Design of a Martian Mining Robot

Team # 22 Manufacturing, Reliability, and Economics

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Sponsor: NASA Robotic Mining Competition

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1. Design for Manufacturing

In the design for manufacturing phase of this report we will discuss how the rover was fabricated and assembled, the time it took to manufacture, the complexity and number of different components integrated into the rover, and show detailed cad drawings to illustrate how the components are integrated together.

1.1 Fabrication and Assembly

Unless specifically mentioned otherwise all hardware for the MARSRAM rover was designed, CAD modeled, and fabricated by team members in the CoE Machine Shop. The lion's share of the welding on the rover was done by the Machine Shop Employees Jeremy Phillips and Mandi Smith who we are especially grateful to for their help and guidance.

1.1.1 Wheels

The wheels for the rover were made by cutting a front and back face from ⅛" thick Al 6061 on a conventional water jet. The wheel cleats (or treads) were sheared in 4.5" sections from ⅛" Al 6061 and bent 45 degrees at the last ½" in a press brake on both sides. 15 cleats were aligned around the wheel face perimeters and tied tight with wire. Once firmly in place each cleat was welded to the wheel face (front and back). The front of the wheel face was designed with through holes to allow the wheel to bolt to a shaft collar fixed around the motor shaft. Figure 1 below shows the CAD model of a wheel and Figure 2 shows an actual wheel one once completed. The final rover incorporates 6 identical wheels.

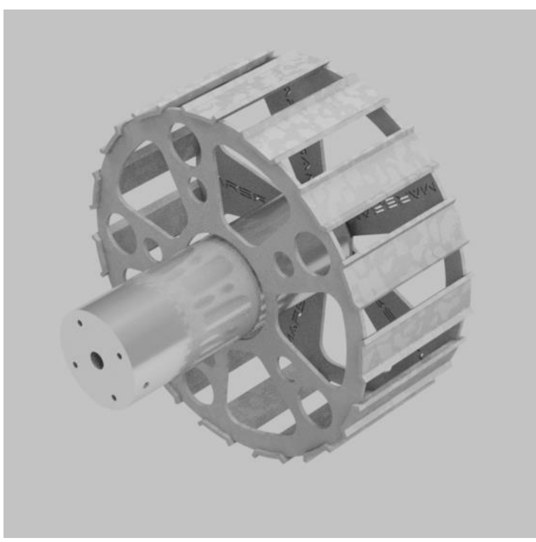
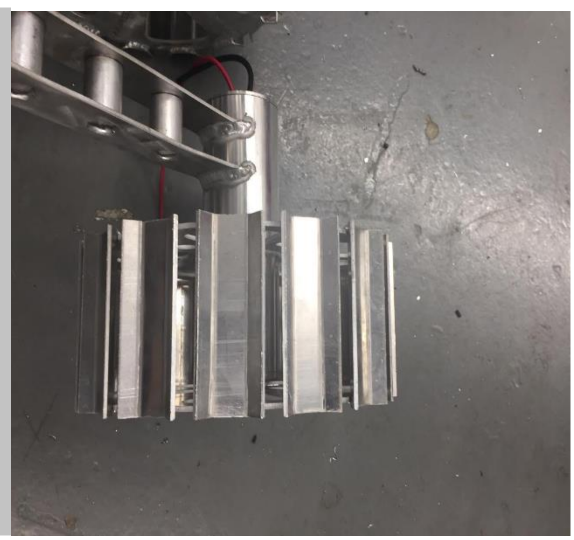

Figure 1: CAD Model of Wheels Figure 2: Manufactured Wheel

1.1.2 Wheel Motor Housing

The motor housings for the wheels were arguably one of the most intricate parts of the rover. Because the success of the rover's mission hinges on all six wheels working correctly, a robust architecture was designed to ensure that the load on the motor shaft was appropriately minimized, the output shaft was supported and centered via external bearings, and the motor itself was protected from dirt and debris via an outer shell with front and back caps. Figure 3 below is an exploded view of the wheel motor assembly. Figure 4 depicts the manufactured motor assembly.

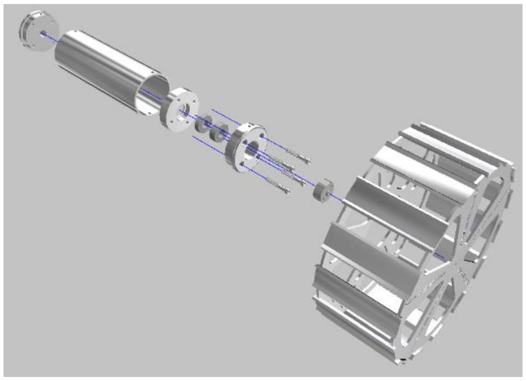

Figure 3: Exploded View of the Wheel Housing

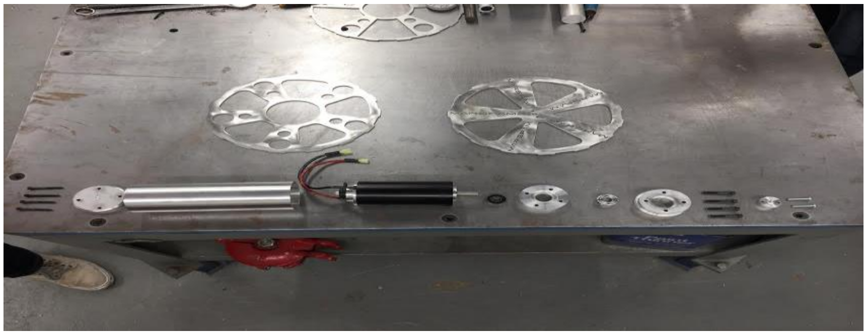

Figure 4: Manufactured Wheel Housing

The motor housing outside tube was initially machined on a lathe from Schedule 40 Aluminum Pipe, 2.5” Nominal ID, each motor housing was cut into 8” sections. Figure 5 shows the outer tube before and after machining to spec on the lathe.

Figure 5: Before/After Machined Tubing

Because the motor itself already had tapped M3 and M4 bolt holes we made caps for both ends of the motor shaft matching the bolt pattern on the front and back of the motor. Between the front of the motor and the motor housing front cap a bearing block was fit to hold a bearing around the motor output shaft. We purchased a generic shaft collar and tapped it to fit an M4 thread pattern. Bolts were then run through the face of the wheel, through a centering pin, and into the threads on the shaft collar. The front cap, back cap, and bearing block were profiled on a waterjet from ¾” Al 6061 bar stock and machined to final spec on a lathe. Finally, a through hole was drilled in the motor tube and the front cap was tapped with a ¼”- 20 x ¾“ bolt used to secure the motor and keep it from rotating in the motor tube.

1.1.3 Rocker/Bogie Legs

The rockers and bogies for the chassis can be likened to a ladder. The side profile of the rocker and bogie were first cut out on a water jet out of ⅛” Al 6061 sheet. Holes were cut out of them and 1” OD Al tubing was lathed down to press fit inside. Each rocker has a total of 10 support tubes between two water cut faces. Each bogie has 4 support tubes between two water cut faces. The bottom of the rockers and bogies were cut to fit around the outside diameter of the wheel motor housings. Once assembled, the rockers and bogies were welded to the wheel motor housing outer tube and the rest of the wheel motor was assembled externally and slid into the shafts. Figure 6 shows a CAD model of the bogie. Figure 7 portrays the manfuactured bogie. Figure 8 depicts the CAD model of the rocker and Figure 9 displays the manufactured rocker. Figure 10 shows the assembled picture of the rocker/bogie legs.

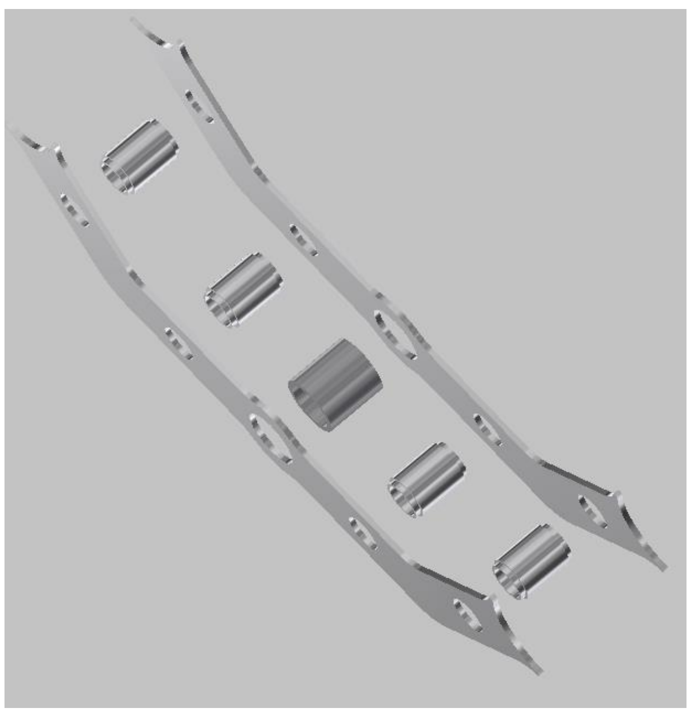

Figure 6: Exploded View of the Bogie

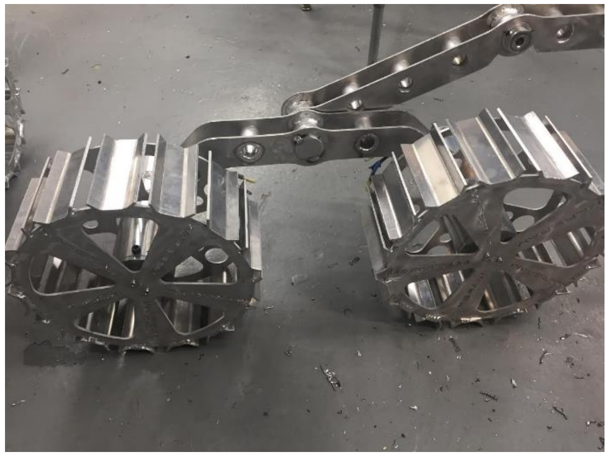

Figure 7: Manufactured Bogie

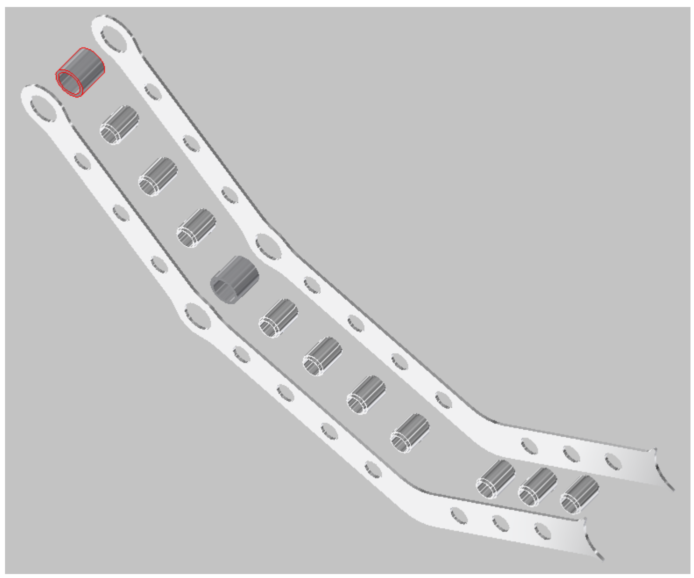

Figure 8: Exploded View of the Rocker

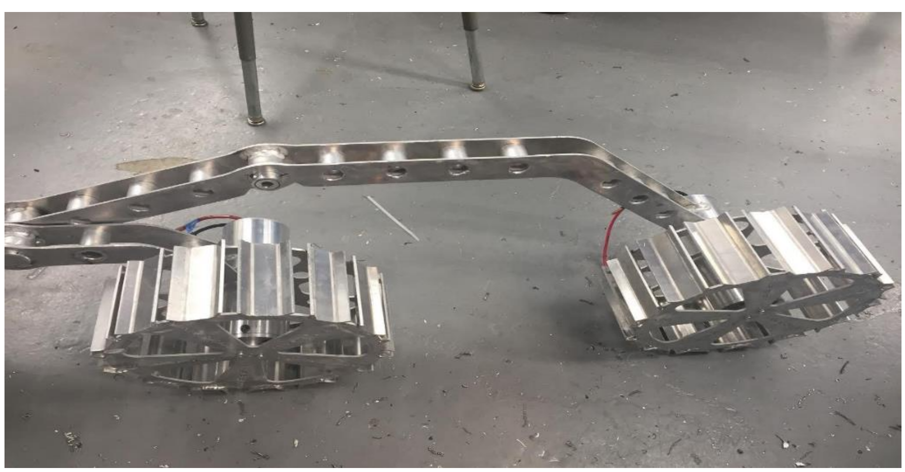

Figure 9: Manufactured Rocker

Figure 10: Manufactured Rocker and Bogie Assembly

For each bogie a custom connecting pin was made to attach it to its respective rocker. The pin was made on a CNC mill to get the perfect profile. It was carefully constructed to limit the rotation of the bogies to +/- 45 degrees with respect to their individual rockers. This rotation limit was implemented to ensure the wheel motor housings did not bump into the bottom of the chassis of the rover. The rotation limiter pin was made in two different parts with one welded into the rocker and one into the bogie of each side of the rover. They are connected via an M5 bolt, threaded about the center axis of rotation. Figure 11 shows the rotation limiters.

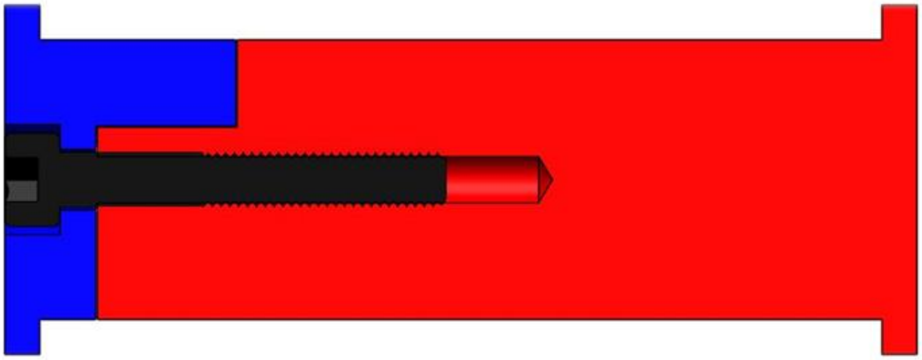

Figure 11: Rotation Limiter

1.1.4 R/B Differential Gearset

A rocker bogie suspension system by design uses a linkage system to connect the rockers across the chassis and ensure that any rotation due to terrain is matched equally and opposite across their shared axis of rotation. We chose to employ a bevel differential gearset to connect the two rockers. Each center pin on the rocker has a ⅜" stainless steel shaft that runs through it and directly into the gearbox. The gearbox frame was cut out on a waterjet, bearings were pressed into it, and 20 teeth - 0.7" OD miter gears were welded to the shafts. Two miter gears were placed on another shaft to run orthogonally to the rocker axis of rotation and act as idler gears to transfer the moment generated on one rocker across to the other. Figure 12 shows the gearbox in and out of the chassis frame.

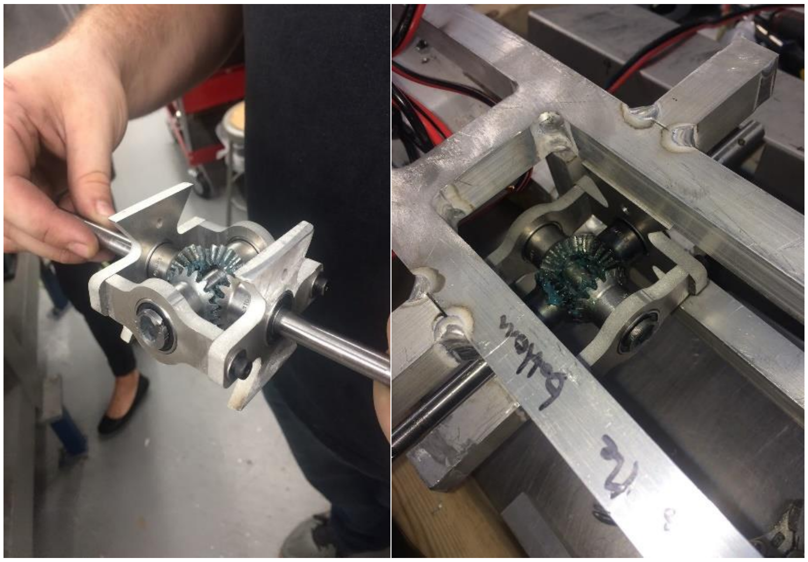

Figure 12: Differential Gearset In/Out of Frame

1.1.5 Chassis Frame

The frame of the robot was constructed almost entirely out of 0.75" OD Al 6061 square tubing. First the 8' sections were cut to their respective lengths on a bandsaw, then they were arranged in the rectangular pattern and welded together as shown in Figure 13. Mounts and brackets to connect the differential gear set and dumping mechanism with the linear actuator were profiled on a water jet and welded onto the frame. Figure 14 depicts the manufactured chassis frame.

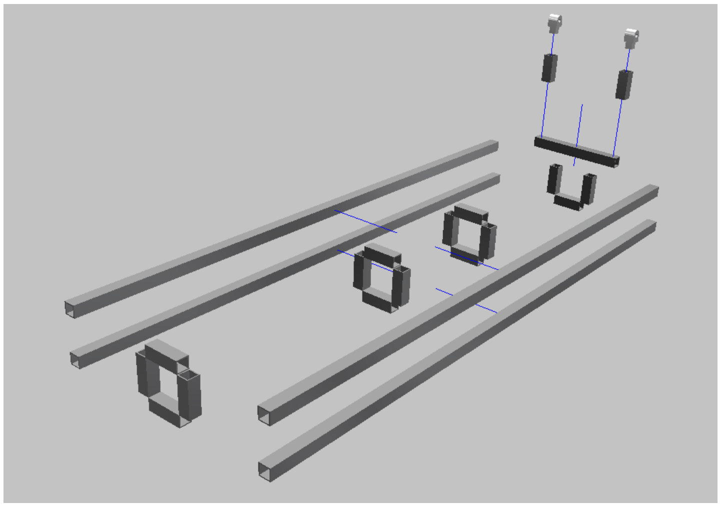

Figure 13: Exploded View of Frame

Figure 14: Manufactured Frame

1.1.6 Dumping Mechanism

The bucket dumping mechanism utilized more of the same 0.75” square tubing to support the bucket. A six bar linkage was designed and integrated to keep the stroke of the linear actuator down to just over 2 inches. The linkages for the six bar mechanism were profiled on a water jet out of ¼” Al 6061. Bushings were pressed into the linkage connection joints and shoulder bolts were used as the bearing surface. The mounting brackets to connect the linear actuator and linkages to the chassis frame and bucket frame were also profiled on a water jet from ¼” Al 6061. Figure 15 shows the exploded view of the dumping mechanism. Figure 16 displays the manufactured dumping mechanism.

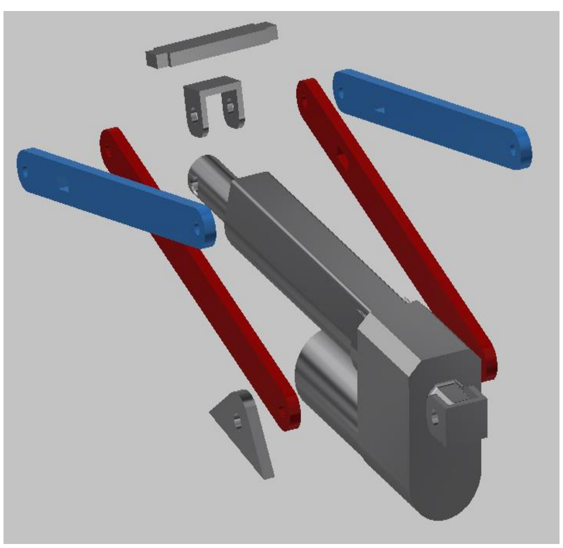

Figure 15: Exploded Dumping Mechanism

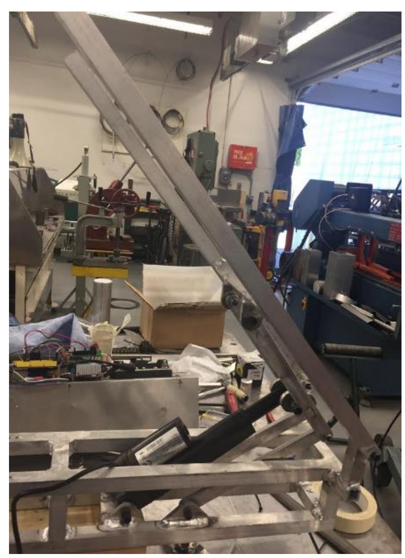

Figure 16: Manufactured Dumping Mechanism

1.1.7 Electronics

The electronics for the rover were spread out along the chassis frame to distribute the weight evenly across the center of gravity and keep the length of wires required to a minimum. Even so, the integration of the electronics is no small task. Firstly, the battery was strapped to the bottom of the frame using brackets made from ⅛” Al 6061. It was positioned near the center of gravity as to not significantly impact the already designed center. Sabertooth 2x60 Motor drivers were used to power each of the wheels and were positioned in a row near the end of the chassis. Next to the motor drivers are in-line relays connecting each driver to each motor. These relays are used as a measure of redundancy so the motors cannot move the vehicle without two separate logic trains enabling them. Behind the motor drivers in the bottom of the frame envelope the motor driver for the linear actuator and a voltage regulator for it were mounted. The rest of the electronics were positioned above the frame including a bus bar, voltage regulator, circuit board, Raspberry Pi 3, and Arduino Mega. Figure 17 shows the electronics above the frame, motor drivers in the frame, and the voltage regulator in the frame

Figure 17: Electronics Mounted on the Chassis

1.2 Complexity and Manufacturing Time

The complexity of our rover was unavoidable. In order to meet the competition guidelines a significant amount of mechanical design and electrical design was required. Few additional electronics were added at the team’s discretion for safety and redundancy. This project had a total manufacturing time of approximately 200 hours.

2. Design for Reliability

Through each phase of the design, including iterated attempts to fix problematic design flaws, every aspect of the rover was engineered for robust characteristics that would ensure long operation periods before necessary maintenance. This primarily focuses on three main factors for generating a functional and reliable design. Initially our main concerns were attributed to dust prevention, as the wind-blown dust particles are a large source of crippling component degradation and malfunction. Additionally, the design focuses on utilizing minimal moving parts, to reduce operational wear on components. Furthermore, because this is a product that will be sent to Mars, minimization of weight is critical.

2.1 Design for Dust Prevention and Dust-Free Operation

Dust prevention is critical in arid climates such as the Martian terrain that would be encountered. Due to the low moisture, combined with ceaseless large-scale windstorms, much of the surface contains loosely packed regolith particles. This causes the fine, angular regolith to be airborne, which covers objects in abrasive material. To reduce the damage caused by this wind-blown abrasive, many parts required additional precautions in the design phase. For many dynamic components, a protective shield was included to keep particles from the mating surface and allow for longevity in operational cycles. As seen in Figure 18**,** a double shielded ball bearing was implemented for each revolute joint. These types of metal shielded bearings are manufactured to hinder particles as small as 15 $\boldsymbol{\mu}$m from entering the bearing internals. The average grain size of Martian regolith JSC-1AF is 27.12 $\boldsymbol{\mu}$m, well above the hindrance grain size for manufacturable shielded bearings. Additional screens and composite layers with fine mesh could also be implemented around mating surfaces to reduce the introduction of contaminates.

Figure 18: Double Shielded Ball Bearing

These types of screens were also implemented on linear actuators as a type of below, to protect the mating surfaces of the actuated inner shaft from collecting debris upon full extension and drawing in the contaminates during the retraction motion. Furthermore, for areas of exposed components, a similar type of fabric was used. To allow for air circulation, fans are used to pull air across components and need to keep contaminants from entering the internal environment which contains electrical drivers and logic processing boards.

2.2 Structural Design for Reliability

Each component of the Chassis and Mining Rig structures were designed to reduce the amount of possible dust collection, while still providing ample strength and functionality. Many components utilize a laddered structure, which mimics an I-beam type construction. This provides large amounts of Inertial bending resistance, Torsional Rigidity and eliminates closed crevices where debris could be trapped. By implementing two parallel plates with crossed supports, a thicker section may be used in anticipated directions of applied loading with usually less weight than other geometry. This structural design does leave weaknesses along axis of unexpected loading. As seen in our Rocker and Bogie designs, they have larger moments of Inertia Longitudinally (Front and back) and Vertically, (Upwards and Downwards) but lacks strength in the Lateral direction (Left and Right). This was done in order to save weight and reduce manufacturing cost. As part of the design, we did not foresee any relevant scenarios that would introduce large Lateral loads.

2.3 Performance Evaluation

Based on the specified design characteristics, the theoretical model should last for a very long time in operation without necessary maintenance. All components are rated for a significant safety factor with respect to normal operations. This is attributed to the assumption that routine repairs is not practical in mining operations on Mars. The general assumption is that the uncolonized planet would not allow for a human or robotic mechanic to perform such maintenance task.

3. Design for Economic

The project currently costs $1,501.95. The components costs breakdown is displayed in Appendix A. The project’s budget was $2,000, leaving $498.05 in the budget. A pie chart of the total funds is displayed in Figure 19.

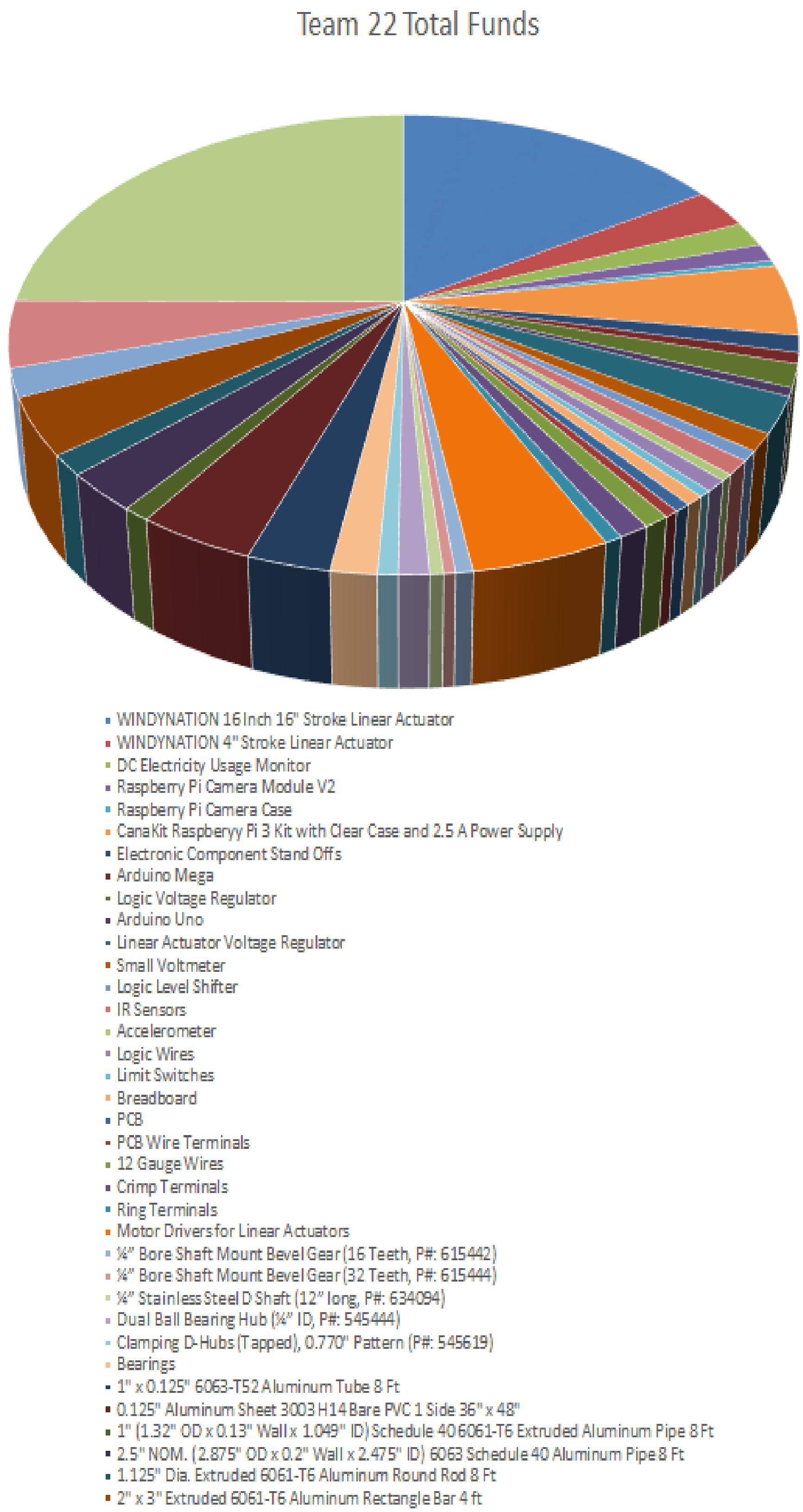

Figure 19: Pie Chart of the Total Funds

The MARSRAM rover is very different in comparison to other competitors in the NASA Robotic Mining Competition. The most similar rover is NASA's Curiosity Rover. This rover cost was approximately $2.5 billion. This is not an ideal comparison because the Curiosity Rover was built for Mars. The comparison between these two costs can be seen in Figure 20.

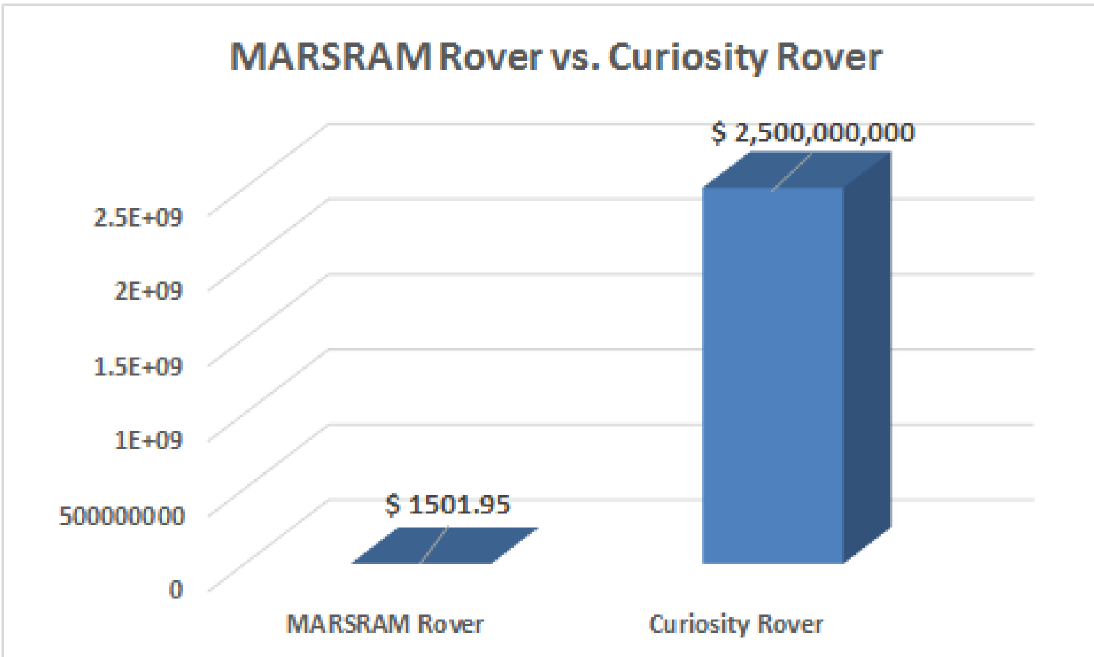

Figure 20: MARSRAM Rover vs. Curiosity Rover Bar Graph

References

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2) "The Real Cost Of NASA Missions." *Popular Science*. N.p., n.d. Web. 07 Apr. 2017. <http://www.popsci.com/real-cost-nasa-missions>.

Appendix A:

Table 1: Parts List

Part	Quantity	Unit Price	Total Price
WINDYNATION 16 Inch 16" Stroke Linear Actuator	4	79.99	319.96
WINDYNATION 4" Stroke Linear Actuator	1	56.99	56.99
DC Electricity Usage Monitor	2	17.99	35.98
Raspberry Pi Camera Module V2	1	24.78	24.78
Raspberry Pi Camera Case	1	8.49	8.49
CanaKit Raspberry Pi 3 Kit with Clear Case and 2.5 A Power Supply	2	49.99	99.98
Electronic Component Stand Offs	2	11.99	23.98
Arduino Mega	1	14.99	14.99
Logic Voltage Regulator	2	16	32
Arduino Uno	1	11.99	11.99
Linear Actuator Voltage Regulator	3	16.83	50.49
Small Voltmeter	4	6.03	24.12
Logic Level Shifter	2	6.99	13.98
IR Sensors	2	9.9	19.8
Accelerometer	1	8.99	8.99
Logic Wires	2	7.99	15.98
Limit Switches	1	8.99	8.99
Breadboard	2	6.49	12.98
PCB	1	11.59	11.59
PCB Wire Terminals	1	9.59	9.59
12 Gauge Wires	1	17.95	17.95
Crimp Terminals	2	10.69	21.38

Ring Terminals	1	12.38	12.38
Motor Drivers for Linear Actuators	2	47.95	95.9
¼” Bore Shaft Mount Bevel Gear (16 Teeth, P#: 615442)	2	5.99	11.98
¼” Bore Shaft Mount Bevel Gear (32 Teeth, P#: 615444)	1	7.99	7.99
¼” Stainless Steel D Shaft (12” long, P#: 634094)	2	4.69	9.38
Dual Ball Bearing Hub (¼” ID, P#: 545444)	3	6.99	20.97
Clamping D-Hubs (Tapped), 0.770" Pattern (P#: 545619)	2	6.99	13.98
Bearings	2	15.99	31.98
1" x 0.125" 6063-T52 Aluminum Tube 8 Ft	4	14.44	57.76
0.125" Aluminum Sheet 3003 H14 Bare PVC 1 Side 36" x 48"	1	81.84	81.84
1" (1.32" OD x 0.13" Wall x 1.049" ID) Schedule 40 6061-T6 Extruded Aluminum Pipe 8 Ft	1	19.06	19.06
2.5" NOM. (2.875" OD x 0.2" Wall x 2.475" ID) 6063 Schedule 40 Aluminum Pipe 8 Ft	1	53.88	53.88
1.125" Dia. Extruded 6061-T6 Aluminum Round Rod 8 Ft	1	27.98	27.98
2" x 3" Extruded 6061-T6 Aluminum Rectangle Bar 4 ft	1	79.44	79.44
0.75" x 3" Extruded 6061-T6 Aluminum Rectangle Bar 4 ft	1	38.94	38.94
0.249" Aluminum Sheet 3003 H14 Bare PVC 1 Side 24"x 48"	1	93.51	93.51
Total			1501.95