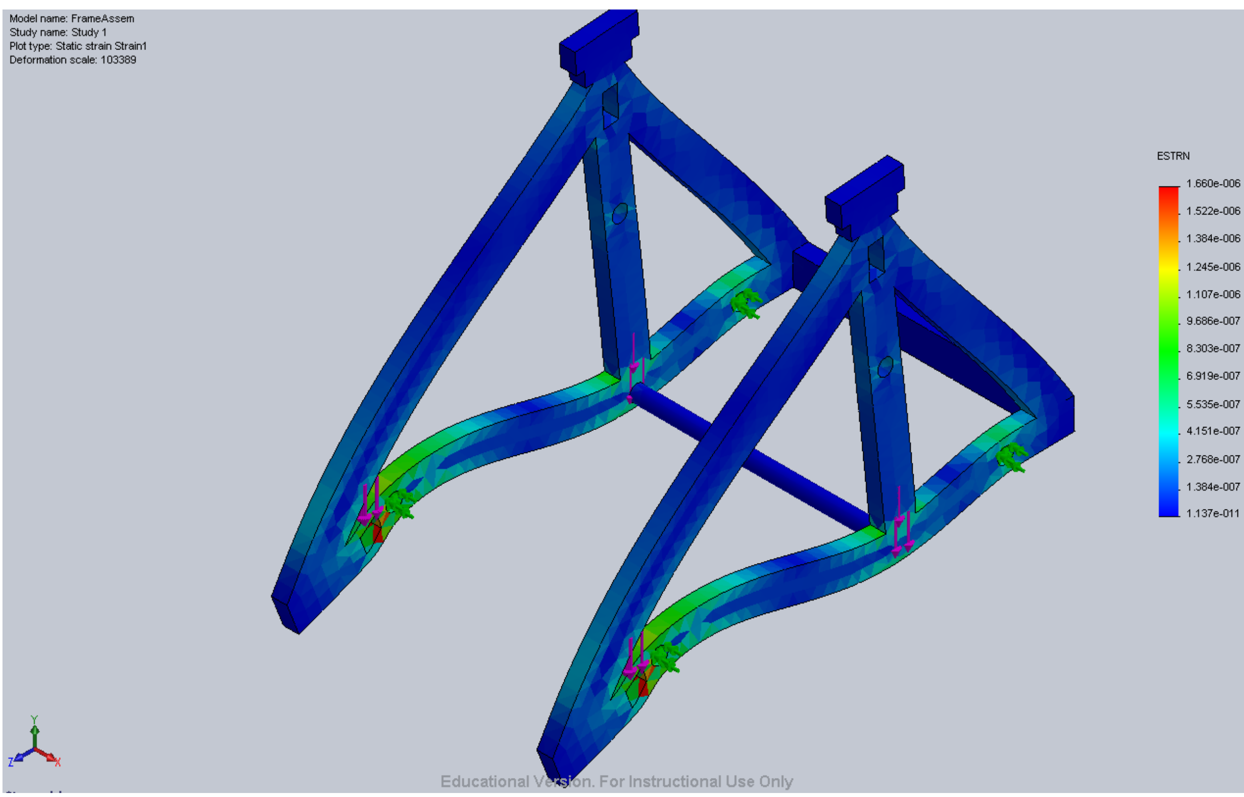


Figure 48: Frame - strain

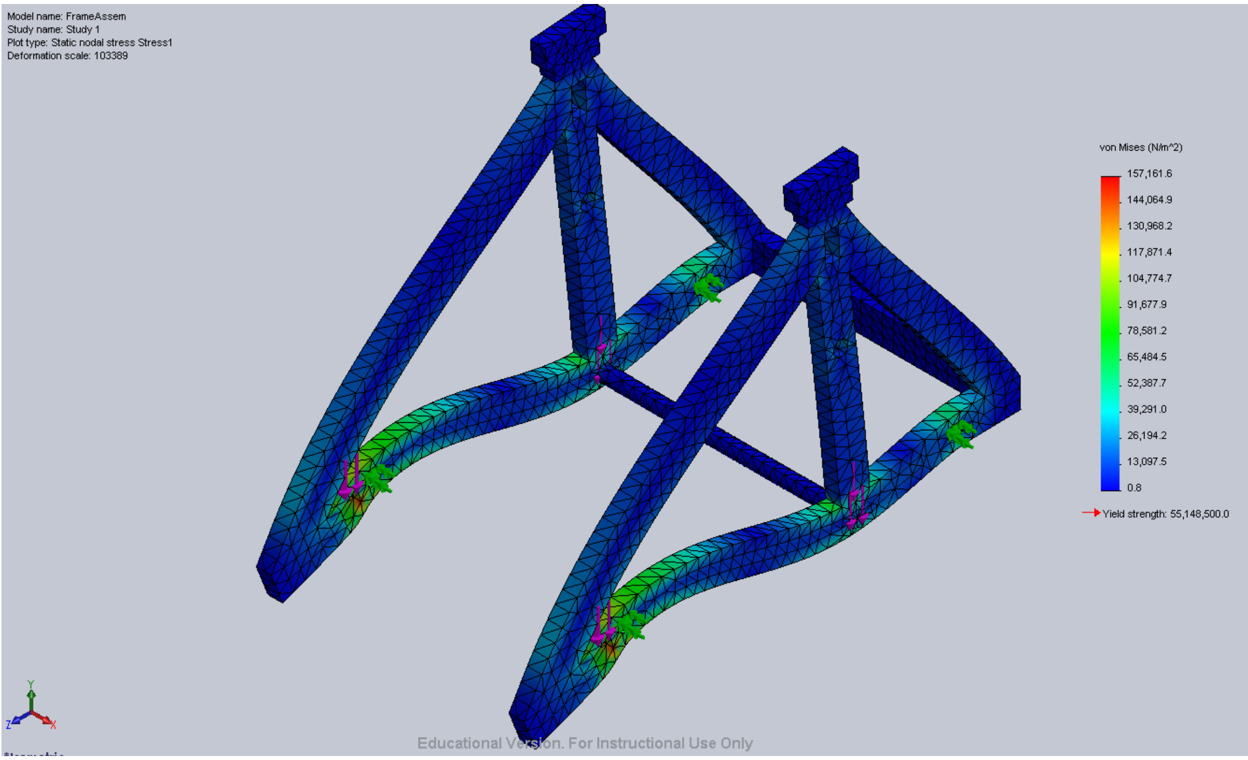


Figure 49: Frame - stress

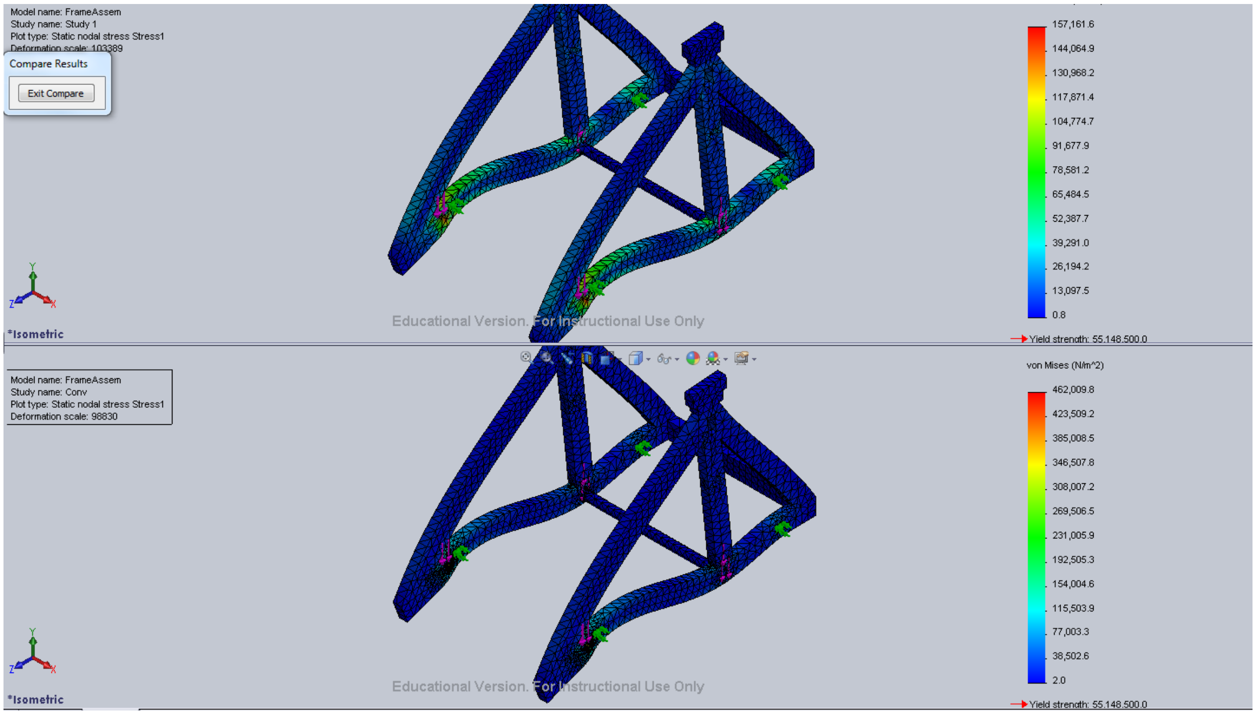


Figure 50: Frame - Stress comparison. Top - regular mesh, Bottom - adaptive mesh control

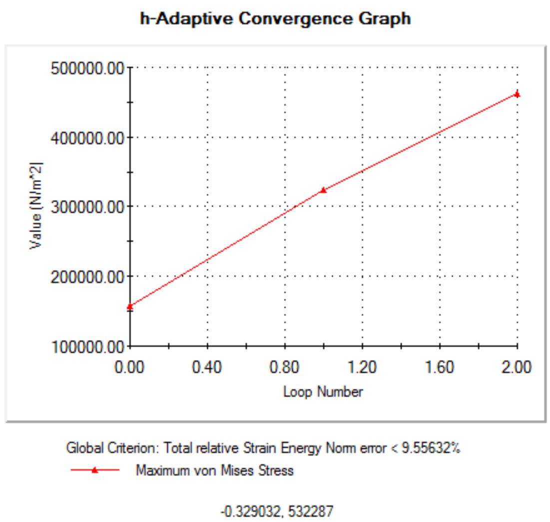


Figure 51: Frame - Adaptive mesh control convergence graph

The first part to be analyzed was the frame itself. Composed as a few different parts, this CAD simulation was based off of a SolidWorks assembly made up of the two halves of the frame and the interconnecting rod about which pivot the bin and the back bar which holds the two halves together. The frame had fixtures at the wheel holes, taking into consideration that the robot will naturally rest on the wheels and a majority of the loads will be acting on those "fixtures". The loads were then simulated to act upon the auger mounts and the collection bin pivot joint where most of the applied loads will be acting. While the simulation results exaggerate the displacement of the frame itself, we can see under some overestimated loading conditions, the frame itself still presents a safety factor of 350.3. As for mesh convergence, the graph provided after 2 loops doesn't necessarily converge, but the plot itself follows a convergence trend where, after more loop iterations, the values will eventually converge, possibly on a high mesh density value due to the slightly more complex geometry of this assembly.

Collector Bin

The following figures represent the CAD simulations for the collection bin of our Lunabot. The bin was analyzed by taking into consideration that the only true fixture for the bin would be the rotating pin that it would be affixed to, which can be examined in the following figures as the congregated mass of arrows in the lower right corner of the bin. This fixture allows the bin to pivot clockwise and counterclockwise, and an outline of the bin's original position is visible within the figures to illustrate how the bin would move under operational loading.

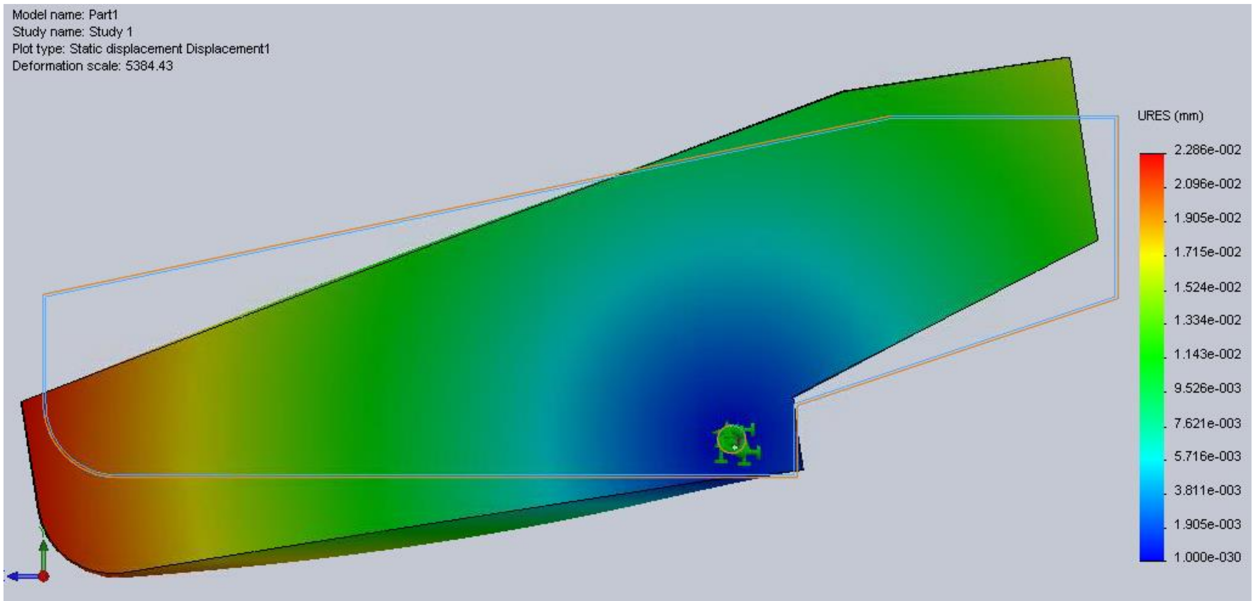


Figure 52: Bin - displacement

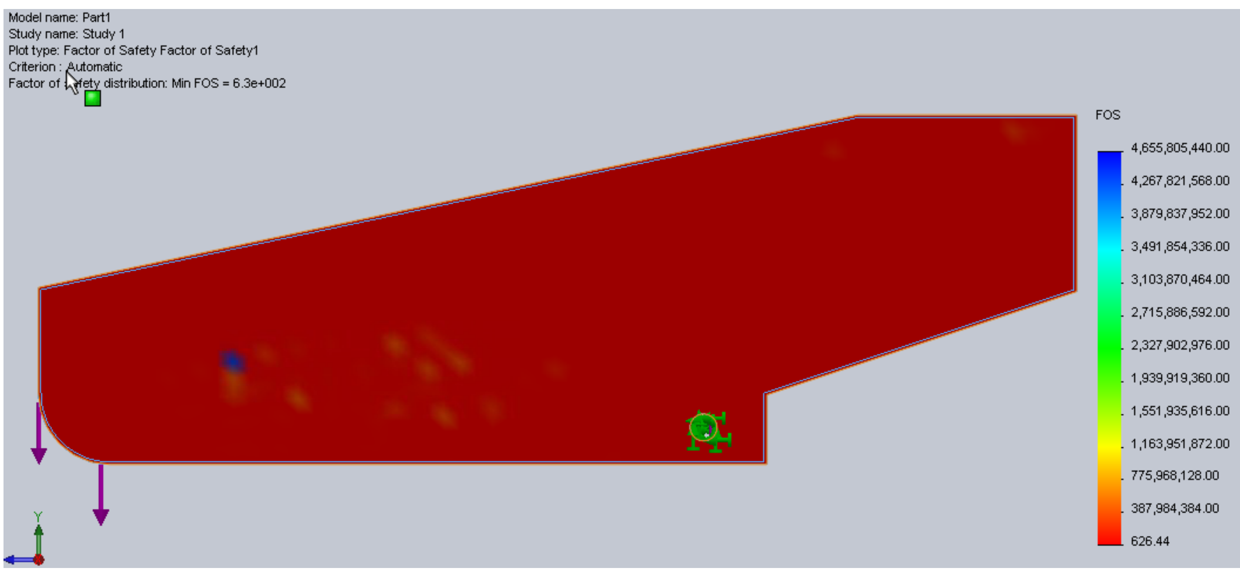


Figure 53: Bin - FOS

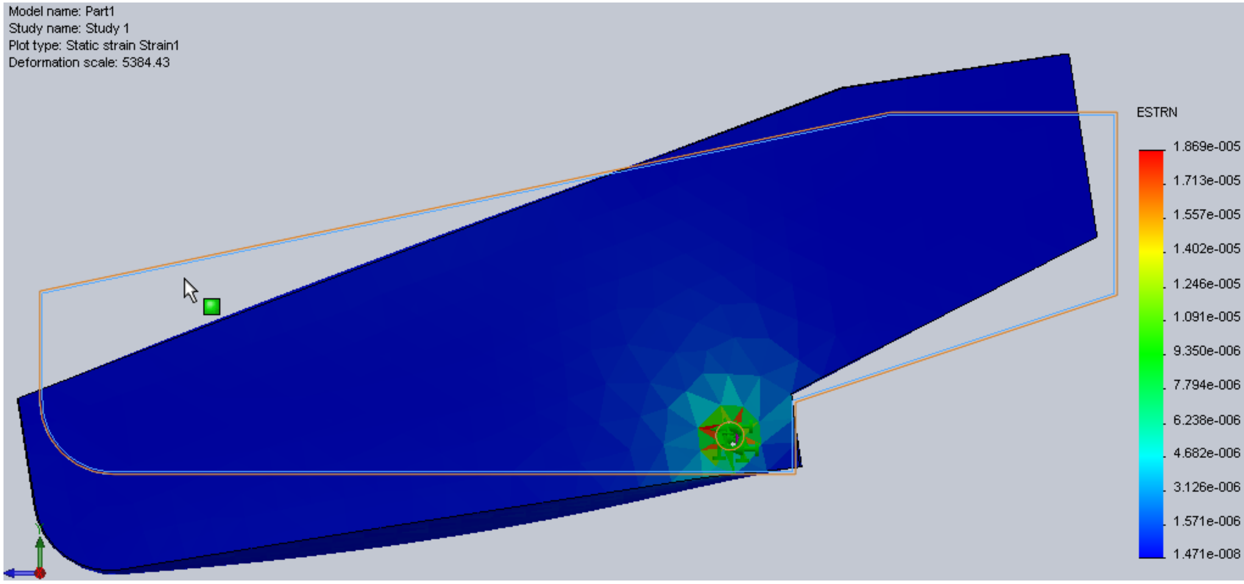


Figure 54: Bin - strain

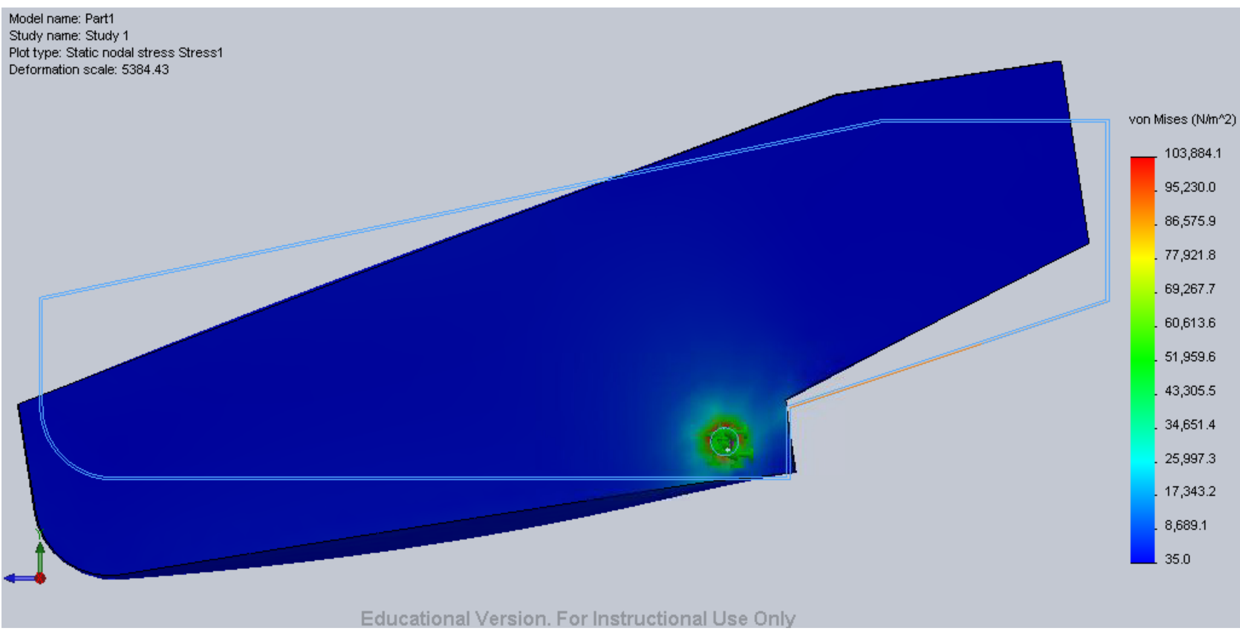


Figure 55: Bin - stress

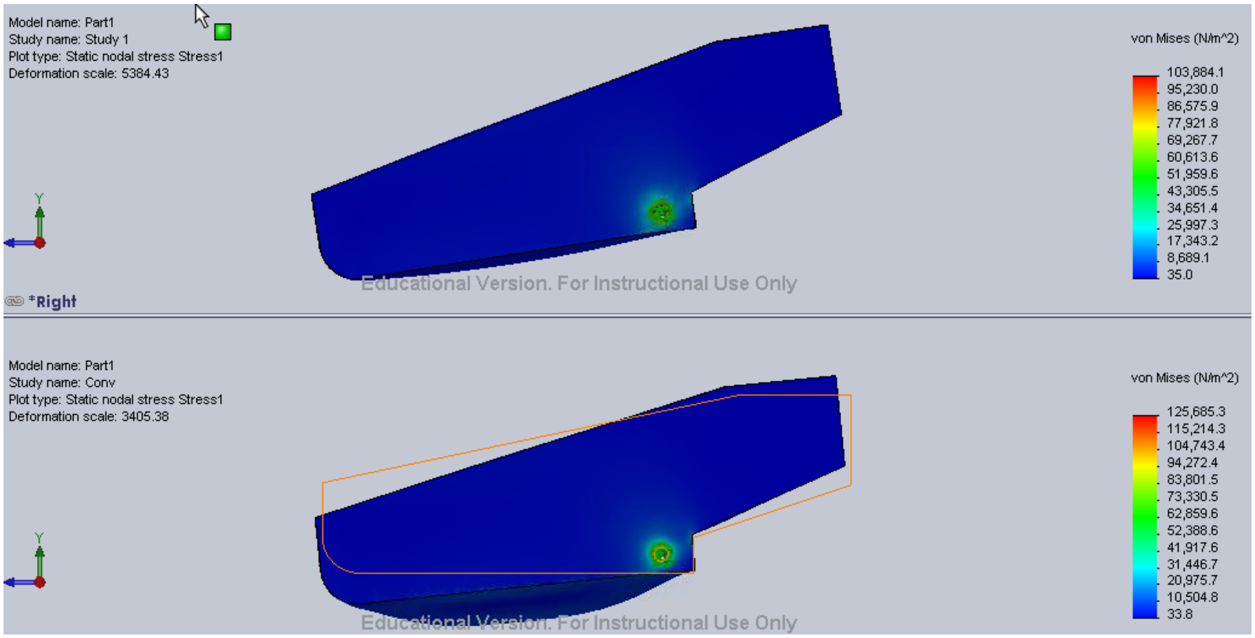


Figure 56: Bin - Stress comparison. Top - regular mesh, Bottom - adaptive mesh control

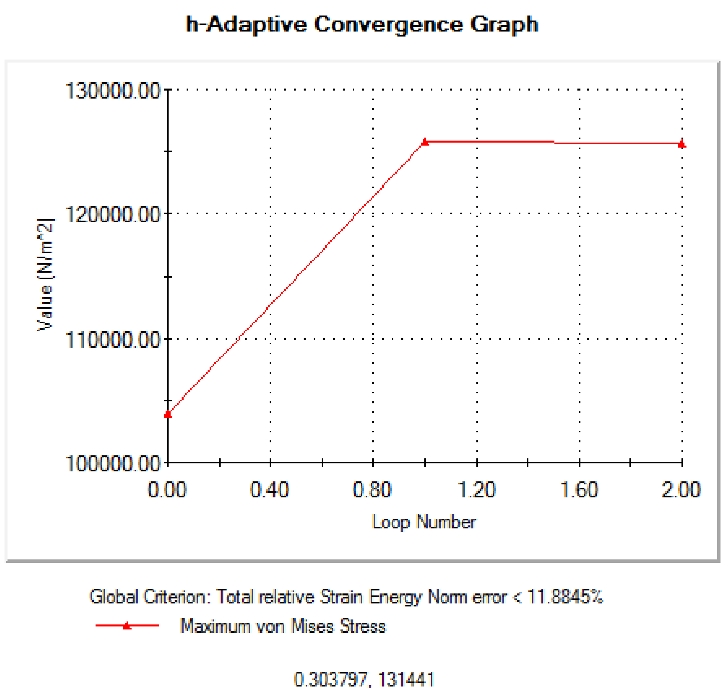


Figure 57: Bin - Adaptive mesh control convergence graph

One must note that for the convergence graph of the bin under adaptive mesh control analysis, the values for the bin actually converge before 2 simulation loops, which is a good thing. This means that the bin, while undergoing CAD simulation analysis, is able to find a relatively accurate mesh density in a short period, therefore reducing the amount of time required to accurately analyze this component. Another item of interest is the comparison plot between the regular single point mesh stress simulation and the adaptive mesh simulation in the figure immediately before this paragraph. The adaptive mesh figure shows a deeper bulge within the lower part of the bin component. Considering that loadings were placed within the bin itself to simulate the weight of the lunar soil simulant to be collected, it is an interest if slightly exaggerated depiction of how the part would perform under normal operating conditions. The Plexiglas bin does have flex to it however to distend so much would be impossible if slightly impressive.

Auger

The first figure presented below illustrates the "displacement" of the auger as it goes through the motion of spinning at high rpms and collects the lunar soil. Keep in mind at the operating rpm for the auger, each of the flat sections of the auger will only see brief contact with the lunar soil but over an extensive amount of cycles. Fixing the ends of the auger's cylindrical center allowed us to observe an instantaneous simulation of both the soil simulant acting against the leading flat edge of the auger, as well as the torque provided from the motor used to spin the auger.

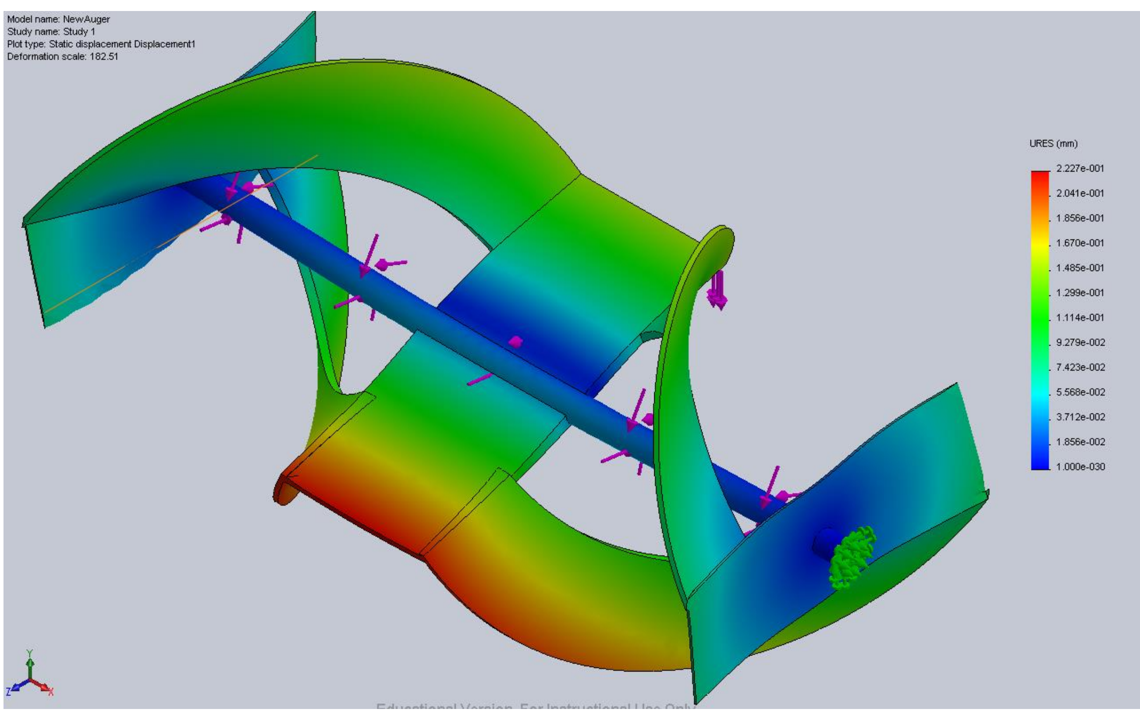


Figure 58: Auger - displacement

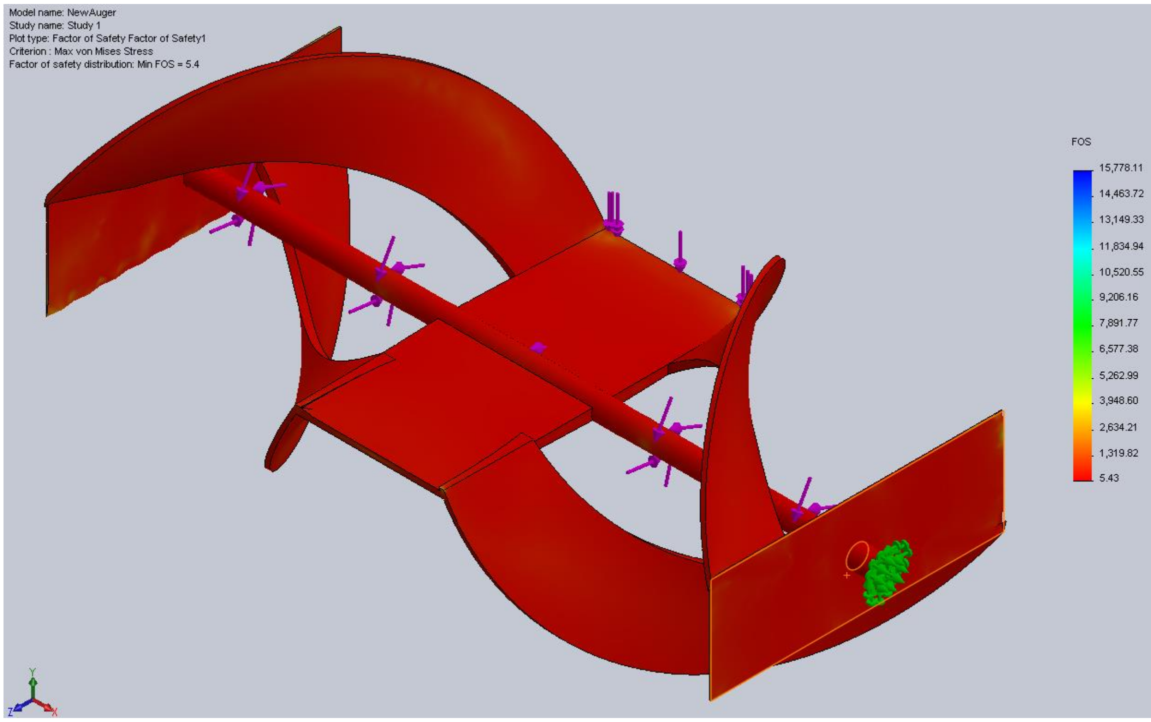


Figure 59: Auger - FOS

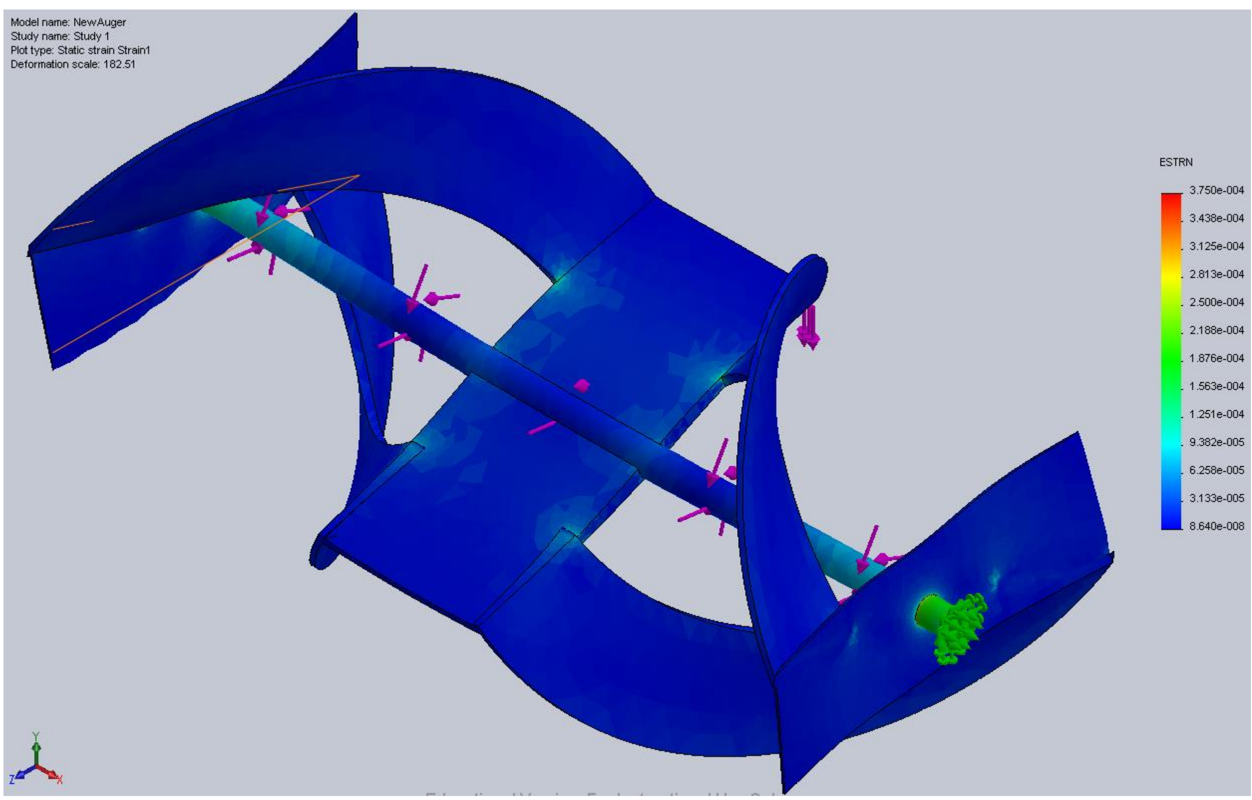


Figure 60: Auger - strain

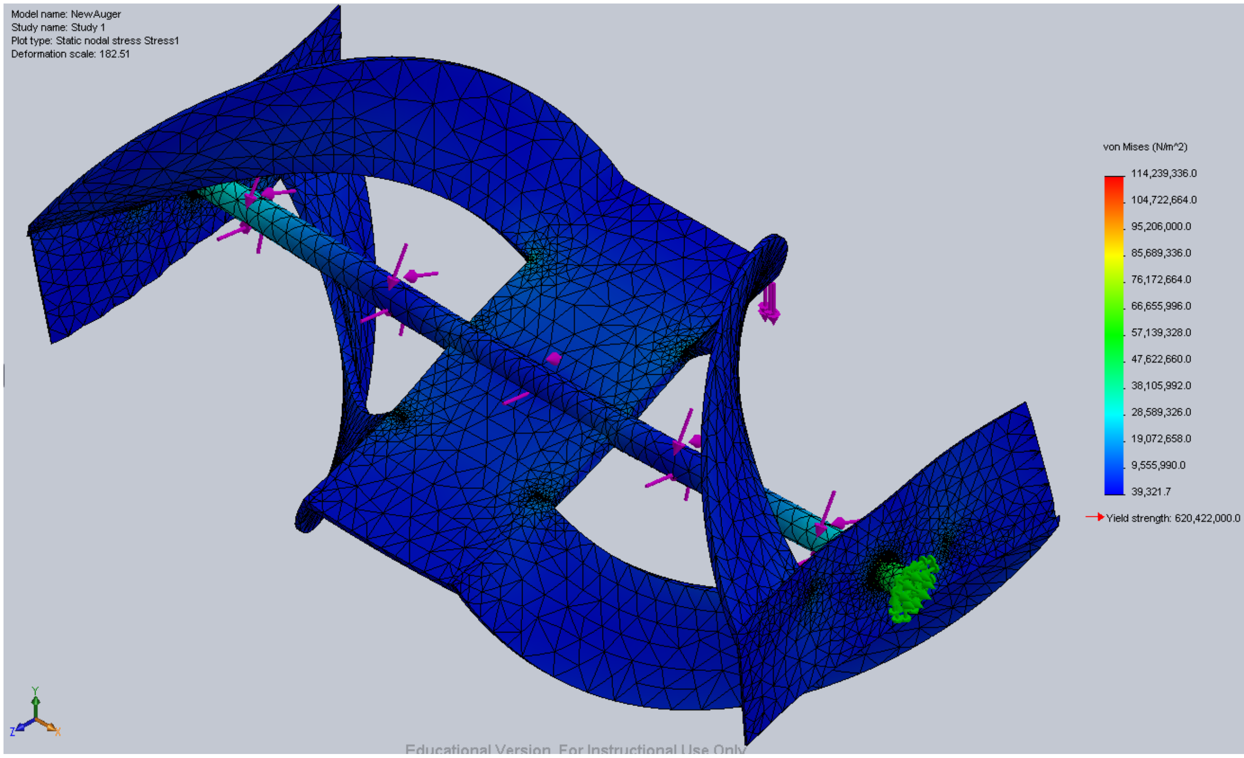


Figure 61: Auger - stress

The preceding figures portray the safety factor, strain, and stress placed on the auger during its operation period. Under the loadings applied in the CAD simulation, the factor of safety resulted in roughly a magnitude of 5.43. This value was derived from the appropriate material selection, fixture and loading selection, as well as the meshing for the figure. While mesh density is important in regards to overall accuracy of the CAD simulation, SolidWorks offered an adaptive meshing function that would loop the process (up to 5-times for h-adaptive meshing) in order to determine if the values for the simulation would converge. The following figure represents the convergence graph of the stress values after two loops of the adaptive mesh process. While the graph itself does not appear to be meshing, the plot did return a global error percentage of 5.3291%. The figure after the plot shows a comparison of the auger under stress analysis, with the top half representing the CAD simulation with a fixed mesh density, while the bottom shows the auger undergoing the adaptive mesh simulation process.

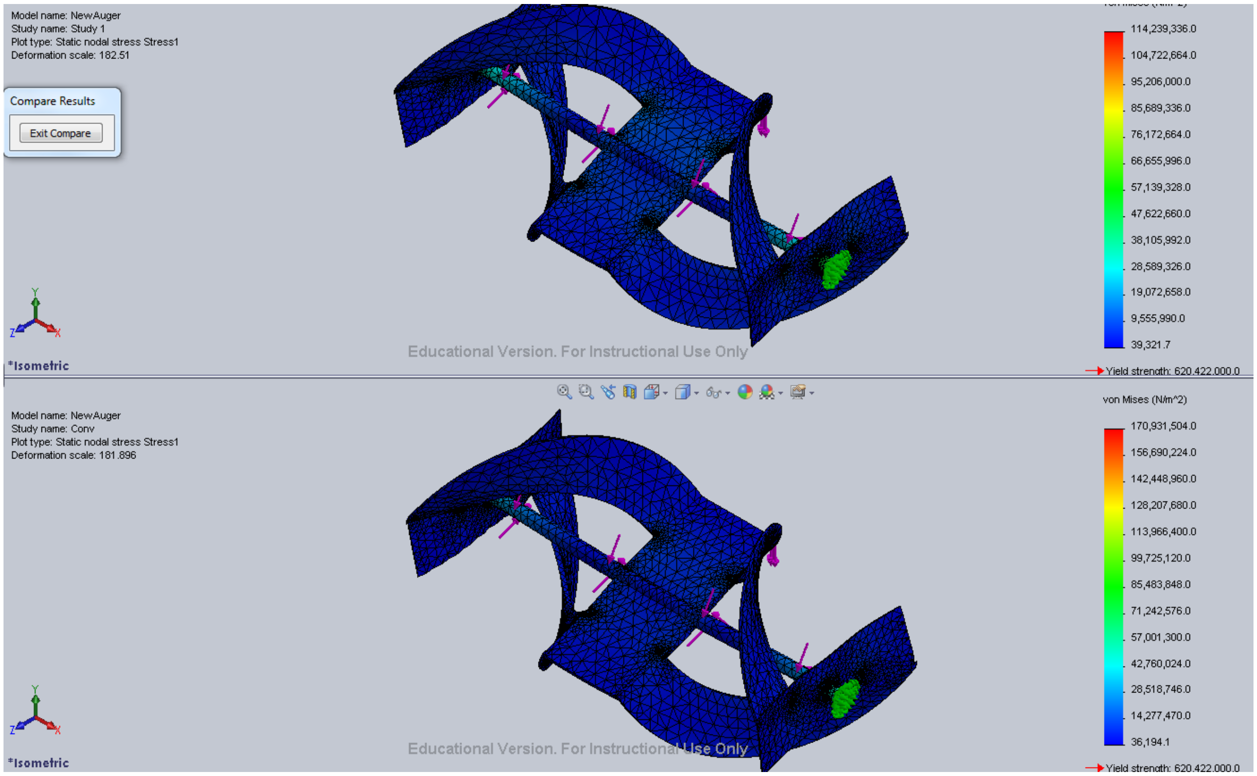


Figure 62: Auger - Stress comparison. Top - regular mesh, Bottom - adaptive mesh control

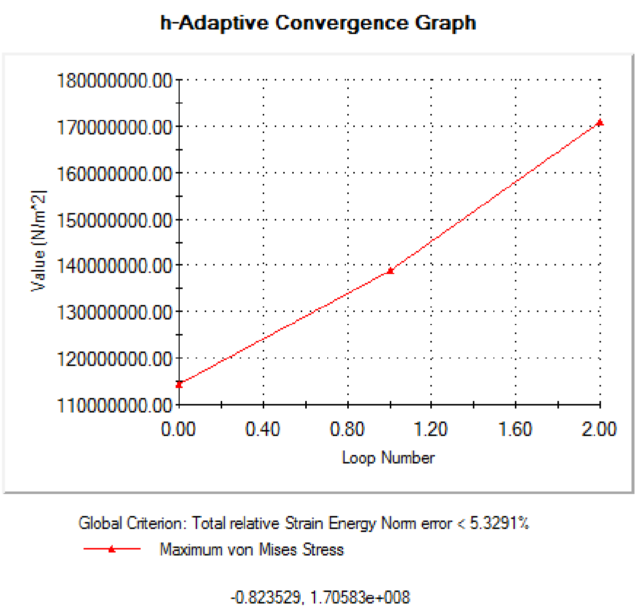


Figure 63: Auger - Adaptive mesh control convergence graph

As in the other cases, a convergence study was done with adaptive mesh controls added. But in the case of the auger, perhaps due to the width of the fins, the stress graphs diverge, indicating a singularity point.

Testing

Preliminary Testing

Initial testing began with the motors acquired from previous teams as well as unused automobile parts. Testing needed to be done in order to determine the state of them. Simply using a 12V battery, the leads were connected from the Denso wiper motors to the battery. The main concern with these motors was the unknown amount of current draw, torque, and rpm as the motor was marked with "12V" as well as the name and model number. Online searches for the motor turned up to be futile. But after testing the motors first-hand, they both equally rotated fast enough as well as having enough torque.

The other motors used – power window and radiator fan motors for the conveyor belt and auger, respectively – were tested in the same manner. The power window motor had enough torque and a moderate speed enough for the conveyor belt to rotate fast enough without recklessly spewing regolith. The radiator fan motor performed similarly in that it had the appropriate rpm for the auger and enough torque as well.

Other items obtained second-hand were the actuators which were graciously given to us by last year's team. The actuators were rated at lifting 200 lbs although are rather long – 12 in. in the receded position. Upon checking with the same battery, the actuators worked as hoped.

Prototype Testing

To be sure everything would run correctly, a mock set up was tested in order to find and troubleshoot any issues before placing the controls onto the robot. It was during this phase that the program could be written to control all the electronics. Beginning with the power source, the 12V 7 amp battery was used connected to a switch for on-off power. This was then run to a 7.5 amp fuse which runs to the external power to the Rover 5 motor driver. Channels 1 and 2 control the left and right DC motors for propelling the wheels, while channels 3 and 4 were set to control each of the linear actuators. The motor driver had all wires soldered to DC motors on the Lunabot and a custom soldered expansion bus which was plugged into the controller pins. Initial testing was done without the implementation of the conveyor belt and auger motors for simpler debugging of the code and will be added at a later time. The wire bus was then connected to the Arduino board through digital pins 2, 4, 6 and 8 to control the speed. Pins 22, 24, 26 and 28 were then used for controlling the direction of the motors. This was where the forward, backward and left and right movements were controlled.

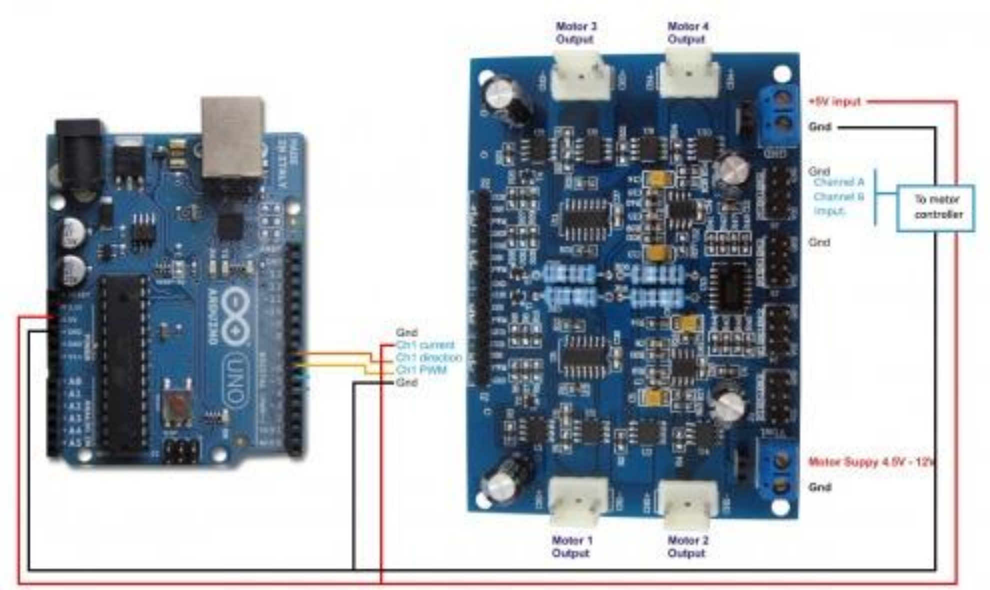


Figure 64: basic setup of Arduino to motor driver

The testing stage was done through a wired connection for majority of the set up. Once everything was set, a program was written in order to control everything via the laptop. Upon testing of the left DC motor, everything ran smoothly and according to code. However, after testing both DC motors at the same time the SP8M3 transistor burned out on channel 1. All motors were researched once more to and tested to find any fault in the current ranges. Once the two DC motors started it was found that there was a current spike upon start-up of .04 amps for each motor almost 1 amp in total. Research reviled that the motor driver has a current rating of 4 amp max and a recommended 2 amp operating current. The tested operating currents totaled only 1.2 amps at max during the operation so testing was continued modifying the motor controller to compensate for the blown transistor on channel 1.

Table 3: Motor power and Current ranges

Motor ratings				
Type	# of components	Voltage	Current (max load)	tested operating current (no load)
DC Desno wiper motors	2	12	1.5Ah	0.04Ah
Dc Ezzy lift linear actuators	2	12	3Ah	.013Ah
DC power window motor	1	12	1Ah	.02Ah
DC radiator motor	1	12	1Ah	0.02Ah
4 Channel motor driver	1	0-12	4Ah	2Ah

During the second test, the set up was changed to the dc motors on both channels 2 and 3 to keep control of the turns and both actuators were connected to channel 4 due to the fact that both will operate at the same time in the same direction so as to not twist and crack the bin. A lower fuse rated at 2 amps was used as well to prevent too much current and destruction of the driver. Upon testing, the fuse was blown instantly proving too much current was being used. A third testing using a 4 amp fuse showed there was still too much current passing through the system. The fuse was then replaced with a 7.5 amp fuse, 0.5 an amp higher than the battery output current. But after flipping the switch it also blew drawing to the conclusion that there must be either a current spike or the motors were drawing much more current than was expected. The following tests consisted of a 12V voltage regulator rated at 1 amp to control the amount of current flowing into the system and prevent any damage to the driver. From this test, it showed that too much current was being restricted for the regulator to tolerate and the regulator's fail safe broke the connection at over 135°C. The final testing of the system was done under the initial conditions but ran a parallel circuit in order to split the current and safely cut the total 7 amps into 3.5 amps. This, however, resulted in an inaccurate set up and burnout of channel 2 as well. By the end of testing, the final conclusion was that due to a lack of experience in electrical engineering, the motor driver was damaged beyond repair and could no longer be used.

Table 4: Testing stages until ultimate failure

Testing	results
1	Burned out transistor on channel 1 of motor driver
2	Burned out 2 amp fuse
3	Burned out 4 amp fuse
4	Burned out 7.5 amp fuse
5	Burned out 12V 1 amp regulator
6	Burned out transistor on channel 2 of motor driver
7	Found that the motor driver is insufficient for driving current needed to run motors.

Future implementations of the Lunabot consists of using a set of relays controlled with the Arduino to switch on and off the power straight to each motor. This method will use all motors at full power while controlling the polarity using four different sets of relays per motor. The next alternative would be to get a motor driver which can handle both the current and voltage required to run all the motors successfully this method however, become more expensive.

Conclusion

This project provided a lot of information in both the mechanical and electrical fields. Mechanically, it proved itself to be structurally sound. All mechanisms worked and operated the proper way as a functioning robot. The electrical portion, however, served too difficult to understand from a mechanical engineer's point of view. There was much fluctuation and it was not simple to reverse steps in order to re-do a particular issue. The project overall was a great learning experience from the initial design in Solidworks to the actually building of the robot, utilizing new and salvaged parts. But what served to also be important was the fact that it taught that the design will not always work. It may also be said that this gives a certain degree of preparation for real industry by showing how one may depend on others, not only within the team but also outside of the circle. In the case with this project, because of a lack of experience in circuits, an outside electrical engineering student was needed for guidance through a major issue with the electrical components.

In addition, the experience had shown how to deal with difficulties when trying to stay within a budget. It was not particularly easy to determine what parts were to be used due to limited funding. Nor was it simple to determine what electronics and components were suitable enough for the needs of the project. These are all real issues to deal with as an engineer. Although the build did come out as expected by trying to keep the design simple, in the end it served its purpose in furthering our knowledge and understanding.

References

[1] "BASIC Stamp General Information." *BASIC Stamp General Information*. Parallax Inc., n.d. Web. Accessed March, 2013.

[2] Bekey, George A. *Autonomous Robots: From Biological Inspiration to Implementation and Control*. Cambridge, MA: MIT, 2005.

[3] Briette, Stephanie, Diego Bolivar, Maria Wilhelm, and Ibrahim N. Tansel, Ph.D. *Lunar Excavator: NASA Lunabotics Competition*. Rep. Final ed. Miami: FIU, 2012.

[4] Garo, Ramon, Narine Harrylall, Janet F. Reyes, and Sabri Tosunoglu, Ph.D. *Pantera: Lunar Regolith Excavator*. Rep. Final ed. Miami: FIU, 2012.

[5] Kennedy, B. A. *Surface Mining*. Littleton, CO: Society for Mining, Metallurgy, and Exploration, 1990.

[6] Cavette, C. (n.d.). Retrieved from http://www.enotes.com/acrylic-plastic-reference/acrylic-plastic. Web. Accessed April, 2013.

[7] "40 Common Minerals and Their Uses." *40 Common Minerals and Their Uses*. National Mining Association, n.d. Web. Accessed 21 Nov. 2013.

Appendix

Arduino Code

```
//-------------------left wheel--------------------

int motor1pin = 2;

int motor1dir = 22;

//-------------------right wheel------------------

//****************** BURNED OUT ******************

int motor2pin = 4;

int motor2dir = 24;

//-------------------Right actuator------------------

int motor3pin = 6;

int motor3dir = 26;

//------------------left actuator------------------

int motor4pin = 8;

int motor4dir = 28;


int spd = 128;


void setup()

{

  pinMode(motor1pin, OUTPUT);

  pinMode(motor1dir, OUTPUT);


  pinMode(motor2pin, OUTPUT);

  pinMode(motor2dir, OUTPUT);


  pinMode(motor3pin, OUTPUT);

  pinMode(motor3dir, OUTPUT);
```

```
  pinMode(motor4pin, OUTPUT);

  pinMode(motor4dir, OUTPUT);


  Serial.begin(115200);

  while (! Serial);

  Serial.println("ready");

  Serial.println("speed is");

  Serial.println(spd);

}

void loop()

{

  if (Serial.available())

  {

//  int spd = Serial.parseInt();

    char key = Serial.read();

//    if (spd >= 0 && spd <= 255)

//__________________________________________________________


//----------------------Chassis Control-----------------------

//    {

      switch(key){

//*******************Go Forward***************************

      case 'w':

      Serial.println("Forward");

      for(int i; i < 5000 ; i++){

//      spd = 255;


//      analogWrite(motor1pin, spd);

//      digitalWrite(motor1dir,HIGH);

      analogWrite(motor2pin, spd);
```

```
      digitalWrite(motor2dir,HIGH);
      }
      analogWrite(motor1pin, 0);
      digitalWrite(motor1dir,HIGH);
      analogWrite(motor2pin, 0);
      digitalWrite(motor2dir,HIGH);

      break;
//**********************************************
//*******************Go Backward***************
      case 's':
      Serial.println("Backward");
      for(int i; i < 5000 ; i++){
      analogWrite(motor1pin, spd);
      digitalWrite(motor1dir,LOW);
      analogWrite(motor2pin, spd);
      digitalWrite(motor2dir,LOW);
      }
      analogWrite(motor1pin, 0);
      digitalWrite(motor1dir,HIGH);
     analogWrite(motor2pin, 0);
      digitalWrite(motor2dir,HIGH);
      break;
////**********************************************
////*******************Go Right***************
      case 'd':
      Serial.println("Right");
      for(int i; i < 5000 ; i++){
analogWrite(motor1pin, speed);
      digitalWrite(motor1dir,HIGH);
```

```
      analogWrite(motor2pin, speed);
      digitalWrite(motor2dir,LOW);
      }
     analogWrite(motor1pin, 0);
      digitalWrite(motor1dir,HIGH);
      analogWrite(motor2pin, 0);
      digitalWrite(motor2dir,HIGH);
      break;
////**********************************************
////*******************Go Left***************
      case 'a':
      Serial.println("Left");
      for(int i; i < 5000 ; i++){
     analogWrite(motor1pin, speed);
      digitalWrite(motor1dir,LOW);
      analogWrite(motor2pin, speed);
      digitalWrite(motor2dir,HIGH);
      }
      analogWrite(motor1pin, 0);
      digitalWrite(motor1dir,HIGH);
      analogWrite(motor2pin, 0);
      break;
//**********************************************
//***************Actuator control
//***************Go up************************
      case 'y':
      Serial.println("Forward");
      for(int i; i < 5000 ; i++){
//      spd = 255;
```

```
//      analogWrite(motor3pin, spd);
//      digitalWrite(motor3dir,HIGH);
      analogWrite(motor4pin, spd);
      digitalWrite(motor4dir,HIGH);
      }
      analogWrite(motor3pin, 0);
      digitalWrite(motor3dir,HIGH);
      analogWrite(motor4pin, 0);
      digitalWrite(motor5dir,HIGH);
      break;
//*******************Go down***************
      case 's':
      Serial.println("Backward");
      for(int i; i < 5000 ; i++){
      analogWrite(motor3pin, spd);
      digitalWrite(motor3dir,LOW);
      analogWrite(motor4pin, spd);
      digitalWrite(motor4dir,LOW);
      }
      analogWrite(motor3pin, 0);
      digitalWrite(motor3dir,HIGH);
     analogWrite(motor4pin, 0);
      digitalWrite(motor4dir,HIGH);
      break;
////*********************************************
//*******************************************
      }//end of switch
//    }//end of if (spd >= 0 && spd <= 255)
  }//if (Serial.available())
}//end of void loop ()
```

Rules and Rubric for NASA's Annual Robotic Mining Competition (2014)

NASA's Fifth Annual Robotic Mining Competition

Rules & Rubrics 2014

Kennedy Space Center, Florida

Introduction

NASA's Fifth Annual NASA Robotic Mining Competition is for university-level students to design and build a mining robot that can traverse the simulated Martian chaotic terrain, excavate Martian regolith and deposit the regolith into a Collector Bin within 10 minutes. There is particular relevance to NASA's recently announced mission to find an asteroid by 2016 and then bring it to Cis-Lunar space. The technology concepts developed by the university teams for this competition conceivably could be used to mine resources on Asteroids as well as Mars. NASA will directly benefit from the competition by encouraging the development of innovative excavation concepts from universities which may result in clever ideas and solutions which could be applied to an actual excavation device or payload. The unique physical properties of basaltic regolith and the reduced 3/8th gravity make excavation a difficult technical challenge. Advances in Martian mining have the potential to significantly contribute to our nation's space vision and NASA space exploration operations.

The complexities of the challenge include the abrasive characteristics of the basaltic regolith simulant, the weight and size of the limitations of the mining robot, and the ability to control it from a remote control center. The scoring for the mining category will require teams to consider a number of design and operation factors such as dust tolerance and projection, communications, vehicle mass, energy/power required, and autonomy.

The competition will be conducted by NASA at the Kennedy Space Center. The teams that can use telerobotic or autonomous operation to excavate the basaltic regolith simulant, called Black Point-1 or BP-1, and score the most points wins the Joe Kosmo Award for Excellence. The team will receive the Joe Kosmo Award for Excellence trophy, KSC launch invitations, team certificates for each member, and a $5,000 team scholarship. Awards for other categories include monetary team scholarships, a school trophy or plaque, team and individual certificates, and KSC launch invitations.

Undergraduate and graduate student teams enrolled in a U.S. college or university are eligible to enter the Robotic Mining Competition. Design teams must include: at least one faculty with a college or university and at least two undergraduate or graduate students. NASA has not set an upper limit on team members. A team should have a sufficient number of members to successfully operate their mining robot. Teams will compete in up to five major competition categories including: on-site mining, systems engineering paper, outreach project, slide presentation and demonstration (optional), and team spirit (optional).

The NASA Robotic Mining Competition is a student competition that will be conducted in a positive, professional way. This is a reminder to be courteous in all your correspondence and all interactions on-site at the competition. Unprofessional behavior or unsportsmanlike conduct will not be tolerated and will be grounds for disqualification. The frequently asked questions (FAQ) document is updated regularly and is considered part of this document. It is the responsibility of the teams to read, understand, and abide by all of NASA's Fifth Annual Robotic Mining Competition Rules and Rubrics, stay updated with new FAQs, communicate with NASA's representatives, and complete all surveys. These rules and rubrics are subject to future updates by NASA at its sole discretion.

For more information, visit the NASA Robotic Mining Competition on the Web at http://www.nasa.gov/offices/education/centers/kennedy/technology/nasarmc.html and follow the NASA Robotic Mining Competition on Twitter at https://twitter.com/NASARMC.

On-Site Mining Category Rules

The scoring for the Mining Category will require teams to consider a number of design and operation factors such as dust tolerance and projection, communications, vehicle mass, energy/power required, and autonomy. Each team must compete on-site at the Kennedy Space Center, Florida on May 19-23, 2014. A minimum amount of 10 kg of BP-1 must be mined and deposited during either of two competition attempts according to the rules to qualify to win in this category. If the minimum amount of 10 kg of BP-1 is not met for an attempt, then the total score for that attempt will be 0. In the case of a tie, the teams will compete in a tie-breaking competition attempt. The judges' decisions are final in all disputes. The teams with the first, second, and third most Mining points averaged from both attempts will receive team plaques, individual team certificates, KSC launch invitations, $3,000, $2,000, and $1,000 scholarships and 25, 20, and 15 points toward the Joe Kosmo Award for Excellence, respectively. Teams not winning first, second, or third place in the mining category can earn one bonus point for each kilogram of BP-1 mined and deposited up to a maximum average of ten points toward the Joe Kosmo Award for Excellence. The most innovative design will receive the Judges' Innovation Award at the discretion of the mining judges.

1) Teams must arrive at the Robotic Mining Competition Check-In Tent in Parking Lot 4 of the Kennedy Space Center no later than 3:00 p.m. on Monday, May 19, 2014; but teams are encouraged to arrive earlier.
2) Teams will be required to perform two official competition attempts using BP-1 in the Caterpillar Mining Arena. NASA will fill the Caterpillar Mining Arena with compacted BP-1 that matches as closely as possible to basaltic Martian regolith. NASA will randomly place three obstacles and create two craters on each side of the Caterpillar Mining Arena. Each competition attempt will occur with two teams competing at the same time, one on each side of the Caterpillar Mining Arena. After each competition attempt, the obstacles will be removed, the BP-1 will be returned to a compacted state, if necessary, and the obstacles and craters will be returned to the Caterpillar Mining Arena. The order of teams for the competition attempts will be chosen at NASA's discretion. See Diagrams 1 and 2.
3) In each of the two official competition attempts, the teams will score cumulative Mining Points. See Table 1 for the Mining Category Scoring Example. The teams' ranking Mining Points will be the average of their two competition attempts.
   A) Each team will be awarded 1000 Mining points after passing the safety inspection and communications check.
   B) During each competition attempt, the team will earn 3 Mining points for each kilogram in excess of 10 kg of BP-1 deposited in the Collector Bin. (For example, 110 kg of BP-1 mined will earn 300 Mining points.)
   C) During each competition attempt, the team will lose 1 Mining Point for each 50 kilobits/second (kb/sec) of average data used throughout each competition attempt.
   D) During each competition attempt, the team will lose 8 Mining points for each kilogram of total mining robot mass. (For example, a mining robot that weighs 80 kg will lose 640 Mining points.)
   E) During each competition attempt, the team will earn 20 Mining points if the amount of energy consumed by the mining robot during the competition attempt is reported to the judges after each attempt. The amount of energy consumed will not be used for scoring; a team must only provide a legitimate method of measuring the energy consumed and be able to explain the method to the judges.
   F) During each competition attempt, the judges will award the team 0 to 100 Mining points for dust tolerant design features on the mining robot (up to 30 Mining points) and dust free operation (up to 70 Mining points). If the mining robot has exposed mechanisms where dust could accumulate during a Martian mission and degrade the performance or lifetime of the mechanisms, then fewer Mining points will be awarded in this category. If the mining robot raises a substantial amount of airborne dust or projects it due to its operations, then fewer Mining points will be awarded. Ideally, the mining robot will operate in a clean manner without dust projection, and all mechanisms and moving parts will be protected from dust intrusion. The mining robot will not be penalized for airborne dust while dumping into the Collector Bin. All decisions by the judges regarding dust tolerance and dust projection are final.

The 30 points for dust-tolerant design will be broken down in the following way:

1. Drive train components enclosed/protected and other component selection – 10 points
2. Custom dust sealing features (bellows, seals, etc.) –10 points
3. Active dust control (brushing, electrostatics, etc.) – 10 points

The 70 points for dust-free operation will be broken down in the following way:

1. Driving without dusting up crushed basalt – 20 points
2. Digging without dusting up crushed basalt – 30 points
3. Transferring crushed basalt without dumping the crushed basalt on your own Robot – 20 points

G) During each competition attempt, the team will earn up to 500 Mining points for autonomous operations. Mining points will be awarded for successfully completing the following activities autonomously:

1. Successfully crossing the obstacle field: 50 pts
2. Successfully crossing the obstacle field and excavating: 150 pts
3. Successfully crossing the obstacle field, excavating and depositing regolith, 1 time: 250 pts
4. Successful fully autonomous run for 10 minutes: 500 pts

For a team to earn mining points in the autonomous category, the team cannot touch the controls during the autonomous period. If the team touches the controls then the autonomy period for that run is over; however, the team may revert to manual control to complete that run. Start and stop commands are allowed at the beginning and end of the autonomous period. Orientation data cannot be transmitted to the mining robot in the autonomous period. Telemetry to monitor the health of the mining robot is allowed during the autonomous period. The mining robot must continue to operate for the entire 10 minutes to qualify for a fully autonomous run.

The teams with the first, second, and third most Autonomous points averaged from both attempts will receive the Caterpillar Autonomy Award and $1,500, $750, and $250 team scholarships respectively. Points will count toward the Caterpillar Autonomy Award even if no regolith is deposited. In the case of a tie, the team that deposits the most regolith will win. If no regolith deposited in the case of a tie, the judges will choose the winner. The judges' decision is final.

Mining Category Elements	Specific Points	Actual	Units	Mining points
Pass Inspections				1000
BP-1 over 10 kg	+3/kg	110	kg	+300
Average Bandwidth	-1/50kb/sec	5000	kb/sec	-100
Mining Robot Mass	-8/kg	80	kg	-640
Report Energy Consumed	+20	1	1= Achieved 0= Not Achieved	+20
Dust Tolerant Design (30%) & Dust Free Operation (70%)	0 to +100	70	Judges' Decision	+70
Autonomy	50, 150, 250 or 500	150		+150
Total				800

Table 1: Mining Category Scoring Example

4) All excavated mass deposited in the Collector Bin during each official competition attempt will be weighed after the completion of each competition attempt.

5) The mining robot will be placed in the randomly selected starting positions. See Diagrams 1 and 2.

6) A team's mining robot may only excavate BP-1 located in that team's respective mining area at the opposite end of the Caterpillar Mining Arena from the team's starting area. The team's starting direction will be randomly selected immediately before the competition attempt. Mining is allowed as soon as the mining line is crossed.

7) The mining robot is required to move across the obstacle area to the mining area and then move back to the Collector Bin to deposit the BP-1 into the Collector Bin. See Diagrams 1 and 2.

8) Each team is responsible for placement and removal of their mining robot onto the BP-1 surface. There must be one person per 23 kg of mass of the mining robot, requiring four people to carry the maximum allowed mass. Assistance will be provided if needed.

9) Each team is allotted a maximum of 10 minutes to place the mining robot in its designated starting position within the Caterpillar Mining Arena and 5 minutes to remove the mining robot from the Caterpillar Mining Arena after the 10-minute competition attempt has concluded.

10) The mining robot operates during the 10-minute time limit of each competition attempt. The competition attempts for both teams in the Caterpillar Mining Arena will begin and end at the same time.

11) The mining robot will end operation immediately when the power-off command is sent, as instructed by the competition judges.

12) The mining robot cannot be anchored to the BP-1 surface prior to the beginning of each competition attempt.

13) The mining robot will be inspected during the practice days and right before each competition attempt. Teams will be permitted to repair or otherwise modify their mining robots anytime the Pits are open.

14) At the start of each competition attempt, the mining robot may not occupy any location outside the defined starting position in the Caterpillar Mining Arena. See Caterpillar Mining Arena definition for description of the competition field.

15) The Collector Bin top edge will be placed so that it is adjacent to the side walls of the Caterpillar Mining Arena without a gap and the height will be approximately 0.5 meter from the top of the BP-1 surface directly below it. The Collector bin top opening will be 1.65 meters long and .48 meters wide. See Diagrams 1 – 3. A target(s) or beacon(s) may be attached to the Collector Bin for navigation purposes only. This navigational aid system must be attached during the setup time and removed afterwards during the removal time period. If attached to the Collector Bin, it must not exceed the width of the Collector Bin and it must not weigh over 9 kg. The mass of the navigational aid system is included in the maximum mining robot mass limit of 80.0 kg and must be self-powered. The target/beacon may send a signal or light beam but lasers are not allowed for safety reasons except for Visible Class I or II lasers or low power lasers and laser based detection systems. Supporting documentation from the laser instrumentation vendor must be given to the inspection judge for "eye-safe" lasers. The Judges will inspect and verify that all laser devices are a class I or II product and they have not been modified (optics or power). Any objects placed on the Collector Bin cannot be more than 0.75 m above the BP-1 surface, and cannot be permanently attached or cause alterations (ie. no drilling, nails, etc).

16) There will be three obstacles placed on top of the compressed BP-1 surface within the obstacle area before each competition attempt is made. The placement of the obstacles will be randomly selected before the start of the competition. Each obstacle will have a diameter of approximately 10 to 30 cm and an approximate mass of 3 to 10 kg. There will be two craters of varying depth and width, being no wider or deeper than 30 cm. No obstacles will be intentionally buried in the BP-1 by NASA, however, BP-1 includes naturally occurring rocks.

17) The mining robot must operate within the Caterpillar Mining Arena: it is not permitted to pass beyond the confines of the outside wall of the Caterpillar Mining Arena and the Collector bin during each competition attempt. The BP-1 must be mined in the mining area and deposited in the Collector bin. A team that excavates any BP-1 from the starting or obstacle areas will be disqualified. The BP-1 must be carried from the mining area to the Collector bin by any means and be deposited in the Collector bin in its raw state. A secondary container like a bag or box may not be deposited inside the Collector bin. Depositing a

container in the Collector bin will result in disqualification of the team. The mining robot can separate intentionally, if desired, but all parts of the mining robot must be under the team's control at all times. Any ramming of the wall may result in a safety disqualification at the discretion of the judges. The walls may be used for the purposes of mapping autonomous navigation and collision avoidance. Touching or having a switch sensor springwire that may brush on a wall as a collision avoidance sensor is allowed.

18) The mining robot must not use the wall as support or push/scoop BP-1 up against the wall to accumulate BP-1. If the mining robot exposes the Caterpillar Mining Arena bottom due to excavation, touching the bottom is permitted, but contact with the Caterpillar Mining Arena bottom or walls cannot be used at any time as a required support to the mining robot. Teams should be prepared for airborne dust raised by either team during each competition attempt.

19) During each competition attempt, the mining robot is limited to autonomous and telerobotic operations only. No physical access to the mining robot will be allowed during each competition attempt. In addition, telerobotic operators are only allowed to use data and video originating from the mining robot and the NASA video monitors. Visual and auditory isolation of the telerobotic operators from the mining robot in the Mission Control Center is required during each competition attempt. Telerobotic operators will be able to observe the Caterpillar Mining Arena through overhead cameras in the Caterpillar Mining Arena via monitors that will be provided by NASA in the Mission Control Center. These color monitors should be used for situational awareness only. No other outside communication via cell phones, radios, other team members, etc. is allowed in the Mission Control Center once each competition attempt begins. During the 10 minute setup period, a handheld radio link will be provided between the Mission Control Center team members and team members setting up the mining robot in the Caterpillar Mining Arena to facilitate voice communications during the setup phase only.

20) The mining robot mass is limited to a maximum of 80.0 kg. Subsystems on the mining robot used to transmit commands/data and video to the telerobotic operators are counted toward the 80.0 kg mass limit. Equipment not on the mining robot used to receive data from and send commands to the mining robot for telerobotic operations is excluded from the 80.0 kg mass limit.

21) The mining robot must provide its own onboard power. No facility power will be provided to the mining robot. There are no power limitations except that the mining robot must be self-powered and included in the maximum mining robot mass limit of 80.0 kg.

22) The mining robot must be equipped with an easily accessible red emergency stop button (kill switch) of minimum diameter of 40 mm on the surface of the mining robot requiring no steps to access. The emergency stop button must stop the mining robot's motion and disable all power to the mining robot with one push motion on the button. It must be highly reliable and instantaneous. For these reasons an unmodified "Commercial Off-The-Shelf" (COTS) red button is required. A closed control signal to a mechanical relay is allowed as long as it stays open to disable the mining robot. The reason for this rule is to completely safe the mining robot in the event of a fire or other mishap. The button should disconnect the batteries from all controllers (high current, forklift type button) and it should isolate the batteries from the rest of the active sub-systems as well. Only laptop computers may stay powered on if powered by its internal battery.

23) The communications rules for telerobotic operations follow.

A. MINING ROBOT WIRELESS LINK

1. Each team is required to command and monitor their mining robot over the NASA-provided network infrastructure. Figure 1 shows
   a. the configuration provided to teams to communicate with their mining robot,
   b. the "Mars Lander" camera staged in the Caterpillar Mining Arena, and Mars Lander Control Joystick provided to the team in the Mission Control Center,
   c. the official timing display, which includes a real-time display of BP-1 collected during the match, and
   d. the handheld radios that will be provided to each team to link their Mission Control Center team members with their corresponding team members in the Caterpillar Mining Arena during setup.

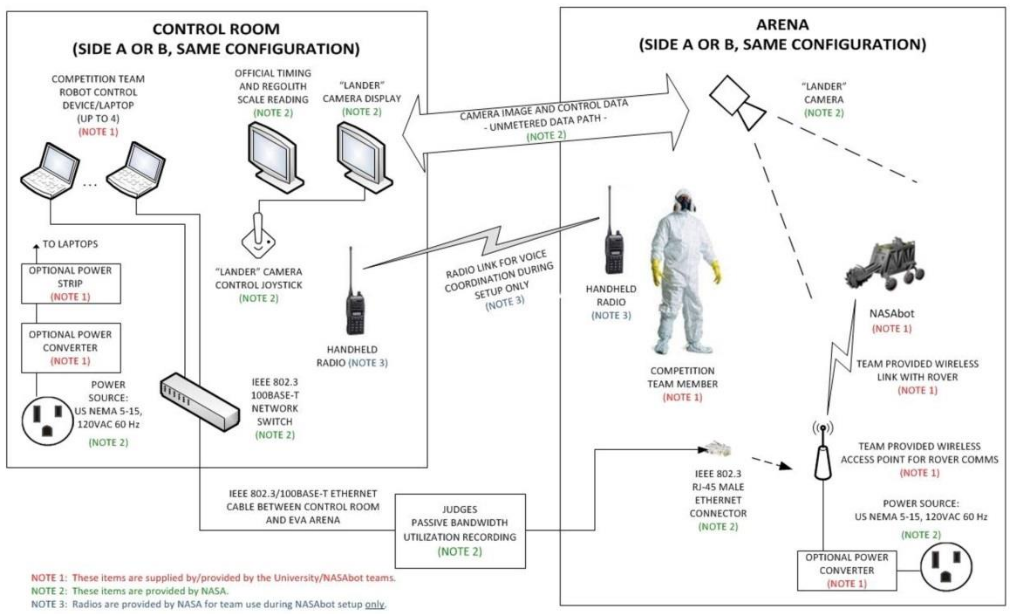


Figure 1

2. Each team will provide the wireless link (access point, bridge, or wireless device) to their mining robot, which means that each team will bring their own Wi-Fi equipment/router and any required power conversion devices. Teams must set their own network IP addresses to enable communication between their mining robot and their control computers, through their own wireless link hosted in the Caterpillar Mining Arena.
   a. In the Caterpillar Mining Arena, NASA will provide an elevated network drop (female RJ-45 Ethernet jack) that extends to the Mission Control Center, where NASA will provide a network switch for the teams to plug in their laptops.
      i. The network drop in the Caterpillar Mining Arena will be elevated high enough above the edge of the regolith bed wall to provide adequate radio frequency visibility of the Caterpillar Mining Arena.
      ii. A shelf will be set up next to the network drop, will be 4 to 6 feet off the ground, and will be no more than 50 feet from the mining robot. This shelf is where teams will place their Wireless Access Point (WAP) to communicate with their mining robot. The Caterpillar Mining Arena will be 150 to 200 feet from the Mission Control Center.
      iii. The WAP shelves for side A and side B of the Caterpillar Mining Arena will be at least 25 feet apart to prevent electromagnetic interference (EMI) between the units.
   b. Power interfaces:
      i) NASA will provide a standard US National Electrical Manufacturers Association (NEMA) 5-15 type, 110 VAC, 60 Hz electrical jack by the network drop. Both will be no more than 5 feet from the shelf.
      ii) NASA will provide a standard US NEMA 5-15 type, 110 VAC, 60 Hz electrical jack in the Mission Control Center for each team.
      iii) The team must provide any conversion devices needed to interface team access points or Mission Control Center computers or devices with the provided power sources.
   c. During the setup phase, the teams will set up their access point and verify communication with their mining robot from the Mission Control Center.

3. The teams must use the USA IEEE 802.11 b/g standard for their wireless connection (WAP and rover client). Teams cannot use multiple channels for data transmission. Encryption is not required, but it is highly encouraged to prevent unexpected problems with team links.
   a. During a match, one team will operate on channel 1 and the other team will operate on channel 11.
   b. Channels will be assigned when the teams check in with the Pit crew chief.
4. Each team will be assigned an SSID that they must use for their wireless equipment.
   a. SSID will be "Team_##."
   b. Teams will broadcast their SSID.
5. Bandwidth constraints:
   a. A team will be awarded the Efficient Use of Communications Power Award for using the lowest average bandwidth during the timed and NASA-monitored portion of the competition. Teams must collect the minimum 10 kg of BP-1 to qualify for this award.
   b. The communications link is required to have an average bandwidth of no more than 5 megabits per second. There will not be a peak bandwidth limit.

B. RF & COMMUNICATIONS APPROVAL

1. Each team must demonstrate to the communication judges that their mining robot and access point are operating only on their assigned channel. Each team will have approximately 15 minutes at the communication judges' station.
2. To successfully pass the communication judges' station, a team must drive their mining robot by commanding it from their mining robot driving/control laptop through their wireless access point. The judges will verify the course of travel and verify that the team is operating only on their assigned channel.
3. If a team cannot demonstrate the above tasks in the allotted time, the team will be disqualified from the competition.
4. On Monday, May 19, 2014, on a first-come, first-serve basis, the teams will be able to show the communication judges their compliance with the rules.
5. The NASA communications technical experts will be available to help teams make sure that they are ready for the communication judges' station on Monday, May 19, 2014, and Tuesday, May 20, 2014.
6. Once the team arrives at the communication judges' station, the team can no longer receive assistance from the NASA communications technical experts.
7. If a team is on the wrong channel during their competition attempts, the team will be disqualified and required to power down.

C. WIRELESS DEVICE OPERATION IN THE PITS

1. Teams will not be allowed to power up their transmitters on any frequency in the Pits during the practice matches or competition attempts. All teams must have a hard-wired connection for testing in the Pits.
2. Teams will have designated times to power up their transmitters when no matches are underway.

24) The mining robot must be contained within 1.5 m length x 0.75 m width x 0.75 m height. The mining robot may deploy or expand beyond the 1.5 m x 0.75 m footprint after the start of each competition attempt, but may not exceed a 1.5 meter height. The mining robot may not pass beyond the confines of the outside wall of the Caterpillar Mining Arena and the Collector Bin during each competition attempt to avoid potential interference with the surrounding tent. The team must declare the orientation of length and width to the inspection judge. Because of actual Martian hardware requirements, no ramps of any kind will be provided or allowed. An arrow on the reference point must mark the forward direction of the mining robot in the starting position configuration. The judges will use this reference point and arrow to orient the mining robot in the randomly selected direction and position. A multiple mining robot system is allowed but the total mass and starting dimensions of the whole system must comply with the volumetric dimensions given in this rule.

25) To ensure that the mining robot is usable for an actual Martian mission, the mining robot cannot employ any fundamental physical processes, gases, fluids or consumables that would not work in the Martian

environment. For example, any dust removal from a lens or sensor must employ a physical process that would be suitable for the Martian surface. Teams may use processes that require an Earth-like environment (e.g., oxygen, water) only if the system using the processes is designed to work in a Martian environment and if such resources used by the mining robot are included in the mass of the mining robot. Closed pneumatic mining systems are allowed only if the gas is supplied by the mining robot itself. Note: the mining robot will be exposed to outside air temperatures averaging 90 degrees Fahrenheit during inspection and while waiting to enter the Caterpillar Mining Arena.

26) Components (i.e. electronic and mechanical) are not required to be space qualified for Martian atmospheric, electromagnetic, and thermal environments. Since budgets are limited, the competition rules are intended to require mining robots to show Martian plausible system functionality but the components do not have to be traceable to a Martian qualified component version. Examples of allowable components are: Sealed Lead-Acid (SLA) or Nickel Metal Hydride (NiMH) batteries; composite materials; rubber or plastic parts; actively fan cooled electronics; motors with brushes; infrared sensors, inertial measurement units, and proximity detectors and/or Hall Effect sensors, but proceed at your own risk since the BP-1 is very dusty. Teams may use honeycomb structures as long as they are strong enough to be safe. Teams may not use GPS, rubber pneumatic tires; air/foam filled tires; open or closed cell foam, ultrasonic proximity sensors; or hydraulics because NASA does not anticipate the use of these on a Mars mission.

27) The mining robot may not use any process that causes the physical or chemical properties of the BP-1 to be changed or otherwise endangers the uniformity between competition attempts.

28) The mining robot may not penetrate the BP-1 surface with more force than the weight of the mining robot before the start of each competition attempt.

29) No ordnance, projectile, far-reaching mechanism (adhering to Rule 24), etc. may be used. The mining robot must move on the BP-1 surface.

30) No team can intentionally harm another team's mining robot. This includes radio jamming, denial of service to network, BP-1 manipulation, ramming, flipping, pinning, conveyance of current, or other forms of damage as decided upon by the judges. Immediate disqualification will result if judges deem any maneuvers by a team as being offensive in nature. Erratic behavior or loss of control of the mining robot as determined by the judges will be cause for immediate disqualification. A judge may disable the mining robot by pushing the red emergency stop button at any time.

31) Teams must electronically submit documentation containing a description of their mining robot, its operation, potential safety hazards, a diagram, and basic parts list by April 30, 2014 at 12:00 p.m. (noon) eastern time.

32) Teams must electronically submit a **link** to their YouTube video documenting no less than 30 seconds but no more than 5 minutes of their mining robot in operation for at least one full cycle of operation by April 30, 2014 at 12:00 p.m. (noon) eastern time via e-mail to Bethanne.Hull@nasa.gov. One full cycle of operations includes excavation and depositing material. This video documentation is solely for technical evaluation of the mining robot.

Shipping

33) **Plan ahead for shipping your mining robot and its battery(s) as some batteries may not be allowed on board airplanes or in shipping containers.** Teams may ship their mining robots to **arrive no earlier than May 12, 2014**. The mining robots will be held in a safe, non air-conditioned area and be placed in each team's Space Pit by Monday, May 19, 2014. The **ship to** address is:

Transportation Officer, NASA
Central Supply, Bldg M6-744
Kennedy Space Center, FL 32899
M/F: KSC Visitor Complex, NASA's Robotic Mining Competition, M/C: DNPS

Note: Do not have the shipping company deliver the mining robot directly to the Kennedy Space Center Visitor Complex. They do not have facilities to store them until the Pits are set up. The shipper will come to the Pass & ID facility right before the Kennedy Space Center gate on State Road 405. Central Receiving will send an escort.

34) Return shipping arrangements must be made <u>prior</u> to the competition. All mining robots must be picked up from the Kennedy Space Center Visitor Complex **no later than 5:00 p.m. on Wednesday, May 28, 2014**. Any abandoned mining robots will be discarded after this date. The **return** shipping address is:

Kennedy Space Center Visitor Complex
Robotic Mining Shipping Area
Mail Code: DNPS
State Road 405
Kennedy Space Center, FL 32899

Caterpillar Mining Arena Diagrams

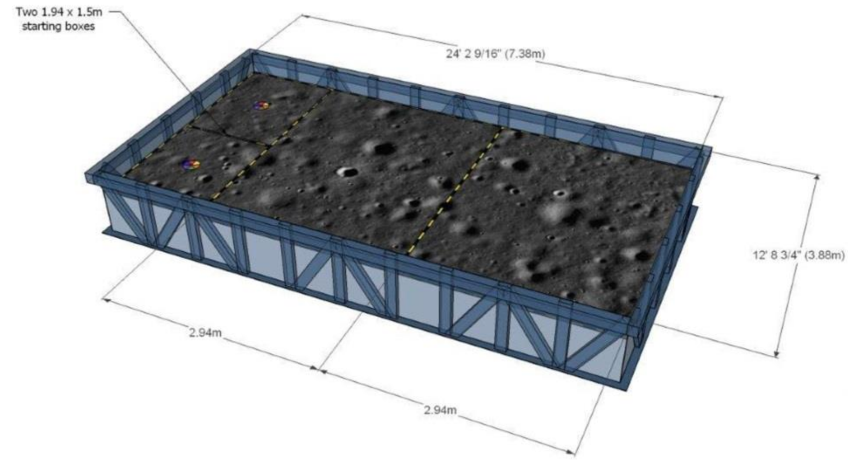


Diagram 1: Caterpillar Mining Arena (isometric view)

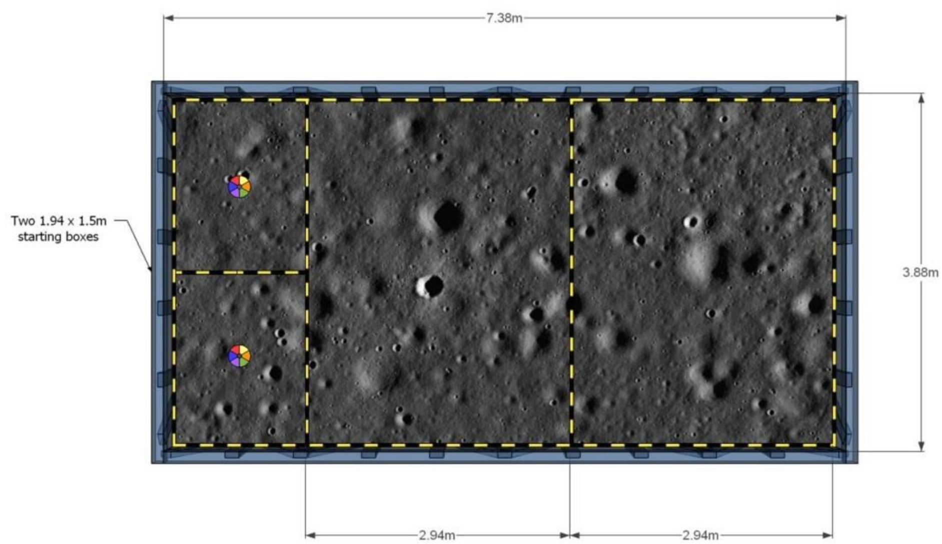


Diagram 2: Caterpillar Mining Arena (top view)

Collector bin Diagram

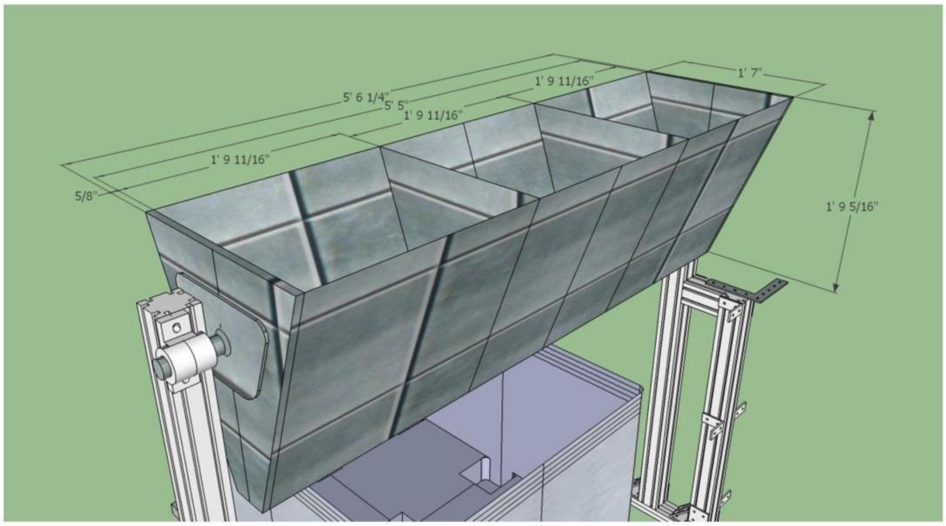


Diagram 3: Collector Bin

NASA's Robotic Mining Competition Systems Engineering Paper

Each team must submit a Systems Engineering Paper electronically in PDF by April 21, 2014 at 12:00 p.m. (noon) eastern time. Your paper should discuss the Systems Engineering methods used to design and build your mining robot. All pertinent information required in the rubric must be in the body of the paper. A minimum score of 16 out of 20 possible points must be achieved to qualify to win in this category. In the case of a tie, the judges will choose the winning Systems Engineering Paper. The judges' decision is final. The team with the winning Systems Engineering Paper will receive a team plaque, individual certificates, and a $500 team scholarship. Second and third place winners will receive certificates.

For reference, undergraduate course materials in NASA Systems Engineering, are available at www.spacese.spacegrant.org.

NASA's Robotic Mining Competition Systems Engineering Paper Scoring Rubric	
Elements	**Points**
Content: • Formatted professionally, clearly organized, correct grammar and spelling, size 12 font; single spaced, maximum of 20 pages not including the cover, table of contents, and source pages. Appendices are allowed and limited to 5 pages, and should referenced in main body. Cover page must include: team name, title of paper, full names of all team members, university name, and faculty advisor's full name. • Title page must include the signature of the sponsoring faculty advisor and a statement that he/she has read and reviewed the paper prior to submission to NASA. • Purpose Statement must be included and related to the application of systems engineering to NASA's Robotic Mining Competition.	There are 3 points for 3 elements.
Intrinsic Merit: • Cost budget (estimated costs vs. actual costs) • Design philosophy in the context of systems engineering; discuss what your team is optimizing in your design approach (light weight? automation? BP-1 capacity? etc.) • Schedule of work from inception to arrival at competition • Major reviews: system requirements, preliminary design and critical design	There are 4 points for 4 elements. Up to 2 additional points may be awarded for exceptional work related to systems engineering intrinsic merit, for a total of 6 points.
Technical Merit: • Concept of operations • System hierarchy • Interfaces • Requirements • Technical budgets (mass, power & data allocated to components vs. actual mass, power, & data usage) • Trade-off assessments • Reliability • Verification of system meeting requirements	There are 8 points for 8 elements. Up to 3 additional points may be awarded for exceptional work related to systems engineering technical merit, for a total of 11 points.

NASA's Robotic Mining Competition Outreach Project Report

Each team must participate in an educational outreach project in their local community. Outreach examples include actively participating in school career days, science fairs, technology fairs, extracurricular science or robotics clubs, or setting up exhibits in local science museums or a local library. Other ideas include organizing a program with a Boys and Girls Club, Girl Scouts, Boy Scouts, etc. Teams are encouraged to have fun with the outreach project and share knowledge of NASA's Robotic Mining Competition, engineering or Martian activities with the local community.

Each team must submit a report of the Outreach Project electronically in PDF by April 21, 2014 at 12:00 p.m. (noon) eastern time. A minimum score of 16 out of 20 possible points must be achieved to qualify to win in this category. In the case of a tie, the judges will choose the winning outreach project. The judges' decision is final. The team with the winning outreach project report will receive a team plaque, individual certificates, and a $500 team scholarship. Second and third place winners will receive certificates.

NASA's Robotic Mining Competition Outreach Project Report Scoring Rubric	
Elements	**Points**
Structure, Content and Intrinsic Merit: • Formatted professionally, clearly organized, correct grammar and spelling, size 12 font; single spaced, maximum of 5 pages not including the cover. Appendices are not allowed, however, a link in the body of the report to a multimedia site with additional photos or videos is allowed. Cover page must include: team name, title of paper, full names of all team members, university name and faculty advisor's full name. • Purpose for this outreach project, identify outreach recipient group(s). • Illustrations must appropriately demonstrate the outreach project.	There are 3 points for 3 elements. Up to 2 additional points may be awarded for exceptional work related to outreach intrinsic merit, for a total of 5 points.
Educational Outreach Merit: • The report must effectively describe what the outreach activity(s) was. • The report must describe exactly how the Robotic Mining Competition team participated. • The report must reflect how the outreach project inspired others to learn about robotics, engineering or Martian activities. • The report must demonstrate the quality of the outreach including how hands-on activities were used to engage the audience at their level of understanding. • The report must show statistics on the participants. Examples include an in-depth or long term outreach project or follow-up with the participants.	There are 10 points for 5 elements. Up to 5 additional points may be awarded for exceptional work related to educational outreach merit, for a total of 15 points.

NASA's Robotic Mining Competition Slide Presentation and Demonstration

The Robotic Mining Slide Presentation and Demonstration is an optional category in the overall competition. The presentation and demonstration must be no more than 20 minutes with an additional 5 minutes for questions and answers. It will be judged at the competition in front of an audience including NASA and private industry judges. The presentations must be submitted electronically in PDF by April 21, 2014 at 12:00 p.m. (noon) eastern time. Teams **MUST** present the slides turned in on April 21st. Visual aids, such as videos and handouts, may be used during the presentation but videos must be presented using the team's own laptop. You may NOT update/modify your slide presentation and present it from your laptop. A minimum score of 16 out of 20 possible points must be achieved to qualify to win in this category. The content, formatting and illustration portion of the score will be judged prior to the live presentation and scored based on the presentation turned in on April 21st. In the case of a tie, the judges will choose the winning presentation. The judges' decision is final. The team with the winning presentation will receive a team plaque, individual team certificates, and a $500 team scholarship. Second and third place winners will receive certificates.

NASA's Robotic Mining Competition Slide Presentation and Demonstration Scoring Rubric

Elements	Points
Content, formatting, and illustrations: • Content includes a cover slide (with team name, presentation title, names of team members, university name, and faculty advisor's name). Also includes an introduction slide and referenced sources. • Formatting is readable and aesthetically pleasing with proper grammar and spelling. • Illustrations support the technical content • Illustrations show progression of the project and final design	There are 4 points for 4 elements. Up to 2 additional points may be awarded for exceptional slides, for a total of 6 points.
Technical Merit: • Design Process • Design Decisions • Final Design • Mining robot functionality • Special features - highlight what makes the mining robot unique or innovative	There are 5 points for 5 elements. Up to 2 additional points may be awarded for exceptional work related to technical merit, for a total of 7 points.
Presentation: • Handles slides and equipment professionally • Engages audience and infuses personality • Creative and inspirational • Demonstrates Robot • Answers questions	There are 5 points for 5 elements. Up to 2 additional points may be awarded for an exceptional presentation, for a total of 7 points.

NASA's Robotic Mining Competition Team Spirit

NASA's Robotic Mining Competition Team Spirit is an optional category in the overall competition. A minimum score of 12 out of 15 possible points must be achieved to qualify to win in this category. In the case of a tie, the judges will choose the winning team. The judges' decision is final. The team winning the Team Spirit Award at the competition will receive a team plaque, individual certificates, and a $500 team scholarship. Second and third place winners will receive certificates.

NASA's Robotic Mining Competition Team Spirit Competition Scoring Rubric				
Elements	**3**	**2**	**1**	**0**
Teamwork: • Exhibits teamwork in and out of the Caterpillar Mining Arena • Exhibits a strong sense of collaboration within the team • Supports other teams with a healthy sense of competition	All three elements are exceptionally demonstrated	Three elements are clearly demonstrated	Two or less elements are clearly demonstrated	Zero elements are clearly demonstrated
Attitude: • Exudes a positive attitude in all interactions, not limited to competition attempt • Demonstrates an infectious energy by engaging others in team activities • Motivates and encourages own team • Motivates and encourages other teams • Keeps pit clean and tidy at all times	All five elements are exceptionally demonstrated	Four elements are exceptionally demonstrated	Three or less elements are clearly demonstrated	Zero elements are clearly demonstrated
Creativity & Originality: • Demonstrates creativity and originality in team activities, name, and logo • Wears distinctive team identifiers • Decorates team's Pit to reflect school/team spirit	All three elements are exceptionally demonstrated	Three elements are clearly demonstrated	Two or less elements are clearly demonstrated	Zero elements are clearly demonstrated
Sportsmanship: • Demonstrates fairness • Shows respect for both authority and opponents • Promotes specific cultural and/or regional pride • Demonstrates fellowship with competitors	All four elements are exceptionally demonstrated	Three elements are clearly demonstrated	Two or less elements are clearly demonstrated	Zero elements are clearly demonstrated
Feedback at Competition	Up to three points for compliment cards collected at the Competition.			

Categories & Awards

In addition to the awards listed below, school plaques and/or individual team certificates will be awarded for exemplary performance in the following categories:

Category	Required/ Optional	Due Dates	Award	Maximum Points toward Joe Kosmo Award for Excellence
On-site Mining in the Caterpillar Mining Arena	Required	May 21-23, 2014	First place $3,000 team scholarship and Kennedy launch invitations Second place $2,000 team scholarship and Kennedy launch invitations Third place $1,000 team scholarship and Kennedy launch invitations Teams not placing 1st, 2nd, or 3rd will receive one point per kilogram mined and deposited up to 10 points	25 20 15 Up to 10
Systems Engineering Paper	Required	April 21, 2014	$500 team scholarship	Up to 20
Outreach Project Report	Required	April 21, 2014	$500 team scholarship	Up to 20
Slide Presentation and Demonstration	Optional	April 21, 2014 and On-Site on May 21-23, 2014	$500 team scholarship	Up to 20
Team Spirit Competition	Optional	All Year	$500 team scholarship	Up to 15
Joe Kosmo Award for Excellence	Grand Prize for Most Points	All Year	A school trophy, $5,000 team scholarship and KSC launch invitations	Total of above points, maximum of 100 points possible
Judges' Innovation Award	Optional	May 21-23, 2014	A school trophy	
Efficient Use of Communications Power Award	Optional	May 21-23, 2014	A school trophy	
Caterpillar's Autonomy Award	Optional	May 21-23, 2014	First place $1,500 team scholarship Second place $750 team scholarship Third place $250 team scholarship	

NASA's Robotic Mining Competition Checklist

All documents are due by 12:00 p.m. (noon) eastern time.

Required Competition Elements

If required elements are not received by the due dates, then the team is not eligible to compete in any part of the competition (NO EXCEPTIONS).

☐ Registration Application*	50 teams are registered
☐ Systems Engineering Paper	April 21, 2014
☐ Outreach Project Report	April 21, 2014
☐ On-site Mining	May 21-23, 2014
o Team Check-in, Unload/Uncrate mining robot	May 19, 2014 by 3:00 p.m.
o Practice Days	May 19-20, 2014
o Competition Days	May 21-23, 2014
o Awards Ceremony	May 23, 2014 (evening)

Optional Competition Elements

☐ Presentation File	April 21, 2014
☐ Team Spirit	All year

Required Documentation

☐ Letter of Support from lead university's Faculty Advisor	With Complete Application
☐ Letter of Support from lead university's Dean of Engineering	January 20, 2014
☐ Team Roster	January 20, 2014
☐ Student Participant Form	January 20, 2014
☐ Faculty Participation Form	January 20, 2014
☐ Transcripts (unofficial copy is acceptable)**	January 20, 2014
☐ Signed Media Release Form	January 20, 2014
☐ Corrections to NASA generated Team Roster	February 24, 2014
☐ Team Photo including faculty (high resolution .jpg format preferred)	March 24, 2014
☐ Team Biography (200 words maximum)	March 24, 2014
☐ Head Count Form	March 24, 2014
☐ Revised Team Roster (no changes accepted after this date)	March 24, 2014
☐ Rule 31 documentation	April 30, 2014
☐ Rule 32 video	April 30, 2014
☐ Shipping Bill of Lading/Commercial Invoice	April 30, 2014

Optional Documentation

☐ Student Resume (optional)	December 2, 2013

* Registration is limited to the first 50 approved U.S. teams. Registration is limited to one team per university campus. Registration will end when NASA approves 50 applications.

** Each student's Transcript must be from the university and show:

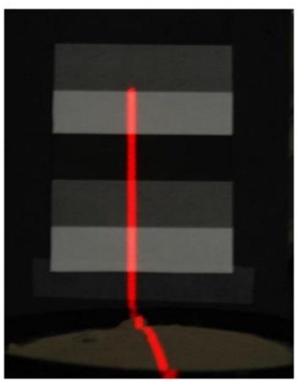
- name of university
- name of student
- current student status within the 2013-2014 academic year
- coursework taken and grades

Definitions

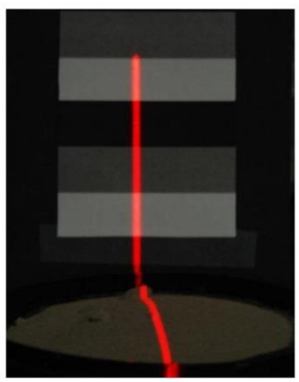
Autonomous – The operation of a team's mining robot with no human interaction.

Black Point-1 (BP-1) – A crushed lava basalt aggregate which is similar to Mars Volcanic Ash. The BP-1 will be compacted with a fluffy top layer similar to the Martian surface. However, it does not behave like sand. The study on BP-1 is available on http://www.nasa.gov/offices/education/centers/kennedy/technology/nasarmc.html. Also, watch the Lunabotics Webcast where Dr. Philip Metzger, a NASA Physicist, describes BP-1 and its behavior. It is available at http://youtu.be/hMfrv7mlxbE. The density of the compacted BP-1 aggregate will be between 1.5 g/cm^3 and 1.8 g/cm^3. The top 2 cm will be raked to a fluffy condition of approximately .75 g/cm^3. There are naturally occurring rocks in the BP-1 aggregate. The coefficient of friction has not been measured for BP-1. BP-1 behaves like a silty powder soil and most particles are under 100 microns diameter. The coefficient of friction and the cohesion of Martian soil have not been precisely measured due to a lack of scientific data from Mars. Instead, they have been estimated via a variety of techniques. Both parameters (coefficient of friction and cohesion) are highly dependent on the compaction (bulk density, porosity) of the Martian soil. Since the properties of Mars regolith vary and are not well known, this competition will assume that Martian basaltic regolith properties are similar to the Lunar regolith as stated in the Lunar Sourcebook: A User's Guide to the Moon, edited by G. H. Heiken, D. T. Vaniman, and B. M. French, copyright 1991, Cambridge University Press. Teams are encouraged to develop or procure simulants based on basaltic minerals and lunar surface regolith particle size, shape, and distribution. BP-1 is not commercially available and it is made from crushed basalt fines. However, JSC-1A is available from Orbital Technologies at: http://www.orbitec.com/store/simulant.html and NU-LHT is commercially available from Zybek Advanced Products (ZAP) at: http://www.zybekap.com/.

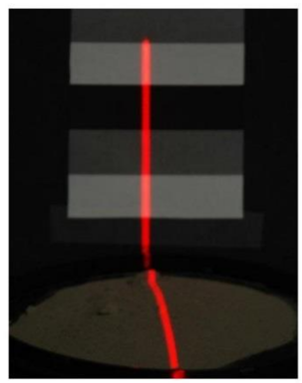
BP-1 reflectivity – NASA performed tests to answer questions about BP-1 reflectivity for LIDAR (or other LASER-based) navigation systems. The laser is not a beam – it is spread out as a sheet that is oriented in the vertical direction, so it is draped across the BP-1 and across a white/gray/black target that is standing up behind the BP-1 in the images. The BP-1 is the mound at the bottom of each image. Teams can get the reflectivity of the BP-1 by comparing the brightness of the laser sheet seen reflected from the BP-1 with the brightness of the same sheet reflected from the white and black portions of the target. The three images are for the three angles of the laser. Note the BP-1 is mounded so they need to account for the fact that it is not a flat surface if they choose to analyze the brightness in the images. The three pictures below were shot with the camera at 10, 16, and 21 degrees relative to the surface. The laser was at an angle of 15 degrees. The camera speed and aperture were set to (manual mode): 1/8 s, f/4.5.



10 degree



16 degree



21 degree

Caterpillar Mining Arena – An open-topped container (i.e., a box with a bottom and 4 side walls), containing BP-1, within which the mining robot will perform each competition attempt. The inside dimensions of the each side of the Caterpillar Mining Arena will be 7.38 meters long and 3.88 meters wide, and 1 meter in depth. The BP-1 aggregate will be approximately .5 meters in depth and approximately .5 meters from the top of the walls to the surface. The Caterpillar Mining Arena for the practice days and official competition will be provided by NASA. The Caterpillar Mining Arena will be outside in an enclosed tent. The Caterpillar Mining Arena lighting will consist of high intensity discharge (HID) lights such as metal halide lights inside a tent structure with clear sides, which is not quite as bright as outdoor daylight conditions. The atmosphere will be an air-conditioned tent without significant air currents and cooled to approximately 77 degrees Fahrenheit. See Diagrams 1 – 3. The Caterpillar Mining Arena steel, primer and paint specifications are as follows:

1. Steel: A-36(walls) & A-992(I-beams) structural steel
2. Primer: Devran 201 epoxy primer, 2.0 to 3.0 mils, Dry Film Thickness (DFT)
3. Paint: Blue Devthane 379 polyurethane enamel, 2.0 to 3.0 mils, DFT (per coat)

<u>Collector Bin</u> – A Collector Bin in the Caterpillar Mining Arena for each competition attempt into which each team will deposit excavated BP-1. The Collector Bin will be large enough to accommodate each team's excavated BP-1. The Collector Bin will be stationary and located adjacent to the Caterpillar Mining Arena. See Diagram 3.

<u>Competition attempt</u> – The operation of a team's mining robot intended to meet all the requirements for winning the mining category by performing the functional task. The duration of each competition attempt is 10-minutes.

<u>Excavated mass</u> – Mass of the excavated BP-1 deposited to the Collector bin by the team's mining robot during each competition attempt, measured in kilograms (kg) with official result recorded to the nearest one tenth of a kilogram (0.1 kg).

<u>Functional task</u> – The excavation of BP-1 from the Caterpillar Mining Arena by the mining robot and deposit of BP-1 from the mining robot into the Collector Bin.

<u>Martian like</u> – Basis of merit associated with feasibility of:

1. Packaging into a small stowed volume for transportation to Mars (1.5 m x .75 m x .75 m)
2. Low mass - it costs $5,000 per kg to send mass to Low Earth Orbit and about 2.5 Million per kg to the Martian surface (based on NASA Mars Science Lab).
3. Simple and reliable – able to operate for 5 years without maintenance on the Martian surface
4. Martian dust tolerant
5. Easy to teleoperate
6. Able to survive a Martian winter

<u>Mining robot</u> – A teleoperated or autonomous robotic excavator in the Robotic Mining Competition including mechanical and electrical equipment, batteries, gases, fluids and consumables delivered by a team to compete in the competition.

<u>Mining points</u> – Points earned from the two competition attempts in the Robotic Mining Competition will be averaged to determine ranking in the on-site mining category.

<u>Practice time</u> – Teams will be allowed to practice with their mining robots in the Caterpillar Mining Arena. NASA technical experts will offer feedback on real-time networking performance during practice attempt. A maximum of two practice attempts will be allowed, but not guaranteed.

<u>Reference point</u> – A fixed location signified by an arrow showing the forward direction on the mining robot that will serve to verify the starting orientation of the mining robot within the Caterpillar Mining Arena.

<u>Telerobotic</u> – Communication with and control of the mining robot during each competition attempt must be performed solely through the provided communications link which is required to have a total average bandwidth of no more than 5.0 megabits/second on all data and video sent to and received from the mining robot.

<u>Time Limit</u> – 10 minutes to set up the mining robot in the Caterpillar Mining Arena, 10 minutes for the mining robot to perform the functional task, and 5 minutes to remove the mining robot.