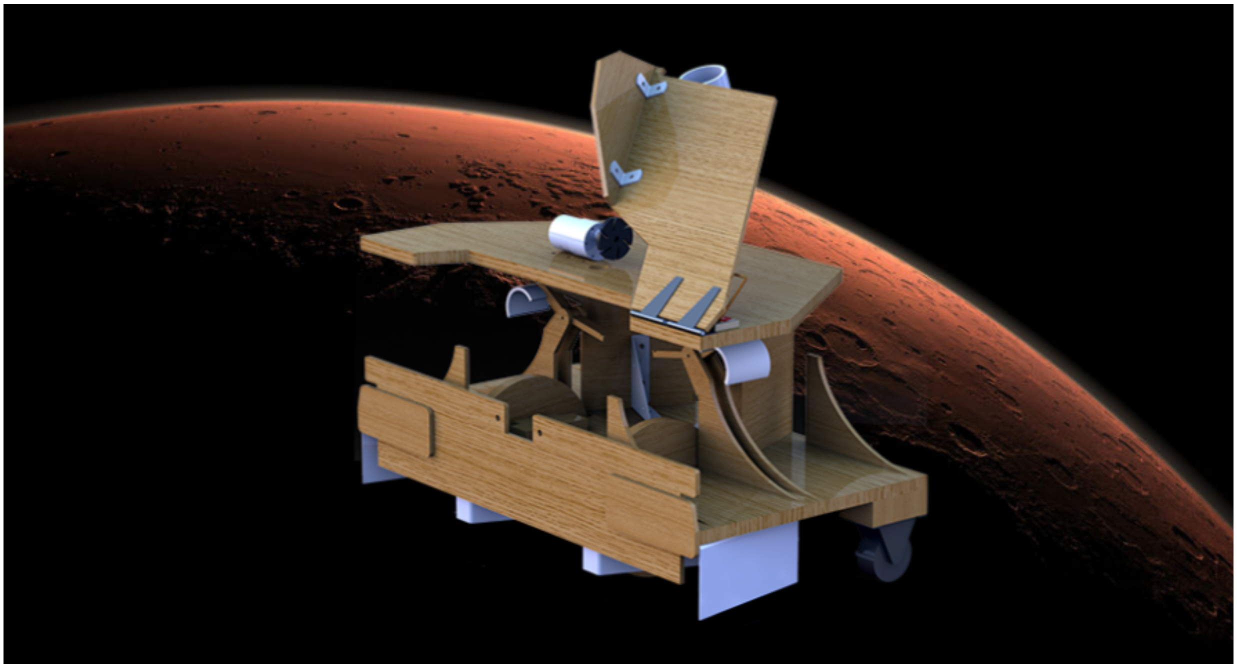
ME 2110-F

Final Report: Mission to Mars



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I. Executive Summary

Creative Decisions and Design (ME2110), a Mechanical Engineering Sophomore design course at the Georgia Institute of Technology requires students to compete in a final design competition, in which students team up to design and build an autonomous robot that must complete a variety of tasks in a given amount of time [1]. Each robot is subject to stringent restrictions in terms of energy forms, materials budget, running time, allotted mechanisms and machine size. The Spring 2017 competition took place on April 7th, 2017 and was scored accordingly: four robots competed at a time on the 'Mission to Mars' track, and the teams were ranked by scores received in this run. Teams with rank 1 or 2 could move on to the later rounds. The specific tasks robot was to perform in each round will be further discussed in this report. In order to acquire the most points in this final competition, the robot was to meet specific requirements in order to facilitate successful design, assembly and operation. Five proposed designs for the final robot each explore alternative options for successfully completing each competition task. This report will discuss each of these proposed designs, the final design chosen and reasons for choosing the selected design. There will be a full description of the chosen system, as well as subsystem presentations. This report will then proceed to discuss the design process for the chosen design and its consequent performance in the prior competitions as well as the Final Competition. Finally, the report will cover potential areas for better robot performance and ultimately how this correlates with system design.

II. Introduction

The *Creative Decisions and Design* "Mission to Mars" final design project presented the challenge of accomplishing multiple tasks with limited space, time and budget. To address these challenges, a machine with the most efficient and feasible subsystems for completing each task was produced. The machine was required to complete the following tasks: clear radioactive materials, collect rocks as resources, land spacecrafts in the Safe Zones in the Mountain Ridges while avoiding the Unsafe Zones, retrieve astronauts and rovers, and place a national flag in the center of the competition track. There are other restrictions on the machine: it must be able to easily clear a 12" x 18" x 24" 'go-no-go' box; the maximum budget for materials was 100 dollars, and the machine must stop all movements 45 seconds after the start [1]. In terms of directly controllable power sources, only pneumatic valves, cylinders, actuators, two motors, two solenoids and five mousetraps could be used in total. In addition, the machine must be triggered by banana plugs, which were connected to the competition track. Most challengingly, the device had to be completely autonomous.

Based on the these restrictions, one of the most difficult challenges was choosing the correct control signal for each step of the competition. The different steps for each task were connected by signal inputs and outputs; and as mechanisms that can generate or receive electronic signals are limited, they need to be distributed carefully to each task. Completing each task with the allotted energy sources was also one of the core challenges. Also, to ensure best reliability, reliable triggering mechanisms must be designed, and the total parts and steps of the functioning machine in order to reduce the probability of malfunctioning need to be reduced. Ultimately, the final robot need to be cautiously built in order to avoid severe consequences like disqualification. Advantages and disadvantages of each preliminary design were evaluated by the team members. Design E was identified as the most feasible option, because it most successfully balances the mentioned task objectives, restrictions, and potential consequences. After building a testing machine for the Qualification Competition, in which the machine was not reliable enough, the team decided to manufacture a new, more reliable, wheel based design ('Optimus') for the final competition. The final design had the most precise control, by using the timers, digital-input sensors and reliable actuators, and the most precise manufacturing mathods including laser cutting and 3D printing. Based off of the Optimus' performance in the final competition, the wheel design is an effective way to accomplish tasks at the mountain range, however it is subject to more random variables than a typical drawer slider based design.

III. Design Overview — Complete System

'Optimus', shown in Figure 1, is a mobile machine driven by motor powered drive wheels that direct towards the mountain so that the competition tasks can be carried out within a close range of target. The device is triggered by banana plugs being closed in circuit. This starts the Motor 1 (shown in Figure 2), which begins turning the Transmission Shaft and the Drive Wheels so that the machine can travel down the ramp and to the mountain range. 0.55 seconds after the start, two solenoids trigger and pull down on the Holding String that connects two Tube Releasing Arms. These arms therefore releases two cylinders off of the side, in order to knock out radioactive material. There is another motor attached to a flange, which holds two strings that control the Astronaut Arm and the Rock Board in the front of the car, as shown in Figure 1. A roller switch, as a digital-input sensor on the front hits the mountain range, causing the Motor 2 begin turning, disengaging the holding strings. This initiates the drop of the Rock Board in front of the collected rocks and releases the Astronaut Arm. As the Astronaut Arm swivels onto the mountain, the flag installed in the Flag Tube, which is mounted on the top of the machine, is launched into the mountain range. The mountain spins and astronauts and rovers hit the Astronaut Arm and fall into the team zone. Then, the machine backs up onto the home zone with the rocks collected.

The control system of the machine is based upon three important features. First, the machine is mostly time controlled. The chance for a timer to malfunction is extremely low and timers are independent of machine movement and outer contact, which makes this control very consistent. The second feature is that Motor 2 was used as the main actuator, which triggers both the front panel and the Astronaut Arm. This design was based on the fact that motors are more consistent and powerful than solenoids. The third feature is the backup system for the switch. Implemented in the machine is an additional timer that triggers Motor 2 three seconds after the run starts. This enables the machine to trigger despite switch malfunctioning.

IV. Design Presentation — Subsystems

There are four main subsystems on our machine, including the “Ridge Competition and Flag Subsystem”, the “Rock Gathering Subsystem”, the “Radioactive Elements Clearing Subsystem”, and the “Propulsion Subsystem”.

The Ridge Competition and Flag Subsystem consists of the Astronaut Arm, the Flag Tube, an L-Bracket that fixed tem together, two Flipping Mousetraps that rotate the Astronaut Board, and a string connected to a flange attached to Motor 2 to hold the board in its original place before triggering , as shown in Figure 3 and Figure 4. When the Motor 2 starts to spin, the geometry of the flange enables the Controlling String, which was initially hooked, to detach, enabling the mousetraps to rotate the Astronaut Arm and the Flag Tube forward. Figure 5 is a visual explanation of this process. The impact between the Astronaut Arm and the Mountain Ridge causes the flag installed in the Flag Tube to fall out along the direction of the Flag Tube and into the Mountain Range. Mousetraps were used to rotate the Astronaut Arm because the amount of motors was strictly limited to 2, and mousetraps are faster and more powerful. The geometry of the Astronaut Arm ensured that it fits the shape of the Mountain Ridge of every track. To ensure secured connection between the Flange and Motor 2, the Flange has a thick center part. To manufacture this complicated shape, 3D-printing was used.

Shown in Figure 2, The Rock Gathering System consists of a Sheet Metal used to gather rock samples when the machine went forward, and a Rock Board that will drop in front of the rock samples at the Mountain Range. The Rock Board is also connected to the flange by a string, which is similar to the Astronaut Arm mentioned in the previous paragraph. A roller-switch, as the Digital-input sensor of the machine, was also mounted on the Rock Board. The geometry of the Sheet Metal was precise so that each rock will fit into its own zone, with some space around it to make sure that the rocks would still stay under the machine even when they had some unintended movements. Also, precise cuts for the Propulsion Subsystem ensured that they doesn’t interfere.

The Radioactive Elements Clearing Subsystem consists of two solenoids as actuators, a Holding String, two Tube Releasing Arms, two Radioactive Elements Wipers (RA Wipers) and eight laser cutted Guiding Ramps, as shown in Figure 6. 0.55 seconds after the banana plugs are connected, the solenoids pulls the Holding String, lifting the two Tube Releasing Arms, as shown in Figure 7. Then, the RA Wipers is released and would roll down the Guiding Ramps, onto the track and knock radioactive materials out of the Home Zone. The RA Wipers were plastic tubes filled with sand to ensure enough mass and kinetic energy, enabling them to knock out the Radioactive Elements. For the sake of precise control and timing, both solenoids are used in this subsystem to increase strength, so that the string can be pulled for an enough distance instantly. For the same reason, the Brachistochrone Curve, which ensures that the RA Wipers roll down to the bottom of the ramp within a fixed amount of time wherever they start at, was used as the curvature of the Guiding Ramps.

The Propulsion Subsystem consists of a 12V worm speed reduction DC motor (Motor 1), a metal Transmission Shaft and two laser-cutted 6-in-diameter Drive Wheels, as shown in Figure 2. In order to increase the strength of the drivetrain and reduce slack inside the drivetrain, three plastic couplers were used. One of them was between the output shaft of the motor, while the other two are between the transmission shaft and the Drive Wheels. To ensure reliability and eliminate the usage of on the transmission shaft, set screws were used to attach couplers to the shafts or wheels. To improve the weight-bearing ability of the drivetrain while still maintaining low friction, roller bearings were used to fix the transmission shaft to the machine body. In order to increase friction between wheels and the ground to ensure straight moving and fast starting, hot glue was added to the outer edge of the Drive Wheels.

V. Methods and Results

The design and building process up to the Final Competition was meticulously laid out using planning and design tools such as a Morphological Chart and a Gantt Chart. As competitions progressed, personal and team responsibilities were reevaluated and priorities were revamped. In order to discern the appropriate design to compete in the final competition, five designs were presented. Each proposed design had varying functionalities and methods of carrying out each task. Ultimately, the winning design was chosen using an Evaluation Matrix (Table 2). The design and building process, as well as each alternative design is discussed in the following section.

In the Qualification Competition, the team "Optimus Primates" used a similar design (Figure 9), with Drive Wheels at the back of the machine. However, during the qualification Competition, the drive wheels failed to successfully pull the rocks back into the home zone. In order to solve this problem, team Optimus Primates conducted tests and then redesigned and rebuilt for a final machine accordingly. During testing, the drive wheel was moved to the front of the system, which allowed it to sit under the main subsystems and reduce the strain on the motor so that it was able to move backwards with the rocks. A counterweight was added to the back in order to make the machine even more stable (Figure 14). Also, to solve the issue of not fully gathering rocks behind the board caused by slipping of the rocks, the depth of the sheet metal was increased.

After extensive testing, Optimus was created. Different from machine used in earlier competitions, whose parts were manufactured by hand, most of the parts of Optimus was laser cut out of either 0.5 inch and 5 mm wood. The actuator flange was 3D printed and the rock catcher was made of tin and bent at particular angles and drilled to the bottom of the machine.

According to Table 4, the overall cost of the resources on Optimus was \$55.54. The bulk of this cost was the acrylic plastic used in the building process to create a casing around the

MyRio and wires on the top for protection. Additionally, the acrylic was laser cut for aesthetic purposes, and a back was placed to hold in the spacecraft since they were not being deployed. Another item that was heavy in cost was the axle for the drive wheel.

In order to prepare for the final competition, team Optimus Primates tested ‘Optimus’ on varying competition tracks roughly sixty times. In the process, the process of plugging in the National Instruments MyRIO and the driver board, setting the machine properly on the track, setting up each subsystem and boxing fully were practiced. As shown in Table 5, a Robot Preparation Checklist was utilized during the competition in order to ensure that the machine was ready for deployment during the final competition. As a result, the boxing and setup process was extremely efficient during the competition.

Prior to the creation of the final design Optimus, a long and deliberate design process took place. Alternative Designs were originally proposed and chosen based off of an Evaluation Matrix (Table 2). After the Qualification Round, the original chosen design was modified completely revamped based off prior competition performance. The alternative designs proposed are discussed below.

Figure 10 shows ‘Alternative Design A’, a motor powered car that moves on five casters. The Astronaut Grabber and Flag Holder are both connected to mousetraps. Once one mousetrap is released, it springs the flag into the center of the mountain range. Once the Grabber Arm is released, it rotates onto the mountain range and as the range rotates, the astronauts and rovers fall off into the home base. The motor powered rotor fits into the mountain range and flips out all of the spacecraft. The rock scooper uses a pulley to scoop up the rocks, and the arms flap out to push the tennis balls and create a barrier to hold them out.

In Figure 11, ‘Alternative Design B’ is shown. This alternative design gets from the home base to the mountain range via sliders and a car that moves along it. The frame holds the sliders and the car, in order to ensure that it can be placed in the 12” x 18” x 24” box easily. Similar to Design A, this design used a fan to flick out each spacecraft from the mountain range, and used a mousetrap powered swivel arm to grab the astronauts and rovers off of the top of the mountain. The flag is launched using the momentum of the car. When the car reaches the bottom of the tracks and jolts, the impact flips the flag off of the flag holder and into the designated spot on the mountain range. Additionally, Design B has cylinders on the side that roll off of the main car and out onto the track to knock away the tennis balls. Before tracks fold out and the car travels among them, the folding arm drops out and down and pulls the rocks in using a pulley and motor.

‘Alternative Design C’ is shown in Figure 12. The front arms are flung out using the mousetraps, and clear the radioactive materials. The front arm flops out of the mountain range due to gravity and momentum, and as the ridge turns, collects astronauts and rovers. At the same time, another two switches will start to detect safe zones and unsafe zones. Tubes containing the provided spacecrafts will be deployed by another solenoid. The tubes will be guided by the ramp and slide into the safe zones. A front flap then drops down, and a motorized wheel then drives the machine backwards to the home zone with the rocks collected. To restrict the movement of the wheels only in one direction, a ratchet mechanism will be used in this design.

Figure 13, ‘Alternative Design D’ is a design based on the machine the team used for the Qualifying competition. The Drive wheels of the Alternative Design D is on the rear of the machine, the position they were in the machine for the Qualifying Competition. To solve the issue of losing traction caused by the weight distribution, which made rear wheel leave the track, two counterweights were added to the rear of the machine. Moreover, this design used accelerometer to detect the impact with the machine and the center tube of the track instead of the switch. This would reduce the amount of digital inputs and thus reduce the possibility of malfunctioning.

During construction of Design D for the qualifiers, it was determined that a horizontal orientation was more viable in order for the machine to successfully collect rocks. Additionally, the team decided to add a swinging panel arm for the flag and astronaut/ rover collection. The resulting build is shown in Figure 9.

Concepts were initially evaluated using Table 2, the original evaluation matrix. Tasks on the evaluation matrix were ranked in terms of importance based of of the Competition Point Analysis Table (Table 1), in which the competition points were analyzed. For example, the maximum number of points a team can earn for successfully landing each spacecraft is 60, which is very high compared to the other tasks. However, 80 points can potentially be lost if the spacecrafts are landed in the wrong parts of the mountain range. Therefore, the spacecraft task was rated 6 on both evaluation matrices (Table 2,3) because it is extremely volatile and therefore not a first priority. On the other hand, the max points to be earned by landing the flag is 60, with no penalty. Therefore, it was assigned a high priority of 9 on the evaluation matrices. Machine characteristics that are required in order to not face disqualification in the competition, such as being small enough to box and autonomous, were given the highest priority on the evaluation matrix of 10. Each concept was evaluated based off of its potential performance for each task on the evaluation matrix.

Design A (Figure 10) scored high in tasks such as landing the spacecraft and collecting rock samples. However, it failed with regard to compactness and ability to place the flag, which as shown in the point analysis, is the most efficient way of gathering points. Moreover, using a fan to flick all spacecraft out of the mountain range is a very effective way to ensure for the highest number of points with respect to the other teams (albeit motor restrictions), however the arms could cause serious potential issues by throwing off the aerodynamics of the cart.

Design B, shown in Figure 11, excelled in compactness and collecting astronauts and rovers, but the downfall of the design came in placing the flag and removing radioactive elements. The machine design of the frame allows for sufficient packing, and visibility of the needed dimensions. However, the flag placement subsystem would be extremely unreliable and dependent on uncontrollable variables such as the track's coefficient of friction.

Design C (Figure 12) had the potential to deposit spacecraft successfully, do to the use of a pneumatic tank and sensors. However, movement of the cart would be actuated by a solenoid, which is not a historically consistent actuator. Also the rock slapper might be unreliable for retrieving rocks because it is dependent on the momentum of the board and the placement of rocks into the home zone would not be exact.

Design D (Figure 13) was based on the machine used in the Team Competition 3, which successfully accomplished the task of gathering astronauts and rovers. It used a ramp to move toward the Mountain Range, which enabled the machine to go faster than other designs that used motored wheels. This made the machine able to retrieve astronauts and rovers before other teams gather them. Arms for clearing radioactive elements were added to the machine and the ramp for releasing spacecrafts was improved. The Side Arms are long enough to clear most of the radioactive materials.

The original Evaluation Matrix created, shown in Table 2, lead to the choosing of Design D, due to Design D's high scores in landing the spacecraft and collecting astronauts and rovers. However, due to alterations made to Design D during the building and testing process up to the qualifying round, in addition to testing after the qualifiers, a fifth design was rendered and a new

Evaluation Matrix was created in order to compare designs (shown in Table 3). According the revised Evaluation Matrix, Design E had the highest rating with Designs D, C, B, A following behind in respective order. Based off of these results, design E is the best option by a large margin. Due to its compact frame, strong wooden structure, and the team members' familiarity with the design, this design was by far the most precise, and thus the most controllable and the most robust. Therefore, it received a rating of 4 in "Robustness", "Stability", and "Controllability" - which have high importance ratings. Nevertheless, Design E's ability to remove radioactive elements was merely a rating of 3 due to the limited amount of space for this subsystem, which was only better than Design D. However, based on the Competition Score Analysis (Table 1) and the team's analysis on past competitions, clearing radioactive elements is relatively unimportant comparing with other tasks, so that if other scores can be gathered consistently, the machine will still be able to have high performances. Therefore overall, Design E was identified as the best combination of simple, yet capable of accomplishing each task.

Team 'Optimus Primates' performed overall consistently throughout each competition. Each prior competition was used to alter design and change approaches to the competition. The following paragraphs discuss the team's performance throughout each competition and how those results were used to improve design and performance, as well as serve as a learning curve.

Team 'Optimus Primates' gathered 6 rocks total on Subsystem Competition 2. During this competition, each team was required to design an autonomous system that gathers 3 rocks materials and brings them up a small ramp to the home base. 'Optimus Primates' got two full rocks, or one full rock and two partial rocks out of three in each of the three trials, therefore adding up to six total rocks. As shown in the CAD Model (Figure 8), a Motorized Cart with a Swinging Arm actuated by a solenoid being pulled out the the Swinging Arm was used by the team. Once the arm swung down over the rocks, the Motor Powered Wheels of the cart were triggered and pulled the entire system backwards and onto the Home Zone. While 'Optimus Primates' tied for first in their lab section F, 6 is far from a perfect score of 9 rocks total. While the 'Optimus Primates' were able to get all three of the rocks on another track, the difference between tracks made it more difficult for the machine to climb the ramp, and resulted in that only two rocks (or one full rock and two partial rocks) per trial run.

The score for Competition 2 could have been improved by accounting for different ramp angles and track friction between the wheels, and using a more precise timing that makes the machine more reliable by programming the motor to reverse for a longer period, so that the machine would be able to back up closer to the edge of home base, in order to ensure full retrieval of the rocks. Placing more hot glue on the wheels to increase friction could also allow the car to move farther. Also, a more reliable way to transmit torque from the motor to the wheels would be needed to make control more precise.

Competition 3 required collection of the astronauts and rovers off of the rotating central mountain range, in addition to placement of spacecraft in the safe zones of the mountain range. However, if the spacecraft were to be inserted into the unsafe zones, it would result in a consequence of -20 points per spacecraft. In this competition, team 'Optimus Primates' received a score of third place. Team 'OP' had a score of 3 astronauts/rovers and 0 spacecraft in round one, 4 astronauts/rovers and 0 spacecraft in round two, and 4 astronauts/rovers and 0 spacecraft in round three.

Due to the fact that the subsystem for deploying spacecraft was not very mature, the spacecraft inserting subsystem was removed from the main frame in order to avoid negative points from wrongful spacecraft placement. While the spacecraft were loaded onto a ramp, the force of impact from the main frame hitting the mountain range launched the spacecraft into the mountain ridge without the control of the mechanism that identify safe zones and unsafe zones, which makes the performance completely random. Additionally, the collected astronauts and rovers were being adequately collected, but then falling onto the installed spacecraft ramp and sliding into the spacecraft zones, reducing the ability of receiving points for retrieving astronauts. These issues could have been avoided by changing to a more reliable triggering system that does not rely on the solenoids and by adding a guiding board to guide the astronauts and rovers away from the Spacecraft Ramp.

The subsystem for collecting astronauts and rovers was extremely effective, considering that all but one were captured throughout the three rounds. However, the arm swung out too hard onto the mountain range, so a string was attached last minute to hold it as a protection. This resulted in the one robot getting caught in the mechanism and did not fall into the home zone. These problems could have been further improved by removing the string and using a more controllable mechanism to restrict the movement of the arm.

The Qualification Competition included all the tasks that would be present during the final competition. Team Optimus Primates finished in 2nd place with a total score of 28 points after competing in 3 heats. The low overall score was a result of inconsistency with flag deployment and an inability to knock out radioactive elements.

In the Qualification Competition, Team 'Optimus Primates' strategically chose to only attempt the astronauts/rover rescue and flag deployment. After completing a Competition Point Analysis (Table 1), the team determined that making sure that the flag could be successfully put into the mountain ridge and receiving solid 60 points was the most efficient way of gathering points.

During heat 1 of the Qualification Competition, 'Optimus' successfully pulled into the lead with a score of 68 points (successfully deploying the flag and retrieving 2 astronauts). However, the flag was stuck on the machine and was not successfully deployed into the Mountain Ridge in the following two runs. The flag was stuck because during the boxing process, the top of the Go-no-go Box continually pressed down on the top of the flag, therefore distorting its orientation. This deformation changed the angle and the direction of the flag, making the flag stuck. This proved the device's inconsistency and failure to fit boxing dimensions, which occurred because in the design process of the flag holder, team 'OP' failed to account for the height of the flag, which increased the device's overall height. Due to this increase in height, the top of the Go-no-go Box continually pressed down on the top of the flag. Without deploying the flag successfully and without attempting to remove radioactive elements. The team scored negative 20 points in both rounds 2 and 3. Upon completing the qualification competition, team 'OP' decided to emphasize redesigning the machine to consistently deploy the flag within proper dimensions and to attempt the radioactive elements task to gather more points.

With an all-new machine 'Optimus', team 'Optimus Primates' entered the third round of the Final Competition. During the Final Competition, team "Optimus Primates" was off to a great start with successfully gathering 80 points in the Round 1, and gathering 46 points in Round 2. The team finished 2nd in both rounds. However, in the third round, the machine only cleared a radioactive element and gathered -42 points, receiving 3rd place and was not able to enter the Round 4.

Though the machine was able to receive the 2nd place in the first two runs of the Final Competition because of its ability of doing the flag task consistently, the machine failed to bring the radioactive materials back to the home zone. This was because there was a small space between the Motor Coupler and the Transmission Shaft, causing some slacking in the Propulsion system. Also, Motor 1 was not fixed onto the Motor Mount tight enough because the team did not have the correct screws, causing even more slacking. Thus, after these two runs, the tea did a maintenance on the Motor Coupler by tightening the screws and adding hot glue between Motor 1 and its mount to reduce slacking. After maintenance, the machine successfully climbed onto the home zone in the third round.

However, during the third round, a Spacecraft of another team was shot at 'Optimus', and stuck under the left Stabilizing Caster, causing the machine to turn left, missing the mountain ridge and thus got no points for the Mountain Ridge tasks. The rock samples also slid out of the machine due to the lack of the blocking effect of the Mountain Ridge, which could have prevented slipping before the deployment of the Rock Board. As a consequence, the Rock Board fell behind the rock samples, and the machine failed to gather the rock samples.

Though the machine only entered the third round, it was still proved to be considered as consistent and reliable. The problem of being interfered by other objects on the track could be solved by adding Sheet Metal around the machine. However, the team thought that the ability for this to happen was extremely low because it was not allowed to intentionally attack other machines on the track according to the competition rules. This proved that the team did not analyze risks comprehensively enough. Nevertheless, the performance of 'Optimus' proved that it could work as intended reliably. It avoided disqualification and, albeit extremely random variables, was able to consistently place the flag. This was due to the tight fit between the Drive wheels and the Transmission Shaft, allowing the machine to travel in a straight line. Also, the motor actuation was extremely reliable and worked every time. These results proved that the precise manufacture process adopted by the team was effective.

VI. Closing

From the Big Design Project of "Mission to Mars" and the class of ME 2110 as a whole, team Optimus Primates developed a set of skills in technical communication, mechatronics control, mechanical design and precise fabrication, became familiar with design tools and manufacture tools, and gained a new understanding on reliability oriented design in each of these perspectives. The continuous group work setting throughout the course of the semester emphasized the need to improve team skills in order to accomplish long-term projects like the Mission to Mars themed design challenge. From the early stages of problem understanding all the way through the design evaluation process, the team carefully considered all task objectives, restrictions, and potential consequences. Balancing these trade-offs the team selected the wheel based design ('Optimus'). During the final competition 'Optimus competed in a total of 3 rounds. While the wheel design proved an effective way to accomplish tasks at the mountain range, it was subject to more external variables ultimately leading to a machine malfunctions in round 3. This inability to handle random track variables during competition ended team Optimus Primates' quest to reach to final round of competition.

VII. Appendices

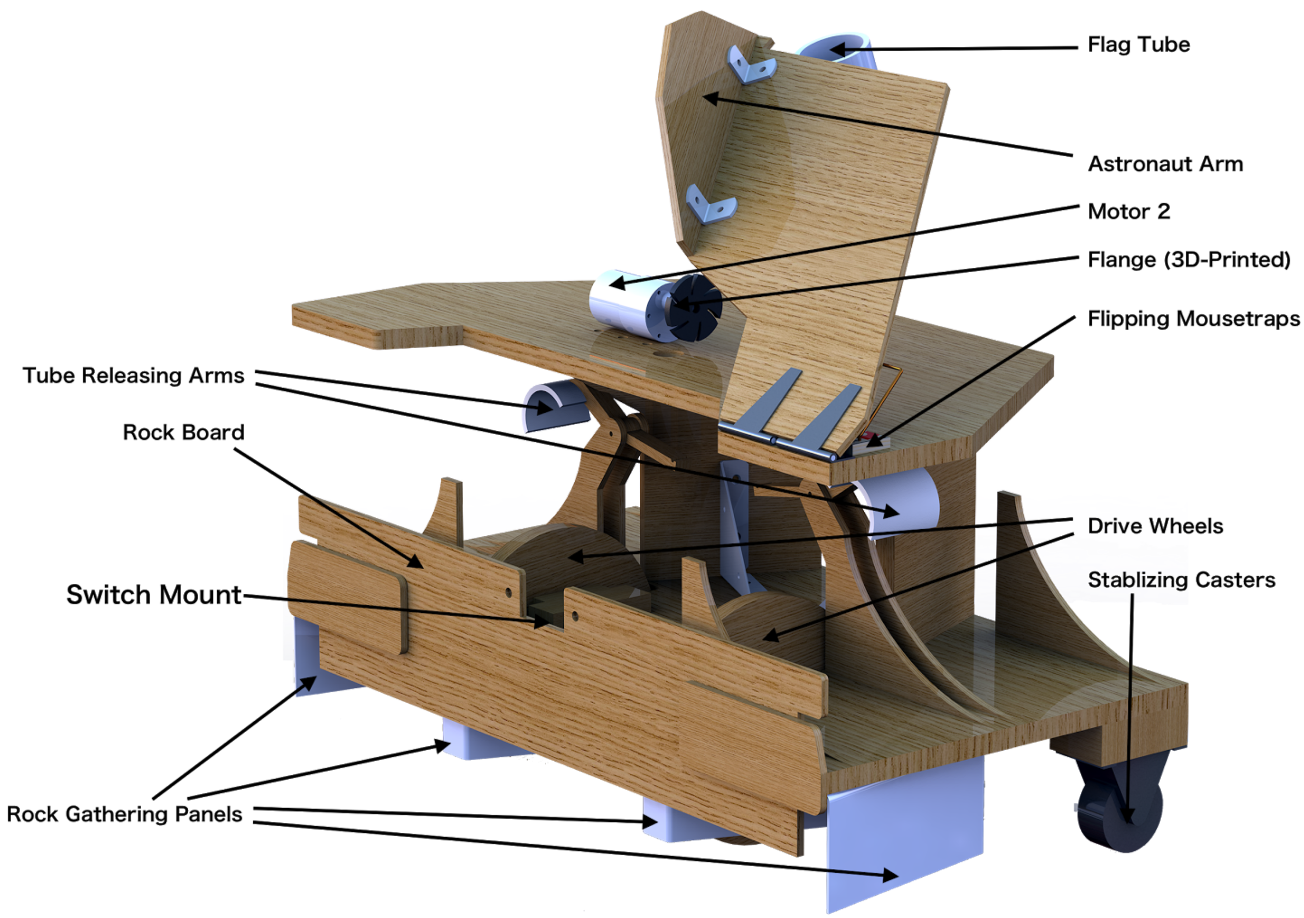

Figure 1. Assembly CAD Model of the Final Competition Machine

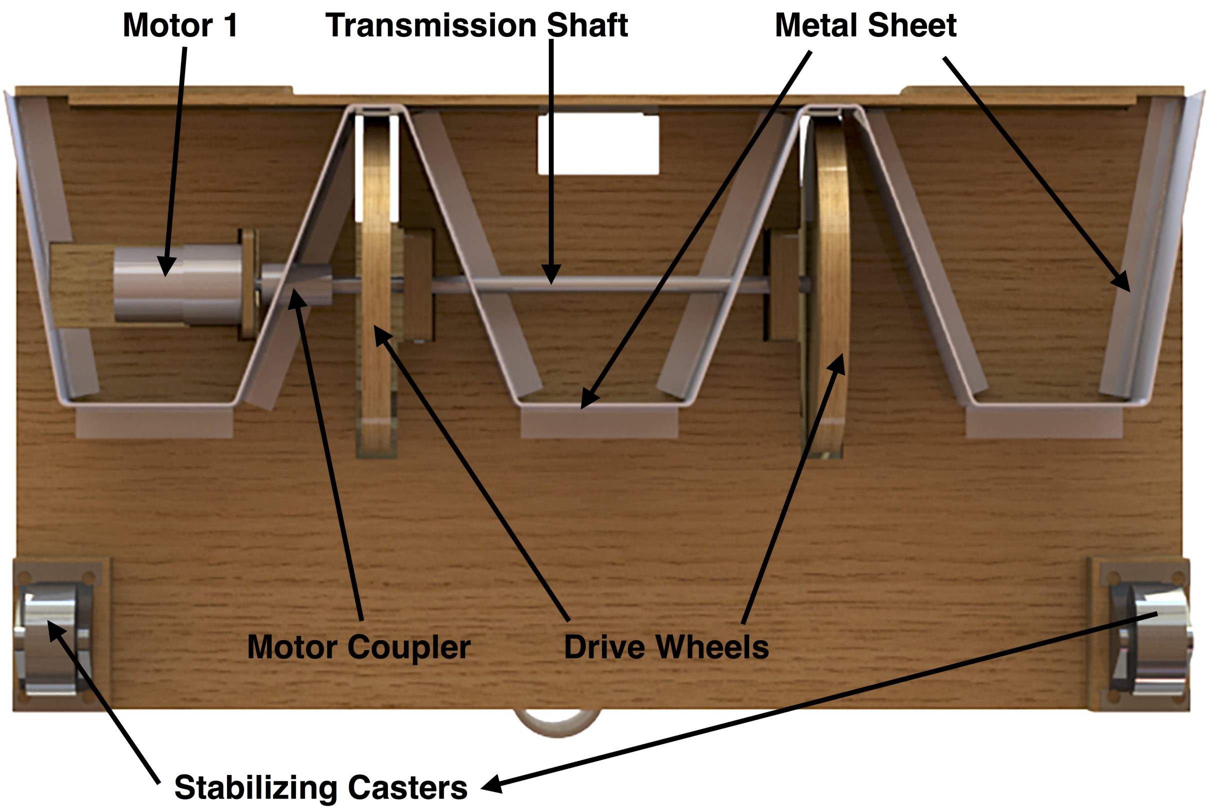

Figure 2. Assembly CAD Model - Bottom View

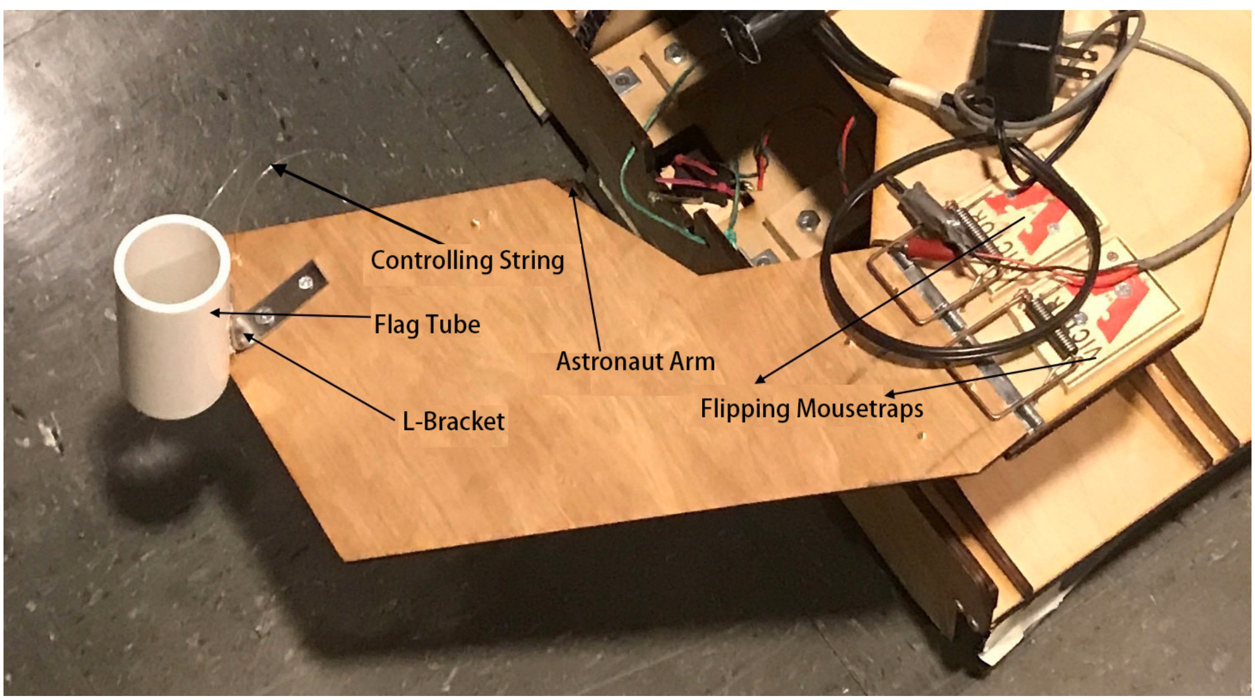

Figure 3. Ridge Competition and Flag Subsystem (Arm Deployed)

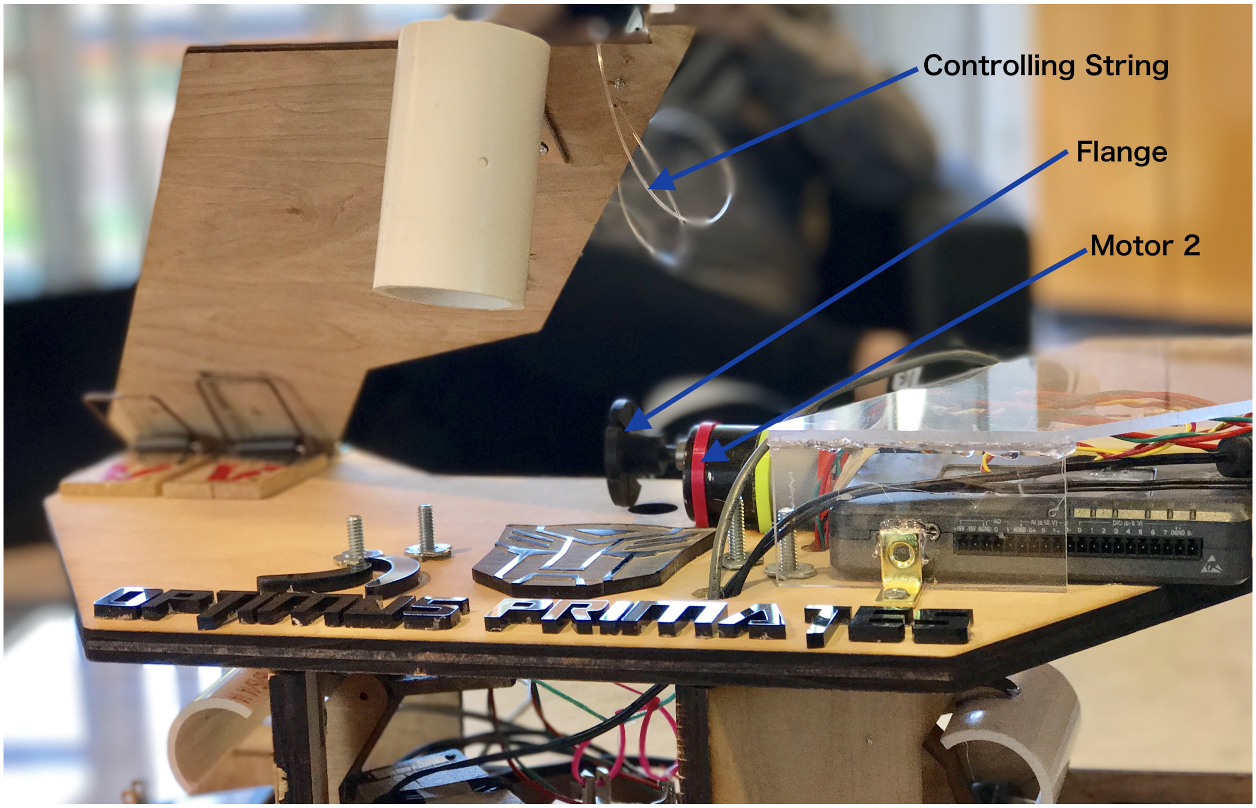

Figure 4. Ridge Competition and Flag Subsystem 2 (Arm Retracted, String not Attached)

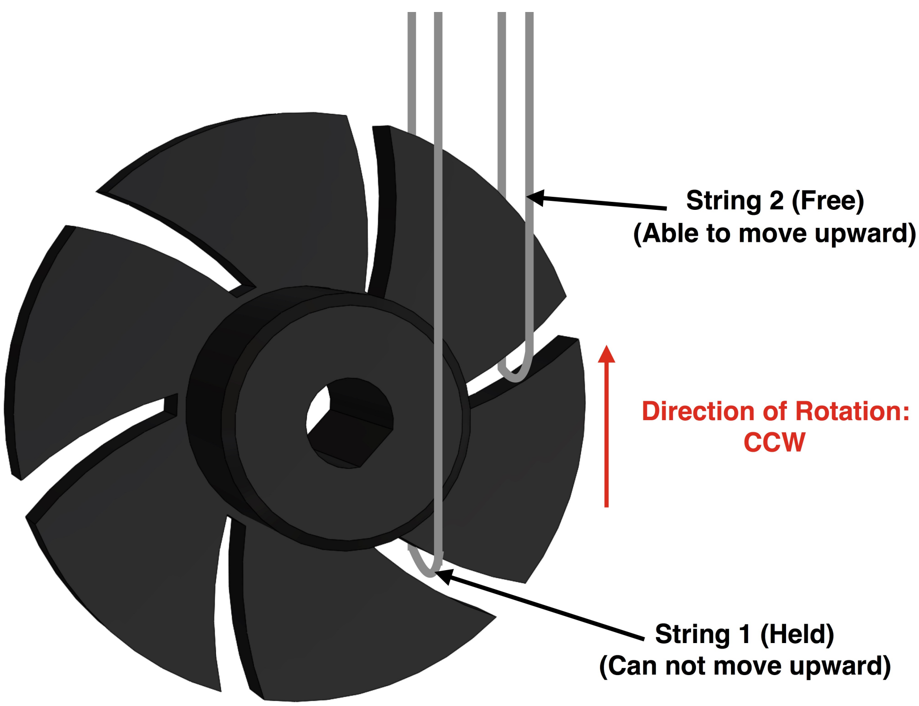

Figure 5. String-holding Flange Explanation

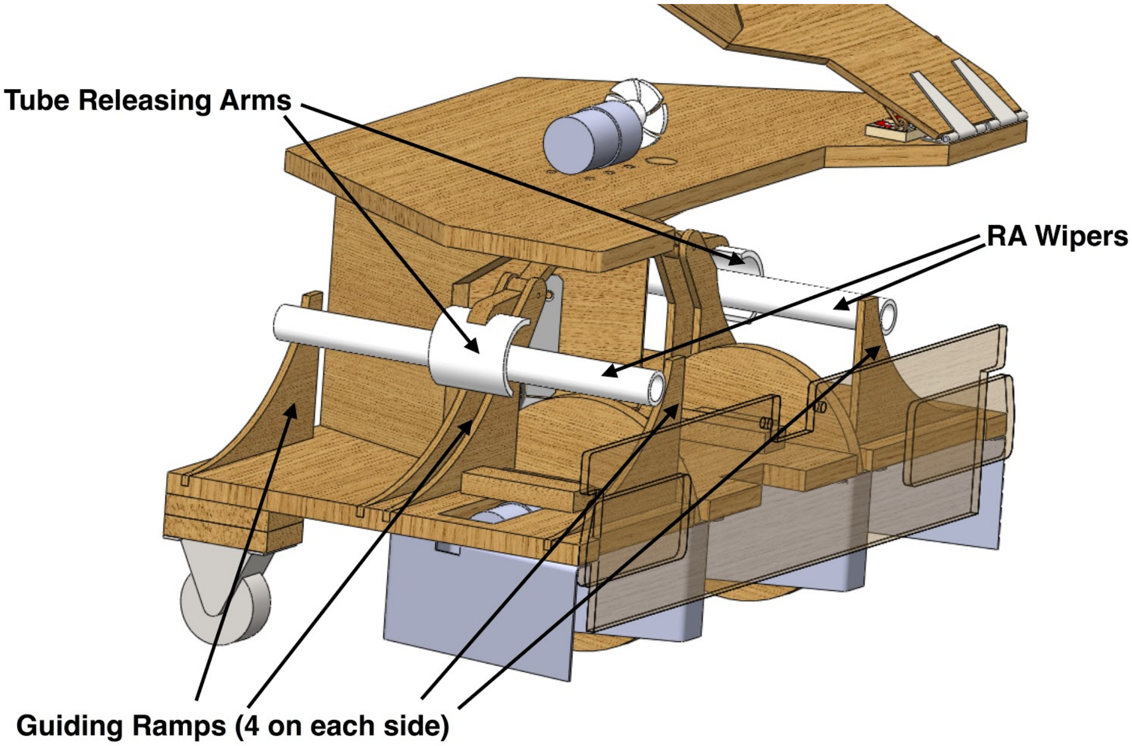

Figure 6. Radioactive Elements Clearing Subsystem

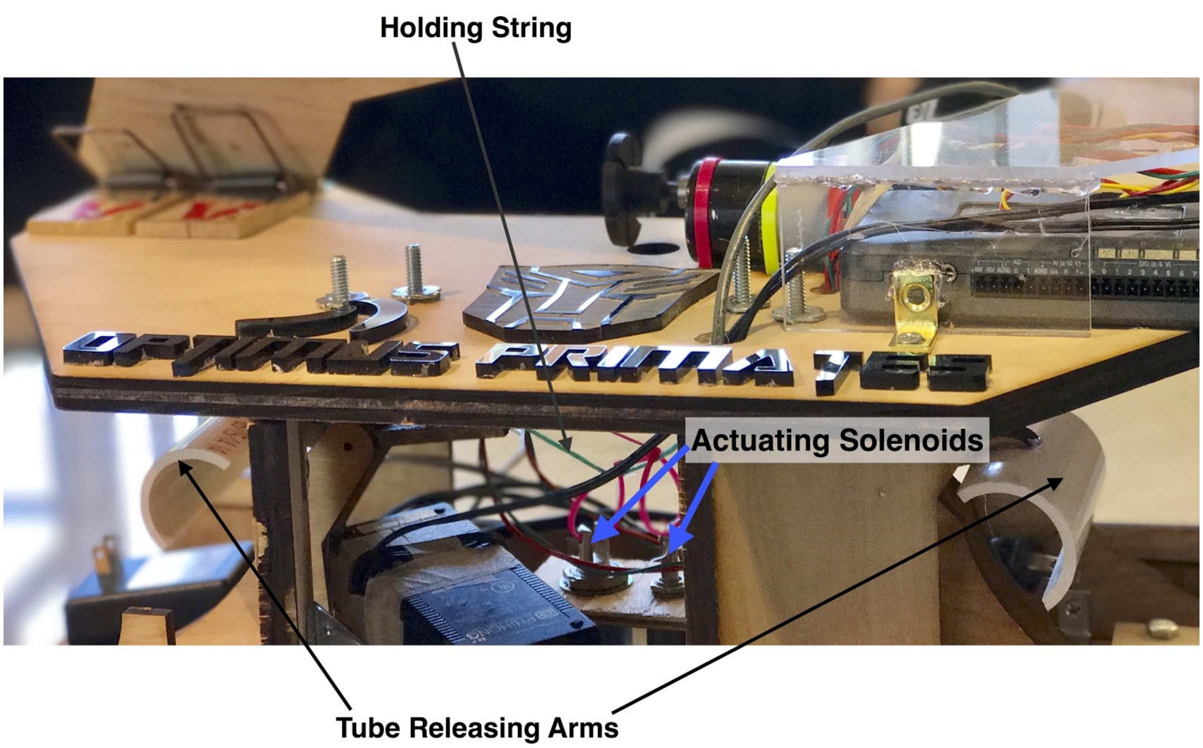

Figure 7. Solenoid-based Actuation Explanation

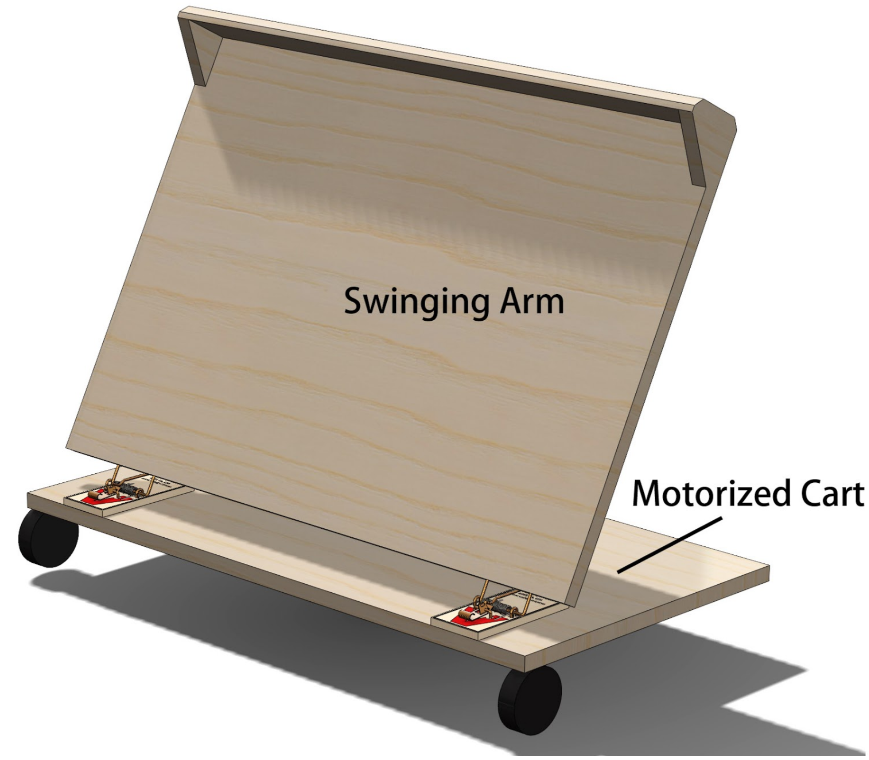

Figure 8. CAD Models of Competition 2 Machine

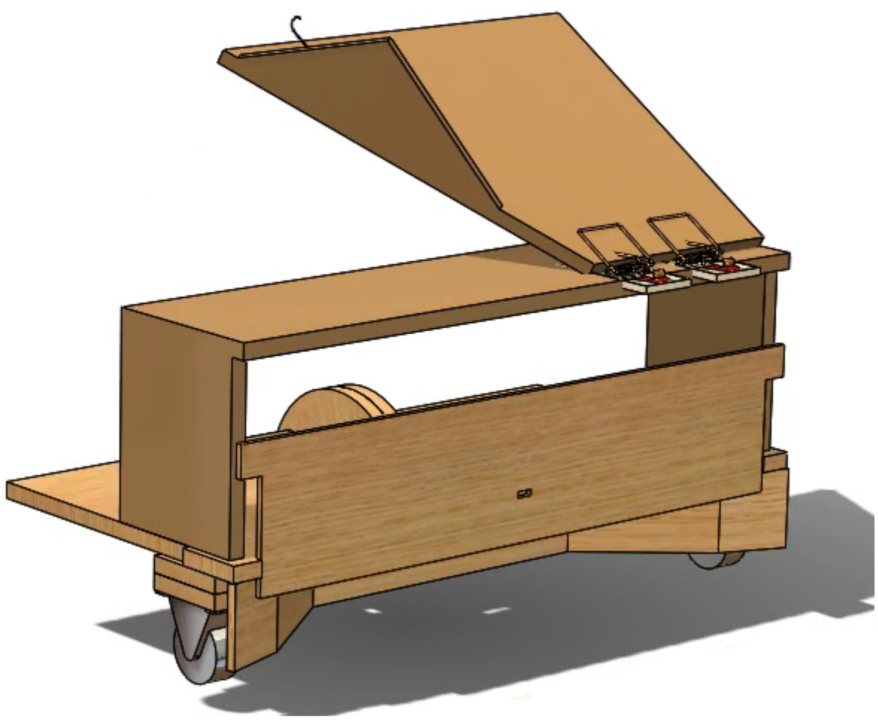

Figure 9. CAD of Qualification Competition Machine

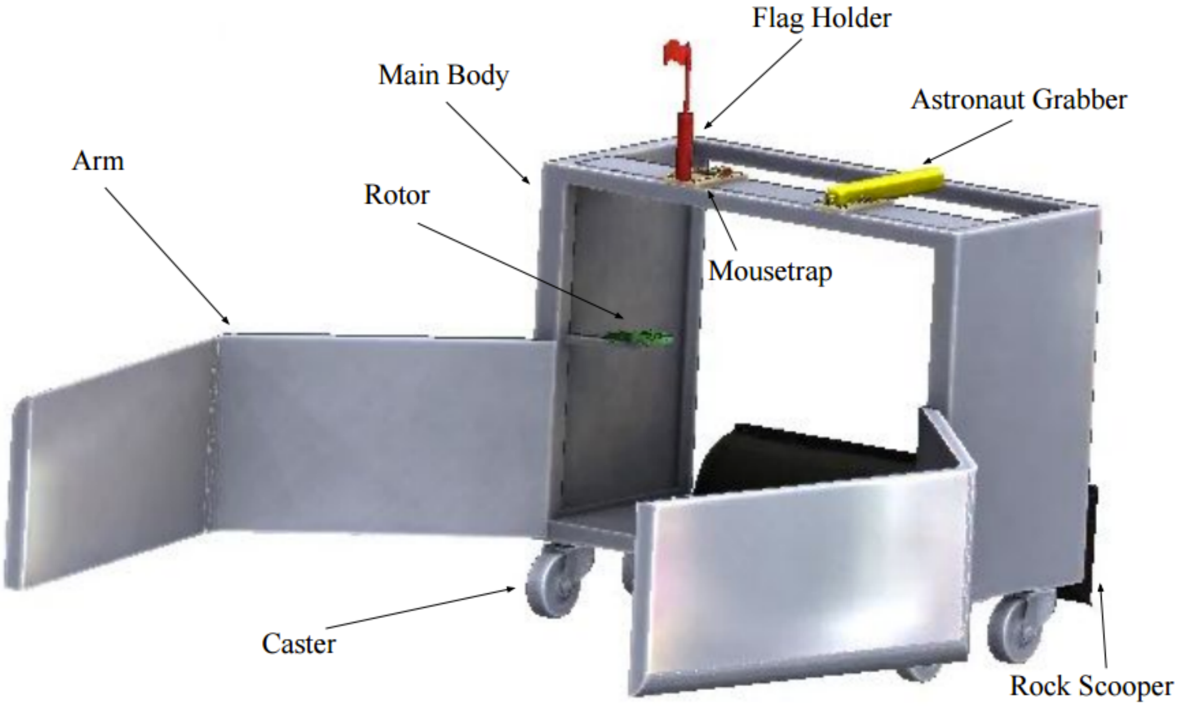

Figure 10. Alternative Design A

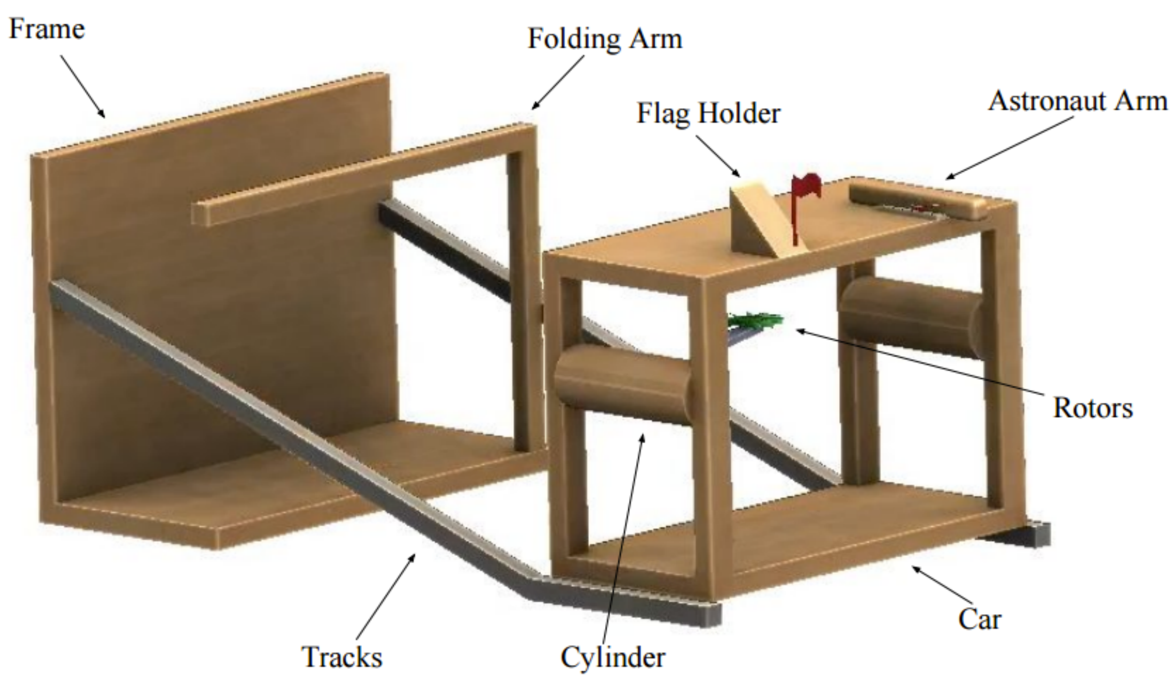

Figure 11. Alternative Design B

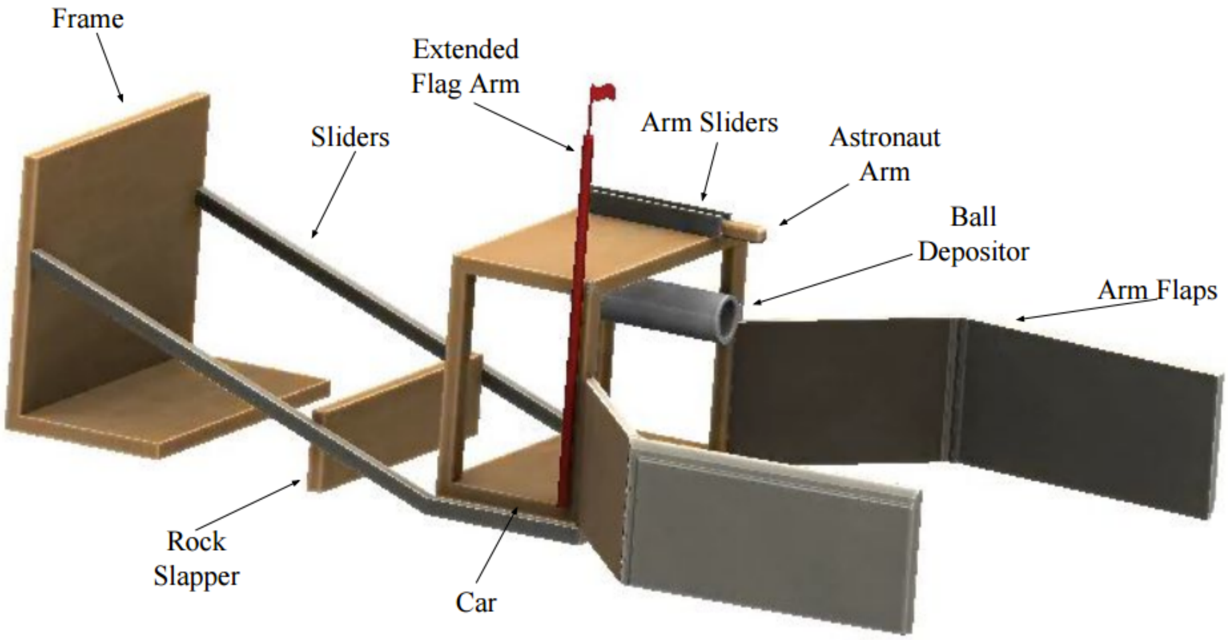

Figure 12. Alternative Design C

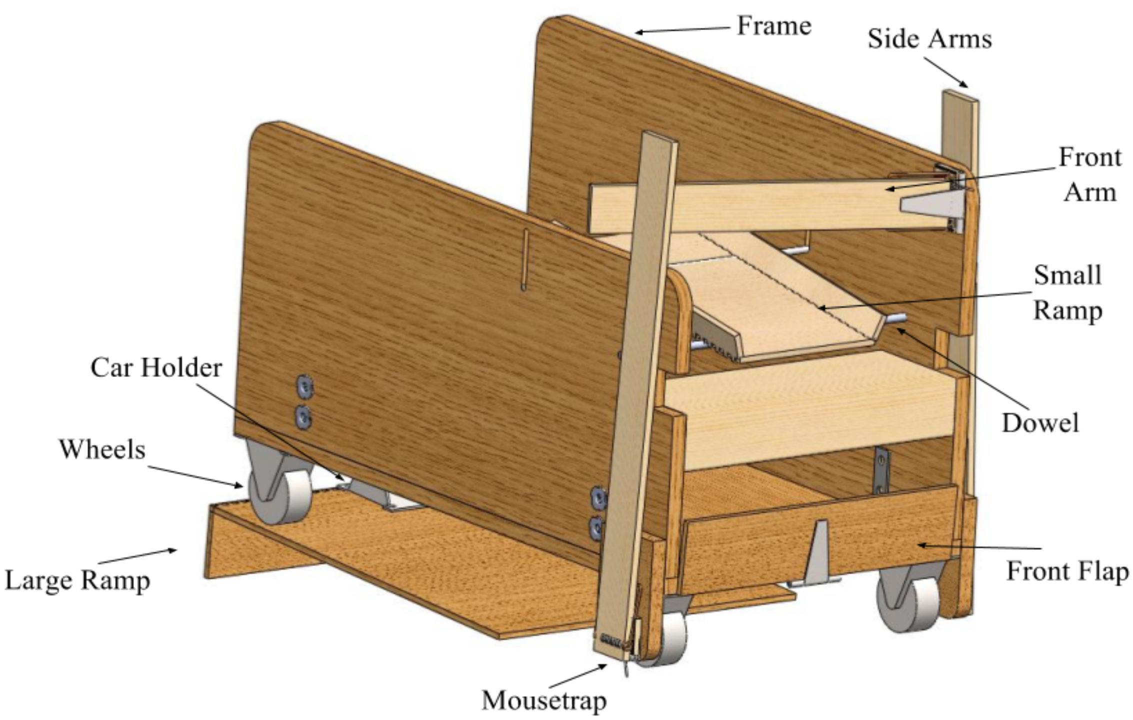

Figure 13. Alternative Design D

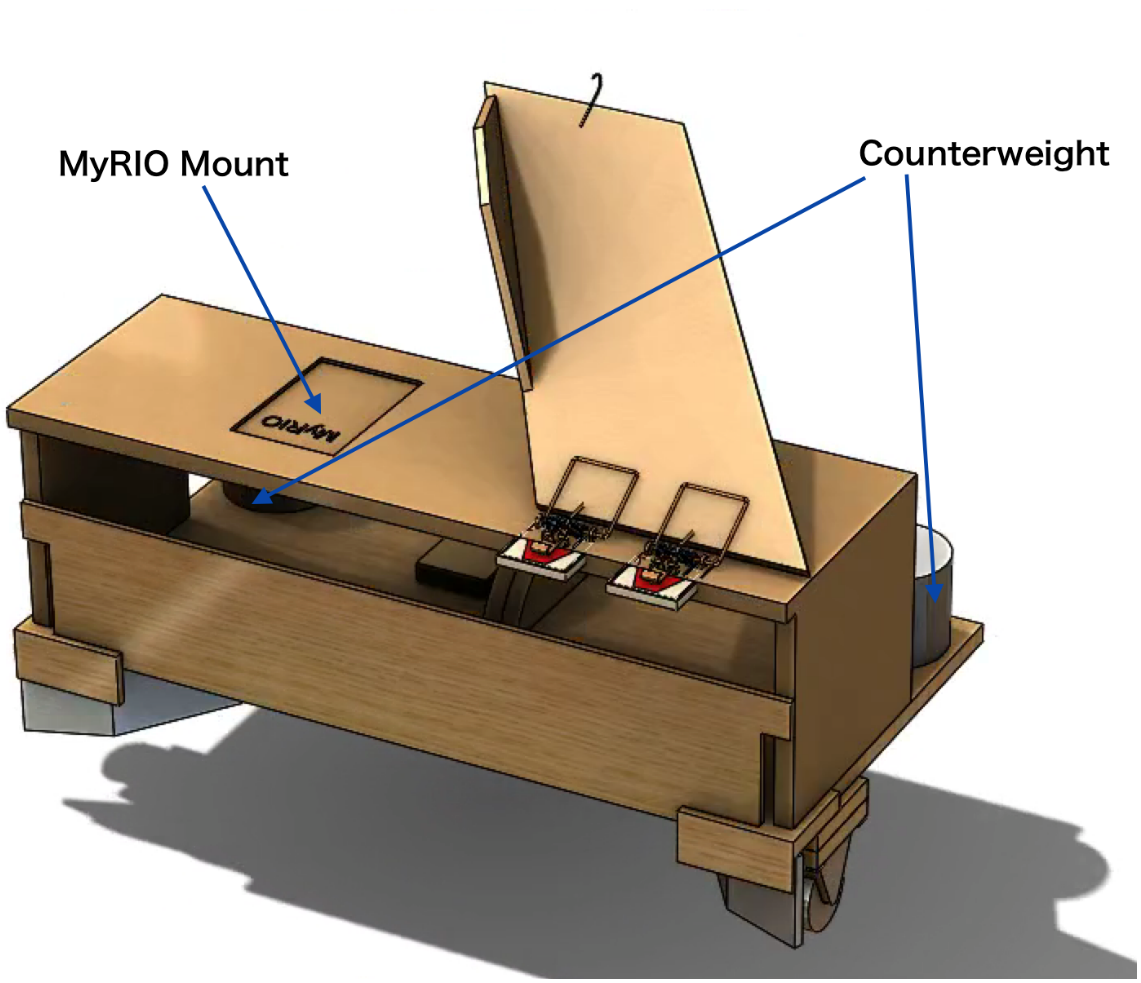

Figure 14. Alternative Design Testing

Task	Competition Point Value	Amount	Partial	Potential Loss	Max Points
Radioactive elements	-6 per radioactive element (full or partial)	8	-	-48	0
Rock samples	18 per rock (full) 9 per rock (partial)	3	27		54
Spacecraft	15 per safe landing -20 per unsafe landing	4	-	-80	60
Rover	28 per rover (full) 14 per rover (partial)	2	28		56
Astronaut	28 per astronaut (full) 14 per astronaut (partial)	2	28		56
Flag	60 per flag	1			60

Table 1. Competition Point Analysis

	Importance	A		B		C		D	
									
Robust	10	3	30	3	30	2	20	4	40
Small/ Compact	10	2	20	3	30	2	20	3	30
Ease of Transportation	7	3	21	2	14	2	14	3	21
Low Cost	7	2	14	3	21	4	28	3	21
Quick Assembly	10	3	30	2	20	3	30	3	30
Autonomous Operation	10	4	40	4	40	4	40	4	40
Places the Flag	9	2	18	1	9	2	18	2	18
Lands the Spacecraft	6	4	24	4	24	2	12	4	24
Collects Astronauts and Rovers	9	3	27	3	27	2	18	4	36
Collects Rock Samples	8	4	32	3	24	2	16	3	24
Removes Radioactive Elements	7	3	21	2	14	2	14	2	14
Sum of Points			**277**		**253**		**230**		**298**
Relative Weight			**0.26**		**0.24**		**0.22**		**0.28**

Table 2. Original Evaluation Matrix

	Importance	A		B		C		D		E	
											
Robust	10	3	30	3	30	2	20	4	40	4	40
Small/ Compact	10	2	20	3	30	2	20	3	30	4	40
Ease of Transportation	7	3	21	2	14	2	14	3	21	4	28
Low Cost	7	2	14	3	21	4	28	3	21	3	21
Quick Assembly	10	3	30	2	20	3	30	3	30	3	30
Autonomous Operation	10	4	40	4	40	4	40	4	40	4	40
Places the Flag	9	2	18	1	9	2	18	2	18	4	36
Lands the Spacecraft	6	4	24	4	24	2	12	4	24	2	12
Collects Astronauts and Rovers	9	3	27	3	27	2	18	4	36	4	36
Collects Rock Samples	8	4	32	3	24	2	16	3	24	4	32
Removes Radioactive Elements	7	3	21	2	14	2	14	2	14	3	21
Sum of Points			**277**		**253**		**230**		**298**		**336**
Relative Weight			**0.20**		**0.18**		**0.16**		**0.21**		**0.24**

Table 3. Revised Evaluation Matrix

ITEM	QTY.	COST/ UNIT	TOTA L COST
1/2" BIRCH PLYWOOD	0.4	$2.50	$1.00
5mm UNDERLAYMENT	4	$0.75	$3.00
ZIP TIES	6	$0.10	$0.60
1.5" PVC PIPE	1	$0.64	$0.64
1/2" PVC PIPE	1.5	$0.23	$0.35
8mm ROD	1	$1.97	$1.97
1/4" - 20 HEX BOLT	9	$0.18	$1.62
1/4"-20 TEE NUT	9	$0.30	$2.66
WOOD SCREWS (VARIES)	36	$3.98	$3.98
2" FIXED METAL CASTERS	2	$2.98	$5.96
3" TEE HINGE	2	$1.64	$3.27
2" CORNER BRACE	2	$3.97	$1.99
1.5" CORNER BRACE	2	$0.67	$1.34
1" CORNER BRACE	10	$0.37	$3.74
5/16" ACRYLIC SHEET	0.5	$19.11	$9.56
3/4" WHITE DERLIN ROD	0.08	$0.58	$0.05
1" WHITE DERLIN BAR	0.08	$11.81	$0.98
SKATEBOARD BEARINGS	2	$1.43	$2.85
25 ft. TAPE MEASURE	1	$10.00	$10.00
TOTAL:			**$55.54**

Table 4. Bill of Materials

1	2	3	4	5	6	Task	Responsibility
						Plug in myRIO and Output Board	Yatong
						Double check that all inputs are securely plugged in	Yatong
						Load the Cylinders	Audrey
						Attach the front board to motor	Sammy
						Wire Placement	Yatong
						Set up machine on track	George
						Load spaceships	George
						Place the flag	George
						Check/ actuate mousetraps	Sammy
						Make sure back is loaded	Audrey
						Engage the Astronaut Arm	George/ Sammy

Table 5. Robot Preparation Checklist

VIII. Sources

[1] The Design Project: Mission to Mars Instructions, http://2110.me.gatech.edu/sites/default/files/documents/Studios/me2110_spring_2017_studio4_missiontomars_rev1.pdf