Fall 2022

MEMS 411: Rock Collection Rover, Group

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MEMS 411, Fall 2022

Rock Collecting Rover Contest

The following report has been prepared for MEMS 411 Mechanical Engineering Design Project and contains information pertaining to the selected project, the Rocker Collecting Rover Contest project. The project required the team to construct a battery-powered, remote-controlled rover that is operated with a first-person camera and can collect “rocks” and hold them off the ground without damaging them. The rover will compete in a competition against all other groups to see which group can collect the most rocks in a five-minute period. Because the rover may be used in a future Washington University in St. Louis Rocketry competition, the rover has a size and weight constraint that dictated design choices. The chosen design consisted of a two-wheeled rover that would fit inside the capsule longways and collect rocks via a roller brush into a 3d printed collection container fitted with a ramp. Due to the weight constraint, a large majority of parts were 3D printed with PLA and with the main base fashioned out of wood. The rover was tasked with three prototype goals to assess its success in rock capacity, rock collection, and maneuverability. The final prototype completed all performance goals without difficulty, doubling the goal for rock capacity, achieving a 97% pickup reliability, and easily completing the agility course intended to assess maneuverability. Additionally, the final prototype weighed in at approximately 1.08 lbs and fit easily within the rocket capsule. Finally, the rover achieved first place in the Rock Collecting Competition, gathering 53 rocks within a five-minute period. The report provides additional information regarding the design concept embodiment, selection, and refinement, as well as addresses safety, manufacturing, and usability concerns.

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1 Introduction

This design project addresses a future competition mission for the Washington University in St. Louis Rocketry team. The mission requires that the payload of the rocket contain a small rover that can be stored securely inside the rocket and removed upon landing. Once removed, the rover must collect as many rocks, in the form of multi-sided die, as possible within a five minute period. The rover will be controlled remotely via a first person camera and must not damage any of the rocks. It is assumed that the rover will not encounter any rough terrain. A successful design will collect rocks efficiently and effectively.

2 Problem Understanding

2.1 Existing Devices

Radio Controlled (RC) products are seen everywhere ranging from space exploration to toys. Each of the examples below provide some functionality that is advantageous to the best car design for the competition. The large cars provide great terrain functionality and camera quality such as the robot, but the Roomba provides better rock collecting attributes. The final existing device is a camera operated jumping toy car that meets more of the competition guidelines based on its size, weight, and durability.

2.1.1 Existing Device #1: Mars 2020 Perseverance Rover

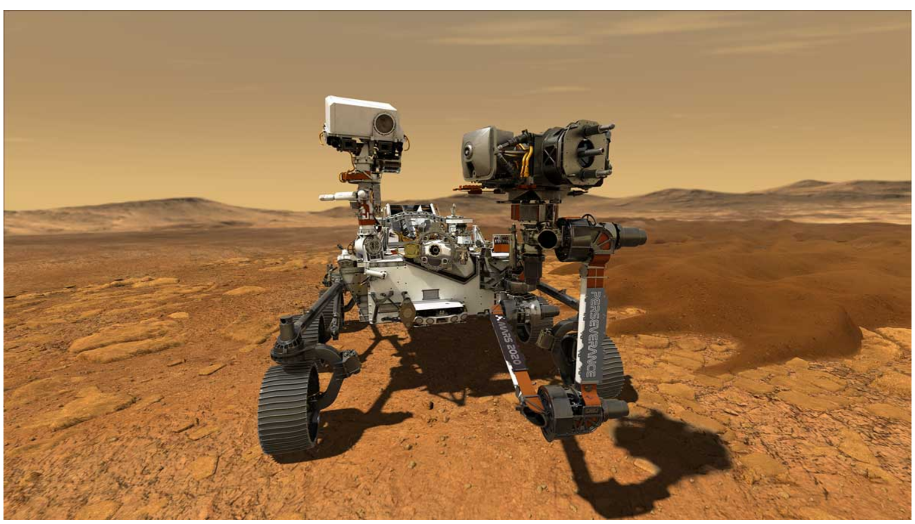


Figure 1: Perseverance Rover (Source: NASA Science)

Link: https://mars.nasa.gov/mars2020/
Description: The mars rover named Perseverance was launched in 2020 and landed a year and a half later in February of 2021. Upon landing the rover was tasked with collecting rocks and soil samples to analyze for a possible trip back to earth. It is a radio-controlled and automated device that is watched and controlled by engineers on earth. Additionally, the rover has a robotic arm that has a maximum range of motion using two "joint" connections. The arm is 7 feet long giving it

the necessary reach to operate around the 9ft x 10ft rover body. There are various cameras on the rover to take pictures, analyze rocks, and navigate using human operators. Lastly, these cameras aid in positioning the arm to pick up samples and maneuver rough terrain.

2.1.2 Existing Device #2: Roomba

Figure 2: iRobot Roomba i3 Series (Source: iRobot)

Link: hhttps://www.irobot.com/en_US/roomba.html
Description: The iRobot Roomba is an autonomous vacuum that is designed to travel across a consumer's floor while cleaning and avoiding furniture. The Roomba uses a three-wheel design that has zero point turning to get out of any situation the robot may have placed itself. The Roomba, depending on the series, weighs 7.44 lbs with its lithium-ion battery. In addition, the Roomba is 13.34 in across and stands 3.63 in tall. It has a suction vacuum that picks up crumbs, hair, and other small objects that may be laying around the house.

2.1.3 Existing Device #3: Remote Control Bouncing Camera Car

Figure 3: Two Wheel R/C Camera Car (Source: Uprara)

Link: https://kidzcountry.com/product/rc-bounce-wheels-car
Description: The Bouncing Remote control car is an agile and lightweight car that has a built-in mini camera. The toy has 360° turn radius and is easy to operate with a two-stick analog transmitter. Additionally, the car has a jumping feature that can launch the car nearly 2.5 ft in the air. The car's small design with large wheels makes it easy to explore small areas with tough terrain using its 7.5×4.5x5.5 in size. As well as the mars rover this toy can be manually controlled through a Radio Remote and seen in real-time with the 720p camera that can be seen through a phone or tablet using Bluetooth.

2.2 Patents

2.2.1 Nut Gatherer and Method of Constructing Same (US 10,201,124 B2)

This patent concerns a device that can be used to pick up fallen nuts with ease and efficiency. As seen in in Fig. 4 ,the cage is constructed with many individual wires and is held together on either side. Both side pieces connect to a handle to allow for operation when standing up. Nuts, or other objects of similar size, are collected by forcefully passing through the spaces between wires and then are unable to fall out.

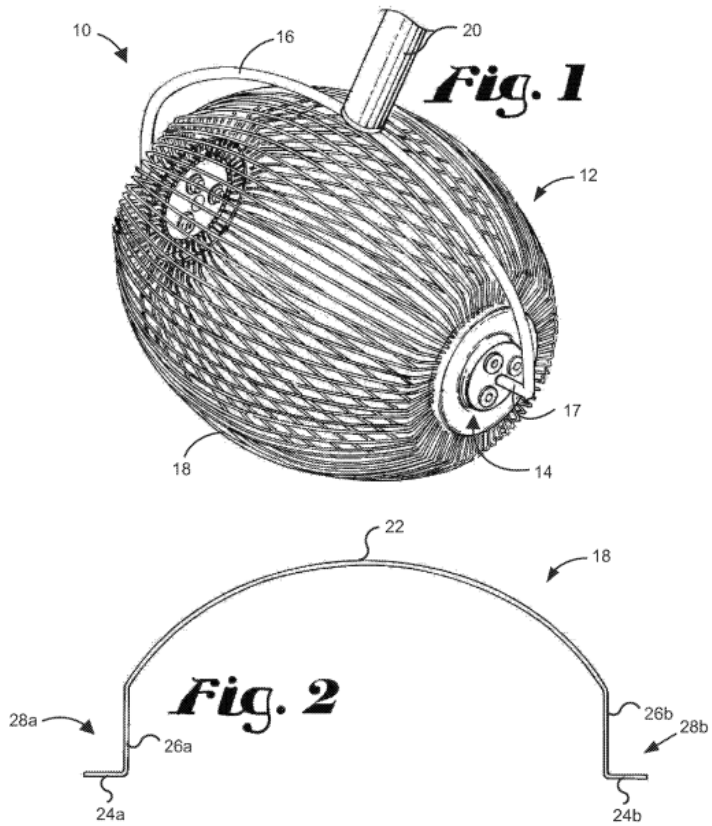


Figure 4: Patent photos of complete construction of the nut gatherer the wire that complete the basket

2.2.2 Two-Wheel Self-Balancing Vehicle with Platform Borne Sensor Control (US 10,843,765 B2)

This patent describes the device colloquially known as the 'Hoverboard'. The device consists of two wheels and is battery operated. The device is also self-balancing, which allows for easy mounting. To mount the vehicle, the operator places their feet on either side of the device near the wheels. Senors in the vehicle platform translate shifts in pressure to motion. The sensors on each side operate independently, allowing the vehicle to turn.

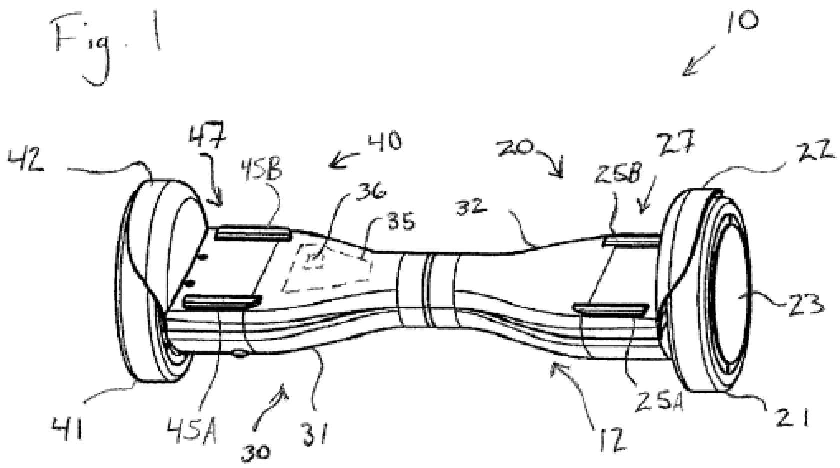


Figure 5: Patent photo of the 'Hoverboard' design.

2.3 Codes & Standards

2.3.1 System Configuration - Standard Practice for Evaluating Response Robot Logistics (ASTM E3132/E3132M-17)

This standard applies to RC robots controlled by an operator from a distance and thus applies to our rover competition. The standard includes a description of how such devices need labels so the product is used in its correct environments. This includes specific descriptions of key dimensions and weights, as well as a list of all key components. This description also directly applies to ground, aerial, and aquatic RC response robots. Our robot being a ground robot manually controlled from a distance must meet these standards for our competition.

2.3.2 Robots And Robotic Devices- Safety Requirements for Personal Care Robots (ISO 13482:2014)

This standard addresses safety measures for personal care robots, particularly those that must operate around people. Though this standard does not specifically cover "toy robots" as stated in the scope of the standard, the standard notes that the procedures in this standard can still be used in applications of this type. In addition, it cites other standards that discuss safety measures pertaining to battery and other electrical devices.

2.4 User Needs

It should be noted of the user needs were specified in a handout and not a part of the interview as they were already given. These include max weight (3.5 lbs), the device has to fit easily within a 5.36 inch diameter by 8.5 inch cylinder, be RC and battery powered, uses a camera to control in first person, and collects, transports, and move the dice/rocks off of the ground.

2.4.1 Customer Interview

Interviewee: Dr. James Jackson Potter
Location: McMillian G052, Washington University in St. Louis, Danforth Campus
Date: September 9^{th}, 2022
Setting: Lecture Hall setting of multiple groups asking Dr. Potter questions about the rules of the contents and the specifications that the device needed to meet.

Interview Notes:
Can the Rover push around multiple rocks or can it only pick up one at a time?

– It can push them around as long as it doesn't damage them

What counts as damaging the rocks?

– Using any sort of adhesive, scratching them, and breaking them all count as damage.

Do you need to dump the rocks out of the rover?

– No. Rocks must only be returned to the start area within the vehicle.

Average mass of the dice (aka "rocks")?

– About 4g each.

Are there any terrain or weather conditions that have to be accounted for?

– No, the testing grounds will be indoors on flat ground.

What sort of hardware is allowed and are there any limitations?

– To simplify and standardize the competition there is a hardware package that includes a 6 channel relay, a RC controller, micro servos and a few options of camera, along with a battery pack to power it all. There is some flexibility with most of the hardware but using the Servos provided is required for motor functions (Tower Pro brand).

What size batteries must be used to power the battery pack?

– Three AAA batteries in series are used to power the battery pack.

Will the rocks be traditional six sided die?

– No, the rocks will be an assortment of different sided die spread randomly around the area.

Can wires be spliced in order to allow more servos to be used on the vehicle?

– Yes, wires can be spliced.

2.4.2 Interpreted User Needs

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	The rover is light	5
2	The rover is small	5
3	The rover can pick up rocks and transport them	5
4	The rover operates remotely	5
5	The rover does not damage the rocks	4
6	The rover is maneuverable	4
7	Uses Tower Pro servos as motors	5
8	Aesthetics	1
9	Rover can withstand some forces for takeoffs and landings	3
10	The rover has a maximum time limit of 5 minutes for collecting	3

2.5 Design Metrics

Many of the user needs are more qualitative restraints than quantitative which makes creating metrics for them difficult as they limit the design rather than a measurable metric.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	1	Total weight	lb	<3.5	<3.5
2	2	Must fit inside cylinder	in	5.36 radius, 8.5 length	same
3	4, ASTM E3132	Uses remote relay and transmitter	Boolean	True	True
4	4	Uses camera and receiver	Boolean	True	True
5	4	Uses battery pack on rover	Boolean	True	True
6	3,6,7	Uses Tower Pro Servos	Boolean	True	True
7	10, ISO 13482	Rover is capped at a top speed	km/h	<20	<10

2.6 Project Management

The Gantt chart in Figure 6 gives an overview of the project schedule.

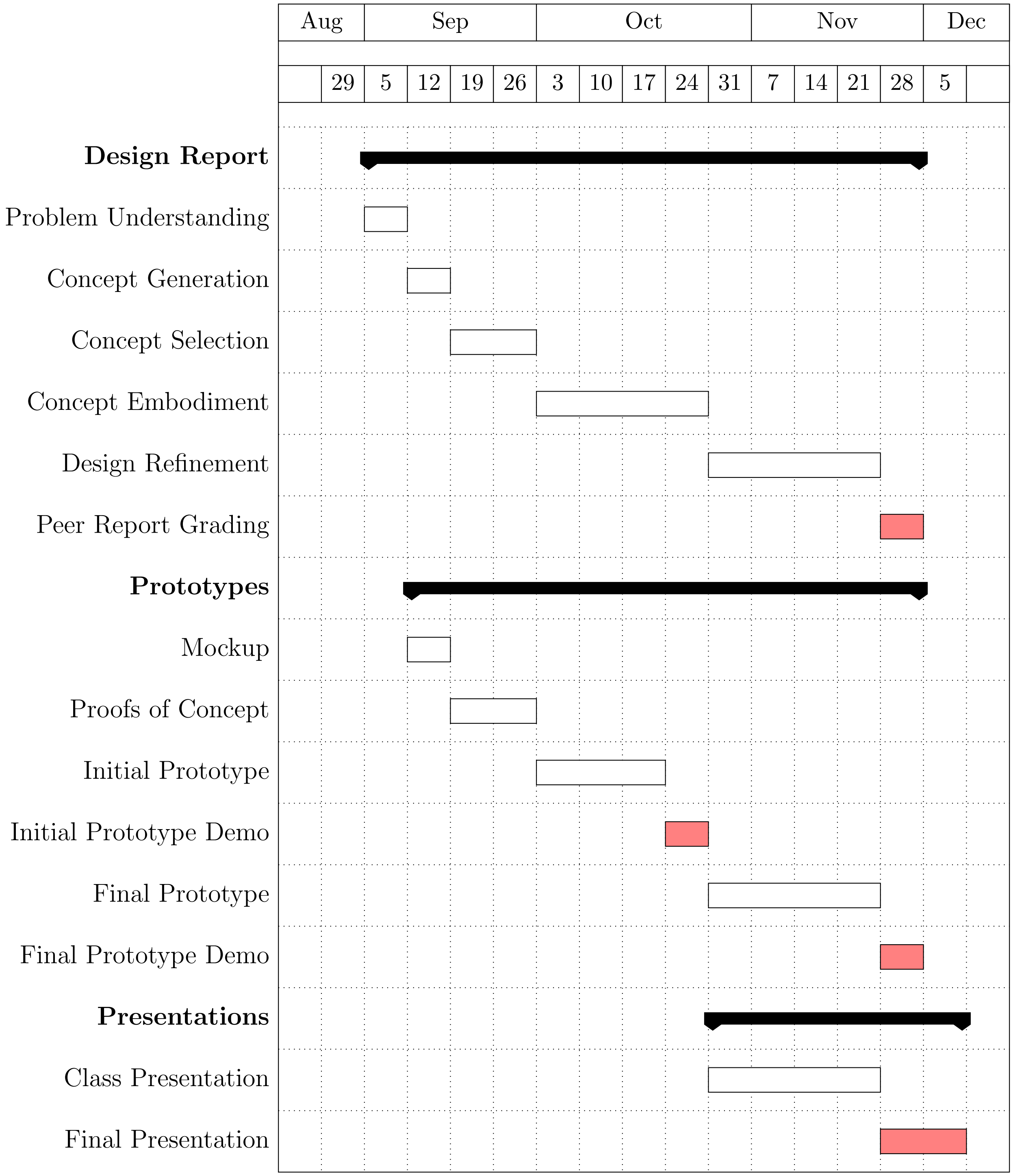


Figure 6: Gantt chart for design project

3 Concept Generation

3.1 Mockup Prototype

The mockup allowed our team to fully understand the necessary size of the RC car. Based on the tube's size, a two-wheel car with a stabilizer was the best solution to ensure rock collecting functionality remained effective. Cardboard, wooden skewers, and masking tape were used to create the mockup. The photos provided below illustrate the main features that we plan to implement in future designs.

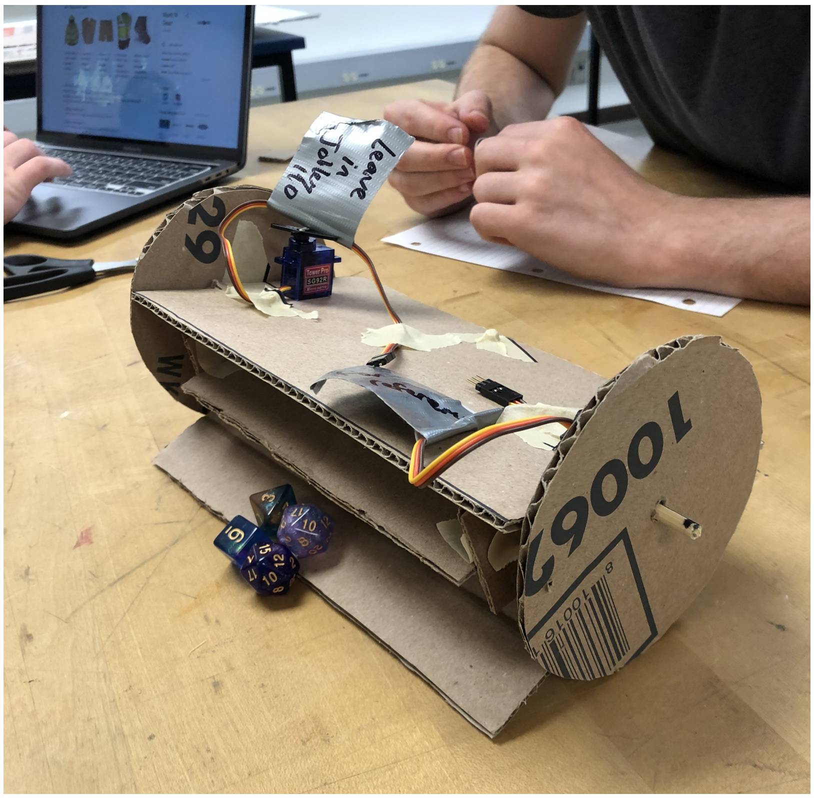


Figure 7: Isometric view of mockup design.

The wheels were constructed to be slightly smaller than the tube's 5.36" radius while the body was limited to the length of the tube (8.5"). During the mockup process, the team realized that the length of the rover would need to account for wheel thickness and any protrusions outside of the wheels.

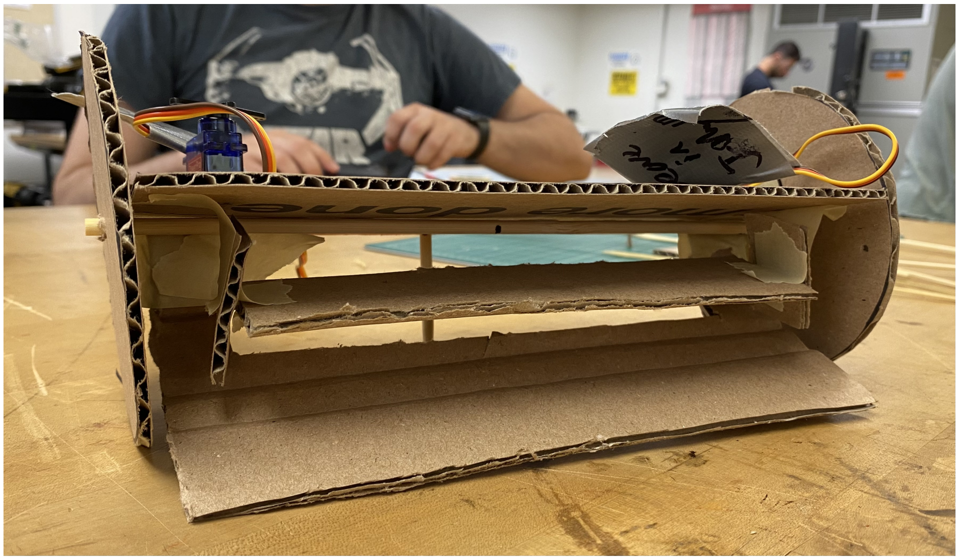


Figure 8: Front view of mockup design.

To collect rocks, the rover has a roller and ramp solution. This design would mechanically roll the rocks up a ramp and into a collection box or mesh netting, which we did not produce in the mockup. The mockup also provided us with insight into the location of the spinning collector and ramp with respect to one another.

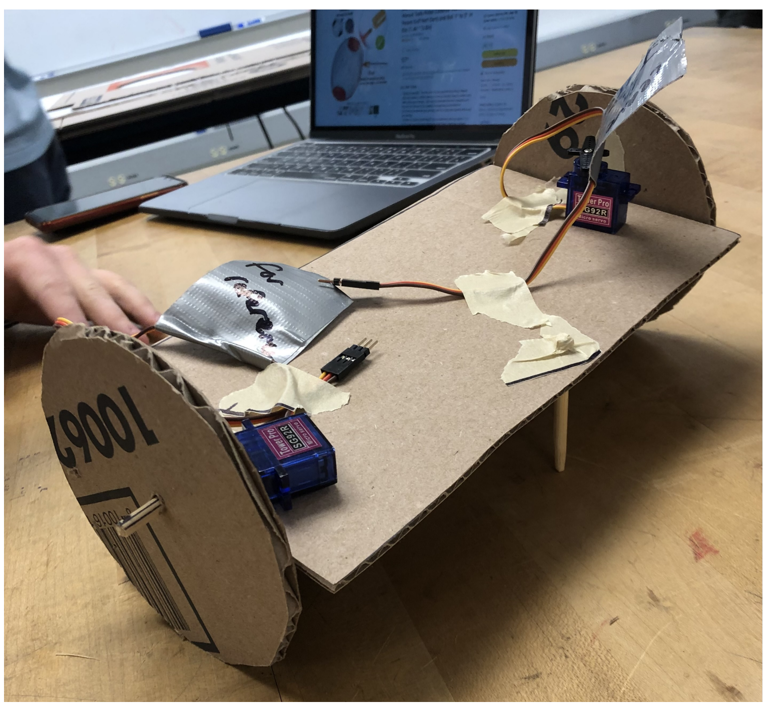


Figure 9: Back view of mockup design.

3.2 Functional Decomposition

The function tree decomposes the main function, the collection of rocks by a battery powered RC rover, into several sub-functions. The sub-functions outline the design constraints set by the rock collecting contest rules.

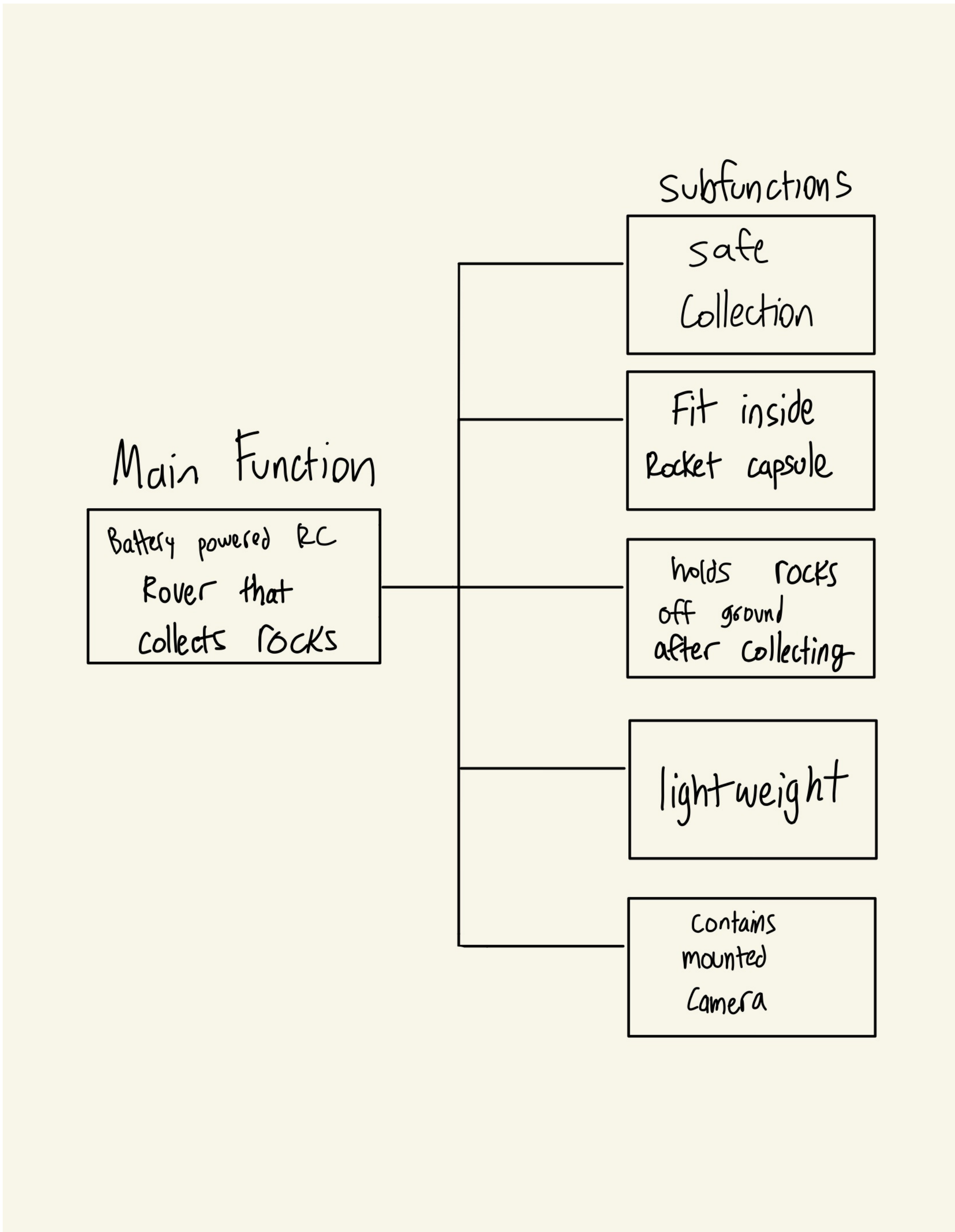


Figure 10: Function tree for Rock Collecting Robot, digitally hand-drawn.

3.3 Morphological Chart

A complete morphological chart for the rock collecting rover can be found below. Each of the five sub-functions in Fig. 10 have a minimum of three solutions. Following the morphological chart, four full concepts demonstrate various designs utilizing the solutions in Fig. 11.

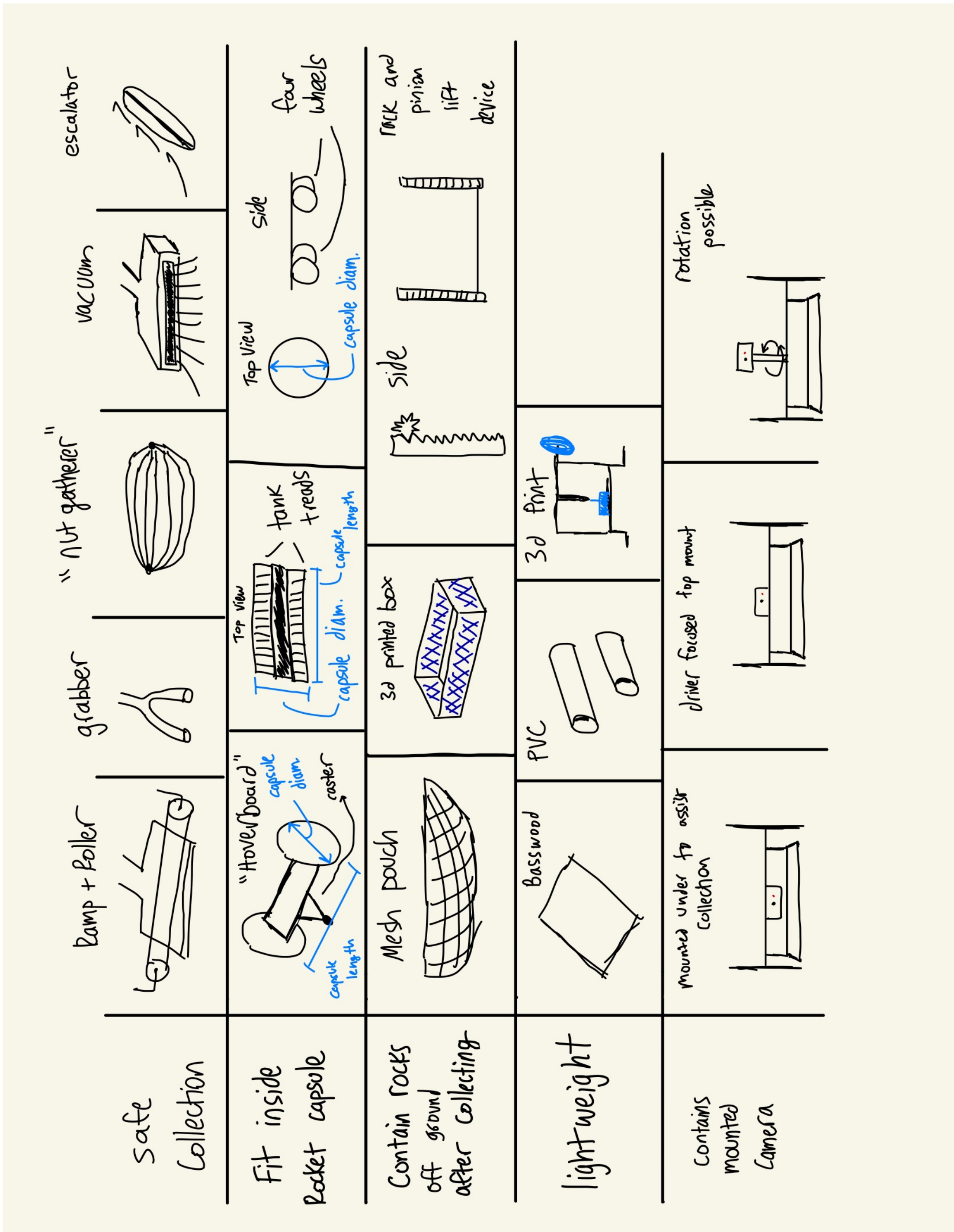


Figure 11: Morphological Chart for Rock Collecting Rover

3.4 Alternative Design Concepts

3.4.1 Concept #1: Dual-Roller

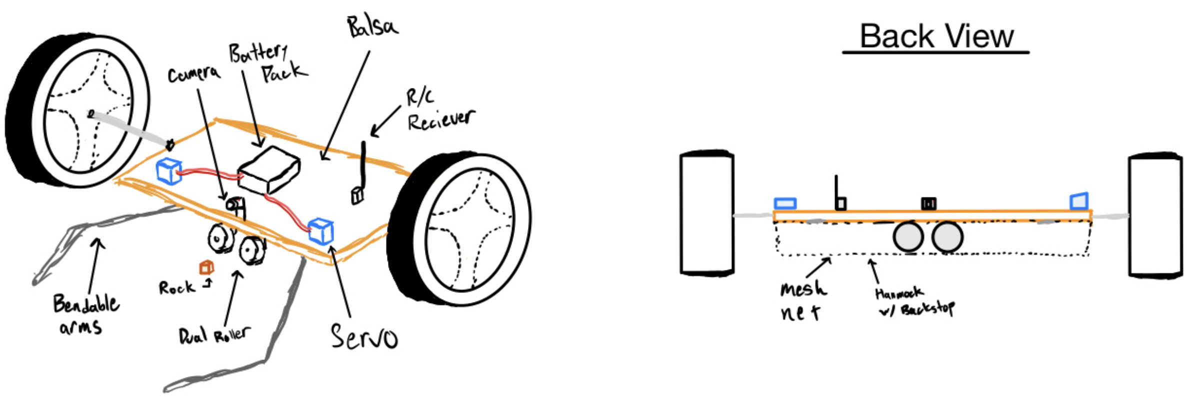


Figure 12: Sketches of the Dual-Roller Design Concept

Description: A transmitter will control the car with 'tank controls' using 360° rotation servos. The dual-rollers are made with squishy rubber that will pinch the dice and launch them into a mesh net. The rollers can be switched on and off with the transmitter, but will only have one rotational speed. The arms will direct the 'rocks' towards the rollers and will bend in and out of the required tube. The base for the electronics will be made with balsa wood and the large tires will be hollow and skinny to meet the weight requirement.

3.4.2 Concept #2: The Tank Bot Concept

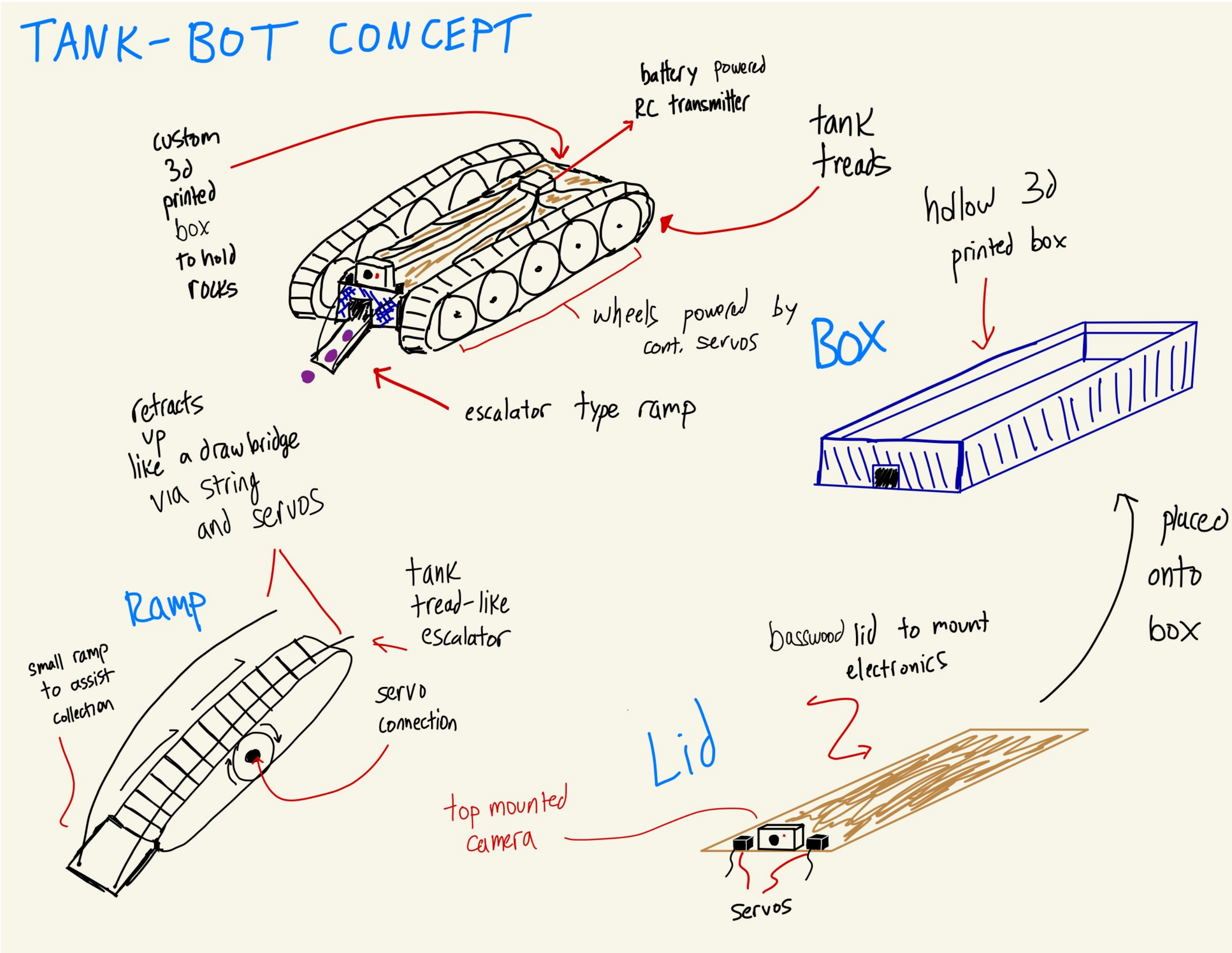


Figure 13: Sketches of the Tank Bot Concept

Description: This concept utilizes tank treads for rover movement. As such, turning radius is sacrificed for a large rock collection container and electronics surface. Rocks enter the vehicle via a small escalator-type ramp powered by a small servo and are placed into the main body of the robot. To ensure the vehicle fits inside the rocket capsule, the collection device is capable of being remotely drawn back into the device until flush with the front face. All other dimensions are limited by the capsule dimensions. A camera mounted on the front of the electronics platform provides a clear view for the driver and the collection mechanism. The electronics surface is constructed of basswood while the rock box is custom 3d printed. All devices, including the receiver and servos for the wheels and collection mechanism, derive power from the main battery pack.

3.4.3 Concept #3: The Long Roller

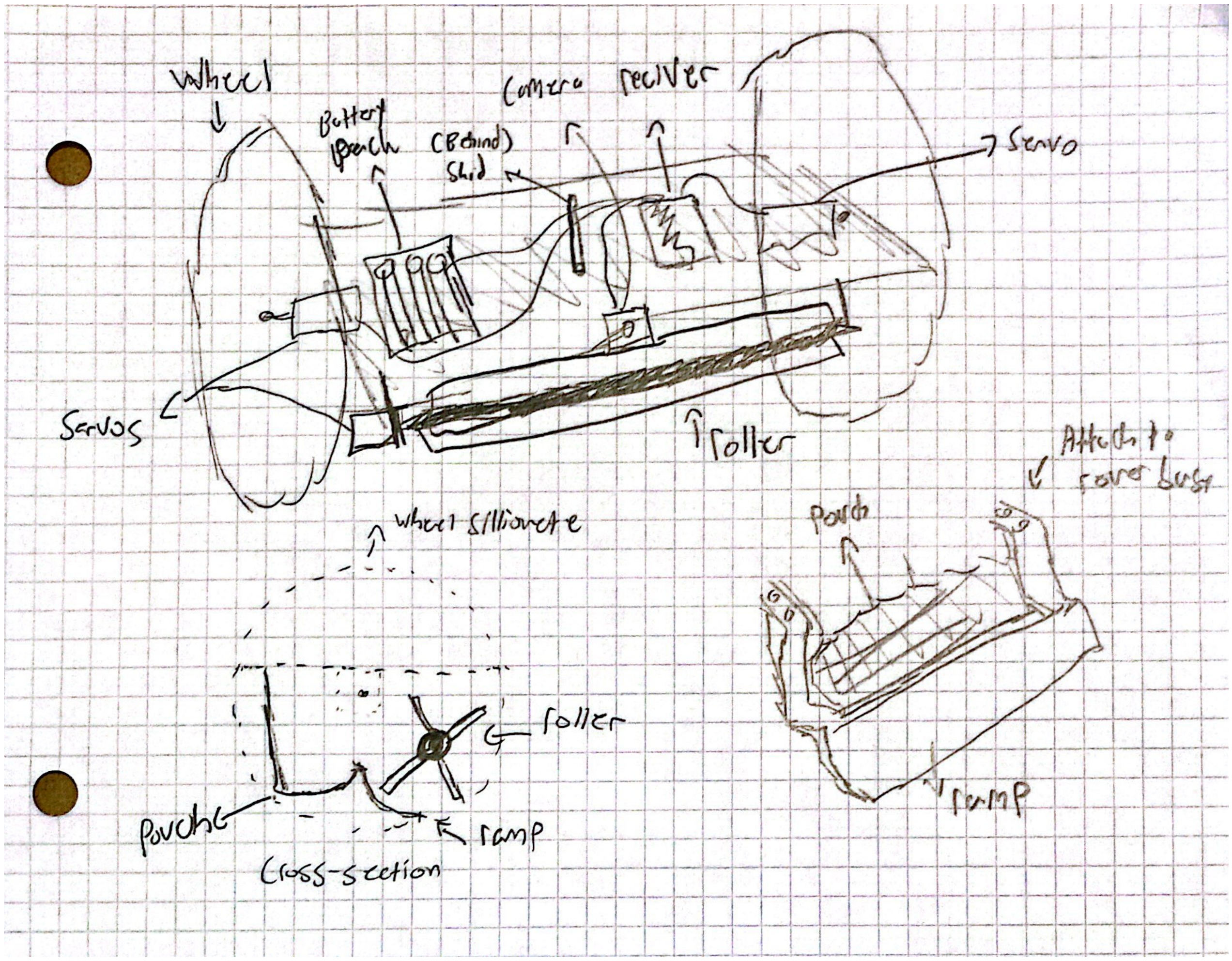


Figure 14: Sketches of the Long Roller Concept

Description: This Concept used 2 wheels with separate motors to drive, which are connected to a relay and eventually a controller. A front mounted camera is present for navigation. The rover picks up rocks by utilizing a long, continuously rotating roller (powered by an additional servo) and a ramp. The roller will push the rocks back and then up the ramp. At the end of the ramp is a drop off into a soft mesh/fabric bag that holds the rock for the duration of the challenge. The roller is set up to follow the curvature of the wheels to ensure it fits within the capsule and the softness of the holding pouch also ensured that the size constraint is kept. The ramp will be attached by 2 lengths that do not fall of into the pouch on each end by the wheels, which attach to the bottom of the main platform of the rover. The receiver, battery and camera will all utilize the space on top of the platform.

3.4.4 Concept #4: The Elastic Catcher

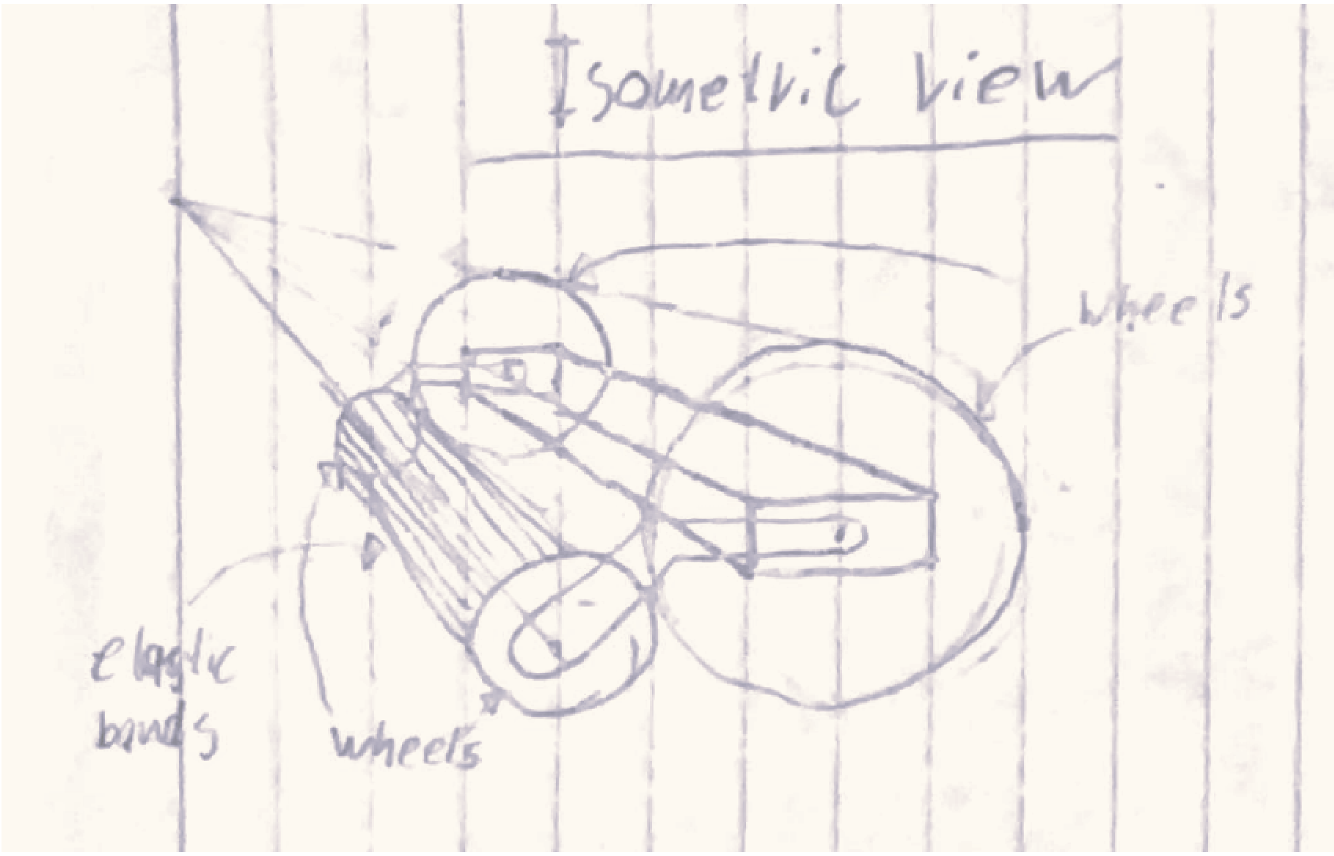


Figure 15: Isometric Sketch of the Elastic Catcher Concept

Description: This concept is similar to concept 3 in many aspects. Only really differing in one key aspect, the method of collecting rocks. This concept will have two additional wheels on the front of it. The wheels will not have any connected motors and are only powered by the movement of the rover. In between theses wheels will be a web of elastic bands stretching from one wheels to the other. The bands will not have enough space the allow dice to pass easily between them, but loose enough to allow the dice to pass if the bands are stretched. The idea behind this is that the as the rover moves over the dice, the elastic catcher will roll over the dice. The weight of the rover will provide enough force to bend the elastic bands around the dice. Trapping it inside the cylinder as the weight of the dice itself wouldn't be enough to allow it to escape.

4 Concept Selection

4.1 Selection Criteria

Three major factors will determine the success of the rover for the competition: the collection and storage of the rocks, and the movement of the rover. For our selection criteria, the first factor was split into rock capacity and pick-up reliability. The second factor was split into maneuverability and ease of operation. Finally, ease of assembly was added to ensure the rover was not impossible to build.

	Rock Capacity	Pickup Reliability	Maneuverability	Easy of Assembly	Ease of Operation	Row Total	Weight Value	Weight (%)
Rock Capacity	**1.00**	1.00	3.00	5.00	1.00	11.00	0.25	25.15
Pickup Reliability	1.00	**1.00**	5.00	7.00	3.00	17.00	0.39	38.86
Maneuverability	0.33	0.20	**1.00**	5.00	1.00	7.53	0.17	17.22
Ease of Assembly	0.20	0.14	0.20	**1.00**	0.33	1.88	0.04	4.29
Ease of Operation	1.00	0.33	1.00	3.00	**1.00**	6.33	0.14	14.48
					Column Total:	**43.74**	**1.00**	**100.00**

Figure 16: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

Ultimately the competition is scored based on how many rocks can be picked up and held, which made both rock capacity and pickup reliability most important. Maneuverability and ease of operation are also both important to ensure that the competition goes well, but have less of an impact on the final scoring. Finally, ease of assembly places last as it is inconsequential to the performance of the rover and we can take lots of time to assemble the rover how we want.

4.2 Concept Evaluation

The weighted scoring matrix (WSM) below details the process for selecting the optimal rover design from the alternative design concepts.

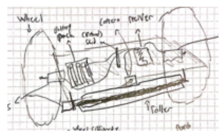
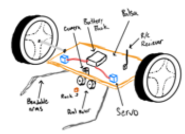
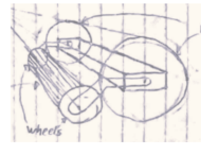
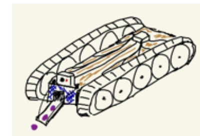
Alternative Design Concepts		Long Roller		Dual Roller		Elastic Catcher		Tank Bot	
									
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Rock Capacity	25.15	3	0.75	3	0.75	3	0.75	4	1.01
Pickup Reliability	38.86	3	1.17	2	0.78	1	0.39	1	0.39
Maneuverability	17.22	3	0.52	3	0.52	3	0.52	2	0.34
Ease of Assembly	4.29	3	0.13	3	0.13	4	0.17	1	0.04
Ease of Operation	14.48	3	0.43	2	0.29	3	0.43	2	0.29
	Total score	**3.000**		**2.467**		**2.266**		**2.071**	
	Rank	**1**		**2**		**3**		**4**	

Figure 17: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

4.3 Evaluation Results

The "Long Roller" was used as the reference rover design and finished as the top-ranked rover based on its ability to satisfy each selection criterion. The "Tank Bot" provided more rock capacity than the Long Roller, however, it failed to compare in every other criterion. Pickup reliability is where the "Long Roller" exceeds the other concepts, its long roller design ensures multiple rock capture and has a great storage design to secure the rocks after collection. The first three concepts have a similar layout, thus scored the same on maneuverability; for example, the rover's turn radius, speed, and controls. The "Tank Bot", having a larger turn radius, was rated lower in this criterion. The "Elastic Catcher" provided an easier assembly because it required fewer electronic configurations to operate as compared to the other concepts. Lastly, the "Long Roller" provides easy operation due to the low precision needed to collect rocks during the drive. The "Dual Roller" received a lower rating as the rocks would need to be centered for collection. In the end, the "Long Roller" design received an equivalent rating in each category giving it a total score of 3.00.

4.4 Engineering Models/Relationships

Three engineering models have been constructed to assist in design-critical decisions involving various rover parameters and measurements.

4.4.1 Camera Placement Model

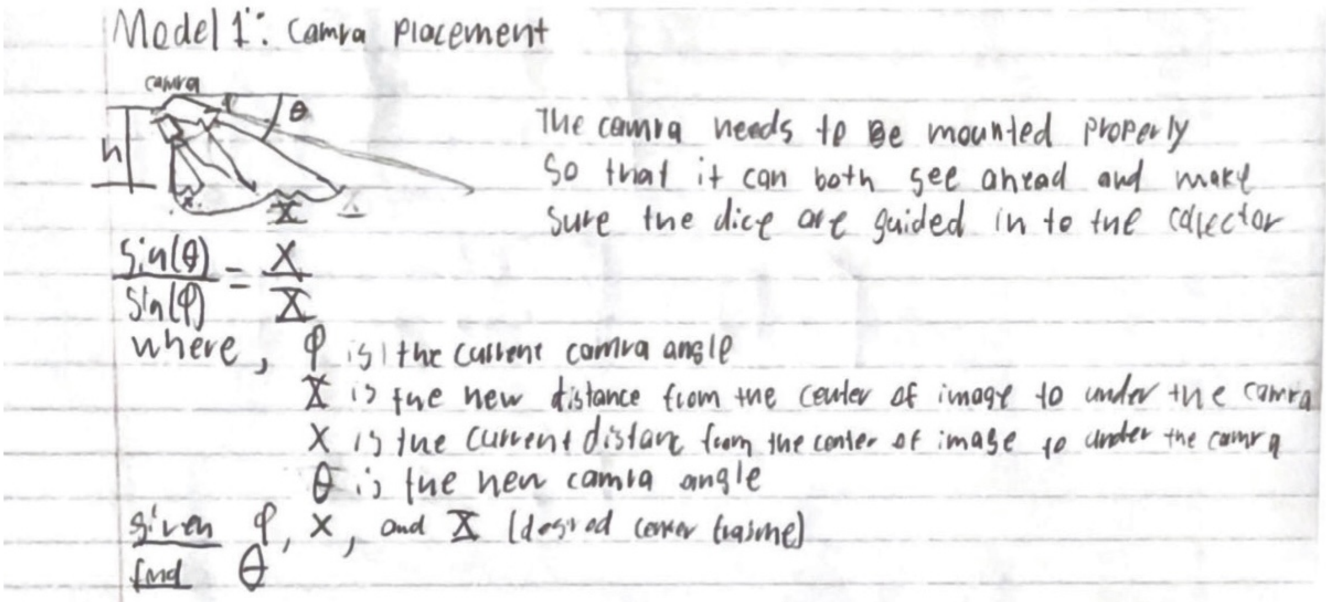


Figure 18: Camera placement model.

We need to angle the camera of the rover in such a way that the driver is able to easily see the rocks from a distance and up close. This will ensure the rover can identify its next target and guide the rocks into the collector. The model will help the team determine the optimal angle to position the camera on the rover to provide the best view for operation. Figure 18 illustrates the proposed model.

4.4.2 Rover Size Optimization

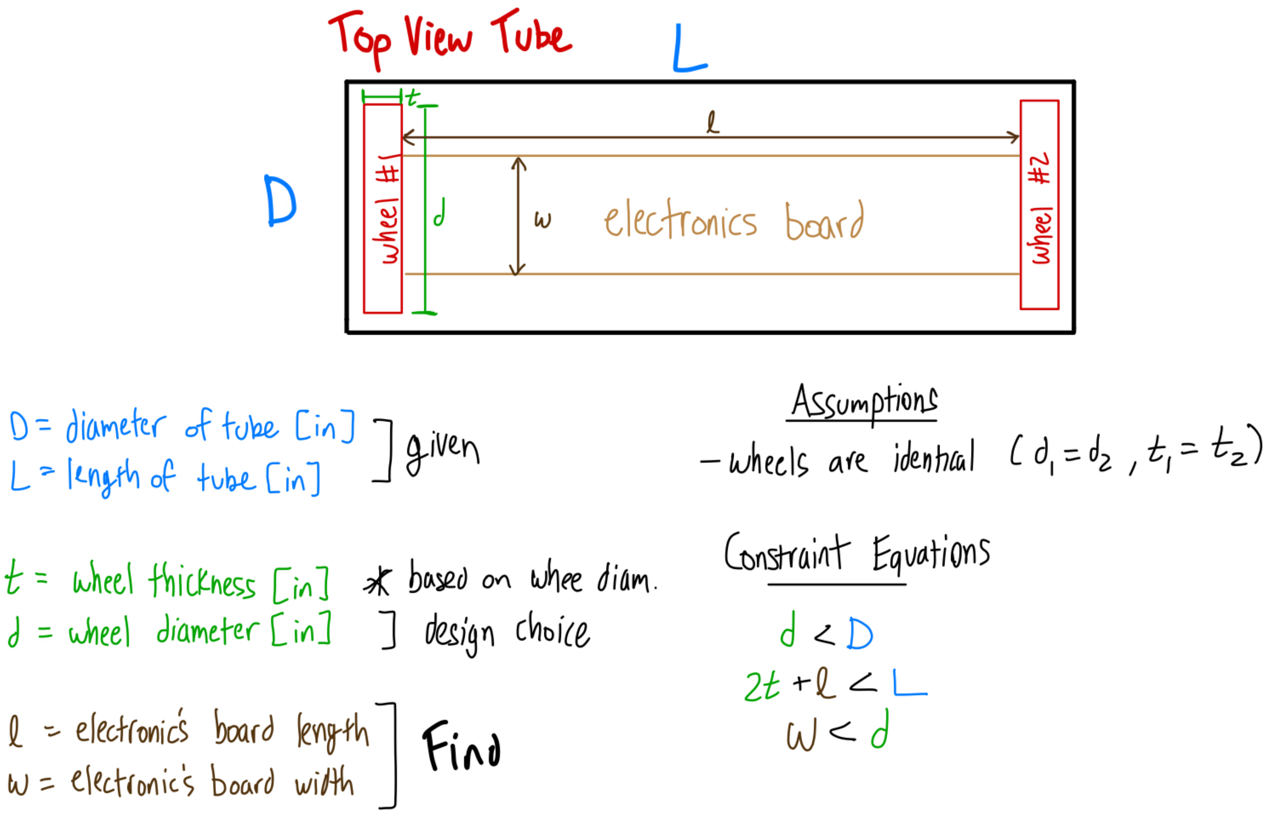


Figure 19: Rover size optimization model.

Due to the width and length constraints established by the contest rules, it is critical to design a rover that will fit inside of the capsule. The rover size optimization model allows for the quick determination of the sizes of the wheels and electronics board based on the constraints. It is assumed that the wheel would be chosen first due to the diameter constraint and the thickness of the prescribed wheel would help determine the board length. The equations provide a means of quickly assessing the necessary size of these different components and is illustrated in Figure 19.

4.4.3 Ramp Size Estimator

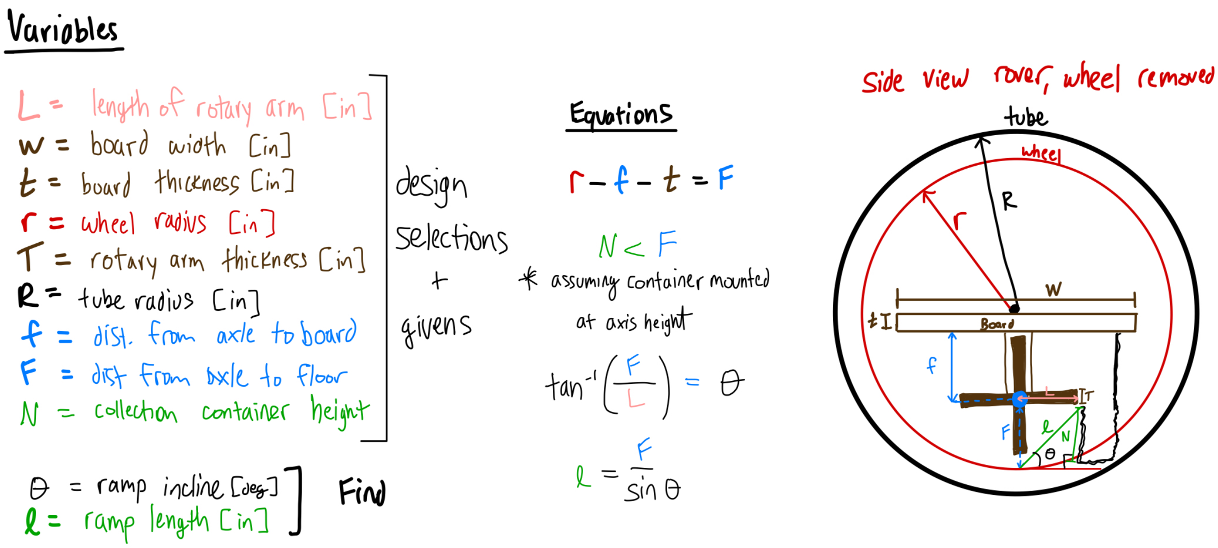


Figure 20: Ramp size estimation model.

The chosen collection mechanism involves a ramp and collection device. Based on the constraint of the tube it would be useful to have a means of determining the size of the ramp. The model assumes that the container is mounted at axis height. The model also assumes that the position of the collection device will already be set to optimally collect rocks, and thus the ramp is the final component to require construction. In addition to providing an estimate of ramp size, it may also provide insight for the construction of the collection container. The proposed model is illustrated in Figure 20.

5 Concept Embodiment

5.1 Initial Embodiment

The prototype was constructed with inspiration from the Long Roller design, Fig. 14, which was determined to be the most effective design from the WSM, Fig. 17. The Long Roller must attempt three performance goals to demonstrate that the prototype is a complete and effective design or can be reasonably improved to become a complete and effective design. The prototype performance goals are listed below:

- 1) The rover can collect more than 28/35 rocks (dice) of varying shapes.
- 2) The rover can carry more than 35 rocks (dice).
- 3) While being remotely operated (controller only sees first-person view from camera), the rover can complete the agility course in Fig. 21 in less than 5 minutes without touching the tape on the ground (shown in red).

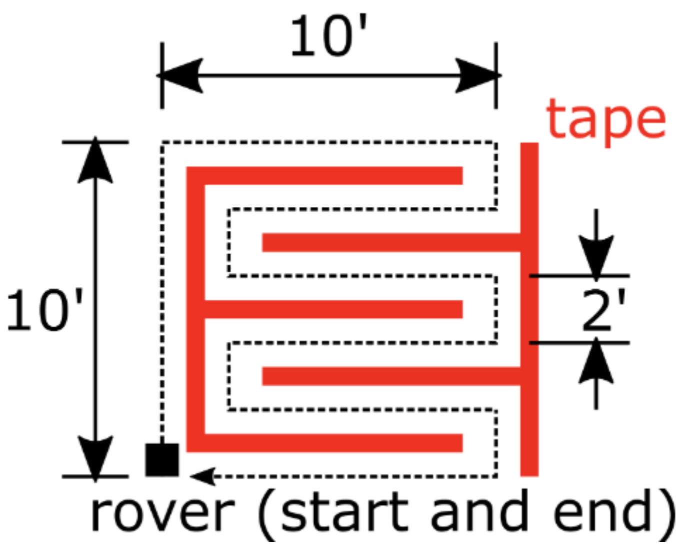


Figure 21: Agility course designed for rover mobility.

Figures 22, 23, 24 provide general dimensions, a large isometric view, and an exploded view with a bill of materials (BOM), respectively. The figures represent the design in the prototype stage and any further improvements made to the design will be shown on the final prototype. Wires and attachments using adhesive were not included in the drawings

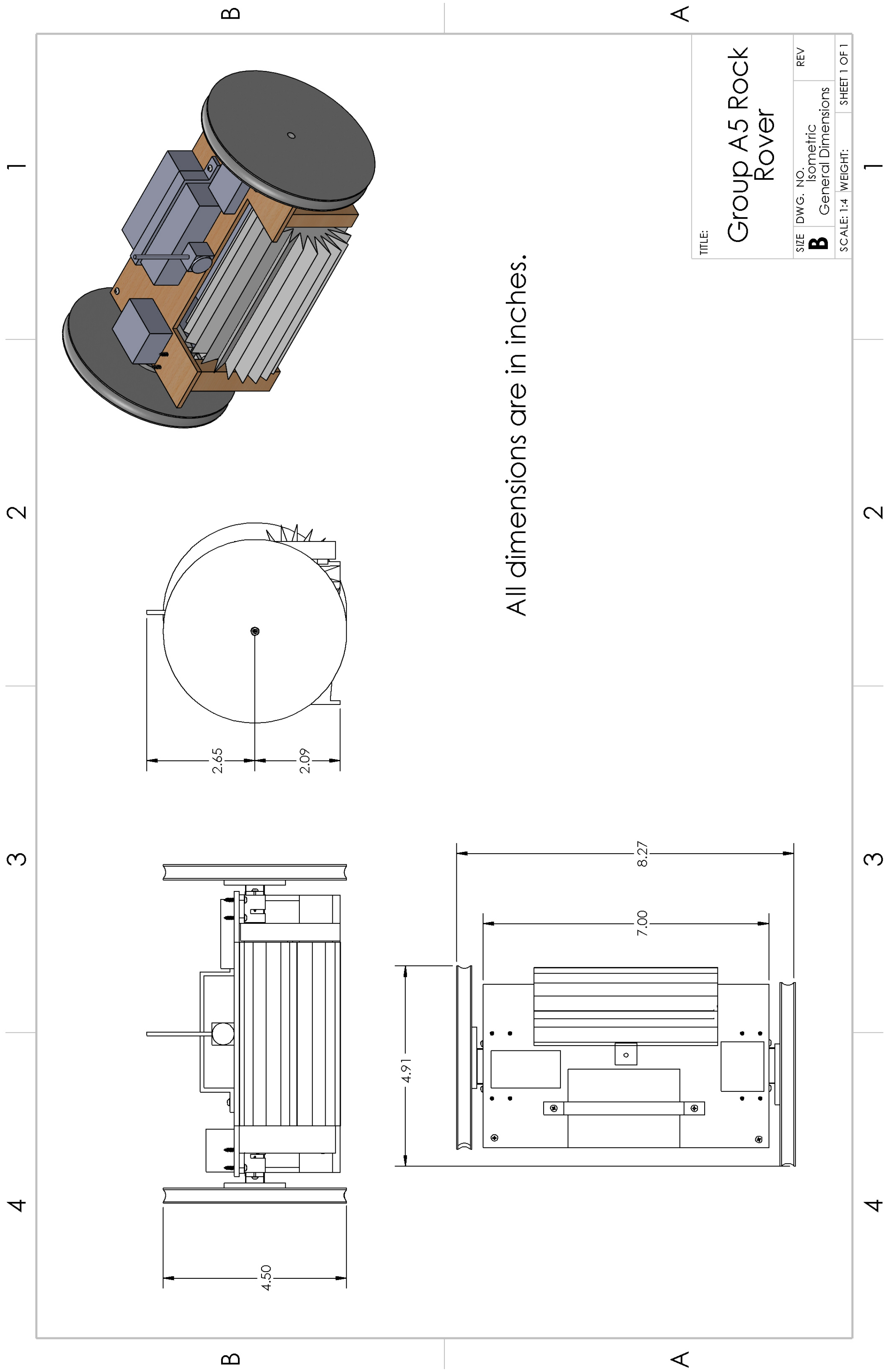


Figure 22: Assembled projected views with overall dimensions.

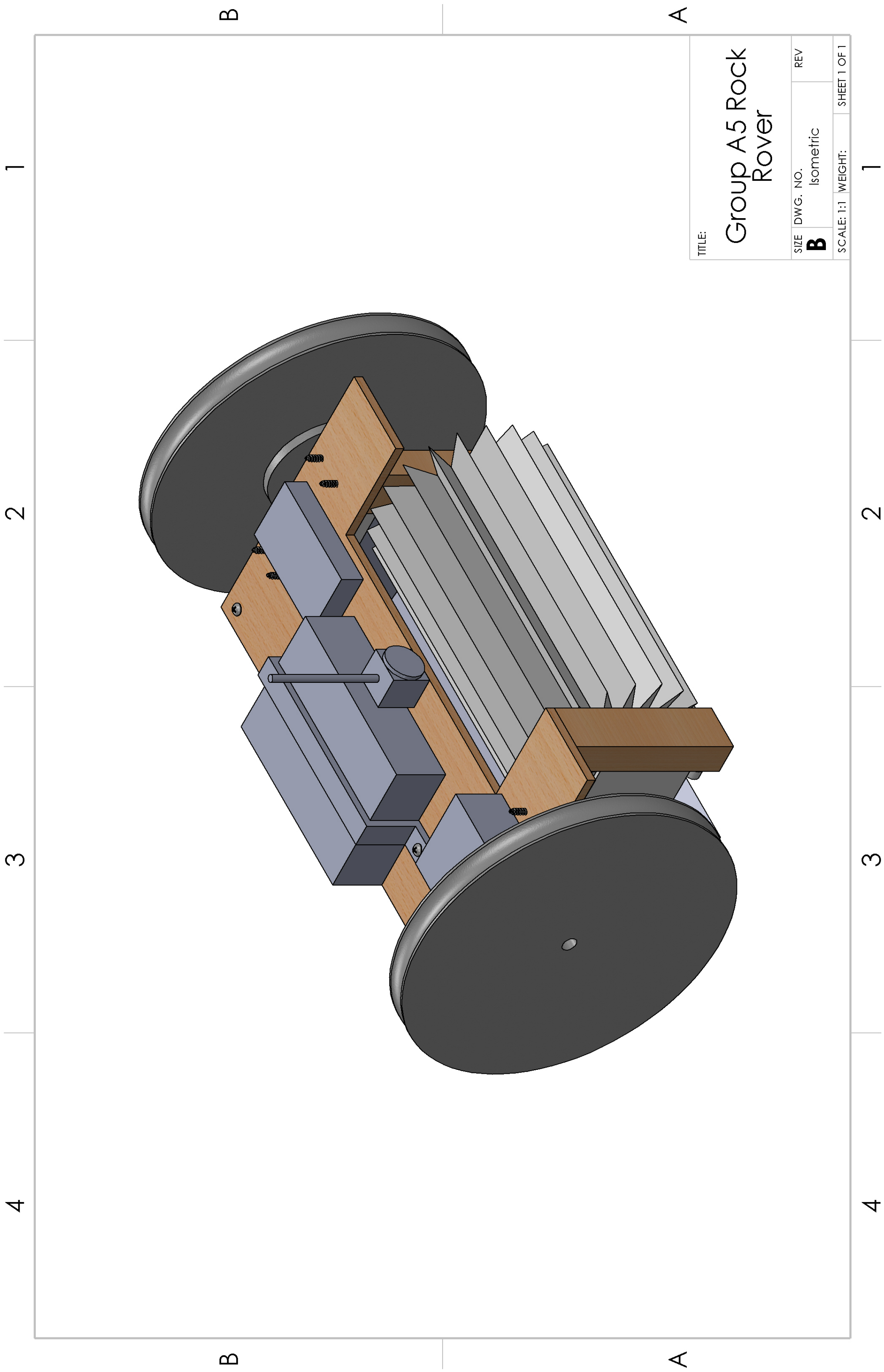
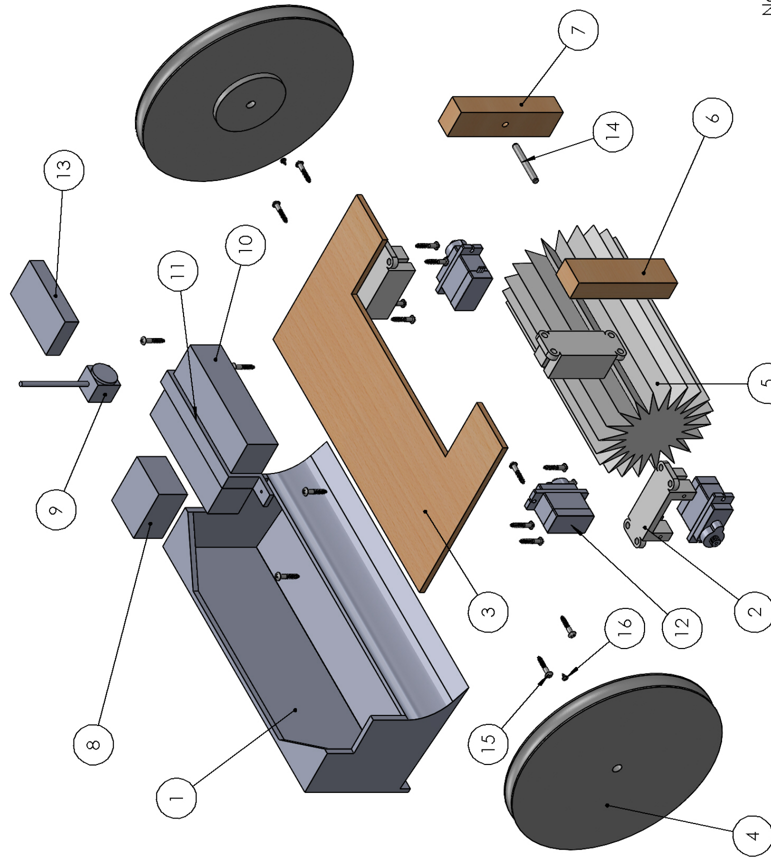


Figure 23: Assembled isometric view



ITEM NO.	PART	DESCRIPTION/PART NO.	QTY.
1	Basket	PLA	1
2	Servo Mount	PLA	3
3	Base Platform	Wood	1
4	Wheel	PLA	2
5	Conair Quick Blow-Dry Hairbrush (Roller)	86240T16	1
6	Roller Servo Mount	PLA	1
7	Roller Mount	PLA	1
8	Spektrum Reciever	AR620	1
9	FPV Camera	600TVL	1
10	Battery	3 AA batteries in-series	1
11	Battery Bracket	PLA	1
12	Fitec Continuous Servo	FS90R	3
13	Urgenex Li-Po Battery	600 mAh, 3.7 V	1
14	Dowel Pin	1/8" x 1L"	1
15	Storehouse Brass Plated Wood Screw	#4 x 1/2" L	18
16	Fitec Servo Screw	.36" L	2

Note: All parts without an associated part number were obtained from the Jolley basement, manufactured by the team, or did not have an associated part number.

Note: All surfaces without an associated screw were attached with hot glue.

TITLE: EXPLODED VIEW WITH BOM AND CALLOUTS

SIZE B | DWG. NO. GROUP A5 | REV

SCALE: 1:2 | SHEET 1 OF 1

Figure 24: Exploded view with call-outs to the BOM.

5.2 Proofs-of-Concept

For our proof-of-concept we were most concerned with the design of the collection mechanism. Shown in Fig. 25, we tested a paddle and ramp dice collector that pushed dice into a rectangle collection basket. This proof-of-concept was included on the cardboard mock-up of the Long Roller, shown in Fig. 8. The paddle and ramp dice collector was deemed to be feasible after testing and it was concluded that it would fit well into the overall Long Roller design. We determined that the collection mechanism with work best with a two-wheel design, as this proved to fit into the tube while maximized the wheel size, the collection window, and the storage space. Though the cardboard mock-up did not provide insight into the collection functionality, it provided insight in the general dimensions and constraints that would be required for the size of rover components.

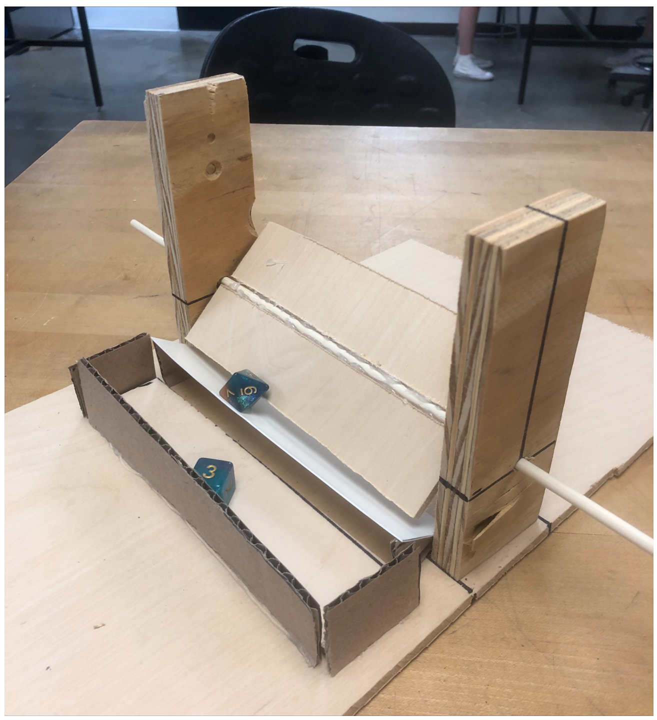


Figure 25: Paddle and ramp proof-of-concept.

5.3 Design Changes

In Section 4, the team used a WSM to choose the best concept based on five selection criteria. A prototype of Long Roller collection mechanism was constructed but struggled to collect dice when tested. The paddle design initially discussed caused issues during dice collection as the dice would become pinned and stop the motion of the roller. The roller was substituted for a repurposed hair brush that provided a smoother rotation and protected the dice from damage upon collection. Furthermore, the wheel design was changed to provide more traction on smooth surfaces. To further reduce this problem, the wheels were wrapped in rubber bands to provide more friction between the floor and wheel contact points. Finally, the cross section of the basket was changed slightly in order to maximize the carrying capacity of the roller.

6 Design Refinement

6.1 Model-Based Design Decisions

For some design decisions, it was necessary to create engineering models. Figure 19 and Figure 20 were proposed in Sections 4.4.2 and 4.4.3, respectively. Using numerical values already chosen from the prototype, they were evaluated in the following sections. A third model was used to estimate the power required to collect five rocks at one time and was compared against the micro-servo data sheet to ensure that adequate power generation was possible.

6.1.1 Model-Based Design Rational #1

Our first model determines the optimum size of the rover so that it fits within the tube, one of the main requirements for a successful prototype. A wheel thickness was chosen arbitrarily and Equations 1, 2, and 3 in Fig. 26 were used to determine the wheel size, length of the electronics board, and board width, respectively. All assumptions and variables are found in Fig. 26. It was determined that the wheel size should be less than 5.36 inches, the board length should be less than 7.5 inches, and that the board width should be less than 4.5 inches.

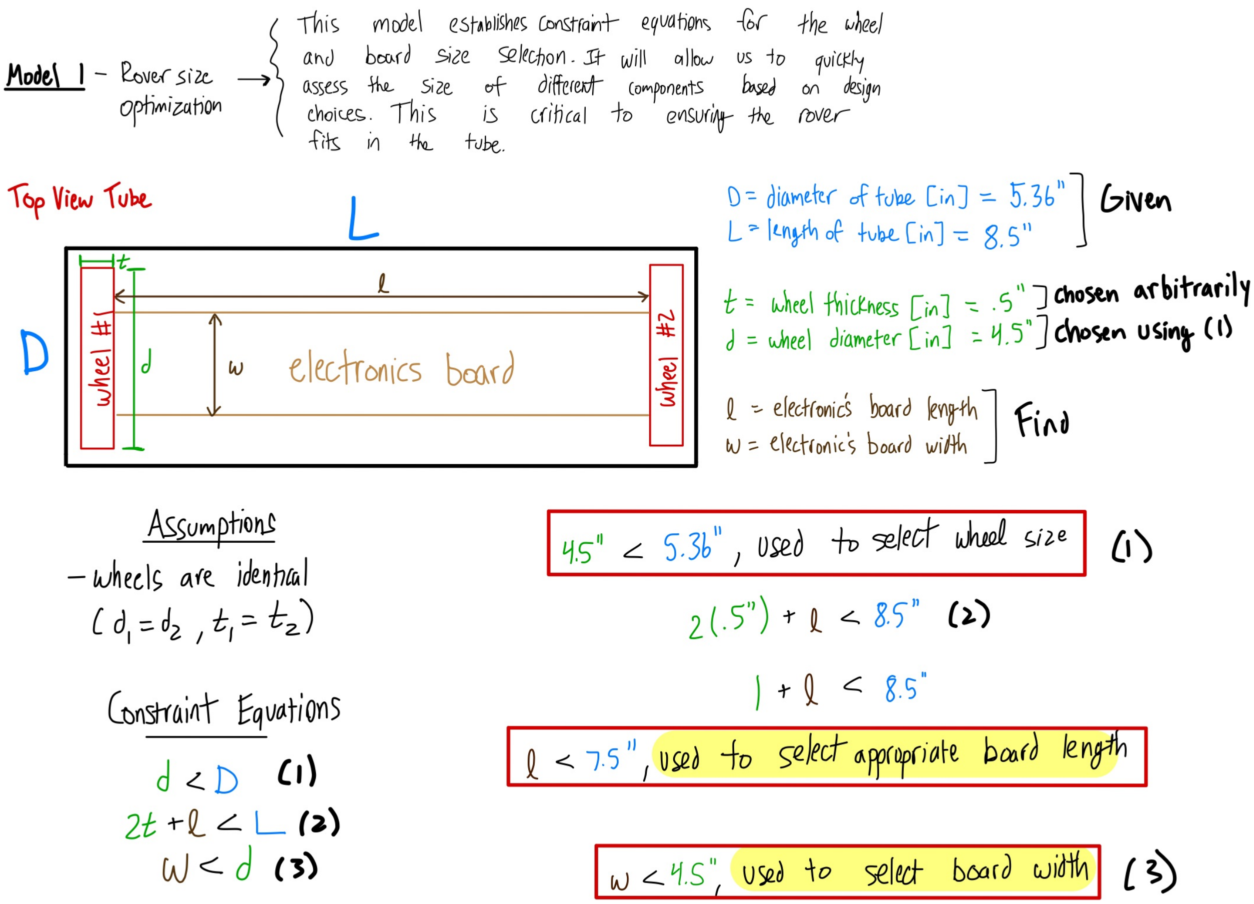


Figure 26: Model-based design rational for Rover Size.

6.1.2 Model-Based Design Rational #2

Our second model provides an estimation of the ramp size that must be used with the maximum collection container size. The collection container must be maximized to ensure that a large quantity of rocks can be collected and thus it is necessary to determine a rough estimate of the ramp geometry that will work with this design. All assumptions and variables are found in Fig. 27. Equations 1, 2, and 3 in Fig. 27 determine the collection container height, ramp pitch angle, and ramp size, respectively. It was determined that the ramp should be pitched at approximately a 51.1 degree angle and that the ramp should be roughly 2 inches long.

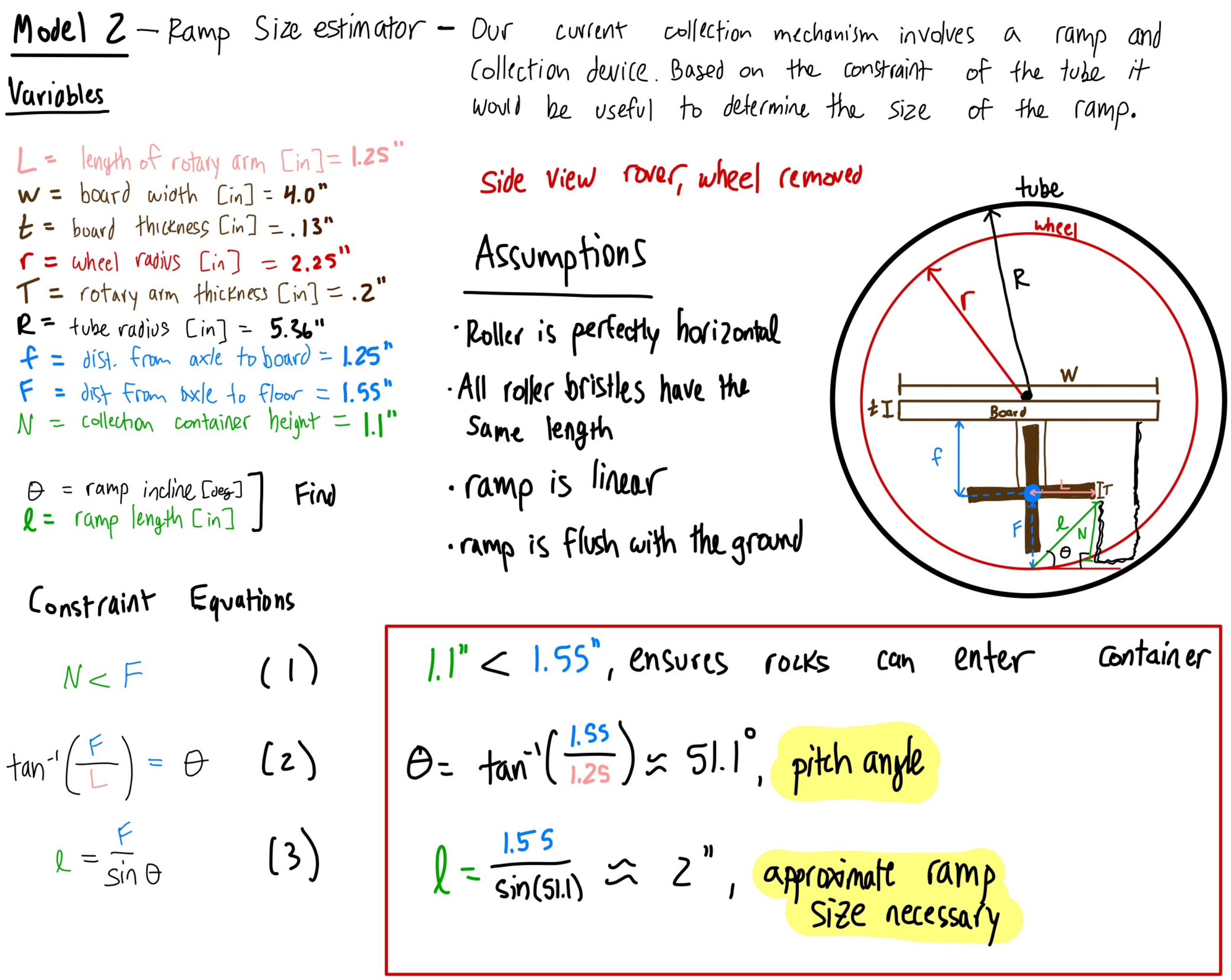


Figure 27: Model-based design rational for ramp size.

6.1.3 Model-Based Design Rational #3

The final model estimates the power required to move the rocks into the collection container with the roller. Because we are using small servos, we needed to ensure that the power generated was enough to handle the quantity of dice before testing the design experimentally. The electrical current data was obtained from *Feetech RC Model Co., Ltd* Specification Sheet [1]. All assumptions and variables are found in Fig. 28. Equations 1, 2, and 3 in Fig. 28 were used to determine the power required to collect the rocks, power generated from the micro-servos, and angular velocity of the roller. It was determined that it would require .05 Watts to collect 5 rocks simultaneously. The continuous micro-servos are capable of providing 2.475 Watts, which well exceeds the required power.

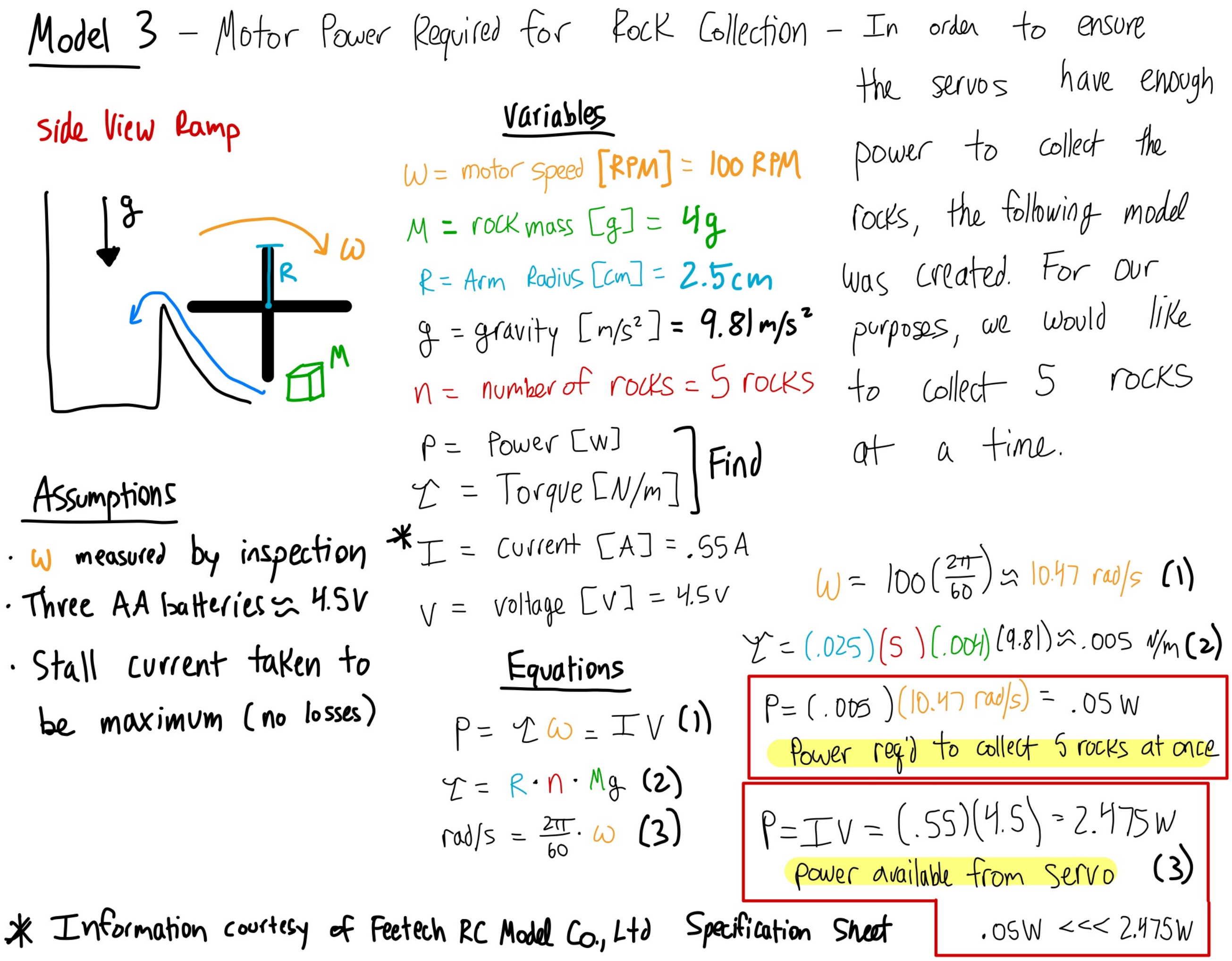


Figure 28: Model-based design rational for rock collection.

6.2 Design for Safety

A safe design identifies hazards proactively by using risk assessment methods. This method is completed early in the design process as it mitigates risks through the entirety of the design process. Using a collaborative approach, each hazard is identified based on its severity and probability during use and construction of the rover. The five largest risks to the operator are identified below and are accompanied by mitigating steps.

6.2.1 Risk #1: Electrical Shock

Description: The rover has exposed electrical components. When working on the rover, the users skin could come into contact with exposed electrical wires as the rover houses two batteries packages to power multiple servos and a live feed camera.

Severity: Marginal; the battery packs used on the rover are fairly low voltage thus electrical burns or scars are unlikely.

Probability: Seldom; all wires are covered in insulation, thus providing protecting to the user when moving live wires. All wire connections use a wire harness to provide additional insulation, as these are most common areas the user will interact with the wires.

Mitigating Steps: The battery pack should always be turned off when working on the rover. The rover should then be inspected to ensure all wires are covered and protected with insulation. Never operate the rover in wet or muddy conditions.

6.2.2 Risk #2: Impact Injury

Description: Upon operation the rover can reach a speed that may cause harm to young children during a collision.

Severity: Marginal; the rover does not reach high enough speeds but could leave a small scratch if crashed into an bystander. The rover is also very small and light which can lead to minimal impact injury if dropped from a table height.

Probability: Seldom; the rover will be operated in a controlled environment where no bystanders can be harmed.

Mitigating Steps: The rover should be operated in a controlled environment with adult supervision. The user should be aware of all obstacles and bystanders in the driving area.

6.2.3 Risk #3: Pinch

Description: Due to multiple moving parts on the rover, some mechanical components could catch and grip human skin to cause pain; a pinching effect. During operation the servos near the wheel and the roller come in to close contact with areas that need to be accessed by the team.

Severity: Marginal; a pinch does cause immediate minor pain. The result will not need medical attention but may cause bleeding in the most extreme cases.

Probability: Occasional; the roller helps contain the dice in the collecting ramp and has little room to access the device after collection.

Mitigating Steps: To avoid being pinched it is important to keep hands clear from moving parts (roller and wheels). In addition, the risk can be completely avoided if the rover is turned off before accessing any collected dice.

6.2.4 Risk #4: Heat Burn

Description: The rover uses a first person view (FPV) camera and antenna to pilot the rover during the contest. The camera heats up very quickly and reaches temperatures too hot to touch during operation. This can lead to heat burns if the rover needs to be worked on during or after use.

Severity: Marginal; the temperature is hot enough to cause minor pain but not hot enough to need medical attention.

Probability: Likely; the camera heats up very quickly during use and remains hot for a few minutes after the battery is disconnected.

Mitigating Steps: To prevent heat burns it is essential to unplug the battery and wait a few minutes before touching the camera. Additionally, a 3D printed holder will be used to secure the camera and act as an insulation for the camera to allow easy adjustment.

6.2.5 Risk #5: Fire

Description: The rover uses a FPV camera and antenna to pilot the rover during the contest. The given camera heats up very quickly and reaches temperatures too hot to touch during operation. This can lead to a possible fire if the camera is used continuously for a long duration.

Severity: Critical; a fire could deem the entire rover unusable and could cause damage to the local operating area.

Probability: Unlikely; the camera does reach a very hot temperature and can lead to the melting of parts and a possible fire if used for an extended duration.

Mitigating Steps: The camera should not be used for extended periods as this is the main reason for an increase in temperature. The battery should be unplugged frequently to reduce the heat. Additionally, the camera will be placed in a plastic holder to protect the base of the rover from the excessive camera heat.

6.2.6 "Heat Map" of Risks

A risk heat map is a matrix used to asses risk data as the colors denote the danger of each risk. The red color is denoted as harmful risks as the green represents small and minor risks. As seen in Fig. 29 are the five risks described above placed into the heat map based on their probability and severity:

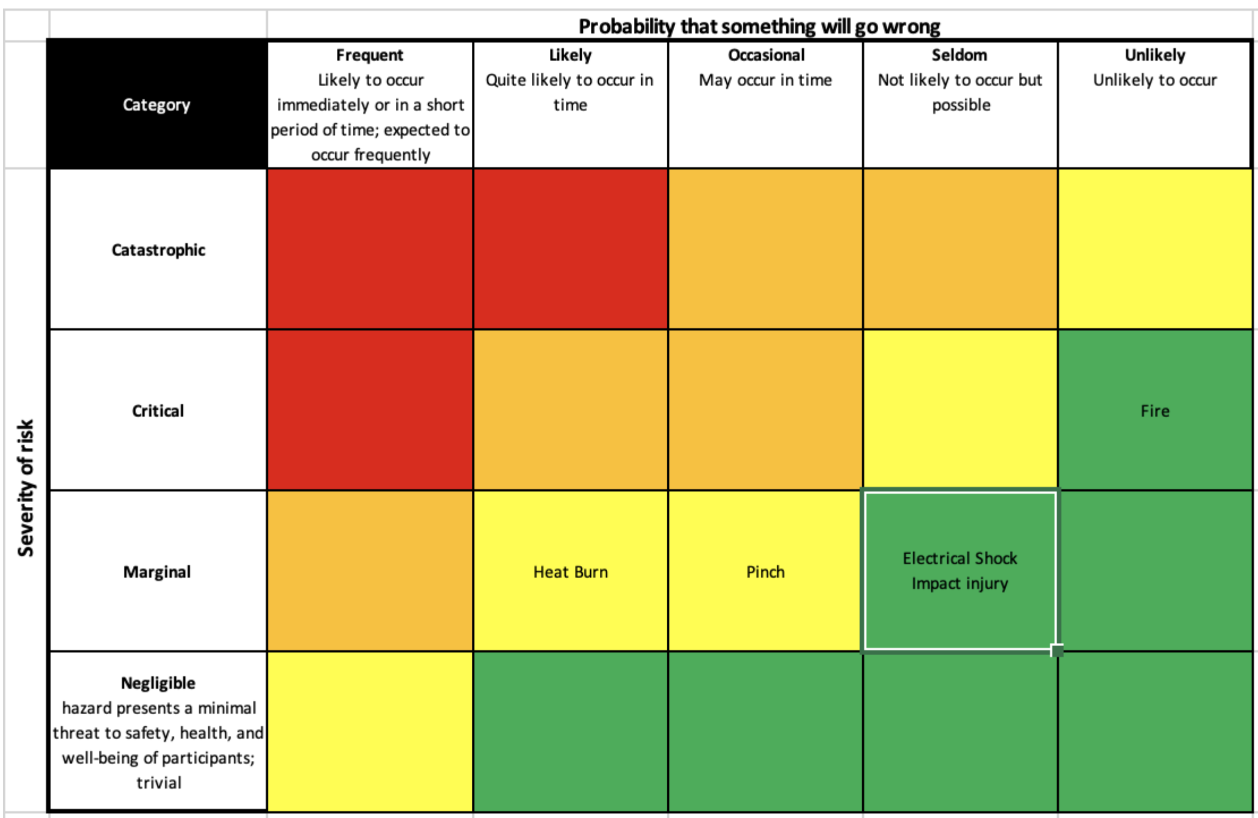


Figure 29: Heat map of risks.

The highest priority risk is heat burn as this risk is likely to happen and has happened the most during the construction. The next highest risk is getting pinched, due to the many moving parts on the rover. The third highest priority is the fire as the camera will need to be used for an extended period in competition and could cause detrimental damage to the rover. The fourth highest priority risk is the electrical shock as the rover has many connections that require frequent use. The lowest priority risk is the impact injury as the rover is piloted in a controlled space.

6.3 Design for Manufacturing

There are 28 different components in the current design. A total of 30 threaded fasteners connect the components together.

The theoretically necessary components are listed in the table below. All of the electronics have

Part	Quantity
Platform	1
Continuous servos	3
Roller	1
Wheels	2
Battery Pack	1
Camera	1
Camera Battery	1
Receiver	1
Battery Pack Bracket	1
Camera Bracket	1
Camera Battery Bracket	1
Receiver Bracket	1
Total	15

to be their own components as they are already created and have very specific functions. For all these components except the servos, these parts must be removed from the rover for charging or other types of maintenance. For these reasons, the brackets for these parts (camera, camera battery, battery pack, and receiver), have to be their own parts. The wheels have to turn independently from the other parts of the rover. The motors are fixed while the wheels are allowed to rotate, thus the wheels are a necessary component. For similar reasons as the wheel, the roller must also move independently from the rest of the rover, thus making it a necessary component. Finally, the main platform is the last vital component to the rover. It must stay stationary while the wheels and roller move, meaning it must be its own part. The easiest way to reduce the total number of components is to incorporate many of the parts into the main platform. With some CAD skills and lots of support, the ramp/basket, servo mounts, roller supports, and the pin could all hypothetically be added to the main platform and be 3D printed as one continuous part. This would both reduce the total number of components and also reduce the number of threaded fasteners by 10. This is realistically impractical due to the complicated geometry of the overall parts, but some combination could be implemented easily.

6.4 Design for Usability

There are several types of impairments that may make the operation of the rover difficult for some groups of people. The following impairments that may affect the usability of the device are addressed below: vision, hearing, physical, and control. Possible solutions and suggestions for those with these impairments are provided.

Vision Impairments:

A vision impairment may impact a user's ability to see the rocks they intend to collect. Using a higher definition camera may mitigate this, but only for some vision impairments. Future iterations could utilize an assistance program or AI that can operate the rover autonomously and may be necessary for some groups to operate the rover efficiently. Color blindness does not pose any difficulty for the operation of the rover, but could be an issue for individuals working with the wires on the device. For this reason, all wires will be labeled clearly and will not rely on color coding.

Hearing Impairments:

Hearing impairments do not pose any difficulty to operating the rover. Hearing, however, is essential to knowing when a rock is stuck or when a rock is fully collected. For future prototypes, an alert light could be designed to sense when a dice is stuck or collected. This would alert the pilot of a possible error or confirmation of a successful rock collection. This will also be useful to any operators controlling the rover out of earshot.

Physical Impairments:

Physical impairments could impact the operator's ability to control the rover effectively. If the user has muscle weakness, arthritis, or limb immobilization, they may have trouble using the transmitter controller. A possible solution would be to design a controller with fewer controls or that could be held easily. With a larger budget, future iterations may be able to produce a voice operated rover, which would require the rover to accept different input devices.

Control Impairments:

We do not recommend operating the rover if you are under the influence or are taking medication that may cause fatigue or muscle weakness. The effective control of the rover will be impacted and may cause damage to the rover and nearby persons or objects. To mitigate this risk, future iterations may use guards and bumpers to mitigate the risk of damage. The same assistance AI used for those with visual impairments could also assist in preventing crashes that would damage the rover and the environment.

7 Final Prototype

Our Final Prototype can be seen in Fig. 30. Few changes were made from the initial to the final prototype. Several additional parts were printed to replace wooden ones and some parts that showed wear were replaced but the overall design was identical.

Figure 30: The final competition prototype with the dice it collected.

When retesting our prototype performance goals with the final iteration of our design, the rover was easily able to complete and surpass the metrics for success in each goal. The prototype performance goals and the results from the final tests are summarized below:

- 1) The rover can collect more than 28/35 rocks (dice) of varying shapes.
  - a) When 35 rocks (dice) were laid out, the rover was able to collect 34 of them, a pickup efficiency of 97%. The only failed pick-up was due to the rock (die) not coming into contact with the roller, which is a driver error and not a mechanism failure.

- 2) The rover can carry more than 35 rocks (dice).
  - b) When filled to capacity, the rover was able to hold a total of 61 rocks (dice). This is nearly double the prototype performance goal of 35.
- 3) While being remotely operated (controller only sees first-person view from camera), the rover can complete the agility course in Fig. 21 in less than 5 minutes without touching the tape on the ground (shown in red).
  - c) The rover was able to complete the agility course, while being remotely operated with the first person camera, in 1 minute and 39 seconds without hitting the tape, suggesting that the rover may be able to complete the course almost four times within the time limit.

Overall the final prototype was a massive success and overachieved by a significant margin the goals set out for it.

For the competition, one additional problem had to be quickly modified on the rover. The competition was on carpet, which was unexpected, so additional rubber band were added to the wheels to add more clearance from the ramp on the bottom. The driving ability was negatively affected by the carpet and made driving much more difficult, causing the rover to become stuck during the competition. Despite this, the rover collected 53 rocks (dice) within the 5 minute window. This is fairly close to our maximum, so we were very happy with the results. This was also the winning number of dice for the competition by a margin of 20 dice which makes us extremely proud of our overall design and performance of our rover in the competition. Check out the rover with the winning trophy in Fig. 31!

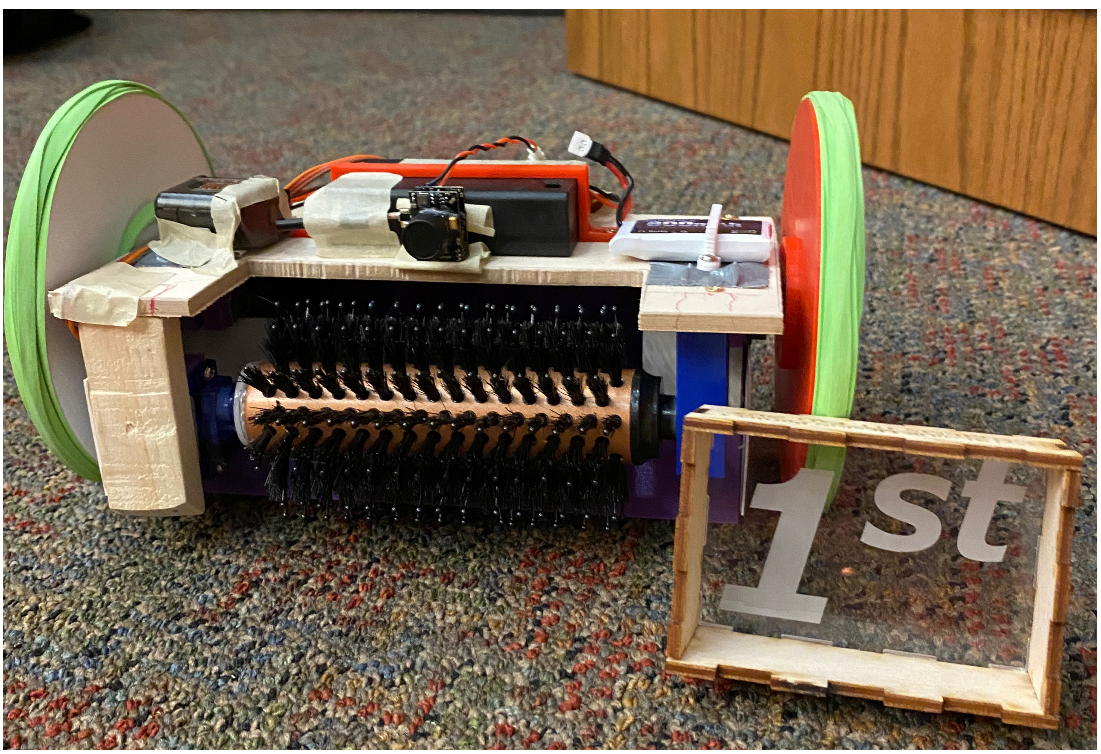


Figure 31: The rover at competition with the first place trophy.

Bibliography

[1] FEETECH RC Model Co. *AA6V 1.5kg.cm Analog Continuous rotation Servo Datasheet*. 2022. URL: https://cdn-shop.adafruit.com/product-files/2442/FS90R-V2.0_specs.pdf.