Design of a Martian Mining Robot

Team # 22 Restated Project Scope & Plan

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Abstract

This report details the requirements for NASA’s 2017 Robotic Mining Competition (RMC). This competition entails on-site mining, a systems engineering paper, and an outreach project report. The on-site mining includes building a robot within the given size and weight limitations that will traverse simulated Martian terrain, excavate regolith and ice simulants, and return them to a collector bin. The systems engineering paper will explain in detail the methodology used during the project's inception, design, build, and testing. The outreach project report will require the team to promote STEM to the community via public outreach as well as social media. This competition is beneficial for NASA because it encourages the development of innovative robotic excavation concepts that possibly could be applied to future excavation missions.

1.0 Project Scope

The scope of this project has a wide breadth as it is a multi-faceted competition. The primary engineering task is to design, build, and compete with other universities in a robotic Martian regolith mining competition. The other parts of the competition include a systems engineering paper detailing the design philosophy, a STEM outreach report, an on-site slide presentation and demonstration on the project, and a grading on how well the team engaged the public and stimulated interest in STEM through social media and organized events. Each of these categories will be discussed in individually in the sections below.

1.1 Competition Criteria

The next few section of this report will discuss in detail the criteria of the NASA Robotic Mining Competition (RMC) that we intend to participate in at the end of the year.

1.1.1 On-Site Mining

The most engineering intensive part of this competition is the development of a Martian Regolith Mining robot. The given problem statement is: "Design and build a mining robot that can traverse the chaotic Martian terrain and excavate the basaltic regolith simulant and ice simulant and return them for deposit into a collector bin." This design is to consider all of the challenges faced when operation in the harsh Martian environment. Some of these challenges include the Martian climate, corrosive chemistry, and UV radiation that a robot on Mars would be subject to during its operational lifespan. The scoring rubric for the competition will be discussed later in this report.

1.1.2 Systems Engineering Paper

Another part of our competition is submitting a Systems Engineering Paper. This will be reviewed by the NASA judges and scored. The paper will be to express the design philosophy used when making high and low level decisions in regards to the hardware, implementation tactics, and general approach to solving the problem of mining Martian regolith. The plan is to include sections such as optimization of our robot, the total schedule followed over the eight month period, an operational overview discussing how part of the robot accomplishes certain goals while mitigating specific failures, and a systems hierarchy to discuss how the hardware is interfaced together to power the total machine and what dependencies the robot has on each specific piece of hardware (FMA, CPM, etc.).

1.1.3 On-Site Presentation/Demonstration

As discussed earlier, the team is required to have a presentation on-site at NASA Kennedy Space Center to discuss the scope of the project and how it progressed over the senior year. This presentation is to include a high level view of the systems engineering paper, detail STEM outreach efforts, social media and public engagement effort, and a presentation of the actual robot and its operation.

1.1.4 Outreach Project Report

An additional report is the Outreach Project Report. Per the requirement of this competition the team must organize events at the K-12 level to stimulate interest in STEM fields of study. This report will include specific criteria related to what events were organized, what activities they were, the number of people involved in them, and what kind of impact the team estimate to have had.

1.1.5 Social Media & Public Engagement

Finally, the last requirement for the presentation includes an effort to reach the public through social media. This involves looking into the representation in the cyber-realm and how the team managed to promote the project through platforms such as Facebook, Instagram, Twitter, and the Website Blog.

1.2 Project Motivation

The next few sections of the report are intended to discuss the motivation behind why this competition exists and NASA's reason for running this competition over the past few years.

1.2.1 Why Mars?

NASA has habitually allocated a large amount of resources to exploring and understanding our celestial neighbor, Mars. This is because of the remarkable similarities between Earth and Mars as compared to Earth and any other planet in our Solar System. Mars is the 4th planet from the Sun and is the only terrestrial planet in the habitable zone besides Earth. Additionally, it has similar surface features and general topography including mountains, valleys, volcanoes, and dried up riverbeds and lakes. Mars also has similar chemistry to Earth with a thin atmosphere consisting mostly of Carbon Dioxide, Nitrogen, Argon, and Oxygen. Previous mission data suggests that millions of years ago Mars could have looked a lot like earth, with liquid oceans and a variety of flora and fauna. Additionally, the planetary processes involved in Mars' evolution into the barren planet it is now, if better understood, could provide us with warning signs and a potential view into Earth's future. Because of these remarkable similarities Mars is the most likely candidate for humans to establish an extraterrestrial colony. A colony on Mars could provide a valuable research base and a touchpoint for further exploration into our galaxy. Additionally, Mars exploration can answer some of the fundamental questions of our human existence including; are we alone in the universe?

1.2.2 Why Regolith?

In order to establish a foothold on Mars and conduct meaningful scientific research a colonization effort must be made. Human researchers, as opposed to robotic counterparts, living on Mars and conducting experiments will rapidly accelerate the rate of understanding. One of the hardest challenges to overcome when living on Mars is having the resources available to support human life. Because of the distance between Mars and Earth, bringing the resources necessary is an almost crippling constraint. However, Martian regolith (dirt) provides some in-situ resources that can be harvested and through basic chemistry, converted into methane, oxygen, and drinkable water. By mining and harvesting the resources available on Mars to support human life a colonization effort is much more attainable in the near future.

1.3 Constraints and Guidelines

NASA provides constraints and requirements for the robot along with a scoring guideline. Seen in Table 1 the scoring sheet shows the positive points section in a light grey and the negative section in a darker grey. 1000 points are granted to the team for having a working robot. The mining portion of the competition points are only earned after ten kilograms of material have been collected with the ice simulant (gravel) being five times per kilogram more than the regolith simulant. Dust prevention points are rewarded at the judge's discretion. As for the dust tolerance, the judges will decide how much regolith the robot collects and how intrusive it is into the operation. Similarly, the dust free operation is awarded for how much dirt is not kicked into the air during the mining operations. Autonomy is broken down into 4 sections with the highest section persisting of no user input into the run and the lowest with not autonomous functions. The two levels between consist of operations that are autonomous. The second highest level is given if the robot can traverse the course with no user input and the third level is for the mining portion.

Table 1: Competition Evaluation Rubric.

Application	Subsection	Points	Conditions
Technical Inspection and Communications Check	Competition	1000 Mining points	Awarded Required to Compete
Mining BP-1 Simulant	Mining	3 Mining Points/ kg (over 10kg)	Awarded based on overall mass
Mining Icy Regolith Simulant	Mining	15 Mining Points / kg	Awarded based on overall mass
Dust Tolerance	Mining	30 Mining Points MAX.	Awarded at Judge's discretion
Dust Free Operation	Mining	70 Mining Points MAX.	Awarded at Judge's discretion
Autonomous Operation	Mining	500 Mining Points MAX.	4 Levels of Autonomy
Data Transfer	Data	1 Point / 50 kb/s	Minimize data transfer
Situational Awareness Penalty	Data	4 Points per Situational Awareness Camera	Penalized, Added to total Data Transfer
Vehicle Weight	Size	8 Points / kg	Penalized
Power Consumption	Energy	1 Point / Watt-hour	Penalized

Table 2: Competition Arena Specifications.

Competition Requirements	**Value**	**Description**
Arena Size	~10 m x 20 m	Total traversable terrain for vehicle
Deposit Trough	1.575m Length 0.457m Depth 0.550m Height	Sole location to deposit mined material from rover
Competition Time Limit	10 min	2 Competition Runs
Mining BP-1 Simulant	0 – 30 cm	Majority of material contained in mining arena
Mining Icy Regolith Simulant	~30 cm	Mixed with BP-1, Concentrated at 30 cm depth
Subterranean Obstacles	Random	Randomly mixed throughout arena
Surface Obstacles	up to 30 cm Width	Large rocks and craters will be placed randomly
Robot Size Limits	1.50 m length 0.75 m width 0.75 m height	Maximum allowable size of robot

A point is deducted for every 50 kilobytes of information transferred to and from the robot through the router. Additional points will be deducted for every situational camera added to the robot: an extra 4 points per camera on top of the negative points from the 50 kb transfer. Every kilogram of weight added to the robot there is an eight point deduction and a point deduction for every watt-hour of energy

The competition arena is a ten by twenty meter box with three distinct sections. On one side of the arena is the dumping trough where the robot will have to dump the collected material. The sizing of the trough can be seen in Table 2. The opposite side of the arena consists of the mining section and is the only location where the robot can collect dirt for the mission. The dirt in the mining area will consist of an approximated section of about 30 cm of regolith simulant that will have an ice simulate underneath. Likewise, there will be subterranean rocks sporadically placed in the area. Between these two areas is the Martian terrain simulation complete with large rocks, craters, and holes that the mining robot will have to cover. The robot at the beginning of the two 10 minute runs will have to be smaller than the limits described in Table 2.

2.0 Design Methods

2.1 House of Quality

A house of quality was created to determine the most important engineering characteristics based off the customer requirements. The customer requirements were extracted from the point system regulations of the competition. The customer importance rankings from 1-5 were

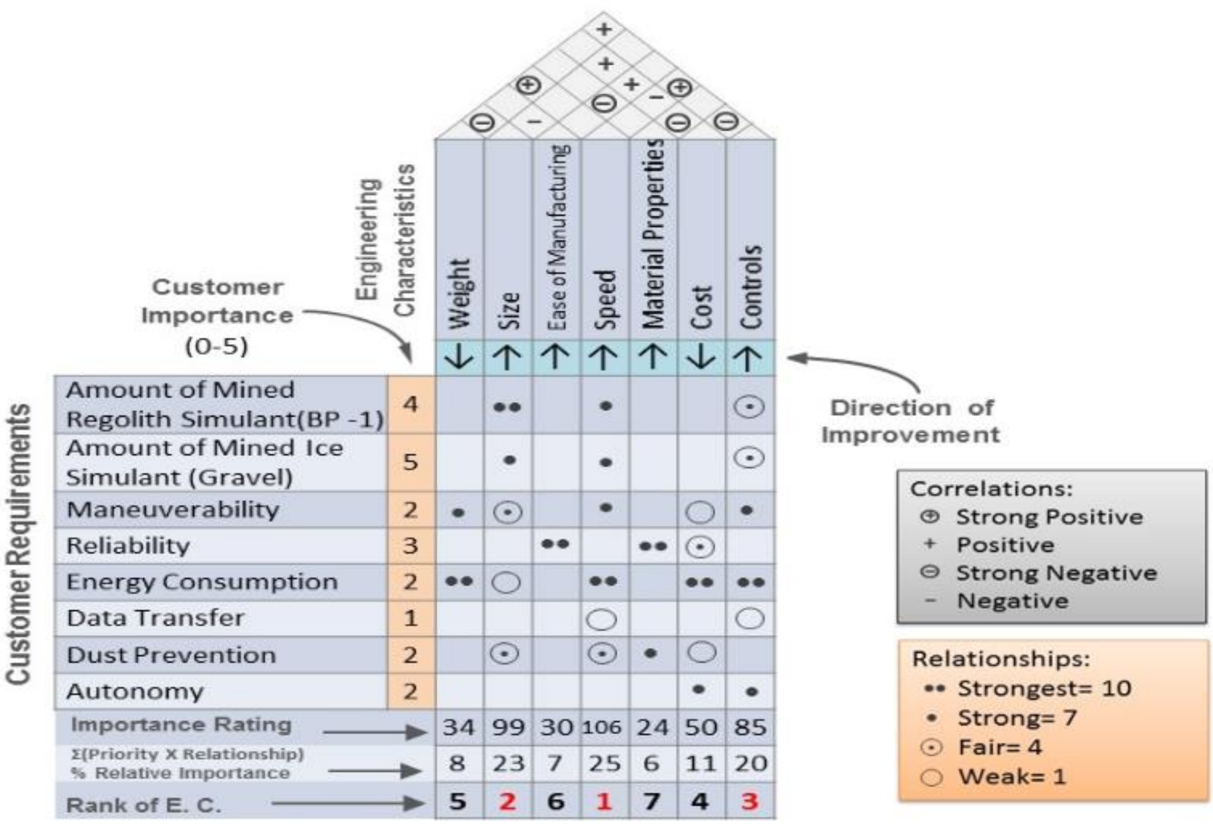

Figure 1: House of Quality comparing Competition Goals and Engineering Characteristics.

determined based off the points allotted in the point system provided by the competition. For example, the amount of mined ice simulant (gravel) was weighted the most, therefore given an importance of 5. The amount of mined regolith simulant (BP-1) had the second highest points, given an importance ranking of 4. The engineering characteristics were compared against each other, which can be seen by the rooftop in Figure 1. The correlation legend is also depicted in Figure 1. This will allow a better understanding of the correlation between each independent engineering characteristic. The direction of improvement arrows were determined by the effect each engineering characteristic would have on our design. For instance, increasing/improving the speed will allow for the robot to move faster, therefore mining faster, and gaining more points. The relationship between the customer requirements and engineering characteristics can be seen in the middle of the diagram. The relationship legend is also depicted in Figure 1. The importance rating was then determined by multiplying the customer importance by the corresponding relationships for each engineering characteristic.

The top three engineering characteristics were found to be speed, size, and controls. The speed of the robot will be the most important characteristic to focus on during the design process. The faster the robot traverses the terrain, the more regolith may be potentially mined, thus more points acquired. As for the size, the larger the size of our robot the more storage for the regolith collection. Bear in mind, the size must still remaining in the volume constraints, 1.5m x 0.75m x 0.75m to start. The controls will be an important characteristic as accurate controls will allow the robot to maneuver through the terrain easily. Furthermore, the better the controls on the mining component, the more regolith that can be acquired.

2.2 Morphological Chart

A morphological chart was created to generate different ideas to design the robot. Figure 2 depicts the morphological chart for this project. The left side depicts the functions listed. The right side portrays the different mechanisms that can perform the function. For example, for the board of the robot, the different options are a Raspberry Pi, Arduino, or BeagleBone Black. In this morphological chart, the two concepts chosen can be seen in red and green. Also included in this morphological chart was the competitor's previous designs. Research of the advantages and

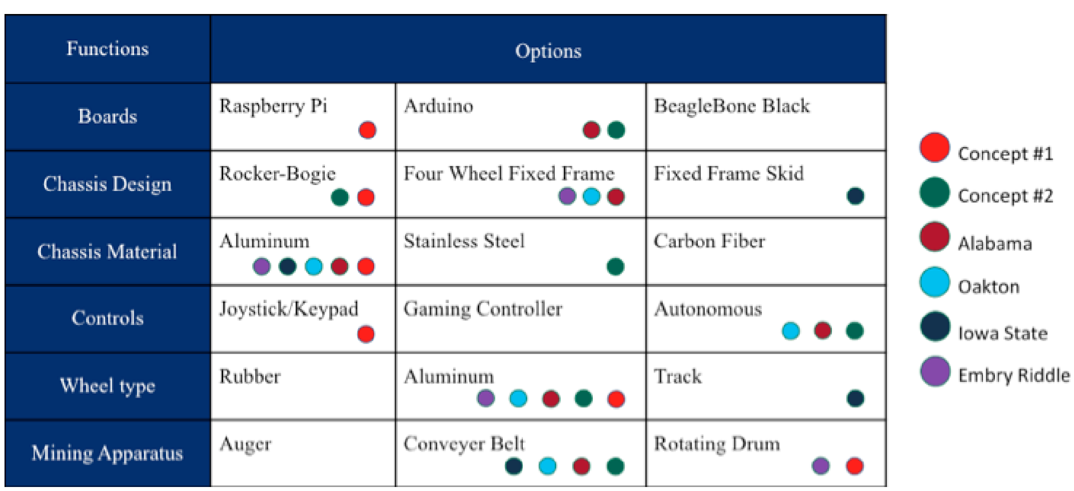

Figure 2: Morphological chart comparing various components in the design.

disadvantages from previous designs allow for the creation of the most robust design concept. Most colleges utilized the four wheel fixed frame, aluminum for the chassis material, autonomous controls, aluminum for their wheel material, and a conveyor belt for their mining apparatus. Currently, the completed design concept has not been chosen, as more research and calculations are needed. The options that are definitely going to be used in the design is the Rocker-Bogie system for the chassis design, aluminum as the chassis material, and aluminum as the wheel type. The Rocker-Bogie system has been chosen as there are numerous advantages to this design. Background research on this design versus the four wheel fixed frame will be more detailed in the next section, Chassis Design. Aluminum has been chosen for the chassis material and wheel type, as this is a material that can withstand the harsh climate of Mars. Aluminum is lightweight, easily machinable, corrosion resistant, and very ductile material.

2.3 Chassis Design

2.3.1 Four Wheel Fixed Frame

For the chassis design, many potential options were researched in order to provide a better understanding of systems that have previously been implemented for various types of Mobile Robots. Many of the competitor's designs consisted of four wheel fixed frame robots, which allows for simple kinematic models, minimal moving parts and purely motor operated handling and propulsion. The simplicity of this type of design allows for ease of manufacturing and focuses heavily on adequate controls systems of the two sets of differential driven wheels. Primary concerns associated with the four wheel fixed frame system is that there is usually appreciable amounts of skid friction that occurs, which causes greater power consumption for equal travel distance. Unlike Ackermann Steered vehicles, where the instantaneous center of all wheels is a singular point, generating the appropriate turn rate to account for the desired heading direction, a fixed system must skid to properly execute a steering. Although much of this frictional loss may be minimized with proper motor control, some amount of skid will still occur. Furthermore, four wheel fixed frame systems do not provide any suspension characteristics, beyond the potential stiffness of pneumatic tires. (If applicable) As one of the main design concerns, this mining rover must traverse potentially rugged terrain with various obstacles, in which a four wheel fixed system is ill prepared for.

2.3.2 Track System

Similar concerns arise with the use of a track system, where all steering generates large amounts of friction and dust collection during continuous operation could be significant. However, track systems present very desirable traits such as large contact surface areas while operating on loose, shifting terrain and provide favorable obstacle maneuverability. Many variations of track systems exist; Skid Steer Double Track (SSDT) system, "Chaos" Multi-legged Track system and the Arm-Crawler Track system. The SSDT system is similar to many tanks in production, it provides high level of obstacle maneuverability, only two independent motors to generate adequate wheel torque and steering and performs very well on a wide range of terrains. The "Chaos" system is an innovative approach to the traditional Track vehicles as a hybrid legged robot. As seen in Figure 3 the Chaos platform has four independently articulated limbs, each with its own track system. This unique approach to the traditional tracked robots allows for substantially greater obstacle clearance similar to most legged robots, but still has the ability to roll like a traditional track system. This combination allows for greater power conservation when compared to many of the legged robots while maneuvering flat terrain, but still allows for the extreme terrains to be traversed with ease. The Arm-Crawler is a combination of the SSDT and Chaos platform, where there are two independently articulated arms in the front while still possessing the full body track system. This allows for the robot to be self-leveling during obstacle maneuvering and use limb articulation, similar to legged robots, to help with extreme obstacles. An example of an Arm-Crawler system may be seen in Figure 3. One drawback to the Chaos and Arm-Crawler platform is that they require many more motors, which contribute to the overall weight and power consumption. Each of these systems obviously possess the desired obstacle avoidance, but also have very troublesome power consumption, dust collection problems and are potentially much heavier and damage prone than other systems. Most of the damage associated with track systems occurs during turning, which on Martian terrain could experience highly abrasive sand and rock during the skid process.

Figure 3: Examples of Tracked system robots; Chaos and Arm-Crawler platform.

2.3.3 Ackermann Steered System

The use of Ackermann steered robots has been much less prominent due to the ability to have many precisely controlled motors at each wheel. Ackermann steer is a prevalent concern in the automotive industry where a single Internal Combustion (IC) is traditionally used, eliminating the potential control systems that are commonly used in advanced robotics. Ackermann steer is a principle that if the vehicle is treated as a rigid body, during turning each point will possess the same instant center. In order to implement this system a complex drive model is used determine the turning rate of each wheel in order to revolve around a common instant center. For more information about Ackermann Steer refer to *Design of an Ackermann Type Steering Mechanism* [5]. Main concerns associated with Ackermann Steered platform is the lack of maneuverability around potential obstacles as well as the requirement of either pneumatic or spring type suspension in order to keep each wheel in contact with the ground while traversing rough terrain. Reliability of the system is another key factor, as the control systems needed in order to regulate proper positioning and heading would require high levels of calibration and demand relatively precise machining and manufacture.

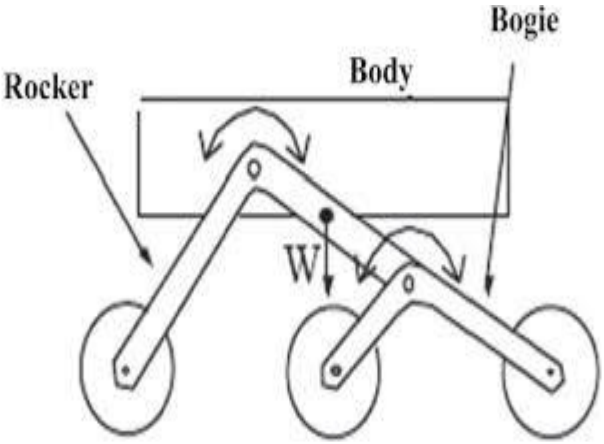

Figure 4: Components of a Rocker-Bogie System.

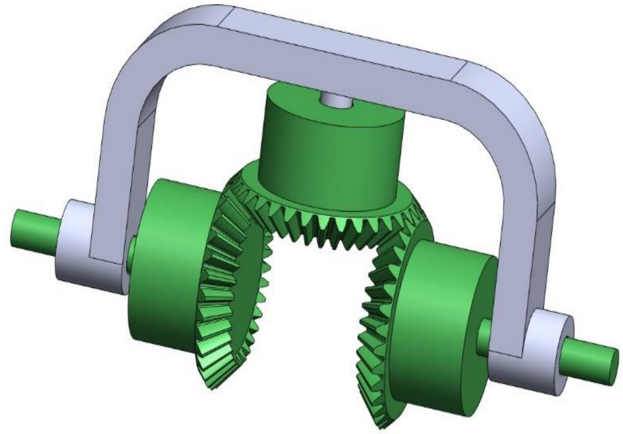

Figure 5: Differential for Rocker-Bogie System.

2.3.4 Rocker-Bogie System

A key aspect in design engineering is to not re-invent the wheel. NASA has implemented the Rocker-Bogie system on many of the Martian rovers to date. To name a few; Spirit Rover (2004), Opportunity Rover (2004) and Curiosity Rover (2012) have all possessed a variation of a Rocker-Bogie System. Reasons for the continued utilization of this platform, is that it does not require the use of conventional spring or pneumatic suspension to maintain continuous 6 wheel contact while traversing rough terrain. The Rocker-Bogie system contains two main components, the Rocker and the Bogie as seen in Figure 4. The Rocker is a long arm which directly connects to a wheel on one end, a pivot point on the Bogie mechanism on the opposite end and pivots about the body somewhere in between, based on the weight distribution. The Bogie is an independent

$$z_t = \frac{s}{\sqrt{\left(\frac{r\sqrt{s^2-h^2}+(h-r)h}{(h-r)\sqrt{s^2-h^s}-hr}\right)^2+1}}$$

$$X_B = \frac{3}{2}X_C$$

$$X_B = \frac{1}{2}(X_1 + X_2)$$

Figure 6: Equations of clearance for Bogie and Wheelbase parameters.

mechanism which has two wheels approximately equidistant from the Rocker pivot.

The feature that stabilizes the two independent Rockers from rotating at different rates is a differential gear set as seen in Figure 5. The differential gear set maintains a continuous connection between both rockers, such that if one rocker were to droop or lift upon encountering an obstacle, the opposing rocker would counter rotate in order to provide a stabilizing torque throughout the chassis all while maintaining six wheel contact. Substantial amounts of research has already been performed on the optimization of Rocker-Bogie Systems. Ullrich, Goktogan and Sukkarieh present a series of relations for the design parameters of the Rocker, Bogie, wheelbase dimensions and relative wheel sizes for desired obstacle clearance, stability and control [6]

2.4 Mining Apparatus Design

Relevant parameters for designing mining equipment to be used on Mars is the minimal gravitational field and the extreme cost of transporting materials to Mars. Thus ideal designs will perform mining tasks with minimal normal force and have minimal weight. Conventional equipment such as excavators, require a large normal force that make them impractical. Various other configurations have been considered for utilization in the design process.

2.4.1 Conveyor Belt Assembly

Many competitors have implemented a conveyor belt system which is either linearly actuated to extend the mining reach, or rotated about a fixed axis on the frame to change the declination angle of the conveyor system. This configuration generates minimal normal force, because as the belt rotates, the ground is either tangent to the mechanism or is already lifting material. Any normal force generated is negligible, due to the limited surface area at any given point. The system is simple to implement, requiring two rotating drums, some type of belt with treads or cleats, a driving motor and a frame structure to align the components. Drawbacks to this system is the limited range of motion, potential for dust collection on internal rotating components and that it struggles to reach and extract the gravel simulant. The type of cleats utilized will define specific qualities of the mining ability. If small cleats are used to generate minimal normal force, it is relatively impossible to mine gravel. If larger cleats or small cleats with fork-like tines are implemented, either the normal force is very large or the structural integrity may be sacrificed.

2.4.2 Rotating Drum Assembly

Embry Riddle Aeronautics University (ERAU) as well as the newest member of the NASA Rovers, RASSOR (2016) both implemented these configurations. The principles of the rotating drum design is that a large scoop edge will acquire material as the drum rotates. In each of these systems the drum continues to mine until the volume is filled. Considerations have been made to use a similar style drum or having the drum self-bailing during operation to fill another container.

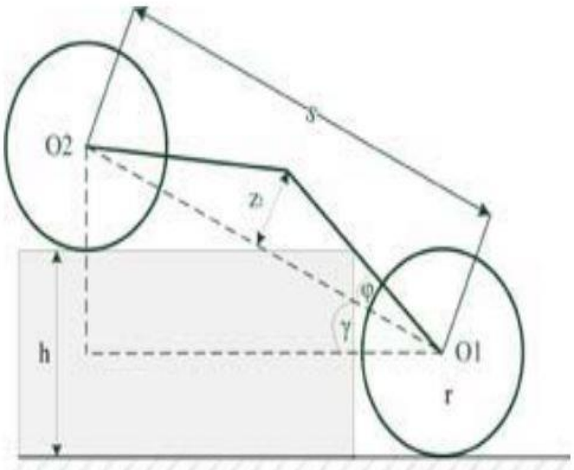

Figure 7: Bogie maximum clearance diagram.

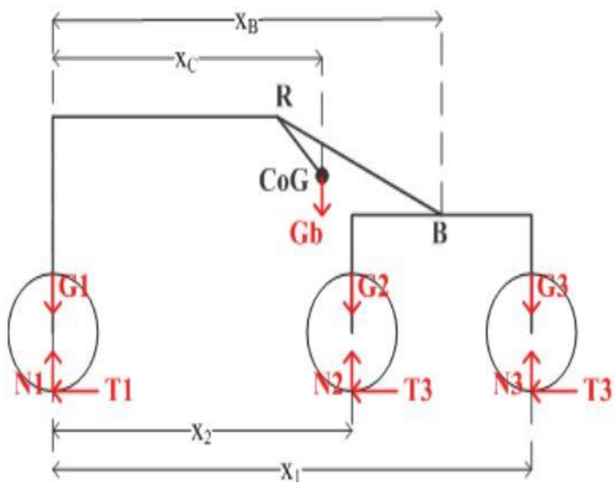

Figure 8: Rocker-Bogie wheelbase parameters

Advantages of this type of design is that it only requires a single motor to generate the revolving motion, in which reversing the polarity will allow the system to empty into the desired bin. Minimal Components are needed and the manufacture of this configuration is relatively simple as it does not rely on tight tolerances or specific parameters to function.

2.4.3 Auger/Archimedes Screw Assembly

Various types of screw like instruments have been used in many types of media for various applications. Advantages to this configuration is the relatively large depth that can be reached and simplicity during the mining procedure, which only requires a single motor to operate. The issues associated with these systems is the ability to implement some combination of linear and angular articulation while still possessing structural integrity. Furthermore, manufacture of a custom Auger bit is fairly difficult and costly, while many commercially available components may not possess desired material or dimensional characteristics.

2.4.4 - Rock Drilling Bucket

Drilling buckets are used for the collection of soil beneath ground level and is proficient at handling cohesive soils like clay or rock and non-cohesive earths like sand and gravel. A drilling bucket can be applied in place of a traditional auger with both using the equivalent construction equipment and vehicles. Unlike an auger, the drilling bucket is capable of handling the material collected and conveying it directly to a location on the surface such as a dump truck. Seen in Figure 9, the drilling bucket is hollow with a rotating toothed edge that rotates around a central axis hub. These teeth combined with a raised lip allows for facile collection of soil at low depths. When the bucket is full the operator can reverse the rotation of the bucket to close the rotating lip located and bottom of the bucket. When dumping the drilling bucket can be opened to release the material by changing the rotation of the bucket and allowing momentum of the collected soil to force the bottom open.

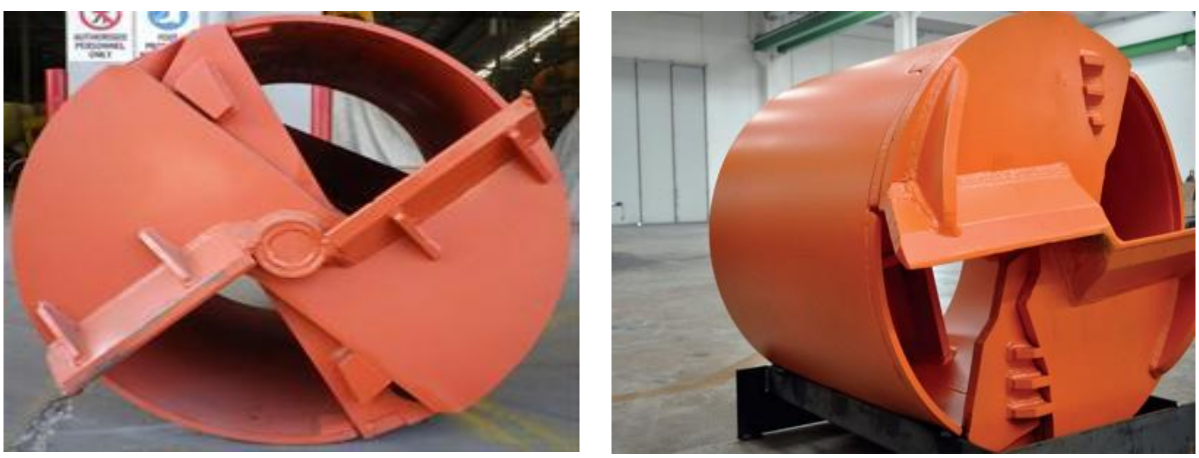

Figure 9: Rock Drilling Bucket.

3.0 - Design and Testing of Mining Drill

After researching other competitors designs who performed well in last year's competition and collecting information about the performance of their mining devices a glaring issue arose. Although all teams scored points collecting top soil regolith most team's designs were unable to collect the gravel simulant that was at a depth of one foot below the surface. Realizing the potential for creating an improved, innovative design for the mining portion of the competition research was conducted on mechanisms in the mining industry. Various mining instrumentations were investigated such as the auger, shovel, pumps, conveyor, blasting, and the rotating drum design. The common devices used for mining in the competition were the shovel, rotation drum, conveyor, and auger. The issues with these designs however are the situational nature of their mining capabilities. An auger can't handle the non-cohesive nature of the mars regolith and commonly failed to collect dirt, but was capable of mining below the surface. The rotating drum design isn't proficient at mining below the surface and can only scrape the topsoil. A conveyor system is a dust prevention nightmare with one end of the conveyor plunged into the dirt leading to the issue of clogging and slippage of the belt.

Realizing the benefit of a self-contained mining apparatus demonstrated by the rotation drum concept that is capable of handling the material post-excavation and transferring the material to a new location a mining device with these qualities was an essential design feature for our project. The issues demonstrated by the rotating drum such as its inability to directly begin mining down instead of a quarry style extraction would need to be addressed. An initial concept design that the team conceived was the combination of an auger and bucket design that would be capable of mining in a vertical direction while holding the mined material. Figures 10 to 13 show the evolution of the mining drill. The earliest design, Figure 11, was a solid based cylinder with an auger flute and catches at the top to guide the mined material into the bucket. When testing this design however the drill required too much normal force to reach the top of the bucket and begin collecting the material. The second design in Figure 10 had a greater attack angle as to see if the normal force could be reduced which had great success when tested. Figure 12 shows the third iteration of the drill bit that increased the attack angle of the flutes while increasing the angle of the point. With the increased attack angle the drill was able to mine into the sand however the device would throw sand instead of displacing it up the flutes. The fourth design shown in Figure 13 tried to rectify this issue by adding railings on the flutes that would guide the sand to the top of the bucket and reduce the throw. The added rail caused the normal force of the drill to increase dramatically and eventually broke the center axle of the drill bit.

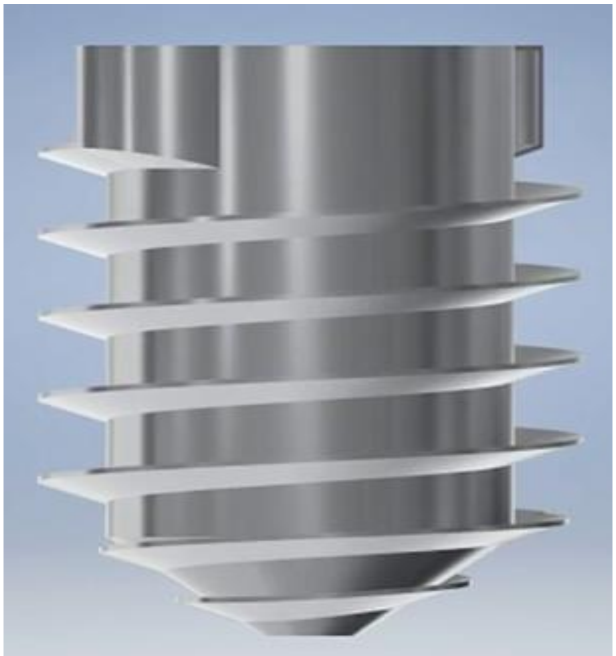

Figure 120: First Iteration (Large cylinder, Single Flute).

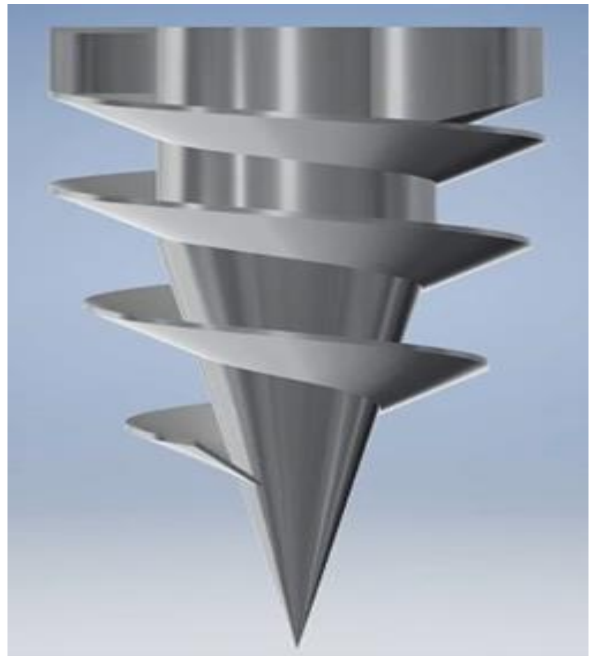

Figure 11: Second Iteration (Large Attack Angle).

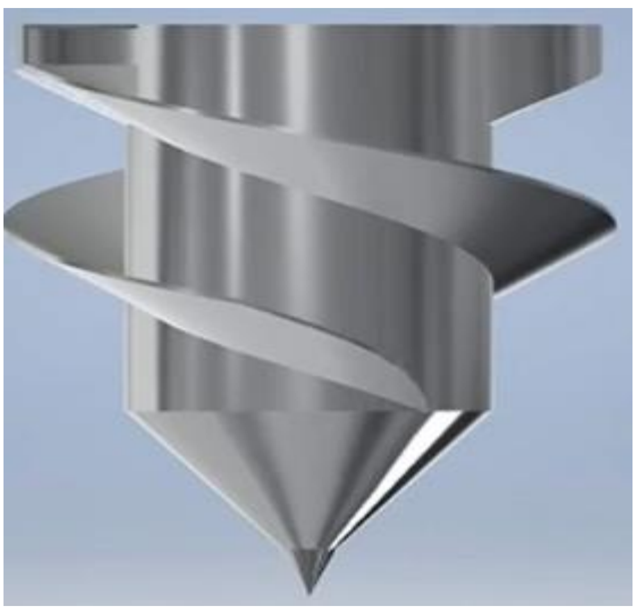

Figure 10: Third Iteration (Steep Point, Increased Pitch).

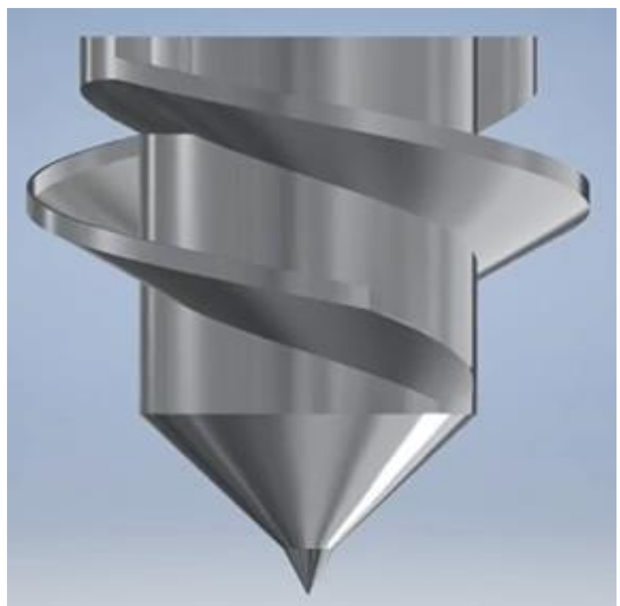

Figure 13: Fourth Iteration (Railed Flute, Similar to three).

3.1 Chassis Design and Selection

The majority of background research for the NASA robotic mining competition was in the winners of the 2016 competition that has similar objectives and constraints to the current year. Seen below are the top two teams for the competition with the University of Alabama robot in Figure 14 and Oakton Community College's in Figure 15.

Figure 14: University of Alabama (RMC 2016).

Figure 15: Oakton Community College (RMC 2016).

Figure 16: Embry Riddle University (RMC 2016).

Figure 17: Iowa State University (RMC 2016).

The UA robot implemented a four wheel fixed frame system that used a skid turning motion to rotate the vehicle back to the scoring trough. Oakton used the same system but with a smaller wheel radius and with a plastic material. The UA robot was able to traverse the landscape fairly easily with its large diameter wheels; likewise, the Oakton's robot was capable of traversing the course with its low weight and size. Also of note the UA robot had control issues with its mining device and lining up the vehicle with the desired mining position.

Iowa State University placed third overall and had a high rating in all categories for the mining portion of the competition as seen in the Figure 17. Unlike UA and Oakton Iowa employed a track system for their frame that provided ample amount of surface area with relatively low dust collection; however, their robot was heavy. Embry Riddle Aeronautical University used a four wheel fixed frame system for their robot again with a skid system similar to University of Alabama. Their wheels had a larger radius than UA with a far smaller chassis.

3.2 Chassis and Mining Selection

Ultimately the team decided to go with a different approach for both portions of the build with a rocker bogie chassis design and a drilling bucket design. The rocker-bogie design was selected for its large stable frame and contact surface area for the wheels. The Drilling bucket was selected after research concluded that it had both characteristics wanted by the team: the ability to contain material and the ability to dig to the gravel. After prototype testing of the drilling bits using 3D printed models of all drill bits it was concluded that the drill bucket was the most efficient and used the least amount of energy to complete its task. Figure 18 is the preliminary design of the drilling bucket and Figure 19 is the prototype design for the rocker-bogie chassis.

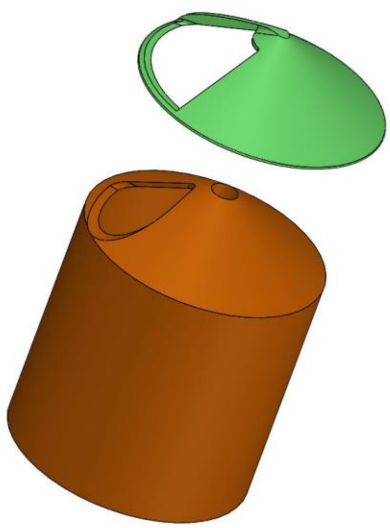

Figure 18: Mining Bucket CAD.

Figure 19: SCRAP 1.0 Popsicle prototype.

4.0 Decoupled System Design

The design of the system was focused on speed, size, and controls. These three engineering characteristics were developed from the house of quality. The house of quality can be seen in Figure 1. The decision to decouple the rover and the mining apparatus was to increase the speed of our system.

The rover will traverse the terrain and drop the mining apparatus off at the mining section of the arena. The mining robot will then strictly mine the regolith while the rover will act as dump truck and deposit the regolith to the bin on the other side of the arena. The decoupling of these two systems will allow the mining robot to continuously mine while the rover drives from the mining robot to the collector bin to deposit the regolith. Decoupling the system will allow the rover to weigh less since the mining apparatus will be detached from the rover, allowing it to cover the terrain faster. Most importantly, the mining robot will constantly be collecting the regolith, increasing the amount of regolith acquired. Also, the decoupled system will increase the amount of gravel acquired, as the mining robot will be in the same spot to reach the gravel since it is one foot under the BP-1 simulant.

In comparison to previous year's competitors, this approach will increase the regolith acquired in a shorter amount of time, therefore increasing the points scored. The top two teams from the 2016 competition, the University of Alabama and Oakton Community College Robotics, are displayed in Figure 14 and Figure 15. Both of these colleges utilized a coupled system; the mining apparatus attached to the rover. This method limits the amount of regolith acquired since these robots must stop mining and deposit the regolith to the collector bin.

Decoupling this system will allow Team 22's robot to increase the speed of the rover by decreasing the weight. Also it will increase the amount of both mined sand and gravel by continuously mining in the same spot. Therefore, this method will increase the amount of points scored. The two different models discussed are described in the sections below.

4.1 Rover Design

After extensive research the team decided to use a rocker-bogie chassis design on the moving rover. After building a few different SCRAPs the team developed a preliminary CAD model shown in Figures 20 and 21 to estimate weight and raw material types/quantities the team should order. Some of the key features of the rover design the team will expand on are the rocker bogie chassis, hollow cavity wheels, and regolith bucket.

4.1.1 Rover Chassis Design

As mentioned in the end of our previous report the team chose to utilize a rocker bogie chassis. This passive suspension system utilized a differential to control the angle of each side of the rocker. This suspension system forces the rover to maintain six wheel continuous contact for optimal traction and control regardless of the terrain it moves over. Between the rockers on each side of the rover a central box housing will contain all of the rover's electronics. On top of the bucket will be the simulant transport bucket fixed on a lever arm that controls its orientation. This design keeps the all of the weight of the rover between the inside edges of each of the wheels for superior cornering and stability. Care will be taken when designating specific placement of components such as motor drivers, batteries, telecommunication hardware, etc. to distribute the weight evenly across the rocker bogie designed center of gravity.

4.1.2 Rover Wheel Design

Because of the constraints operating in the Martian environment a significant amount of time and consideration was placed into designing a wheel that was lightweight, could stand up to the extreme temperature changes on the Martian surface, could support weight of the rover in loose and inconsistent terrain, all while not taking up too much space because of the competition volume constraints.

Ultimately it was decided that an important feature would be a large aspect ratio so that the weight of the rover didn’t dig itself into the loose terrain but still manage obstacles. The wheel is 10in in diameter and 4in in depth. Because of its size we decided to make the wheel itself hollow

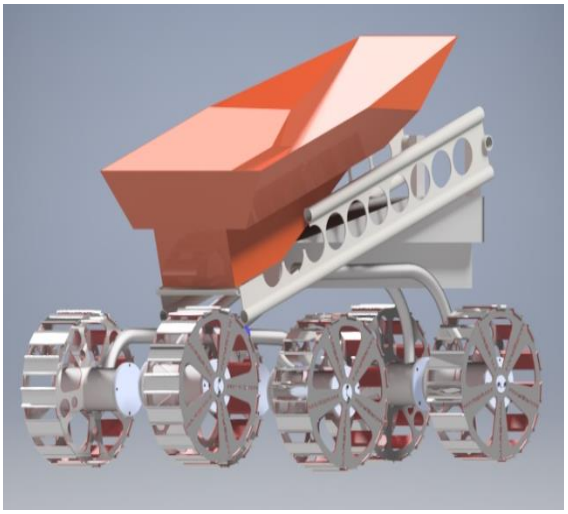

Figure 20: Mining Rover Isometric View.

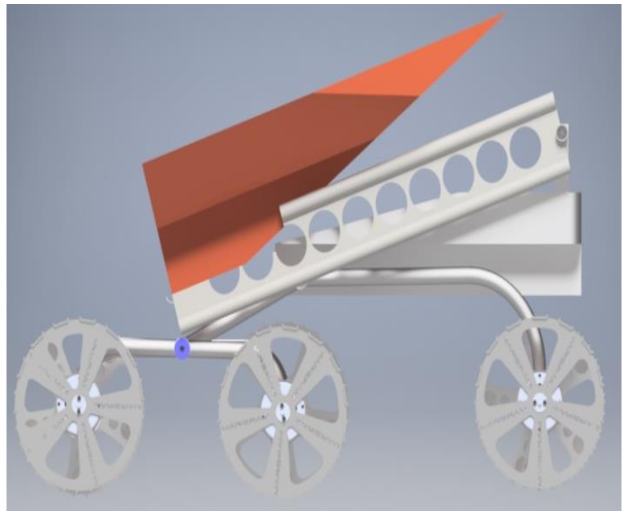

Figure 21: Mining Rover Side View.

to cut down on weight and allow sand that would inevitably make its way inside during operation a chance to escape. The center of the wheel would also be utilized to house the wheel motor itself, helping to distribute the 4lb motor weight to the outside of the rover to give as much stability to the robot as possible. Figure 22 shows the CAD model of the wheel and Figure 23 shows a partially fabricated prototype wheel.

One can see from examining the Figure 23 shows the face of the wheel was water-jetted from 1/8th in AL 6061 sheet while the cleats were bent from 1/8th in Al 6061 on a sheet metal brake, cut to size on a Bandsaw, and welded to the face. This entire wheel (without the motor and motor housing) weighs less than 2 lbs, proving that our design successfully gave us a large wheel at a small weight cost.

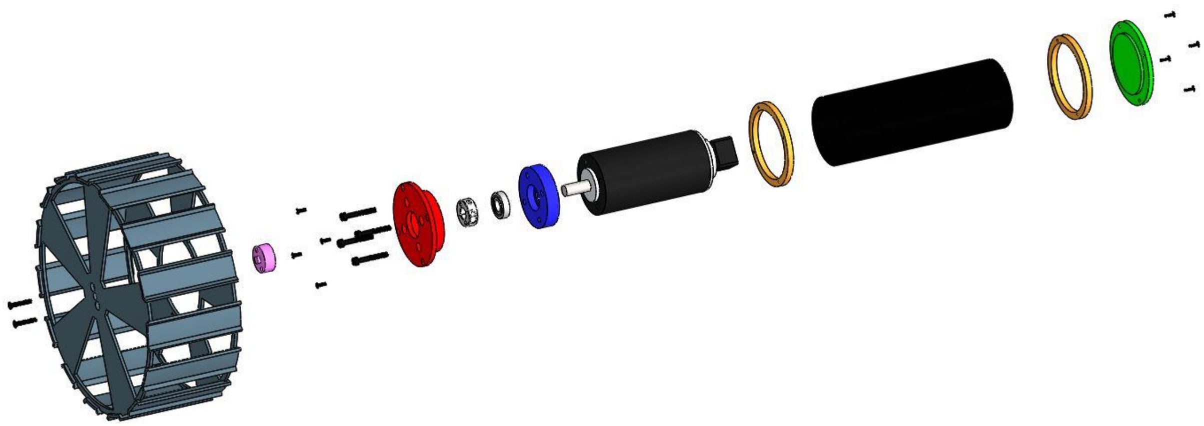

Figure 22: Exploded View of Rover Wheel Motor Assembly.

When deciding on the geometry of the wheel we were mindful of the way the motor should mount and control it. The motor mounts inside of a housing that the inner face of the wheel rotates about on a fixed bearing while the outside face of the wheel is driven by the motor shaft. This setup allows the motor to drive the wheel without the weight of the wheel being solely balanced on the output shaft of the motor.

Figure 23: Manufactured Wheel, Based on CAD.

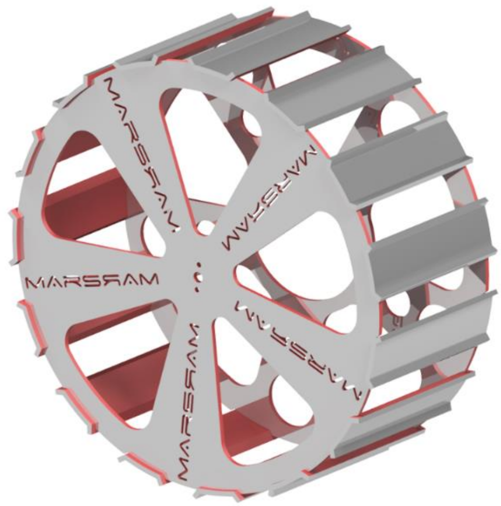

Figure 24: CAD design of 10 inch hollow wheel.

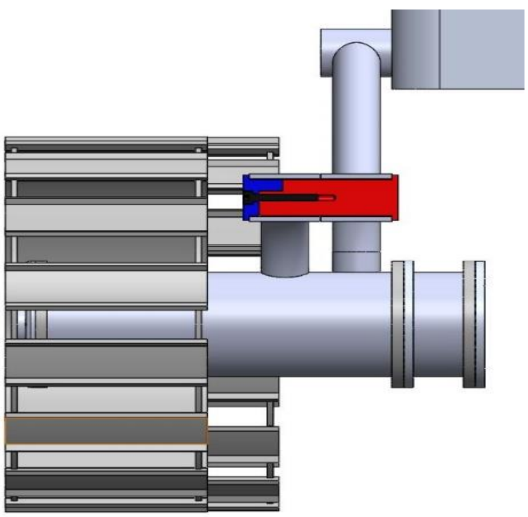

Figure 25: Cross-Sectional View of Rotation Limiter.

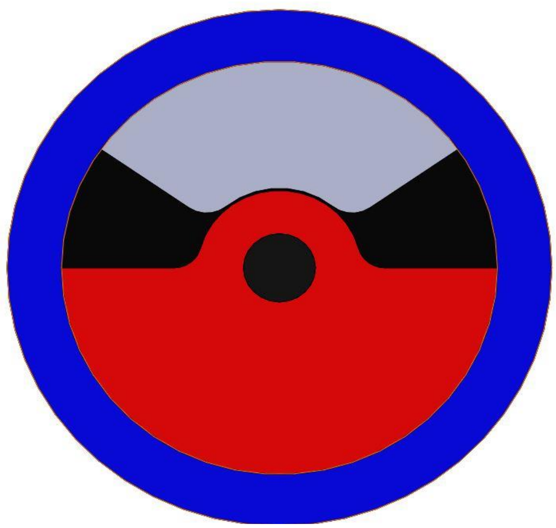

Figure 26: Rotational Limiting Pin.

Each of the six wheels will be powered by their own motor so that they can equally contribute to the motive effort and provide the controller with the highest possible degree of agency over the rover's movement.

One design concept that will be implemented is a rotational limiter in the pin joint of the Bogie, in which it attaches to the Rocker. From the experimental dynamic testing of SCRAP 1.0, a trend was observed that during the excursion of obstacles larger than 1.5 times the diameter of the wheel, the Bogie would flip over-center. To alleviate this issue, the rotational limiting methods were researched. The design chosen, based on simplicity, is a rotational pin which will be welded to the two bodies (Rocker and Bogie respectively) and be fastened together. This design will utilize solid aluminum pins which have been machined to specific angles. Based on the current geometry of the chassis, an equal range of motion Fore and Aft, will allow for 35 degrees of rotation without interference and still allowing the six-wheel contact desired from this chassis platform. As seen in Figure 21, the Rocker and Bogie will be fastened together by the rotational pin components. Figure 26 demonstrates the pin at neutral rotation (parallel to the ground surface). Figure 27 demonstrates the maximum forward (clockwise) range of motion of 35 degrees. Figure 28 demonstrates the maximum rearward (counter-clockwise) range of motion of 35 degrees.

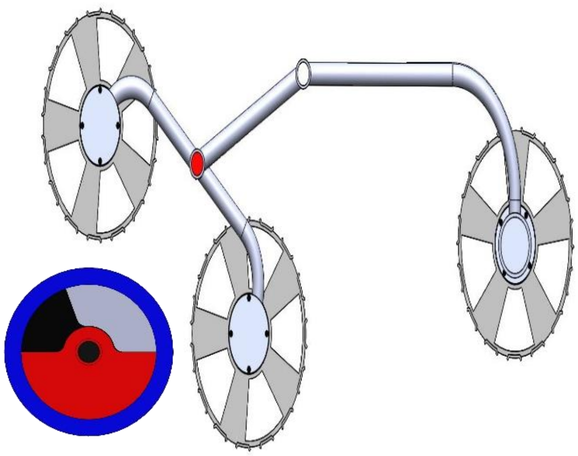

Figure 27: Maximum Forward motion of Bogie.

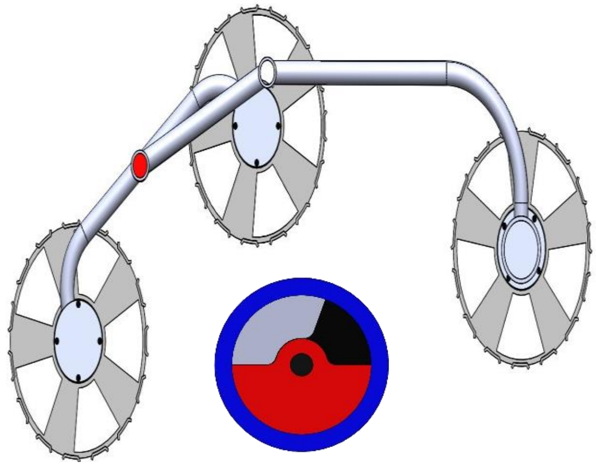

Figure 28: Maximum Rearward motion of Bogie.

4.1.3 Rover Bucket

The main function of the rover is to transport the mined regolith and ice simulants so its largest component will be the bucket used to hold the simulants. The size and shape of the bucket were decided on for 3 purposes: to hold the maximum amount of regolith the mining drill can pick up, support the weight and geometry of the mining rig during initial deployment and redeployment, and facilitate the offloading of regolith to the appropriate collection bin.

Because the mining rig is not capable of relocating itself the rover's bucket will be the only mode of transportation the rig has if for any reason it needs to be moved after its initial deployment. The inside of the bucket will have geometry shaped to cradle the mining rig when maneuvered to an appropriate orientation.

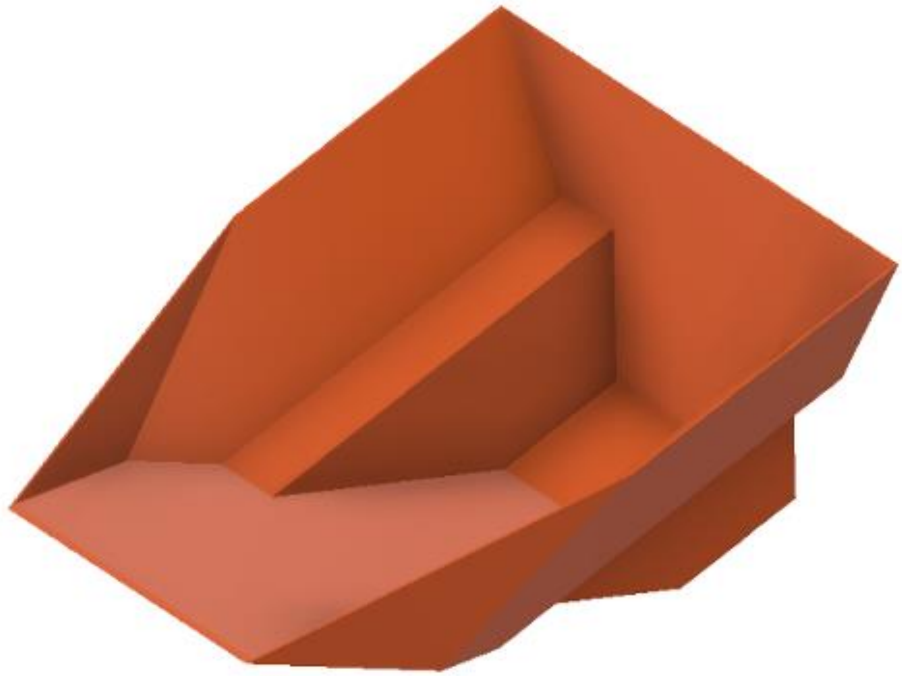

Figure 29: Sheet Aluminum Bucket Design.

The bucket must also be shaped to facilitate quick off-loading of the simulants after they are gathered. The bucket will be tilted about the rear axis by a linear actuator and the corresponding edge is sloped upwards so the simulants will easily slide out. Figure 29 shows a close up of the bucket.

Figure 30: Isometric View of Mining Rig.

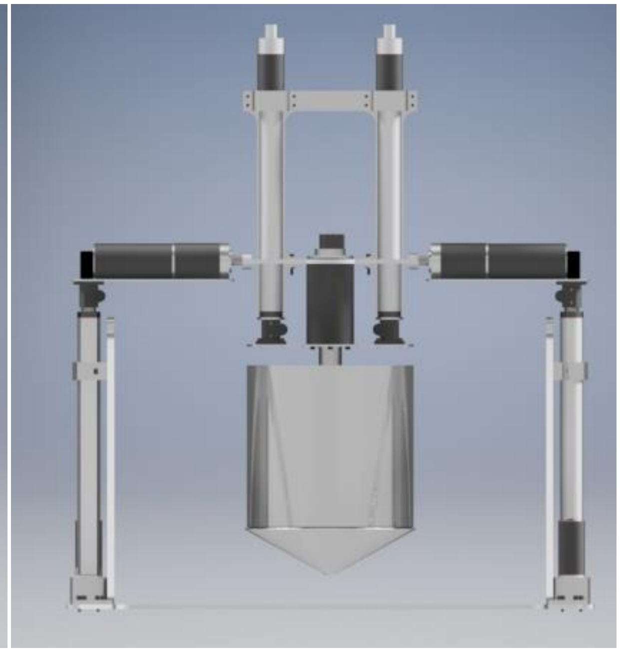

Figure 31: Front View of Mining Rig.

4.3 Mining Rig Design

After several iterations, prototypes, and test runs we decided on the mining component we plan to use. The rig will contain 4 linear actuators and three brushed DC motors as shown in Figure 30.

The drill component of the mining rig will utilize permanent magnets to hold itself open or closed. There are two sets of parallel linear actuators to facilitate movement of the drill. Each of the 4 actuators has a 16in stroke and can support up to 275 lbs. In the fully closed position the tip of the drill will be just above the ground. The two actuators fixed at the base expand upwards to allow the mining rig to position itself 16in above the ground while the two actuators fixed at the top of the rig expand downwards to allow the mining rig to drill itself 16in into the ground. The base of the mining rig is to be cut from 1/4th inch thick AL 3001 sheet and the triangular supports from 1/8th inch thick AL 3001 sheet to provide a sturdy and wide base to stabilize the entire rig during operation. The orientation of the top linear actuators and drill can be adjusted by two motors. This is necessary to hoist the rig on the rover for initial deployment as well as keep the rig in the initial volume constraints. Figure 32 shows the rig in two positions: at full expansion and retraction of opposite pairs of actuators.

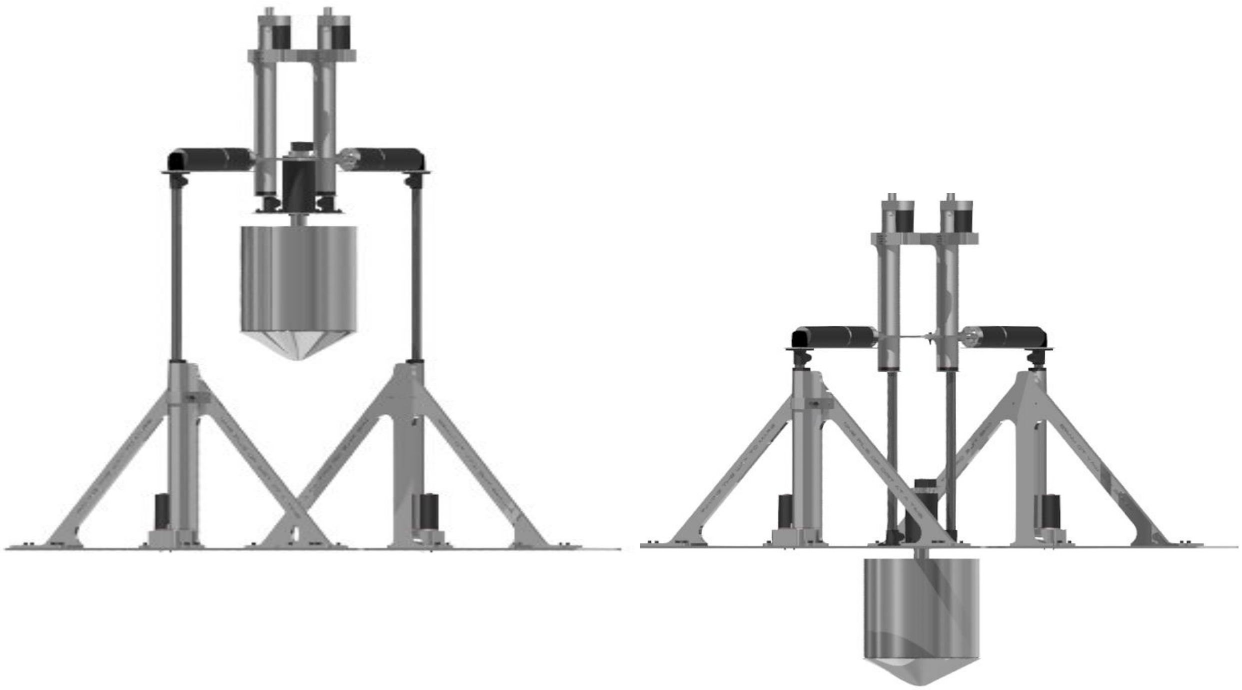

Figure 32: Two extreme positions of Mining Rig Motion. (Left at Full Expansion, Right at Full Retraction).

4.3.1 Mining Rig Drill Design

We wanted to design a mining apparatus that could easily collect both the sandy regolith simulant found on the top layer of the arena and the gravel ice simulant. We chose a "rock bucket" type of system that is slightly modified to fit our needs. Similar to a salt and pepper shaker, the drill will have a conical cap that can rotate around the center axis; closing or opening a hole into

Figure 33: CAD of Mining Bucket Design (Open and Closed configurations).

the drill. This allows us to control when the simulants can enter or exit the drill's hollow center. Figure 33 shows a CAD model of the drill with the cap covering the hole and with it exposed.

4.4 Mining Rig and Rover Simultaneous Operation

The purpose of decoupling the mining rig and the rover into two separate, independently controlled systems is to increase the efficiency of the mining operation. Historically teams have attached some type of mining apparatus to a rover to make a mobile mining device. Although intuitive, this design philosophy constrains the entire system to either mining and not transporting regolith, or transporting regolith and not mining. There is a loss in time and therefore general efficiency as the two processes are coupled and restrict the other when engaged. Additionally, the weight of the mining component has to be transported in all of the rover's movements, whether or not it is full of regolith. By separating the systems we tackle a few different issues at once, albeit, introducing some new challenges that must be overcome. As a team, however, we've decided that by carefully constructing the geometry and planning the operation of the systems we can mitigate the impact of the additional design challenges.

Per the competition requirements the system will have to deploy together while remaining in the competition deployment volume and weight. To fit the space required the system will start with the mining rig loaded on the rover. The rover will then drive out to the mining area in the arena and drop off the mining rig. After the mining rig completes its first dig it will raise up so the rover can drive into it and the mining drill can release the regolith into the rover. As the rover

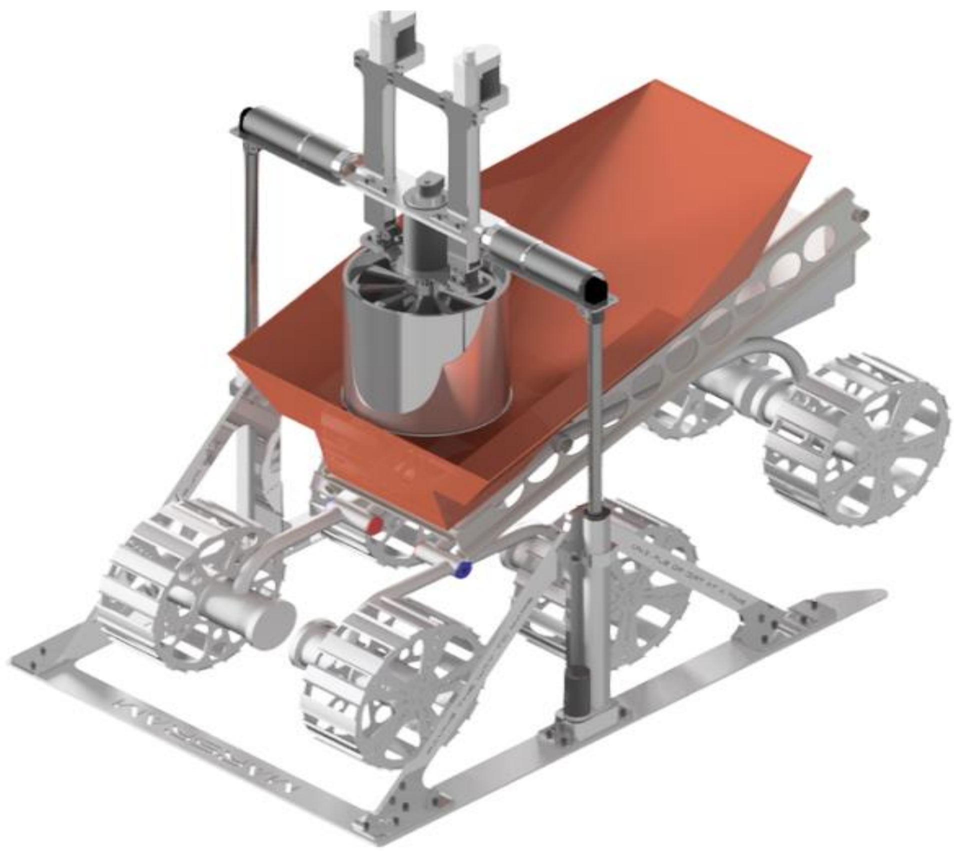

Figure 34: Isometric View of Rover and Mining Rig.

drives across the arena to deliver the regolith to the collection bin the mining rig can begin digging again so when the rover returns for the next load it is already full and ready to dump again. By allowing the system to collect regolith and traverse the competition arena simultaneously a significant amount of time per load of regolith delivered is saved. Once a flow has been established the time between deliveries of regolith load will only be dependent on how fast the rover can travel across the arena and dump each time. Figure 34 shows how the rover will drive under the mining apparatus for the regolith to be transported between the systems.

5.0 Community Outreach

The competition requires teams to be involved with the community by promoting science, technology, engineering, and mathematics (STEM). The competition requires teams to be involved with the community by promoting science, technology, engineering, and mathematics (STEM). Team 22 has been in contact with Challenger Learning Center, Lego League/Robotics Club, SAIL High School, Sealy Elementary School, and FAMU Developmental Research School. During these visits, the team will give a description of the project and display their current robot. Also Lego Mindstorms NXT will be used to allow the kids to become more familiarized with using LabVIEW and coding. LEGO Mindstorms NXT is a robotic kit that provides as a teaching tool to help kids program and is controlled by a joystick. This will aid in promoting robotics to kids of all ages.

6.0 Challenges

The biggest challenge for Team 22 is the delay in manufacturing due to the water-jet being down. This delay pushed back the set manufacturing dates two weeks. This is an unforeseen problem that in turn shortens the amount of time for modifications. The team will have to work more efficiently manufacturing and modifying the robot to make up for this pushback. While the water-jet was down, the team worked on ensuring all the designs were easily manufacturable. This will aid in the ease of manufacturing.

7.0 Gantt Chart

The Gantt chart can be seen in Appendix A-1. The tasks in red are the tasks the entire team will work on together. The tasks in blue depict the tasks Alexandria and Zachary will work on. The tasks in green portray the tasks that Andrew and Jonathan will work on.

This spring semester the team has finalized the robot’s designs to ensure the all parts are as easily manfuacturable as possible. Currently, the team is in the manufacturing and testing phase. Andrew and Jonathan are working on the chassis build. They are building one of the rocker-bogie wheels to guarantee that the designs are accurate before manufacturing all wheels. They plan to have the chassis completely built by February 10, 2017. Directly after, they will start manufacturing the mining apparatus. This should roughly take two and a half weeks, resulting in a completion date of February 28, 2017.

Presently, Alexandria and Zachary are working on Phase 4 – Testing. This encompasses motor/controls testing. They will have to write a program for skid steering for the driving of the rocker-bogie. They will finish motor controls testing by February 7, 2017. Wireless motor control testing will be the next step for the controls. This will be accomplished by February 15, 2017. After, telecommunication testing will be completed. This will allow for the user to telecommunicate to the rocker-bogie and the mining apparatus. All aspects of the robot should be controlled via telecommunication by February 22, 2017. This will lead into experimental testing. This consists of testing for debugging and functionality. This testing will gather data from the various runs. The data collected will entail the speed of the robot, the amount of regolith it collects, and other pertinent data. This data will then allow the transition into Phase 5, Modifications. There is an allotted time for mining component modifications, chassis modifications, and programming modifications. This testing and modifications will be exhausted until school is over, April 28, 2017. Phase 6 is the competition at NASA's Kennedy Space Center from May 22, 2017 to May 26, 2017.

8.0 Budget

The budget for this project was $2,000 from the NASA Space Grant Consortium. Dr. Clark has graciously donated many motors and boards that are feasible in our application. This donation minimized the spending of the parts needed for this project. The rest of the parts purchased were aluminum tubing, sheets, rounded piping, and rectangular piping. These were purchased from Online Metals resulting in a total of $734.98. This will allow for the manufacturing of the rocker-bogie system as well as the mining system. This leaves the project with $1265.02 to spend on possible modifications and unforeseeable problems.

9.0 Conclusion

The goal of the project has remained the same, to create a mining robot to excavate the basaltic regolith simulant and ice simulant. The team has finalized the designs for the rocker-bogie limitations and mining drill. Also the team has revisited these designs to ensure ease of manufacturability. The team is in contact with several schools to promote STEM outreach. Currently, the team is working on manufacturing the chassis and working on the controls for the wheels. Ideally, the chassis and the mining apparatus will be built by February 28, 2017. Also the mechatronics controls for the robot will ideally be completed by February 22, 2017 to allow enough time to begin experimental testing and modifications.

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APPENDIX A-1. Gantt Chart

Task Name	Start	Finish
MARSRAM Robot Design and Competition Preparations	**Wed 9/14/16**	**Fri 5/26/17**
Phase 1 - Research	Wed 9/14/16	Thu 9/29/16
Phase 2 - Modelling and Design	Thu 9/29/16	Wed 1/18/17
Rough Prototypes	Thu 9/29/16	Thu 11/3/16
CAD Designs	Mon 10/3/16	Fri 1/13/17
Ordering Parts	Fri 11/18/16	Fri 12/9/16
Finalized Designs	Mon 1/9/17	Wed 1/18/17
Phase 3 - Manufacturing	Mon 1/9/17	Tue 2/28/17
Chassis Build	Mon 1/9/17	Fri 2/10/17
Mining Build	Fri 2/10/17	Tue 2/28/17
Phase 4 - Testing	Wed 1/25/17	Fri 4/28/17
Motor/Controls Testing	Wed 1/25/17	Tue 2/7/17
Test Wireless Motor Control	Wed 2/8/17	Wed 2/15/17
Telecommunication Testing	Fri 2/10/17	Wed 2/22/17
Experimental Testing	Wed 2/22/17	Fri 4/28/17
Phase 5 - Modification	Mon 2/13/17	Fri 4/28/17
Mining Component Modifications	Tue 2/28/17	Fri 4/28/17
Chassis Modifications	Tue 2/28/17	Fri 4/28/17
Programming Modifications	Tue 2/28/17	Fri 4/28/17
Phase 6 - Competition	Mon 5/22/17	Fri 5/26/17