Fall 2022

MEMS 411: Remotely Operated Rock Collecting Vehicle

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Mechanical Engineering Design Project
MEMS 411, Fall 2022

Rock Collecting Rover

This report outlines the design process for creating a rock-collecting rover for Dr. Potter that may be useful for a future NASA Student Launch competition. The parameters of this design are that the rover must weigh less than 3.5 pounds and fit inside a cylinder 8.5" long and 5.38" in diameter. It must also be RC transmitter/receiver operated, controlled completely through a camera view that is attached to the vehicle, and carry its collected rocks. The "rocks" in this report are dice of all shapes.
After many iterations, the rover was chosen to collect rocks through a rotating fan controlled by a servo motor that contact each rock as the rover drives up to it, and push it onto a ramp that leads the rock to the body of the rover.
The design goals of the rover are three-part: 1.The rover must be able to hold at least 35 rocks at one time. 2.The rover must be able to pick up at least 28/35 rocks placed. 3.The rover must be able to complete an outlined agility course in under 5 minutes.
The design outlined in this report is able to complete all design goals, and effectively collects and transports rocks as intended.

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1 Introduction

The objective of this project is to produce a Rock-Collecting Rover capable of collecting and storing objects titled rocks. The Rock-Collecting Rover's technology could apply to future WU Rocketry Competitions which have needed unique devices in the past that can do a task and can be stored in the rocket. This design has many limitations with the strictest being: size constraints (D = 5.36" H = 8.5"), weight limit (<3.5 pounds), and price(<400 dollars). Additionally, the rover will be battery operated, remote controlled, and possess an onboard camera. The rover will have 5 minutes to pick up as many rocks as it can. These rocks are dice that range from 4 to 20 sides with an average weight range of 4.10 – 4.5 g. Overall, the goal of this competition is to produce a rover that can quickly and efficiently collect and store rocks. [**MatWeb1045**].

2 Problem Understanding

2.1 Existing Devices

There are many devices that already fit the description of the Rock Collecting Rover. The three design below exhibit what the rock collecting rover could be. Each device has a different important feature, such as unique rock collecting mechanism or storage system.

2.1.1 Existing Device #1: Tonka Talking Robot Dump Truck

Figure 1: Tonka Talking Robot Dump Truck (Source: Live Auction World)

Link: https://www.liveauctionworld.com/RARE-TONKA-TALKING-ROBOT-DUMP-TRUCK_i26442879
Description: The Tonka Talking Robot Dump Truck is a battery-operated toy that can scoop, claw, and talk. This toy features two adjustable arms that can be rotated to its rear compartment. One arm has a claw that is able to open and close. The other arm has a scooper with 3 ridges. The rear compartment is modeled after a dump truck with 3 sides and an open back. The compartment can rotate up so that the objects in the compartment can spill out the back. The toy is 14" long.

2.1.2 Existing Device #2: That

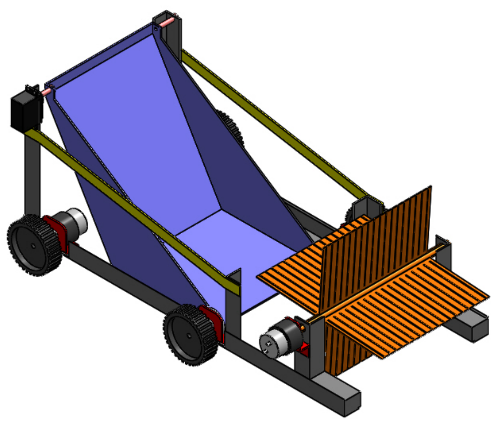


Figure 2: Garbage Collection Robot (Source: Nevon Projects)

Link: https://nevonprojects.com/garbage-collection-robot-using-wireless-communication-technology/
Description:The Garbage Collection Robot was created to combat the growing garbage crisis. It uses a rotating flapped piece to trap trash and rotate it to a back compartment. It is controlled by a computer program so it moves along a defined path. The program also controls the robot's reactions to its environment and surfaces. It also has textured wheels.

2.1.3 Existing Device #3: Garbage Collector Robot

Figure 3: Garbage Collector Robot (Source: Youtube/Muhammad Ansar)

Link: https://www.youtube.com/watch?v=1nc09xnC7M0
Description:The Garbage Collector Robot is designed to pick up boxes of trash and store them in the back compartment. The robot has two arms that move together to pick up a box and dump it in the back compartment. This back compartment is unique because when it is full it can roll over to a specific area and dump out the trash. It does this by rotating the back compartment and then restoring its initial position. This robot can follow a taped path.

2.2 Patents

2.2.1 Position data-powered control system for camera and stage equipment for automated alignment to defined mobile objects (DE202010013678U1)

This patent combines the use of known components in the Spidercam with a data processing program to automatically align, position, and move camera and lighting units versus manually. The unit is fitted with a device that allows for position data determination, which is sent to a digital interface for processing. The same device allows for coordinates to be sent to the carrier unit to orient the camera to the desired position. Though the system as a whole can be oriented autonomously with remote-control, this may be enabled or disabled as desired.

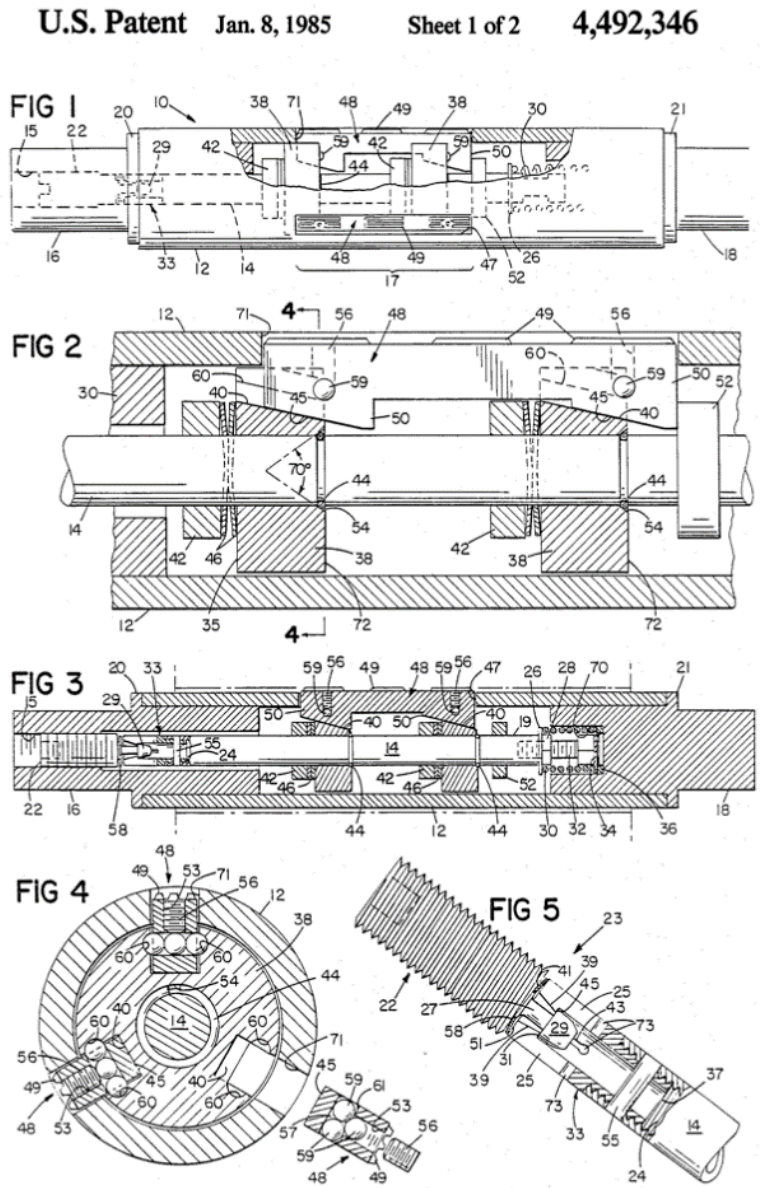


Figure 4: Patent Images for expansible shaft

2.2.2 Vehicle remote control system (US5596319A)

This patent is utilized for the construction of a remote-controlled vehicle system. Key parameters of the system include:

- a camera in-line with the direction the of car movement
- a remote-control station used to maneuver the operations of the vehicle
- various sensors to track the operational aspects of the vehicle, such as speed or direction

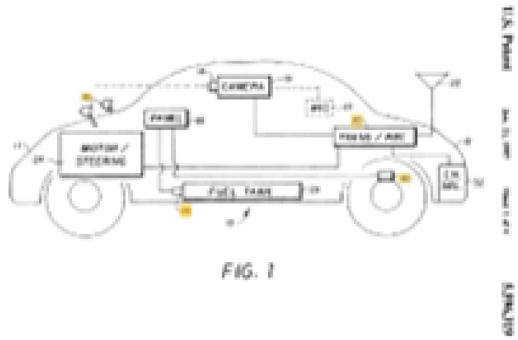


Figure 5: Patent Images for Vehicle remote control system

2.2.3 Remote-controlled toy trash truck (US6264528B1)

This patent describes the movements of a remote-controlled toy trash truck capable of picking up items. The vehicle is capable of motion, maneuverability, and lifting objects as illustrated in the images below. It supports a bin that holds objects after they are picked up and a load-lifting arm that is attached to the main frame of the system.

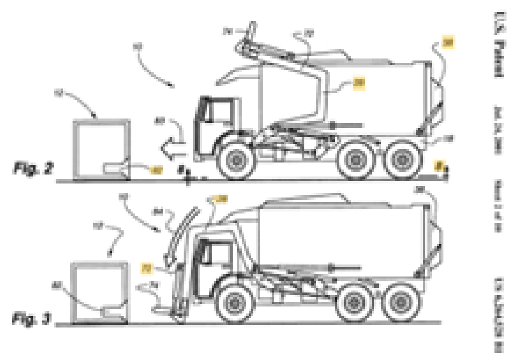


Figure 6: Patent Image for Remote-controlled toy trash truck

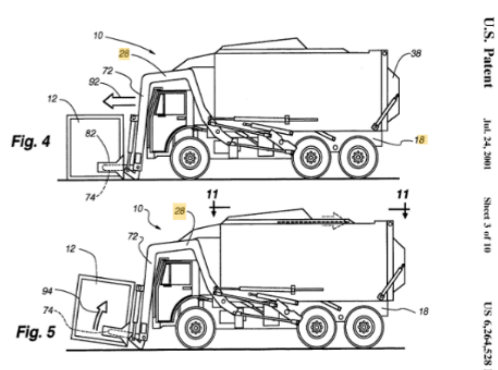


Figure 7: Additional Patent Image for Remote-controlled toy trash truck

2.3 Codes & Standards

2.3.1 Safe Temperature of Electronic Devices (CFR 1505)

This standard applies to the maximum acceptable temperature of an electronic device that may come in casual contact with the user or is otherwise accessible but not intended to be touched on a regular basis. The temperature of any surface may not exceed 149 degrees Fahrenheit. Furthermore, all surfaces that may come in contact with the user must be accessible by a temperature probe of diameter 0.75 in. This ensures that any surface accessible to the user is also accessible to be temperature regulated.

2.3.2 Mechanical and Electrical Safety of Toy Vehicles//(ASTM F963-17)

This standard outlines important safety precautions and procedures for toy vehicles. Outlined in this standard are tests regarding the safety and use of sharp edges, small parts, and battery operations. For example, this standard outlines on any part requiring a hinge, there must be sufficient clearance between the movable and stationary parts of the object that is at least the diameter of the hinge radius.

2.4 User Needs

Dr. Potter was interviewed as our customer for the rock collecting rover competition. Our user needs and design metrics were evaluated based on the knowledge gathered in the following interview.

2.4.1 Customer Interview

<u>Interviewee</u>: Dr. James Jackson Potter
<u>Location</u>: McMillian G052, Washington University in St. Louis, Danforth Campus
<u>Date</u>: September 9^{th}, 2022
<u>Setting</u>:The whole interview was conducted in the lecture hall, and took ∼45 min. Multiple teams had the opportunity to ask questions regarding the rock collecting rover competition. Dr. Potter presented the standard equipment that will be used across all groups and demonstrated use of the RC transmitter. He also provided references for the ”rocks” being used in the competition and potential onboard camera options.

<u>Interview Notes</u>:
Are the ”rocks” standard 12-sided dice?

- Dice range from 4-20 sided, selected from a DD 28 pack

What is the mass of the rocks?

- Size ranges, but on average one can assume 4-4.5 grams.

Do rocks need to be picked up one-by-one or can they be moved prior to collecting them?

- The rocks can be moved before you pick them up.

How many rocks can should we expect to pick up/how many rocks will be on the board?

- The board will consist of a rock matrix, with rocks 1 feet apart. The grid will be 10 feet by 10 feet, so considering the base camp in the middle, one can expect 120 rocks available.

What conditions can we expect the rover to experience?

- Weather and difficult terrain will not be a concern because the competition will most likely be conducted in Jolley.

What are the general requirements for all rovers to meet?

- The entire vehicle must fit in the provided cylinder, be able to be removed without resistance, and cannot manually be modified upon removal. The vehicle must be less than 3.5 lbs. Every team will you the provided RC transmitter/reciever along with micro servo motors.

What are the performance goals?

- Pick up the most rocks in 5 minutes. The rocks must be collected and held in the vehicle.

2.4.2 Interpreted User Needs

After performing our interview and referencing our design prompt, our user needs were compiled in Table 1 below. Needs were ranked on an importance scale from 1 to 5, with 5 being the most important.

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	The vehicle can collect and house rocks	5
2	The vehicle fits inside provided cylinder without being manually modified	5
3	The vehicle is light	4
4	The vehicle picks up the most rocks within the given time frame of any team	5
5	The vehicle uses the designated RC transmitter/receiver	5
6	The vehicle is remotely guided by an onboard camera	5
7	The vehicle does not harm the rocks in any way	4
8	The vehicle uses micro servo motors to operate	5
9	The vehicle complies with all applicable codes and standards	4

Many needs established by the customer were also competition requirements, therefore demanded an importance level of 5.

2.5 Design Metrics

Design metrics were derived from each user needs. Benchmarks were established for ideal performance as well as acceptable performance in each category. Some target specifications will be evaluated based on passing an established goal, whereas as others were given numerical targets. The target specifications listed in Table 2 will guide our design.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	3	Total weight	lbs	3.5	2.5
2	2	Total volume cylinder	in^3	< 190	< 190
3	5,8	Uses required RC Transmitter/Receiver and micro servo motors	binary	pass	pass
4	1	Total rock load capacity	lbs	$> .15$	$> .30$
5	1	Total volumetric rock capacity	in^3	> 22	> 35
6	4	Speed at which vehicle can collect rocks	rocks/sec	$> .05$	$> .1$
7	6	Field of view of on board camera	degrees	180	360
8	7	Visual inspection of rocks post collection to ensure no damage	binary	pass	pass
9	9	Temperature probe ensures that under no operation of the vehicle, any surface surpasses safety temperatures outlined in CRF 1505	deg F	< 149	< 100
10	9	The distance between all movable via hinge and stationary components of the rover must be at least the radius of the hinge	binary	pass	pass

2.6 Project Management

The Gantt chart in Figure 8 gives an overview of the project schedule.

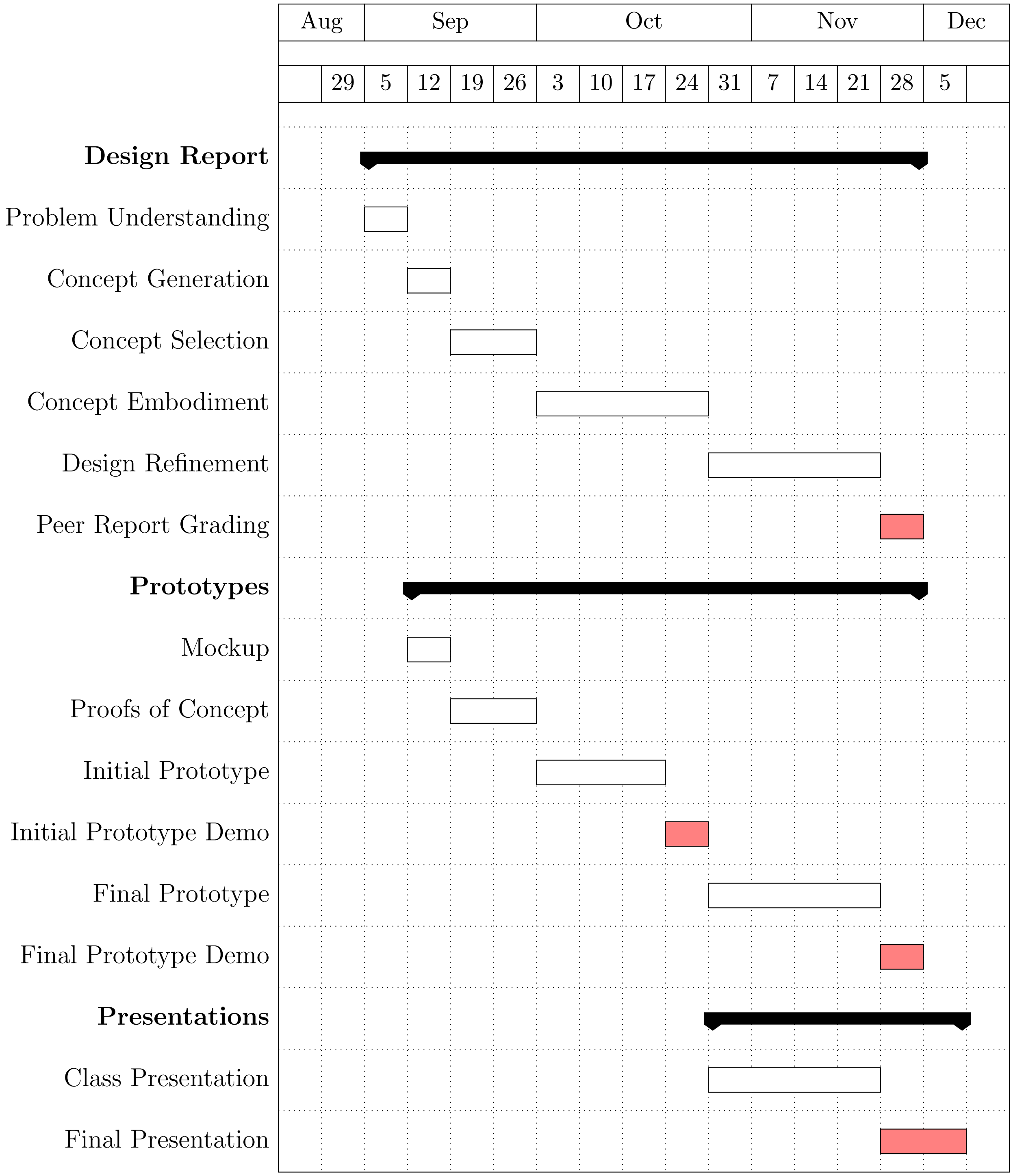


Figure 8: Gantt chart for design project

3 Concept Generation

3.1 Mockup Prototype

An initial mockup was constructed to prototype a potential design for the rock-collecting rover. The concept behind the design was to have rotating blades that drag rocks up a curved slope and deposit them into the vehicle. The mockup was extremely helpful in understanding the required mechanics and sizing for this design. We learned that the blades would have to be much larger to lift the rocks high enough to be dropped into the hole. The mockup highlighted that the sloping of the curve and hole positioning would need to be precisely calculated to ensure success. We also found a potential issue of camera location that will need to be resolved.

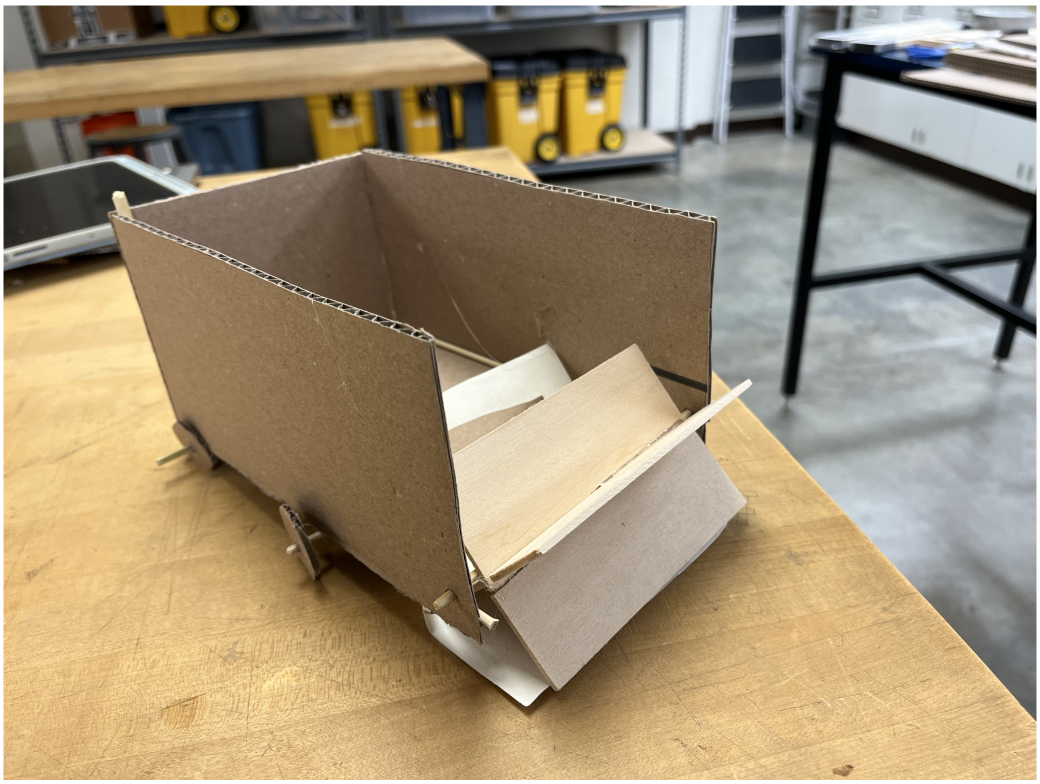


Figure 9: Mockup Isometric View

Figure 10: Mockup Side View

Figure 11: Mockup Top View

3.2 Functional Decomposition

Below is our completed function tree.

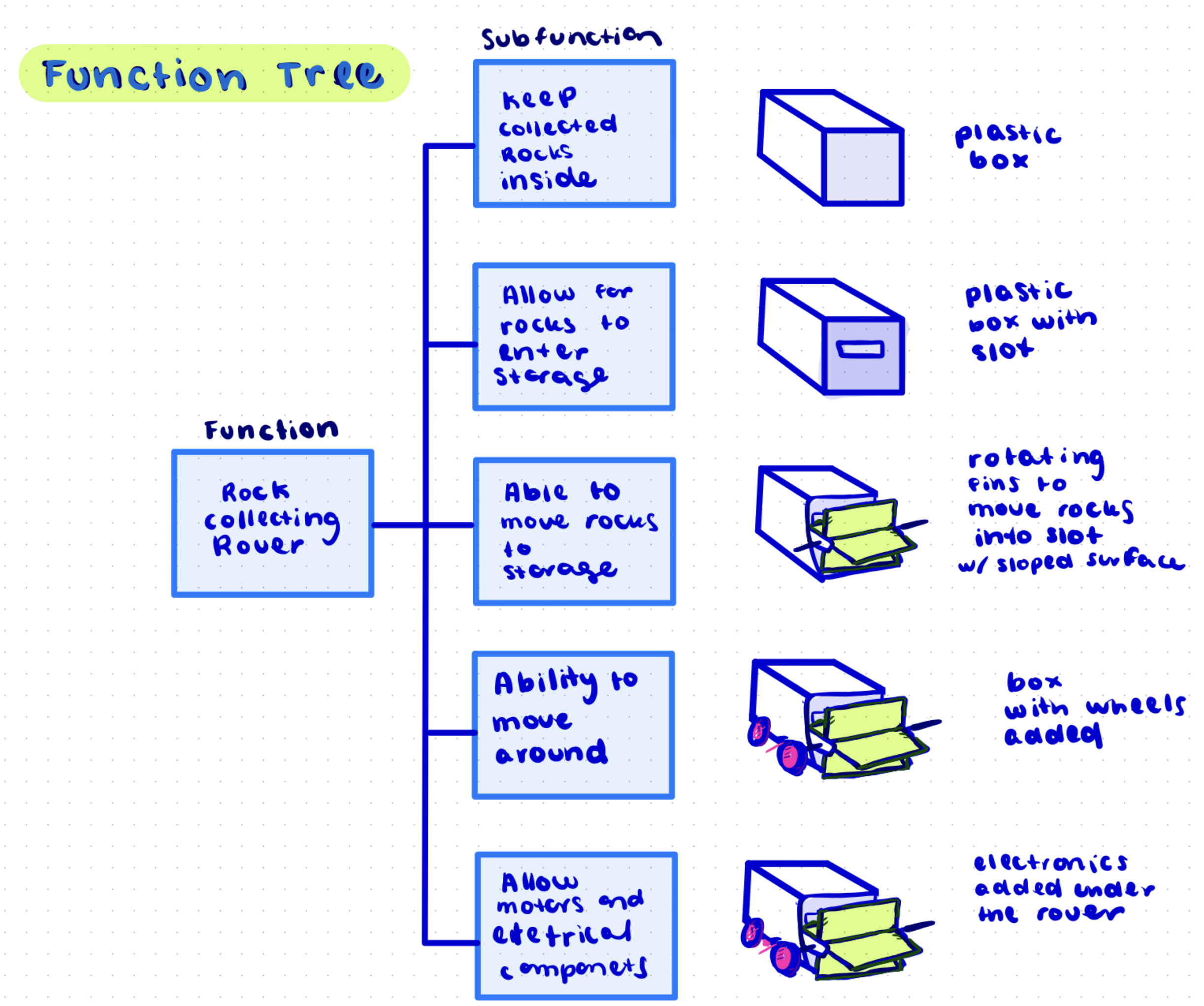


Figure 12: Function tree, hand-drawn and scanned

3.3 Morphological Chart

Below is an image of our morphological chart. It outlines some of the potential designs possibilities considered as we make our rock-collecting rover.

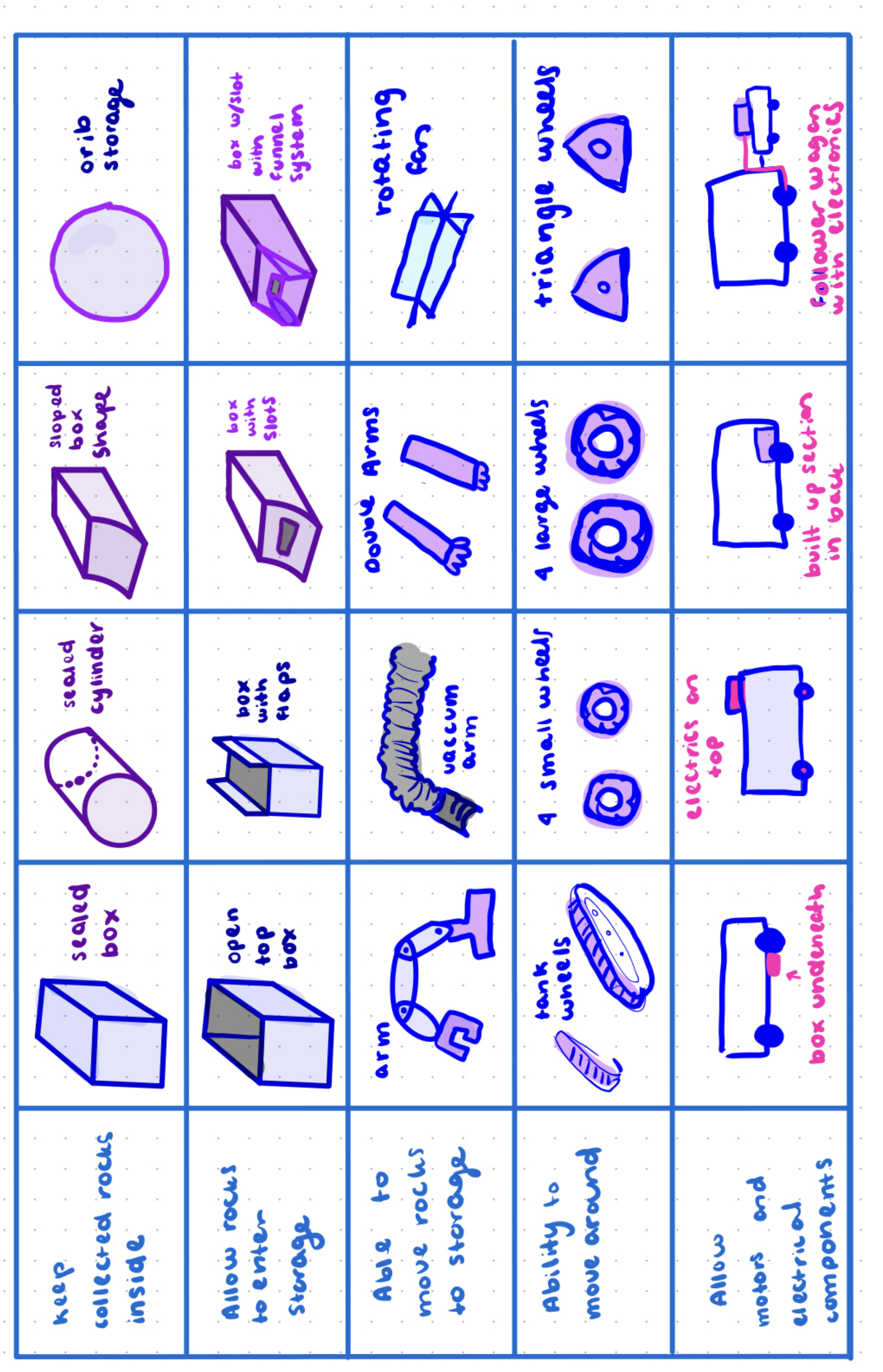


Figure 13: Morphological Chart for Useless Box

3.4 Alternative Design Concepts

3.4.1 Concept #1: Robotic Arm

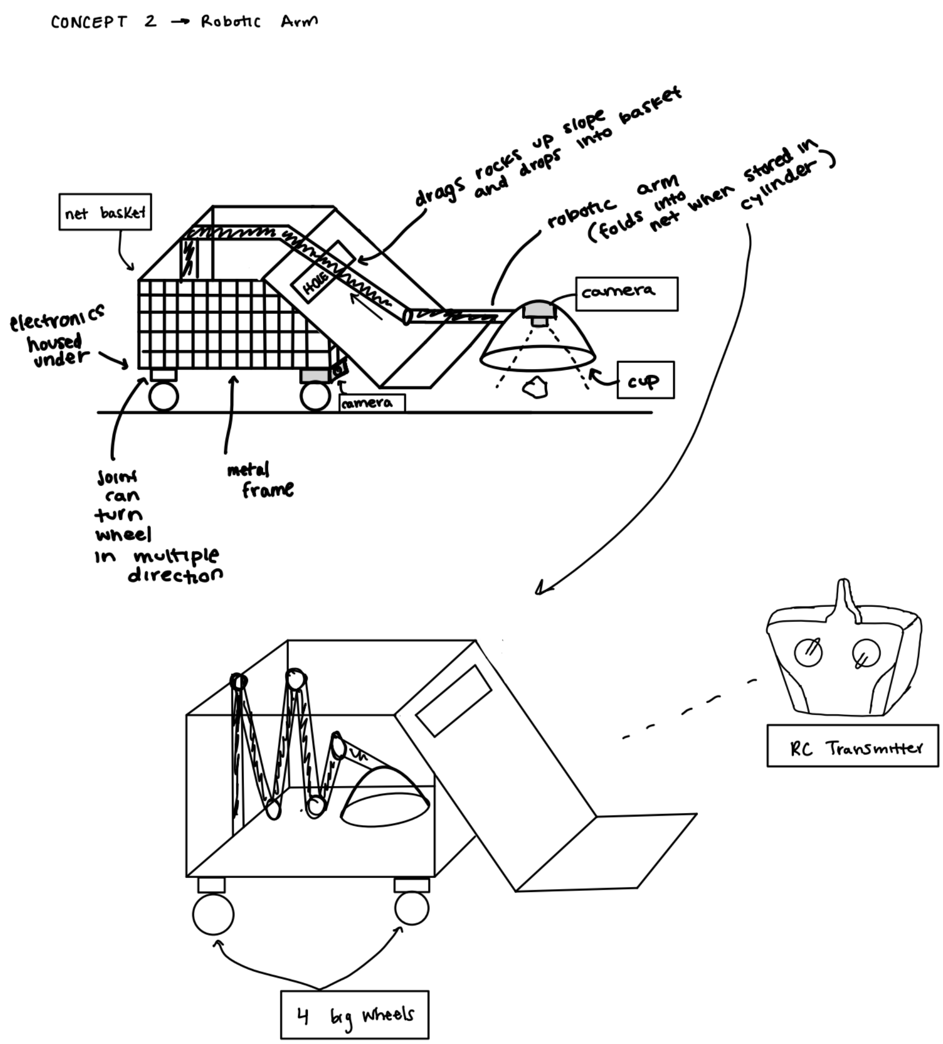


Figure 14: Sketches of Robotic Arm concept

Description: The main compartment of the vehicle that houses the rocks is a net basket. A robotic arm with a cup on the end closes on top of a rock and drags it up a sloped surface. There is a hole at the top that the rocks drop into. The base has a metal frame that connects the wheels and also houses the electronics. There are two cameras, one to guide the vehicle around the board and one inside the cup to ensure the rock is grabbed.

3.4.2 Concept #2: Scoop Design Concept

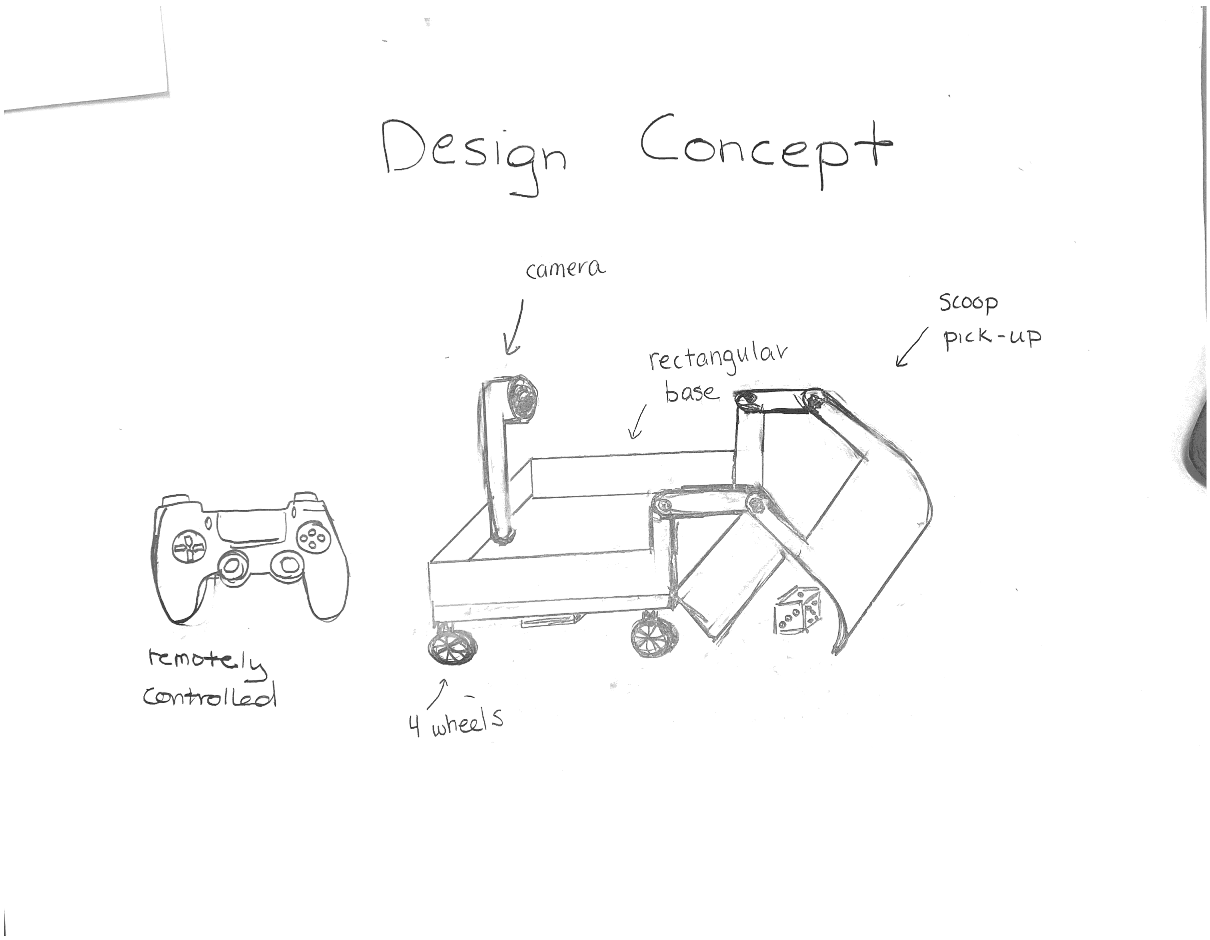


Figure 15: Scoop Design Concept

Description: This concept utilizes a rectangular base which would hold the dice off the ground. It has an arm that scoops the dice onto an sloped surface, pushing it towards main component of the base. There are four wheels that move the base around the surface. There is one camera attached to the back of the base, which allows for a wide-view of where the robot is moving.

3.4.3 Concept #3: The Rotating Fan

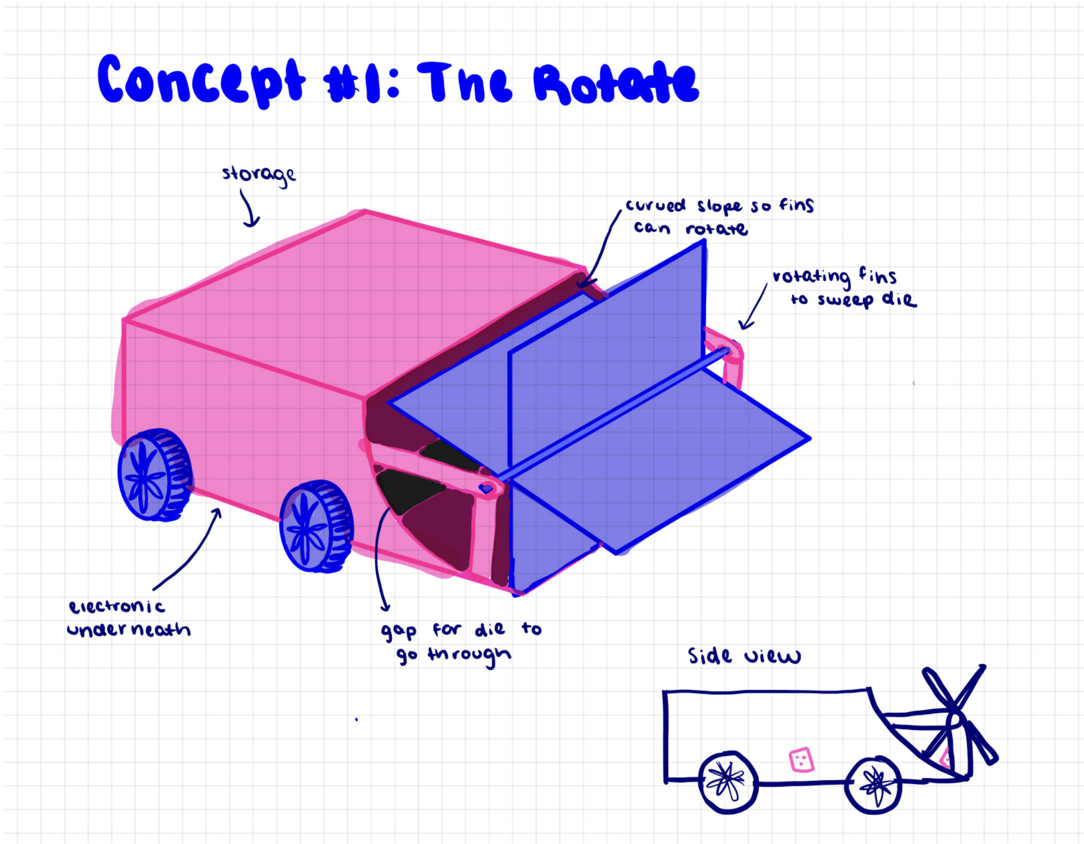


Figure 16: The Rotating Fan

Description: The main concept of this design is a remote-controlled rotating fan. This fan is able to rotate the rocks up a ramp. At the point where the rock starts to fall onto the fan, there is a slot. With the slot placement, the rock will fall into a closed box. The wheels and box will be close to the ground so that the fan has enough rotating area.

3.4.4 Concept #4: The Vacuum

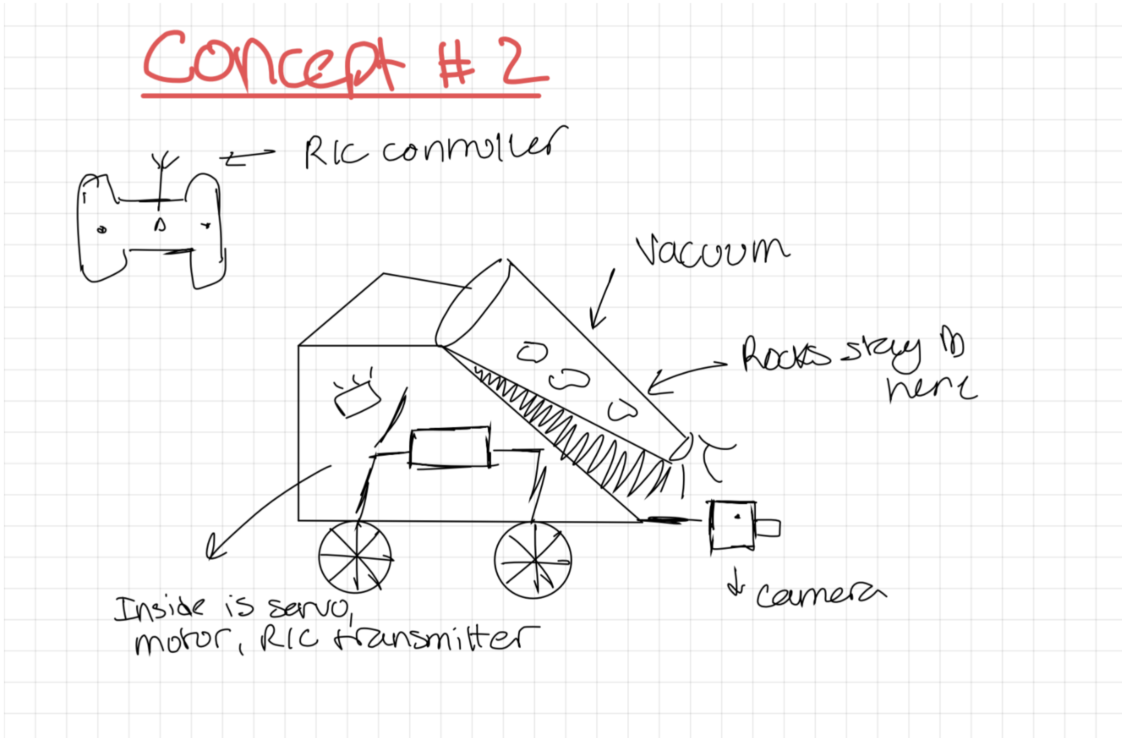


Figure 17: The Vacuum

Description: This concept utilizes a vacuum to suck up the dice within the rover. The dice are then held within the vacuum chamber itself, functioning as a device that not only collects the dice, but stores them long-term. The wheels and base of the rover will be close enough to the ground to ensure that the vacuum will have enough power to collect the dice. Furthermore, this rover will be controlled using a stock R/C transmitter and receiver, and will utilize a camera by the base of the vacuum opening to navigate and find dice efficiently.

4 Concept Selection

4.1 Selection Criteria

To determine the weighting of each of our selection criteria, we used a Analytic Hierarchy Process. We concluded that the most crucial aspects of our device were speed, rock load capacity, maneuverability, size, and field of view. Using the matrix below, we compared each criteria and determined the comparative numeric ratings.

	Speed of Collection	Rock Load Capacity	Maneuverability	Size	Field of View	Row Total	Weight Value	Weight (%)
Speed of Collection	**1.00**	3.00	1.00	0.33	3.00	8.33	0.23	23.36
Rock Load Capacity	0.33	**1.00**	0.33	0.33	0.33	2.33	0.07	6.54
Maneuverability	1.00	3.00	**1.00**	3.00	1.00	9.00	0.25	25.23
Size	3.00	3.00	0.33	**1.00**	0.33	7.67	0.21	21.50
Field of View	0.33	3.00	1.00	3.00	**1.00**	8.33	0.23	23.36
					Column Total:	**35.67**	**1.00**	**100.00**

Figure 18: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

Using a weighted scoring matrix, we compared our four design concepts. The rotating fan was used as the reference concept, as we presumed it would perform the best across the most criteria.

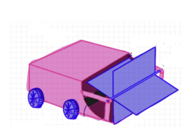
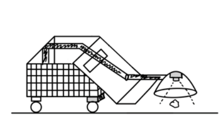
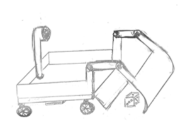
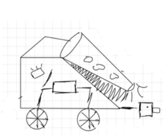
Alternative Design Concepts		**Rotating Fan**		**Robot Arm**		**Scoop Design**		**Vaccuum**	
									
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Speed of Collection	23.36	4	0.93	2	0.47	3	0.70	3	0.70
Rock Load Capacity	6.54	3	0.20	3	0.20	3	0.20	2	0.13
Maneuverability/Ease of Control	25.23	4	1.01	2	0.50	2	0.50	3	0.76
Size	21.50	3	0.65	2	0.43	2	0.43	3	0.65
Field of View	23.36	2	0.47	3	0.70	3	0.70	3	0.70
	Total score	**3.252**		**2.299**		**2.532**		**2.934**	
	Rank	**1**		**4**		**3**		**2**	

Figure 19: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

4.3 Evaluation Results

The Rotating Fan scored the highest out of all our four concepts. In regards to speed of collection, the Rotating Fan can be continually rotated and can scoop any rock up the ramp that is directly in front of it. The Robot Arm would require the operator to extend the arm and retract the arm to collect each rock, which would be significantly slower. The scoop and vacuum would take average lengths of time to collect the rocks, but must stop to operate the collection action which takes time. In regards to the rock load capacity, most designs had similar capacity. The Vacuum scored slightly lower because it would require a large fan and closed compartment to suction up the rocks (taking up space in the vehicle). Maneuverability and ease of control was an important factor. The Robot Arm would be difficult to maneuver because the arm would need to be precisely extended directly on the rock to capture it. The Vacuum also lower scored than the rotating fan because a low power vacuum would need to be executed in the exact right position to suck up the rock. The Scoop Design mechanism would be difficult to operate, therefore it also scored low in this category. In regards to size, the rotating fan is fairly self contained, whereas the rest of the designs are bulky and/or require extending components. Finally, field of view was a low scoring category for all designs. Due to the fan spanning the entirety of the front of the vehicle in the Rotating Fan design, it is difficult to place a fan. This is why the Rotating Fan scored lower than average in this category. Overall, the Rotating Fan was the best design for our selected criteria.

4.4 Engineering Models/Relationships

The following engineering models will help us and determining specific design aspects of our device.

4.4.1 Model 1: Geometric Model

This model will be used to determine the placement and size of the rotating fan because positioning is crucial to the functioning of the device. The blades must be large enough to contact the rock, but not too large that they get stuck on the ramp or fail the sizing requirement. The sizing is dependent on the required cylinder, therefore y and x will be determined first. In addition, h will be known from the sizing of the rocks.

Variables:
r = *Length of fan blade*
R = *Radial distance from a fan axle to ramp*
h = *Average rock height*
H = *Vertical distance from bottom of vehicle to fan support*
x = *Distance from ground to bottom of vehicle*
y = *Height of vehicle*
L = *Horizontal distance from fan axle to ramp*

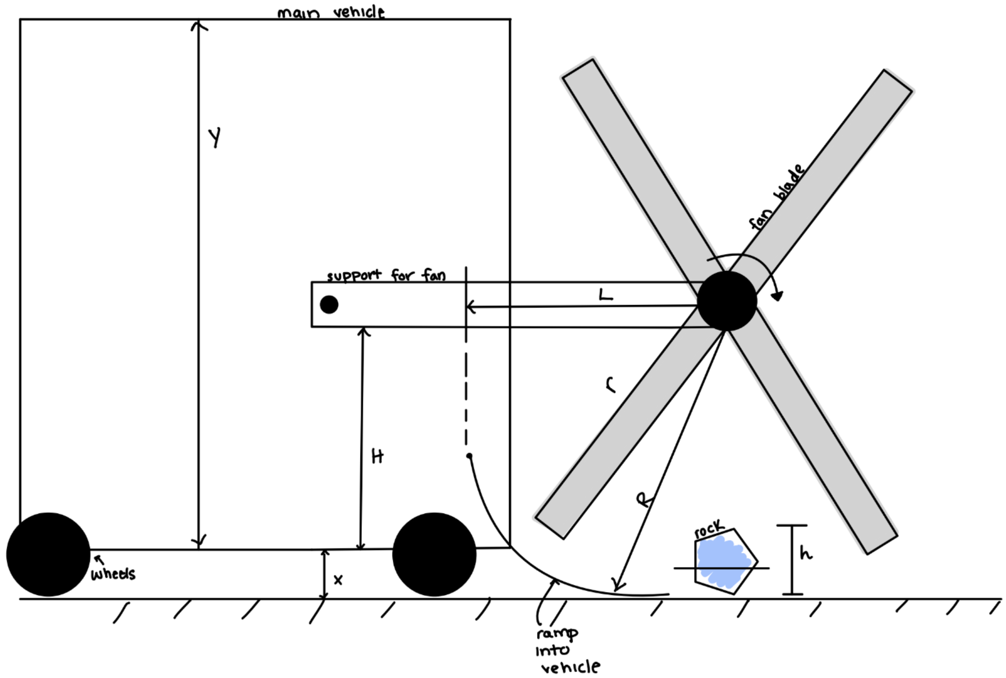


Figure 20: Geometric model to determine fan placement and sizing

The relations below can be used to determine the optimal proportions for each component. The distance R must be maintained from the ramp at all times.
$H = r - x$
$R - r = (1/3) * h$
$y = 2r$
$L = R$

4.4.2 Model 2: Max Torque-Speed Determination

Based on the micro servers chosen, certain attributes are known about the capabilities of the motors. We must ensure that given our 4.5 V battery, the micro servers can turn the fan at our desired speed. The stall torque and max speed are provided by the manufacturer at two different voltages [1] . We can interpolate to estimate the values at our battery voltage. Given our known rock mass and blade size, we can determine the maximum applied torque and maximum potential rpm.

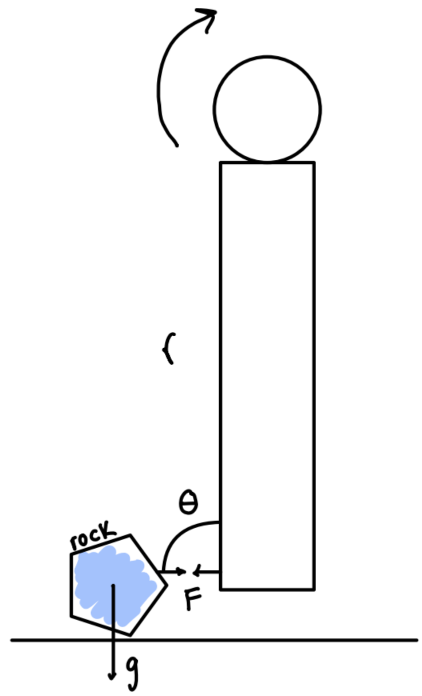


Figure 21: Diagram depicting applied torque on rock by fan blade

Using the known Stall Torque and No Load Speed, we can determine our maximum rotational speed from the torque we calculate. This relation will also tell us if it is physically possible to pick up our desired number of rocks with the given motors. The following equations will be used:

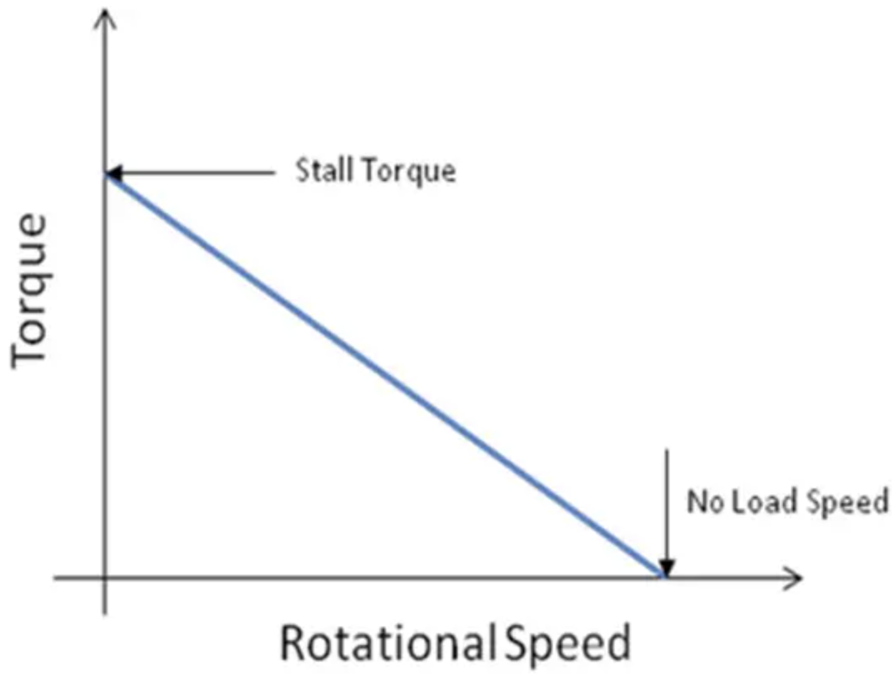


Figure 22: Torque-Speed Graph for DC Motors [2]

m=mass of rock
g=acceleration due to gravity
F= Force applied to rock from fan blade
T= applied torque
θ *= angle between applied force and moment arm*
r= length of fan blade

$F=mg$
$T=Fr\sin\theta$
$T=(mg)(r)$

4.4.3 Model 3: Camera Angle Projection

This model shows the camera position that is needed to view the dice during capture. The rover design uses rotating fins to pick up dice. The fins are large and obstruct the view of the dice on the ground. This means that a camera that is able to swing out to the side will allow for a greater view of the ground. The model is dependent on the angle between the model's body and the rod holding the camera. The second angle is the set viewing angle of the camera which is 120 degrees.

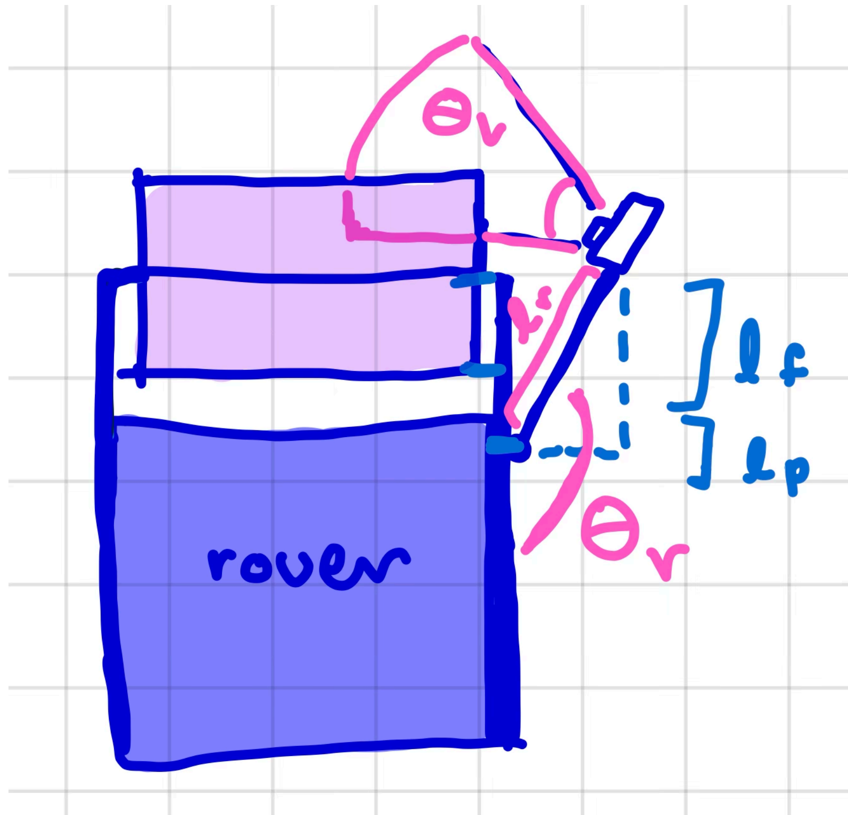


Figure 23: Diagram of camera position relative to main body

Variables:
θ_v =viewing angle of the camera
θ_r= angle between rover body and rod
l_p= length between pivot and edge of fan
l_f= side length on one fin

The relation between the variables is found below:
cos(180 - θ_r) = $(l_f + l_p)/l_r$

5 Concept Embodiment

5.1 Initial Embodiment

Figures 25, 26, and 27 below display our assembled initial prototype. Fig. 25 contains overall dimensions (in mm), in addition to an isometric view of our model. Fig. 26 displays an enlarged isometric view from a different angle. Fig. 27 is an exploded view of our prototype, with its corresponding Bill of Materials.

To test the functionality of our prototype, we established three performance goals. Our first performance goal is the ability for our rover to collect at least 28 out of the 35 rocks (dice) it attempts to collect. To pass our second performance goal, the rover must be able to carry at least 35 rocks at a given time. Our final performance goal requires our rover to successfully complete an outlined agility course, while being remotely operated (via an onboard camera), in under 5 minutes. The agility course is outlined in tape (Figure 32), which our rover must avoid in order to complete the test.

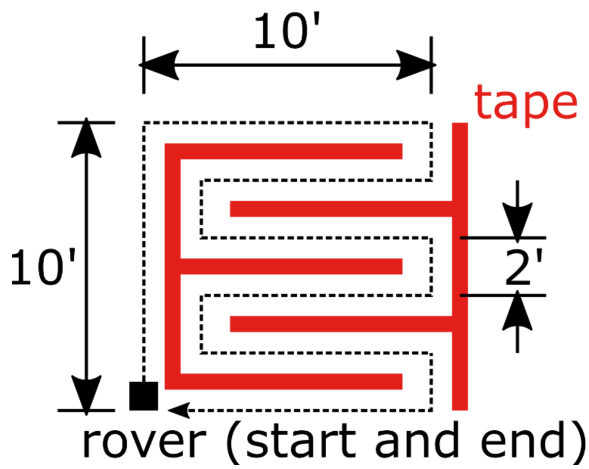


Figure 24: Agility course for Performance Goal 3

Our initial prototype was able to successfully complete all three performance goals. We held all 31 of the available dice, and collected all 31 of the dice we attempted to collect. We completed the agility course in 2 minutes and 57 seconds using the remote control. The only aspect of the performance goals we did not achieve was the using an onboard camera. We have yet to incorporate the camera, which will be added in the final prototype.

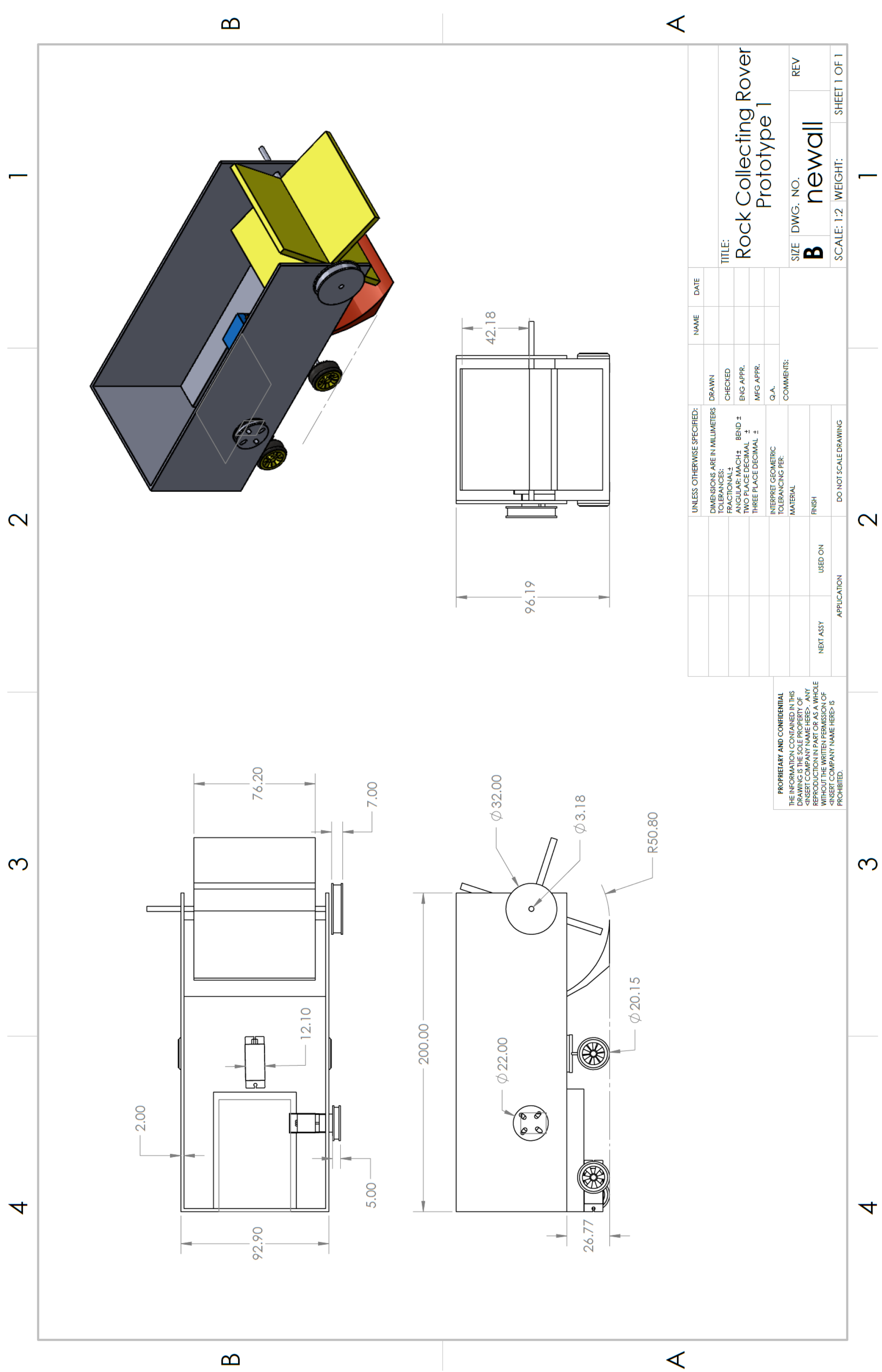


Figure 25: Assembled projected views with overall dimensions

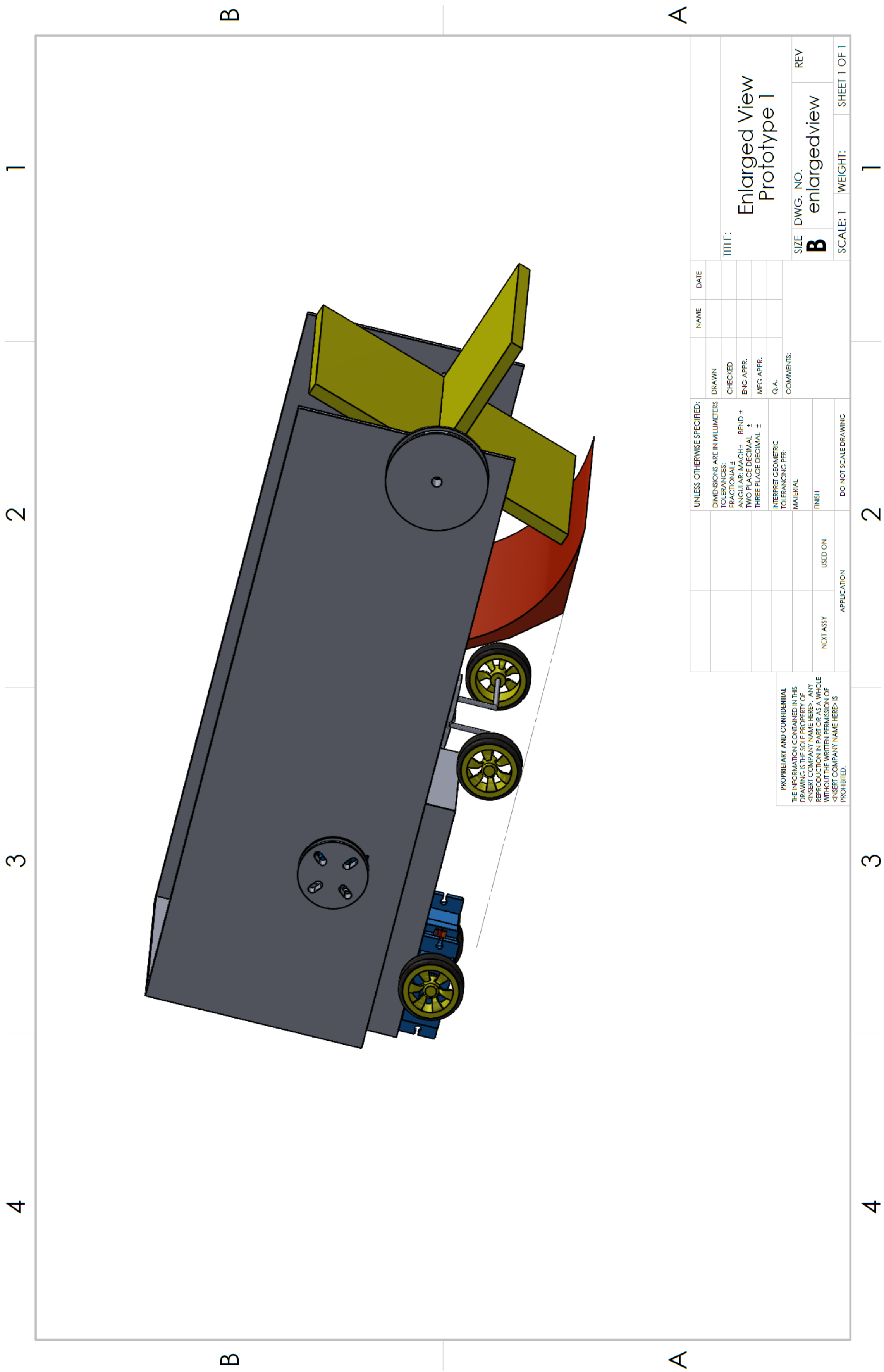
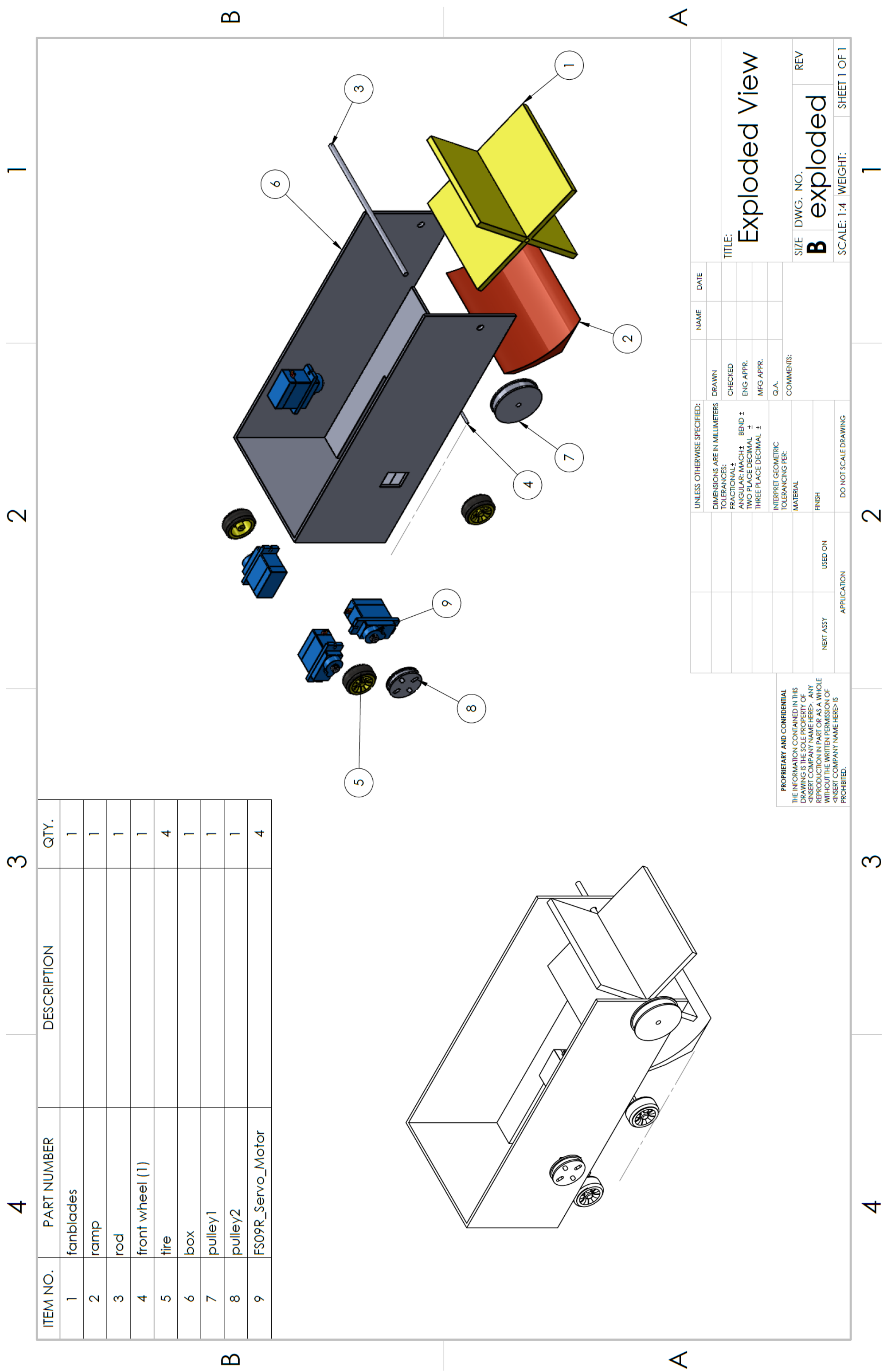


Figure 26: Enlarged Assembled isometric view



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	fanblades		1
2	ramp		1
3	rod		1
4	front wheel (1)		1
5	tire		4
6	box		1
7	pulley1		1
8	pulley2		1
9	FS09R_Servo_Motor		4

Figure 27: Exploded view with callout to Bill of Materials (BOM)

5.2 Proofs-of-Concept

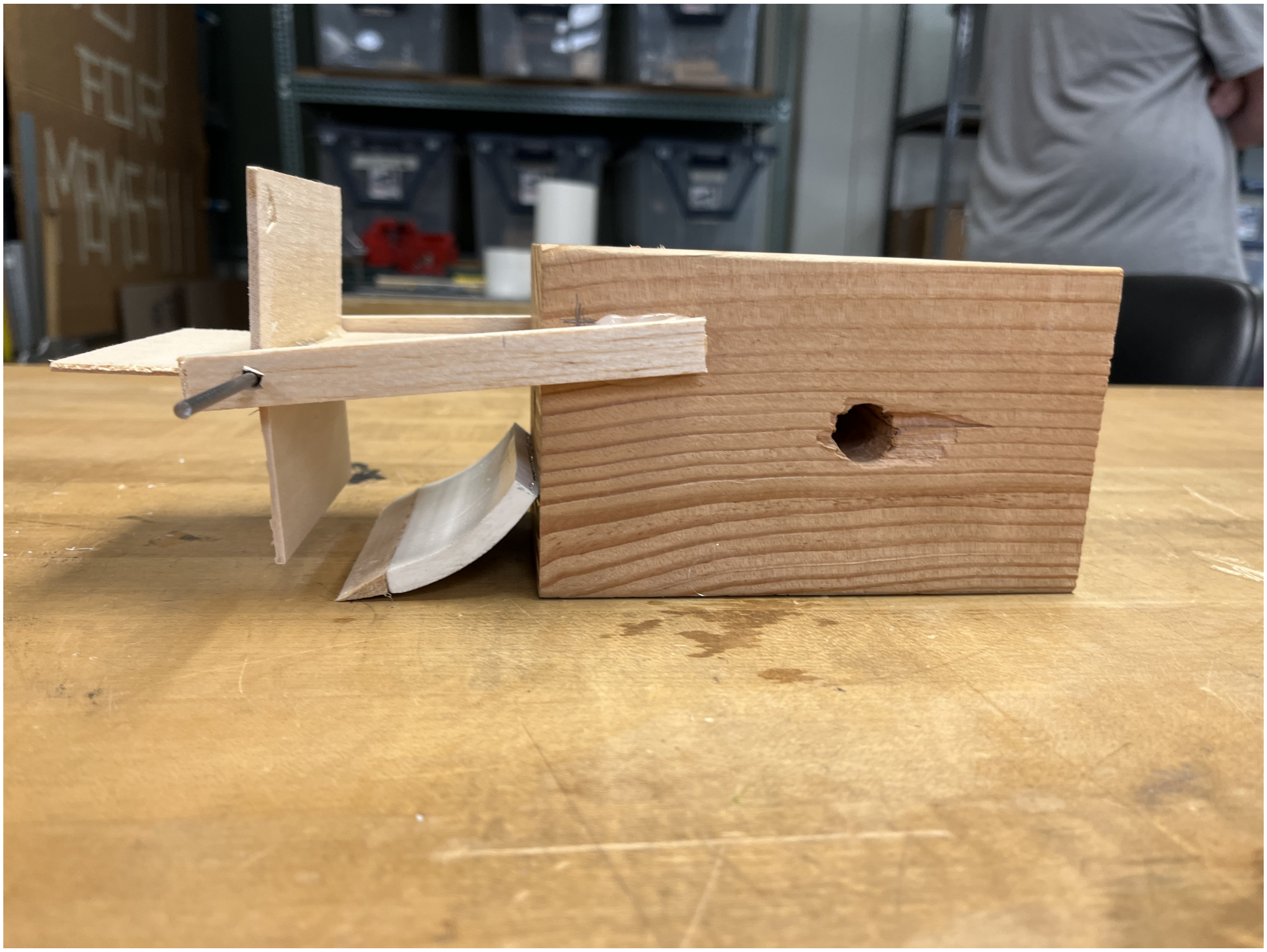


Figure 28: First proof-of-concept

Our first proof-of-concept was used to test our fan mechanism, that was planned to use for dice collection. As can be seen in Figure 28, we used a block of wood to represent our vehicle, and attached our ramp and fan to it. The ramp was made with PVC and balsa. The fan was made with balsa and a metal axle.

For our second proof-of-concept we connected our fan to motor and rotated it via the rc controller. This proof-of-concept proved the capability of the continuous servo motor to rotate the fan using the remote control.

Our initial prototype was shaped by the proof-of-concept testing. Some key factors that it made us consider were weight balance, wheel placement, height limitations, and particularly helped us conceptualize the fan mechanism. We realized that our ramp needed to precisely match the curvature of the fan as it rotated to ensure smooth rotation. The placement of both fan and ramp had to be exact in order to make certain the "rocks" were both picked up and transferred into the vehicle. To ensure this, the ramp height had to be low enough that a rock would drop into the base of the vehicle prior to the fan turning the full 90 degrees. If the ramp height was too high and the fan continued to rotate past 90 degrees, the fan blades would carry the die with as it turned.

Regarding the fan mechanism, the second proof-of-concept demonstrated the necessary placement for the motors to rotate the fan. In order to conserve space, the motors would need to be flush to the side of the vehicle. This would require the rotating motion of the motor to be transferred with some mechanism.

5.3 Design Changes

Upon analyzing our proof of concept, we knew that we needed to make some functionality changes in order to make our rover operate according to its goals. Namely, we added some design changes to control the front and back wheels with two separate servo motors. Using a separate servo motor for the front wheels allows the vehicle to turn via the swivel motion of the motor, while the back wheels drive forward and back motion. For the front wheels we added a bar with two prongs, two turns the wheel left or right depending on the the spin of a continuous vertical motor in the base of the vehicle. We also moved the wheels under the base of the vehicle to conserve space. Furthermore, adjustments had to be made in order to rotate the fan continuously. A pulley system was used that connected the axle of the fan to a servo motor in the back. The continuous motion of the back motor drove the rotation of the fan via a rubber band. The rotation of the fan allowed us to collect rocks as the rover moves. Lastly, the fan was embedded directly into the rover as opposed to protruding out as shown in Figure 28 in order to be compliant with the size restrictions of our design. These changes were incorporated into our initial prototype.

6 Design Refinement

6.1 Model-Based Design Decisions

6.1.1 Model 1: Geometric Model

The following geometric model was used to determine fan placement and sizing. Known values were based on sizing constraints, or established earlier in the design process. Overall height of the vehicle (y) and average rock height (D) were dependent on the provided materials (i.e. the cylinder and dice). Wheel diameter (w) and the axle diameter were based on the physical parameters of the parts we chose.

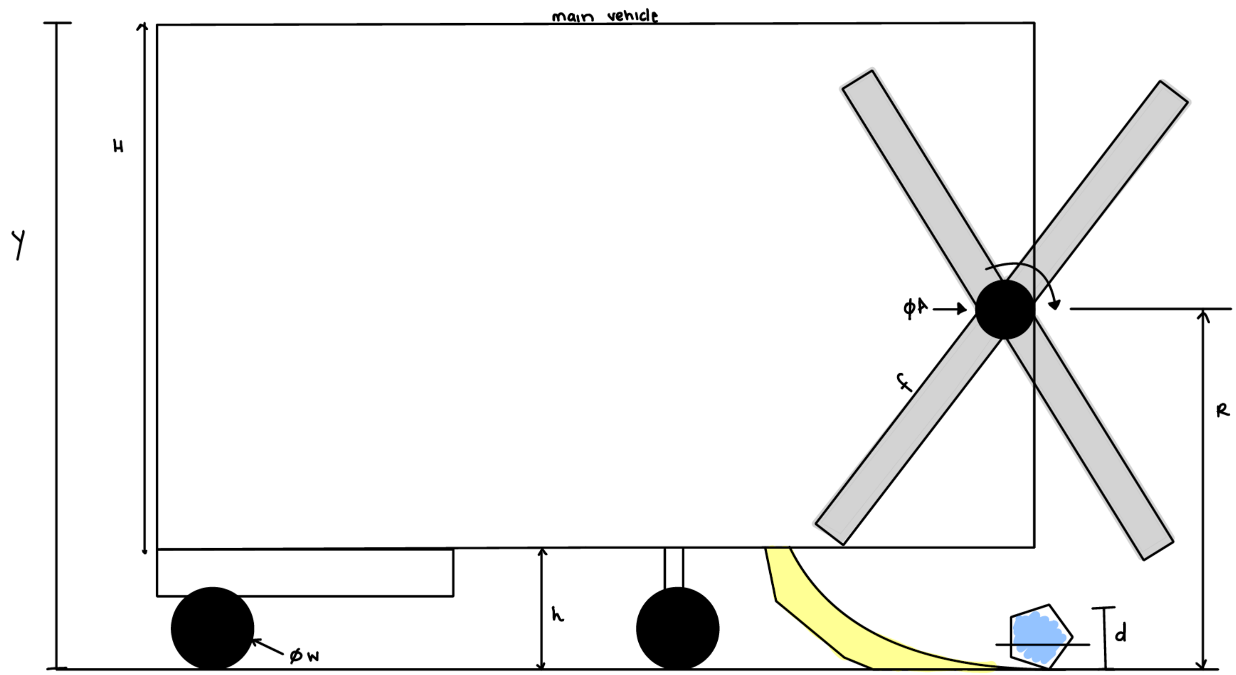


Figure 29: Geometric model for fan positioning

Table 3: Table of known values.

Known Variable	**Known Value (mm)**
Maximum Height, y	96.19
Average Rock Height, D	17.78
Wheel Diameter, w	20.15
Axle Diameter, A	4
Vehicle Height off ground, h	26.77

Table 4: Table of unknown values.

Unknown Variable
Fan blade length, f
Axle height from ground, R
Vehicle body height, H

The first relationship below was used to determine the length of the fan blades based on the maximum vehicle height, the axle diameter, and the average rock height. We determined that the gap between the floor and any given rock should be approximately 3/20 the average height of a rock to ensure the rock is pushed all the way up the ramp and prevent the blades from getting caught on the ramp.

$$f = .5(y - A - .15D) \tag{1}$$

$$f = .5(96.19 - 4 - .15(17.78)) = 44.7615 \pm .4mm \tag{2}$$

The next equation was used to determine the vehicle body height using the overall maximum height and the vehicle height off ground.

$$H = y - h \tag{3}$$

$$H = 96.19 - 26.77 = 69.42 \pm .08mm \tag{4}$$

Equation 5 below solves for the axle height off the ground.

$$R = .15d + f + .5A \tag{5}$$

$$R = .15(17.78) + 44.7615 + .5(4) = 49.4285 \pm .4mm \tag{6}$$

6.1.2 Model 2: Optimal Angle of Rotation for Wheels

This model is used to determine the angle for rotation of the front wheel holder when placed between extruded elements of the main box frame. It is assumed that the optimal angle of rotation will be produced when the axis of rotation for the front wheel part is placed halfway between the extruded features of the base. The known variables listed below will be used to find the optimal angle, θ.

Table 5: Table of known values.

Known Variable	**Known Value (mm)**
Inner tire radius, r	28.72
Thickness of a tire, t	8.00
Length of half of the front wheel holder, p	39.69
Distance between extruded parts, d	52.53
Half distance, w	26.26

Table 6: Table of unknown values.

Unknown Variable
Max angle of rotation (inner radius), θ_r
Max angle of rotation (outer radius), θ_R
Outer tire radius, R

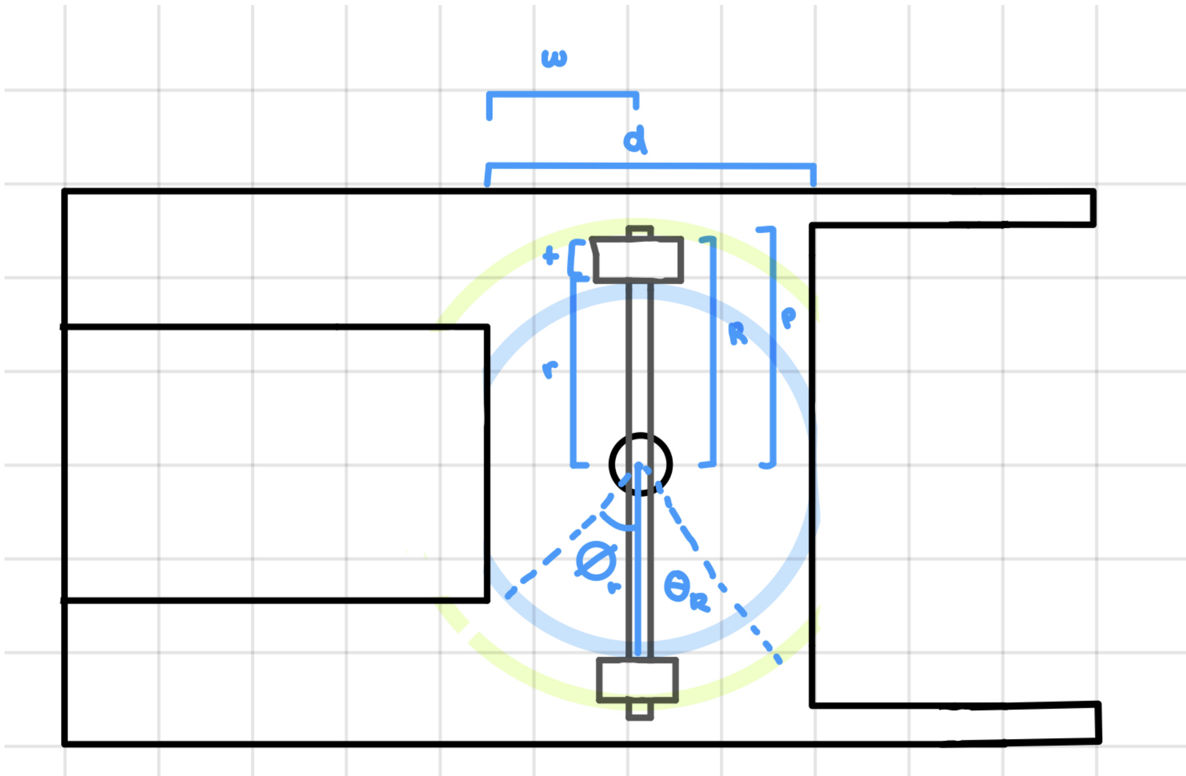


Figure 30: Geometric model to optical angle of rotation for wheel

The equations below solve for the unknown variables:

$$R = r + d \tag{7}$$

$$\theta_r = \arcsin(w/r) \tag{8}$$

$$\theta_R = \arcsin(w/R) \tag{9}$$

The found values based of this model are :

$$\text{R} = 36.72 \text{ mm} \quad \theta_r = 66.11^\circ \quad \theta_R = 45.65^\circ$$

6.1.3 Model 3: Angular Velocity due to Gear Ratio

This model demonstrates the relationship between the gear size and angular velocity. Known values consisted of the gear sizes and the documented angular velocity of the servo motor attached to the smaller gear.

Table 7: Table of known values.

Known Variable	Known Value (mm)
Radius of smaller gear, r	11.00
Radius of larger gear, R	16.00
Distance between gears, d	122.42
RPM of servo, w_r	130 (rpm)

Table 8: Table of unknown values.

Unknown Variable
Larger gear angular velocity, w_R
Smaller gear angular velocity, w_r

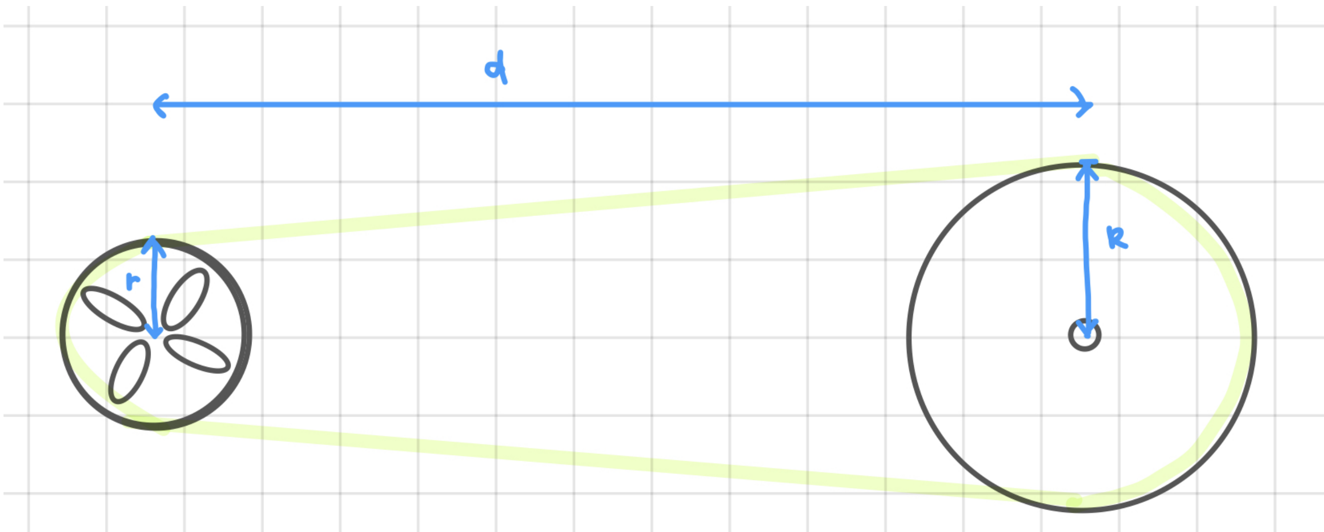


Figure 31: Ratio of gears model

The angular velocity is inversely related to the radius of the gears. The equations below solve for the unknown variables:

$$\frac{R}{r} = \frac{w_r}{w_R} \tag{10}$$

The found value based of this model is :

$$w_R = 89.38RPM$$

6.2 Design for Saftey

To identify the potential safety risks that our device imposes, we had to identify the ways in which our device may fail. After identifying potential hazards, we can address those safety risks in our design. Based on the severity and probability of each outcome, a heat map was created.

6.2.1 Risk #1: Vehicle Collision with Human

Description: A loss of communication to the vehicle via the RC transmitter or poor human operation may lead to a vehicle-human collision and potential injury.
Severity: The severity of this risk occurring is **critical**. If the transmitter were to lose connection with the vehicle this would be a critical failure. The operator would no longer have any ability to control the device. If the device continues its motion it could collide with a person and injure them, or critically injure the device by colliding with an object.
Probability: The probability of this occurring is **seldom**. It is possible that the transmitter could glitch and stop transmitting but unlikely. However, this risk could also occur to do poor

user error while operating the remote control which is why we designated the probability as seldom.
Mitigating Steps: Steps to take reduce the risk on a vehicle collision is to confirm that everyone is ready and outside the range of the device before beginning any motion. In addition, we can have all members sit on an elevated surface to prevent collision. To ensure the transmitter connection remains strong we can ensure we stay within a reasonable distance at all times.

6.2.2 Risk #2: Rubber Band Snaps off Pulley System

Description: Rubber band that connects the two pulleys may snap off and act as a projectile
Severity: The severity of this risk occurring is **critical**. If the rubber band were to break the pulley system that operates the fan will no longer function, and the vehicle will no longer be able to collect rocks which is critical to the performance. In addition, getting hit with the rubber band could inflict an injury.
Probability: The probability of this risk occurring is **occasional**. The rubber band snapping due to the the continuous tension it is under is not an unlikely risk.
Mitigating Steps: One way to mitigate this risk is to replace the rubber band consistently to prevent fatigue. In addition, all members should wear eye protection and stand very far back when operating the device.

6.2.3 Risk #3: Battery Malfunction

Description: Battery malfunction while charging can lead to potential exposure to acidic liquids, release of hydrogen gas, or electrical burn.
Severity: The severity of a battery malfunction would **catastrophic**. The chemical side effects of a battery malfunction are severe, which is the risk level is the highest severity.
Probability: The probability of this occurring is **unlikely** due extreme uncommonness of newer batteries releasing hydrogen gas incurring chemical burns.
Mitigating Steps: Our method to mitigate this risk is to not be in the room while battery is charging.

6.2.4 Risk #4: Scraped by End of Rotating Metal Axle/Screw

Description: The fan blades are attached by screws on either ends. The rotating metal screws that protrude from the body of the vehicle have the potential to scrape or scratch the user.
Severity: The severity of this risk is **marginal**. The scratch would not harm the vehicle and would only minorly harm a person, therefore the severity it low.
Probability: The probability of this occurring is **occasional**.
Mitigating Steps: One way to mitigate this risk is to ensure the axle does not protrude too far from the vehicle and sand down end to prevent metal splinters or potential cuts.

6.2.5 Risk #5: Finger Pinched by Rotating Fan

Description: Fingers get pinched in small gaps between rotating fan blades and floor, or between fan blades and the ramp.
Severity: The severity of this occurring is **marginal**. Getting a finger stuck in the fan blades would not be a critical failure, and would not be a critical injury.

Probability: The probability of this occurring is **seldom**. It is more than unlikely that this may occur, but less probably than occasionally.
Mitigating Steps: Our method for reducing the risk is to ensure that no person is near the machine when operating. In addition, we plan to confirm that everyone is ready before beginning rotation.

		Probability that something will go wrong				
	Category	**Frequent** Likely to occur immediately or in a short period of time; expected to occur frequently	**Likely** Quite likely to occur in time	**Occasional** May occur in time	**Seldom** Not likely to occur but possible	**Unlikely** Unlikely to occur
Severity of risk	**Catastrophic**					Battery malfunction while charging
	Critical			Rubber band snaps off pulley system	Vehicle collision with human	
	Marginal			Scraped by end of rotating metal axle/screw	Pinched by rotating fan	
	Negligible hazard presents a minimal threat to safety, health, and well-being of participants; trivial					

Figure 32: Heat Map

Based on the heat map, the rubber band snapping off is our highest priority issue. To account for this issue we will replace the rubber band every 15 runs to prevent fatigue. Our next highest priority risks are the vehicle colliding with a person, our battery malfunctioning, and a person getting scraped by the rotating metal screws. Most of these issues can be mitigated by ensuring everyone present is aware of their surroundings prior to turning on the vehicle, and at an appropriate distance away. The battery malfunctioning is extremely unlikely, but would be a catastrophic, therefore the priority is raised to a middle tier priority. Our lowest priority issue is getting pinched by the rotating fan.

6.3 Design for Manufacturing

In our current design, there are 17 parts excluding threaded fasteners. There are approximately 4 fasteners that are used in the final design of our rover. The parts that are theoretically necessary for this design are as follows:

1. Motor (4)
2. Tire (4)

3. Fan blades
4. Ramp
5. Box
6. Pulley Wheels (2)
7. Front Wheel Mechanism
8. Camera
9. Threaded Screws for Axle (2)

In our design, it is necessary that the fan blades remain its own component of the system since it needs to be able to freely rotate, and would not be able to do so if it were permanently attached to the box or ramp. The fan is necessary to the collection of rocks, and if the fan was unable to rotate about its center no rocks would be pushed up the ramp.
Similarly, the pulley that attaches to a motor must be separate from the box so it is able to freely rotate the fan. Two pulleys are required to translate the motion of a single motor to the fan at the front. This is necessary to conserve space by allowing the motor to be housed at the back of the vehicle.
The two threaded screws that functioned as our fan axle had to be a separate component from the fan blades in order to execute our design. The screw threaded through the pulley wheel from the outside, therefore spinning the pulley wheel using a friction fit. Based on this configuration, two screws were required on either side of the fan that traveled through the outside of the box and into the fan.
Lastly, each of the four wheels of the system are necessary individual components, in order to individually rotate and drive the rover in the desired direction. If they were directly connected to the base in our design, we would not be able to pivot the vehicle.
A method to eliminate parts would be to combine the front pulley wheel and the threaded screw it is attached to. The pulley turns the screw via a friction fit, but this step could be removed all together if the wheel incorporated an axle for the fan blades.

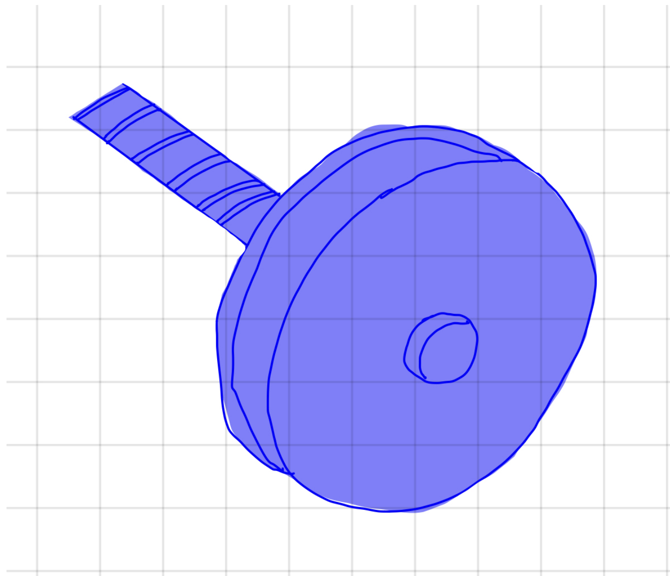


Figure 33: Simplifying Front Wheels

Our rover is close to the minimum number of components necessary for its operation, but a few adjustments, such as simplifying the fan/pulley mechanism, would allow us to have simpler manufacturing.

6.4 Design for Usability

Vision Impairment: A vision impairment could significantly affect someone's ability to use our design because our rover must be guided solely by an on-board camera. Certain types of visual impairments, like color blindness, would not impede any usability because the user does not need to differentiate between colors to pick up the objects. Yet conditions like presbyopia could affect the users ability to see the device and navigate the operation. One way to combat this problem is to ensure the computer displays are very large with high resolution. Also ensuring that the cameras are stable on the vehicle and not shaking that may disorient the viewer. Another way to tackle this problem would be by implementing sensors and voice-activated commands that alert the user when a rock is in the vicinity. Sever vision impairment could result in the device being unable to be operated.
Hearing Impairment: Having a hearing impairment would not result in any major effect on the usability of the device. Our current set up does not incorporate sound as a means of operation. As such, the only limitation that a hearing impairment may provide is if running into technical difficulties. For example, a user with hearing impairments may not be able to hear the tires get stuck on an item or the noise of the remote pairing with the motors. This may make it slightly more difficult to identify the cause of the issue, but would not impede overall usability.
Physical Impairment: Our device relies on the user to control and decide the path our robot will take. Depending on the physical impairment and its severity, it could prevent the user from being able to operate the remote-controlled vehicle if they struggle with fine motor skills, or if operating the controller exasperates their physical impairment. A potential solution is to decrease the number of buttons required, add larger attachments to control the switches, or ensure that all the controls used are in the same area of the controller. For example, larger joysticks could be added to main controllers that can be grasped by the entire hand instead of just by someone's fingers.

Control Impairment: Similar to the physical impairment, having a control impairment could impede operation. Our robot turns very quickly and needs a quick response so that it remains on target. A customer with a control impairment may not be able to react in time when attempting to operate multiple controls on the remote. For simplicity, we can ensure that the remote controls are linked to channels that make sense operationally. For example, forward and back should be linked to a vertical control and left and right should be connected to a horizontal control. Another way to modify our device to improve its usability is to create a stop/pause button or have multiple speeds. This way, those using our rover can alter the settings in a way that makes it easier to operate.

7 Final Prototype

7.1 Overview

Our final prototype matches our initial prototype closely, with a few alterations to improve efficiency and optimize sizing. Our fan collection method remained the same. The pulley system that drives our fan can be clearly seen in Figure 34 below. A motor placed within the vehicle rotates the back wheel, which drives the front pulley via the rubber band. Threaded screws functioned as both axles for the fan and an attachment method between the front wheel and fan. Therefore, the rotation of the pulley turns the fan and scoops up rocks. The fan and ramp can be clearly viewed in Figure 35.

The motion of the vehicle is controlled by three motors. The two wheels in the back control the forward and back motion. Their servo motors rotate in sync because they are are connected to the same port. The front wheel mechanism controls left-right motion. One vertical servo motor in the base of box, that can be seen in Figure 36, rotates the two front wheels together and turns the box.

The camera sits above the fan on top and the battery is housed in a pocket in the base of the vehicle.

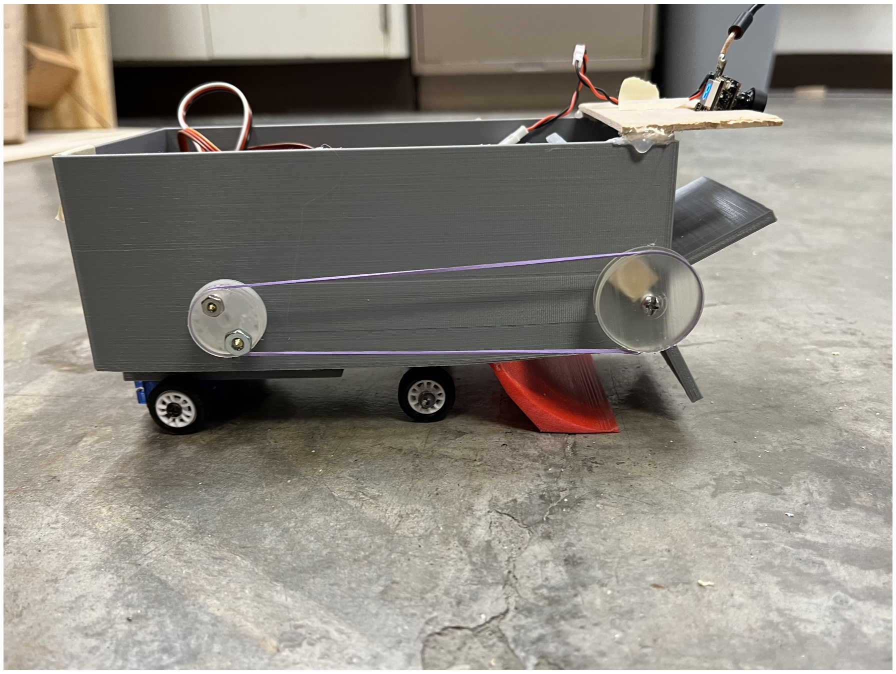


Figure 34: Side View Final Prototype

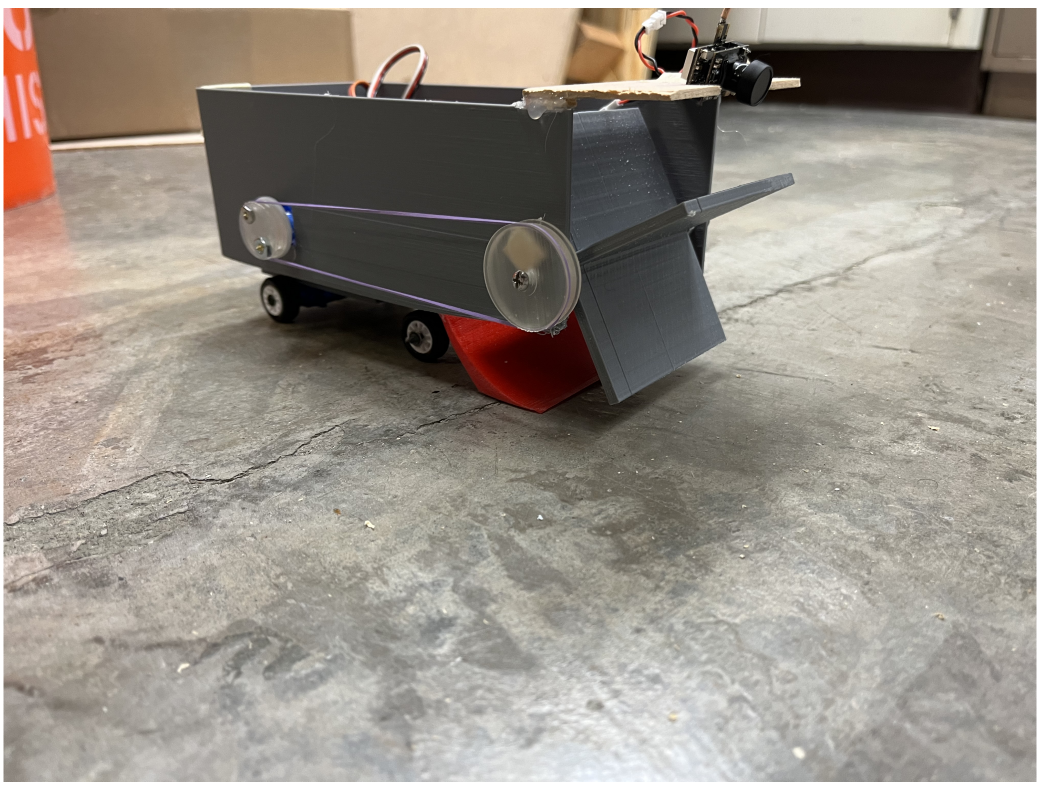


Figure 35: Front Angle Final Prototype

Figure 36: Top View of Final Prototype with 35 rocks in Base

7.2 Performance

Performance Goal 1
Description: Rover can collect more than 28/35 rocks of varying shapes
Outcome: Collected 33/35 "rocks" of all shapes
Performance Goal 2
Description: Rover can carry over 35 rocks at a time
Outcome: Holds all 35 available "rocks" (pictured in fig. 36)
Performance Goal 3
Description: While being remotely operated, the rover can complete the outlined agility course in under 5 minutes
Outcome: Completed agility course in 4 minutes 33 seconds using the camera view

Bibliography

[1] *Continuous Rotation Micro Servo*. URL: https://www.adafruit.com/product/2442.

[2] Danielle Collins. *The Torque Equation and The Relationship with DC Motors*. URL: https://www.motioncontroltips.com/torque-equation/.