Design of a Martian Mining Robot

Team # 22 Midterm I Report

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Sponsor: NASA Robotic Mining Competition

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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 our design philosophy, a STEM outreach report, which will be discussed later in this report, an on-site slide presentation and demonstration on our project, and a grading on how much we 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. Our 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 rubric for how we are scored in the competition aspect 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. We plan to include sections such as optimization of our robot, the total schedule we followed over the eight month period we develop this robot, 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 we will give a presentation on-site at NASA Kennedy Space Center to discuss the scope of our project and how it progressed over our senior year. This presentation is to include a high level view of the systems engineering paper, detail our STEM outreach efforts, our social media and public engagement effort, and a presentation of our actual robot and its operation.

1.1.4 Outreach Project Report

An additional report we are to submit is the Outreach Project Report. Per the requirement of this competition we are to 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 we organized, what activities they were, the number of people involved in them, and what kind of impact we estimate to have had.

1.1.5 Social Media & Public Engagement

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

For the competition 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. For having a working robot there is an automatic 1000 points granted to the team. For the mining portion of the competition points are only earned after 10 kgs of material have been collected with the ice simulant gravel being five times per kilogram more than the regolith simulant. For the dust prevention points are rewarded at the judge's discretion. For 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. For every kilogram of weight added to the robot it is an eight point deduction and a point deduction for every watt-hour of energy

The competition arena is a 10 by 20 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 below. 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.

1.4 Previous Competitors

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 2 and Oakton Community College's in Figure 1.

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. Both robots experienced issues traversing the course. The UA vehicle collected regolith in the wheel that bogged down the system; likewise, the

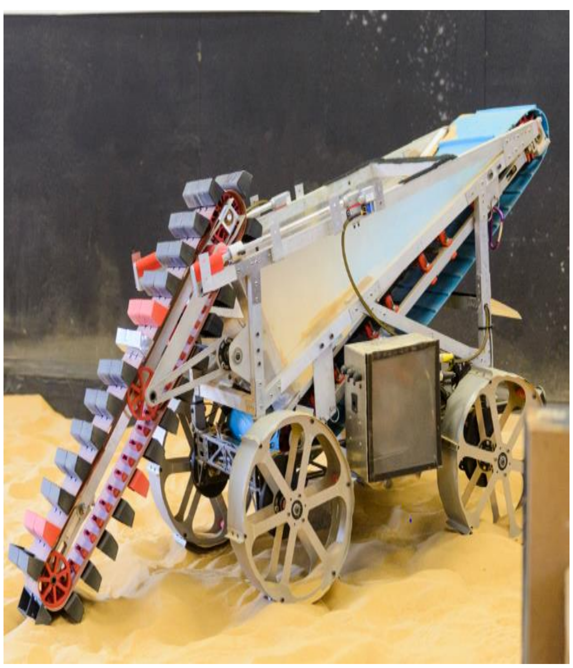


Figure 1: Universe of Alabama Robot (2015).

Figure 2: Oakton Community College Robot (2015).

Figure 3: Embry Riddle University Robot (2015).

Figure 4: Iowa State University Robot (2015).

Oakton wheels did not have enough surface area when the rover had dirt and would continually dig itself into holes on the return runs. Also of note the UA robot had dust issues with the motors and conveyor belt digging apparatus with continual build up in the joints.

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 1. 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, the robot was slow moving and had to avoid all obstacles in the Martian terrain simulation in the arena. The vehicle used a similar conveyer style mining apparatus to University of Alabama but with a dust shield greatly reducing the dust collection issues.

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. The mining apparatus that ERAU used was a rotating drum mechanism that could rotate in one direction to mine and the opposite to deposit greatly reducing the weight of their vehicle along with less power consumption and dust issues; however, the rotating drum could not collect as much regolith as its competitors. NASA has recently revealed their current Martian mining devices that uses the same technique for mining as ERAU but with two rotating drums as to collect more material.

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 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 5. The correlation legend is also depicted in Figure 5. 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 5. The importance rating was then determined by multiplying the customer importance by the corresponding relationships for each engineering characteristic.

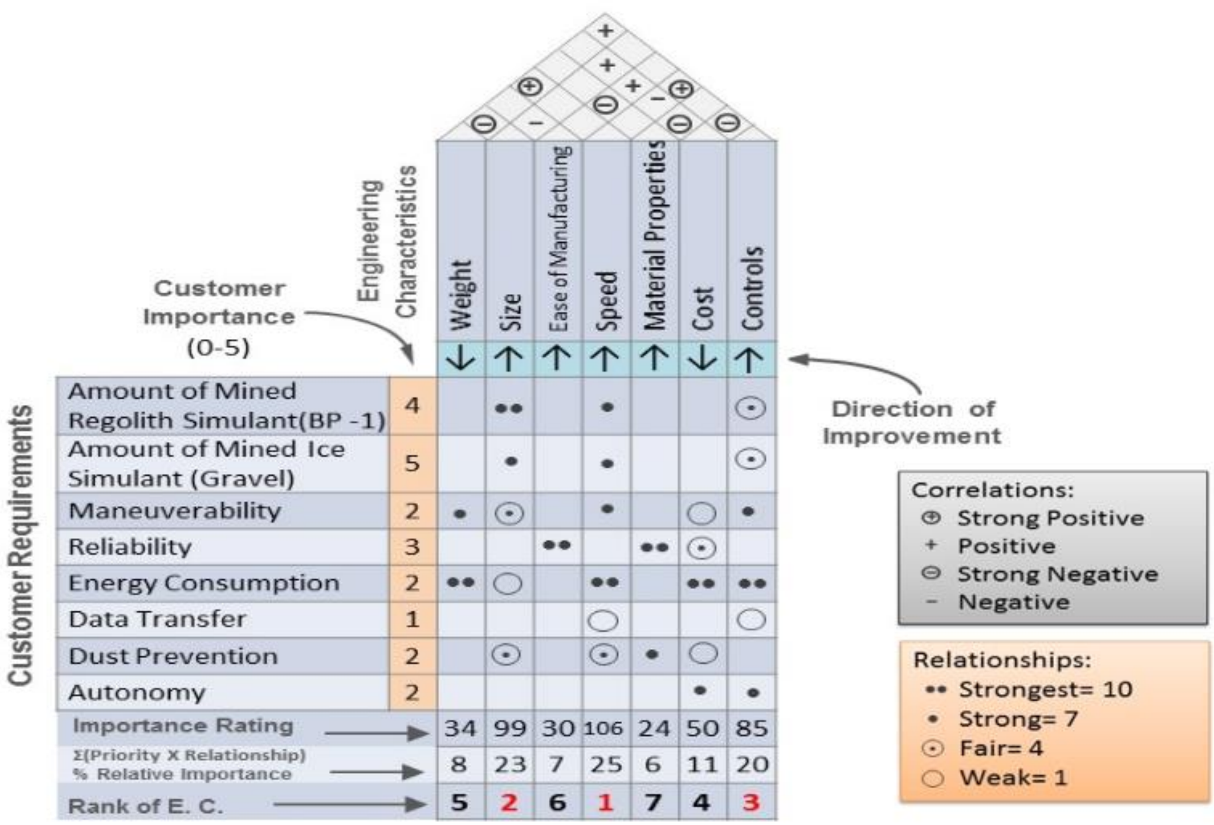
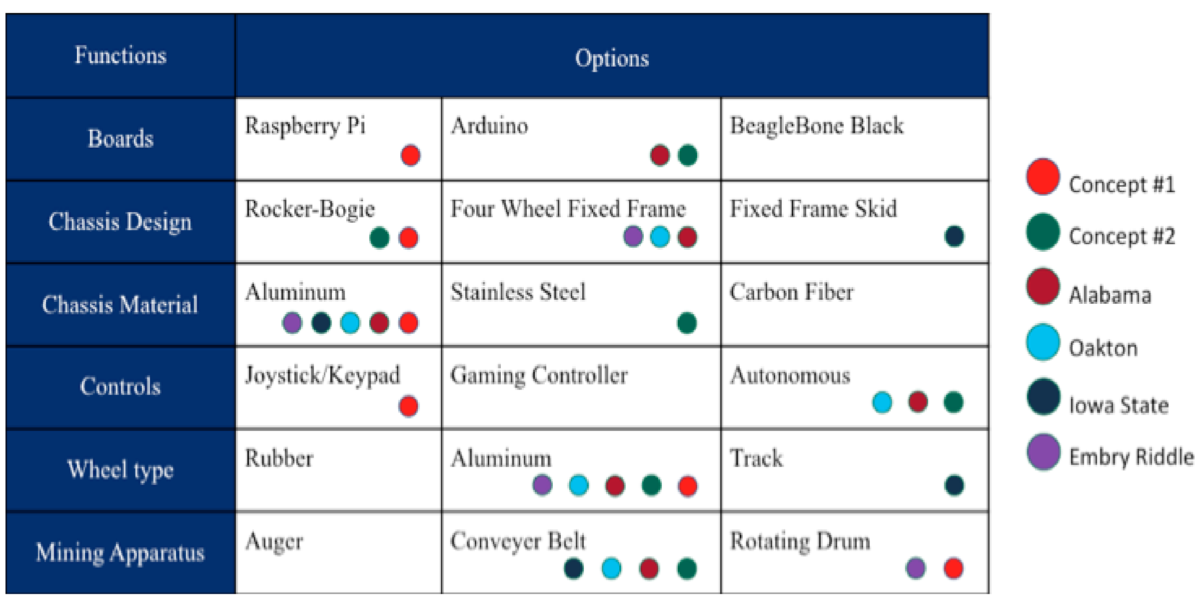


Figure 5: House of Quality comparing Competition Goals and Engineering Characteristics.

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 6 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 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.



Functions	Options		
Boards	Raspberry Pi	Arduino	BeagleBone Black
Chassis Design	Rocker-Bogie	Four Wheel Fixed Frame	Fixed Frame Skid
Chassis Material	Aluminum	Stainless Steel	Carbon Fiber
Controls	Joystick/Keypad	Gaming Controller	Autonomous
Wheel type	Rubber	Aluminum	Track
Mining Apparatus	Auger	Conveyer Belt	Rotating Drum

Figure 6: Morphological chart comparing various components in the design.

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 7 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 7. 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 7: 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.

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

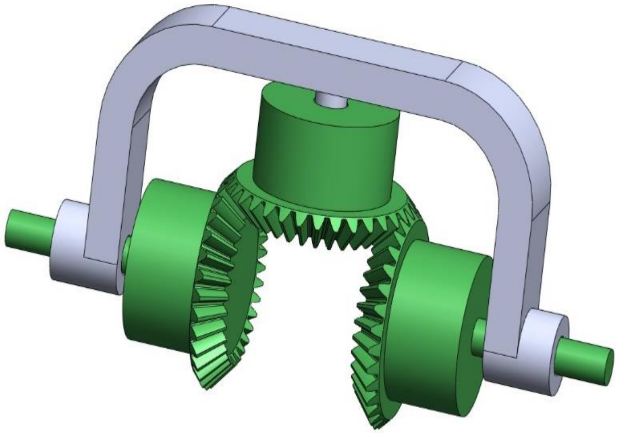


Figure 8: Differential for Rocker-Bogie System.

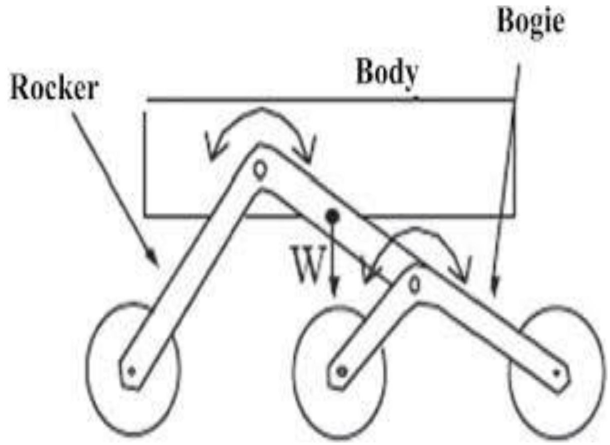


Figure 9: Components of a Rocker-Bogie System.

The feature that stabilizes the two independent Rockers from rotating at different rates is a differential gear set as seen in Figure 9. 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]

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

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

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

Figure 10: Equations of clearance for Bogie and Wheelbase parameters.

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. 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

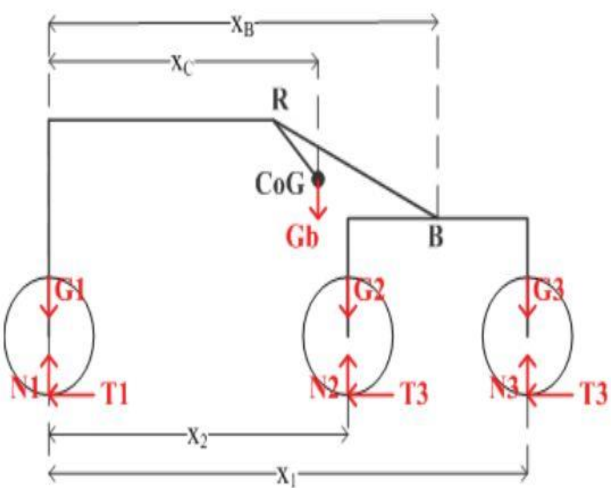


Figure 11: Rocker-Bogie wheelbase parameters

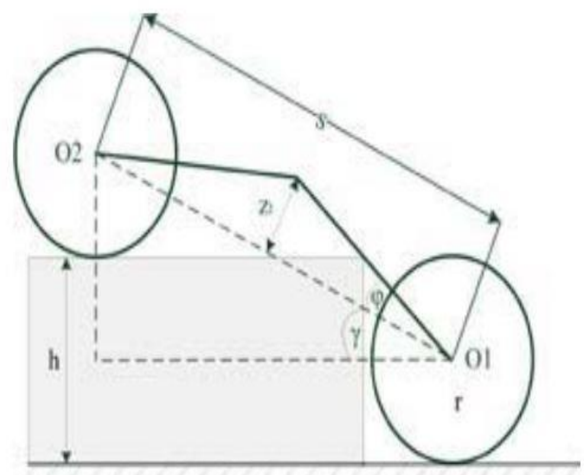


Figure 12: Bogie maximum clearance diagram.

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.

3.0 Scheduling and Resource Allocation

3.1 Gantt Chart

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

Currently, the design and prototype phase is being worked on. The design phase entails background research on the previous year's competitors, creating a house of quality, and morphological chart. This was used to give a better understanding of the engineering characteristics to focus on, as well as generating concepts and ideas for possible designs. Phase 1 will be accomplished by 10/31/16. Phase 2 encompasses building rough prototypes of the chassis design and the mining component. Also, this design includes preliminary CAD drawings of the chassis and the mining hardware based off the rough prototypes. Lastly, this phase includes mechatronic hardware research. Research will include motor and control testing, telecommunication testing, and determining the wireless motor controls. Phase 2 will be accomplished by 11/14/16.

The materials of this project will then be ordered over winter break (11/14/16). This will allow over a month for shipping and handling. Ideally, all the parts will be shipped by the start of the spring semester, 1/11/17. This will lead into the Phase 3, Testing. This includes building a functional prototype and performing experimental tests 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 4, Modifications. There is allotted time for mining component modifications, chassis modifications, and programming modifications. Phase 5 is the competition at NASA’s Kennedy Space Center from 5/22/17 - 5/26/17.

3.2 Budget

The budget provided for this project is $2,000. Funds have not yet been allocated to any particular part of the project, as the design has not yet been finalized. Dr. Clark has graciously donated many motors and boards that is feasible in our application. This will allow the spending on other parts.

Figure 13: SCRAP 1.0 Obstacle Testing

4.0 Results

Based off the background research and morphological chart, the Rocker-Bogie chassis design was chosen. The Rocker-Bogie was the optimal design because it will be able to traverse the obstacle course with ease. Also, it is a springless system that would be advantageous on Mars. This Rocker-Bogie will implement a skid steering system. In order to test this design, a SCRAP (Scaled Configuration Regolith Acquisition Prototype) 1.0 was created. This can be seen in Figure 13.

This prototype was created out of popsicle sticks, cardboard tubing, wooden dowels, and hot glue. The purpose of producing this design was to simulate the Rocker-Bogie system. The prototype was able to easily traverse obstacles, such as steps. This allowed for the team to build a better understanding of the Rocker-Bogie design and how to scale it up to the final design.

Aluminum was chosen over stainless steel and carbon fiber as the chassis material because it is lightweight, corrosion resistant, and ductile. Likewise, the wheels were chosen to be made of aluminum rather than rubber or tracks because of its dust prevention advantages and the ability to withstand the harsh Martian climate.

5.0 Conclusion

While the project has not been finalized some design specifications have been decided upon. A rocker-bogie chassis design has been selected for the current iteration of the project. Aluminum has been chosen as the chassis material and the wheel material. The robot's CPU will be implementing a Raspberry Pi as the main control board. The current setup of the vehicle will allow it to traverse the arena with ease. In the future weeks the team will finalize a mining apparatus design along with creating a secondary rough prototype to determine its functionality. This mining prototype will then be attached to the chassis prototype to ensure the compatibility of the overall design. The wheels on the prototype will also recreated to simulate the ratios presented in the papers along with a tread simulant.

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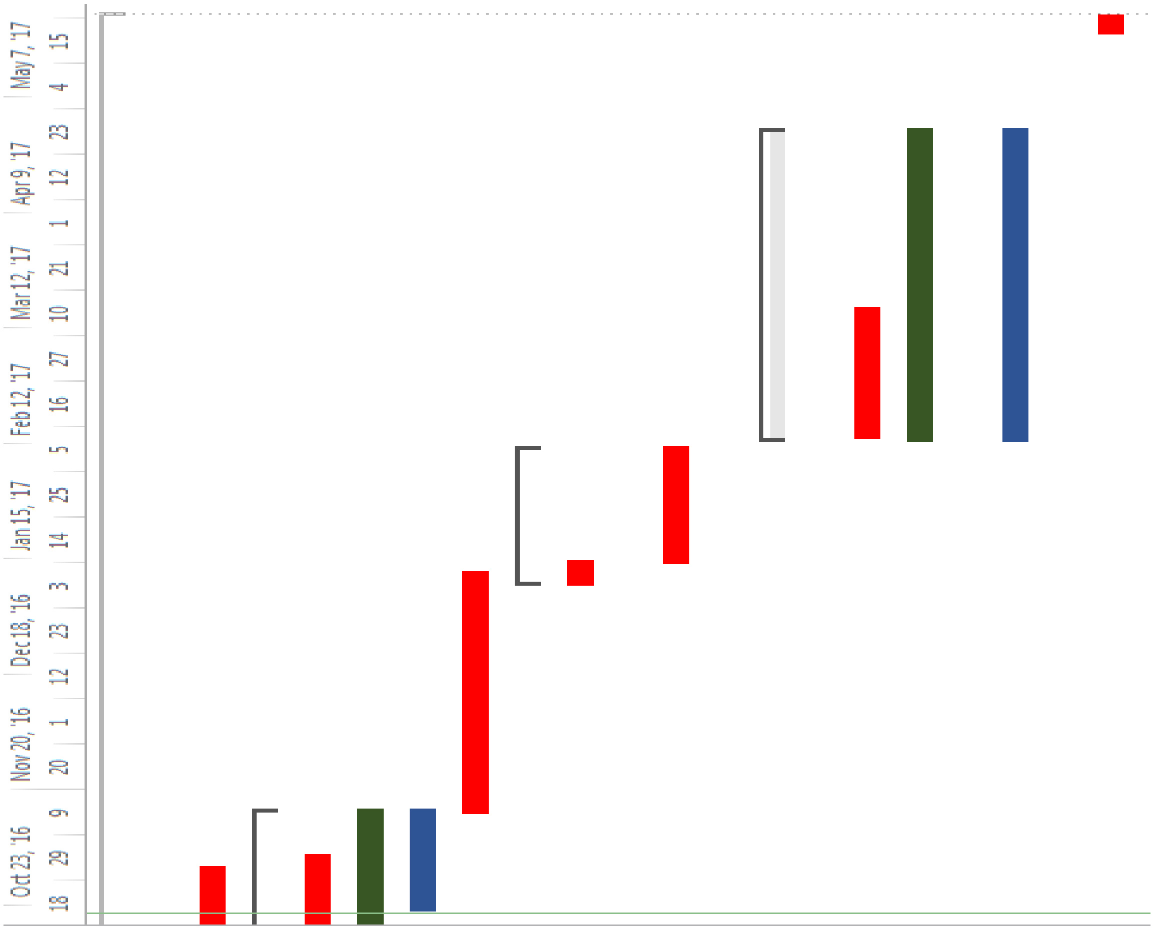
APPENDIX A: Gantt Chart



	Task Mode	Task Name	Start	Finish
0		**MARSRAM RMC**	**Wed 9/14/16**	**Fri 5/26/17**
1		Phase 1 -Design	Wed 9/14/16	Mon 10/31/16
2		**Phase 2 - Prototype**	**Thu 9/29/16**	**Mon 11/14/16**
3		Rough Prototypes	Thu 9/29/16	Thu 11/3/16
4		Preliminary CAD	Mon 10/3/16	Mon 11/14/16
5		Mechatronic Hardware	Sat 10/22/16	Mon 11/14/16
6		**Ordering/Shipping**	Mon 11/14/16	Wed 1/11/17
7		**Phase 3 - Testing**	**Mon 1/9/17**	**Fri 2/10/17**
8		Functional Prototype	Mon 1/9/17	Fri 1/13/17
9		Stage 1 - Experimental Testing	Sat 1/14/17	Fri 2/10/17
10		**Phase 4 - Modification**	**Mon 2/13/17**	**Fri 4/28/17**
11		Mining Component Mod.	Mon 2/13/17	Thu 3/16/17
12		Chassis Modifications	Mon 2/13/17	Fri 4/28/17
13		Programming Modifications	Mon 2/13/17	Fri 4/28/17
14		Phase 5 - Competition	Mon 5/22/17	Fri 5/26/17