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Group M: ARLISS Canister Vehicle

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FL19 MEMS 411 Mechanical Engineering Design Project

ARLISS Canister Vehicle

This project is a dicycle designed for the ARLISS Canister Competition. In this competition, the device is loaded into a rocket which is then launched to about 12000 ft before releasing the device. Then it must safely land and autonomously navigate to a predetermined GPS location on the ground. Due to the fact that this is a mechanical engineering design project and the time restrictions of this class, we focused on the physical aspect of the project, such as building a device that can survive the launch and landing and traverse several kilometers through the desert, forgoing the autonomous navigation and control aspect. We began the design process by interviewing our client, Dr. Potter, and analyzing the user needs he gave us. We then came up with a variety of potential designs for the device, and weighed the pros and cons of each concept, selecting the best possible option. Three prototype performance goals were developed: the prototype can travel a certain distance with various terrain, the prototype can resist impact in a drop test, and the prototype can release the parachute and drive away following the drop. We then went through several iterations of the design, considering engineering models and running a series of tests designed to ensure that the device can fall from the rocket and navigate through desert terrain. These tests included surviving a drop of at least three stories, being able to release the parachute, and then drive away without us needing to modify anything on the device. Tests also examined the ability of our device to traverse gravel and sand over several kilometers on a single battery charge. Our final design succeeded in all three performance goals.

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1 Introduction

The ARLISS competition encourages university students and faculty to design, build, and launch prototype robots that not only collect flight data, but also autonomously navigate to a target GPS location on the ground after being launched to an altitude of about 12,000 feet. This is an international competition that travels to the launch site in Nevada every year since 1999. To be considered the winner of the competition, the prototype must fit inside a designated launch tube, autonomously navigate to within a ten mile radius of the target, and there must be proof of controlled guidance to the target. Since this is a mechanical engineering design project, we are not focusing as much on the coding and autonomous aspect of a robot, but more on producing a ground or air based robot that could navigate over rugged desert terrain and withstand the forces and vibrations of takeoff, flight, and landing.

2 Problem Understanding

2.1 Existing Devices

To begin this project, existing designs were researched to see what products or prototypes are already on the market that perform similar tasks. Three existing devices are investigated below.

2.1.1 Existing Device #1: MakeBlock mBot

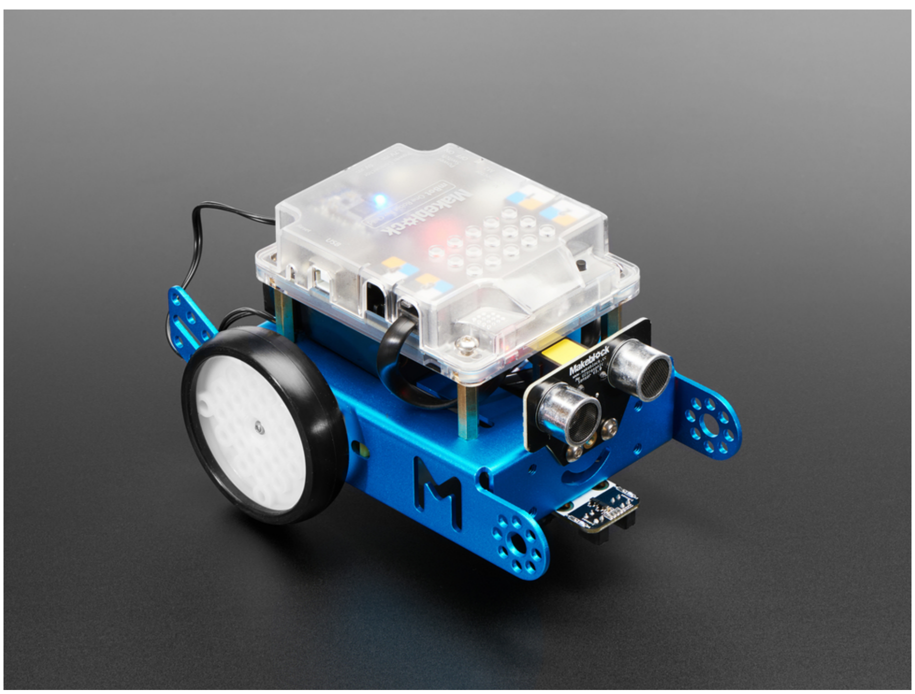


Figure 1: MakeBlock mBot (Source: Adafruit)

Link: https://www.adafruit.com/product/3640
Description: The MakeBlock mBot is a robotic kit that introduces the user to robotics. The kit contains everything necessary to build the rover, including a screwdriver. No other tools or soldering

is required. The electronic parts are based on the Arduino open-source ecosystem. The kit comes with various projects, such as obstacle avoidance and line following. The user can also add on accessories like servo motors or LED displays. The robot can be programmed two different ways. The first is the graphical drag-and-drop software where the user can send and receive commands from the robot wirelessly. The second is the Arduino IDE which allows for C/C++ access to all the hardware for advanced autonomous control through USB connectivity during programming. This mBot is also Bluetooth compatible, so it can be used wirelessly through mobile phones and tablets. There is also another version of the mBot, the 2.4 GHz version, which uses a USB dongle for wireless connectivity to a desktop computer. The power source can be a 3.7V lithium battery (charger on-board) or 4 AA batteries which are not included. The mBot Robot Kit costs $99.95.

2.1.2 Existing Device #2: DJI Phantom 4 Pro

Figure 2: DJI Phantom 4 Pro (Source: DJI)

Link: https://www.dji.com/phantom-4-pro
Description: The DJI Phantom 4 Pro is a quadcopter, or a multi rotor helicopter that is lifted by four rotor arms and propellers. It has a FlightAutonomy system which includes dual rear vision sensors, in addition to forward and downward sensors, and infrared sensing systems on its sides for obstacle sensing and avoidance technology in five directions. These sensors scan the drones environment and help autonomously avoid crashes with things like trees, buildings, or anything else the drone might encounter mid-flight. The propellers have been improved in this model from previous models to reduce noise and for increased stability through sinusoidal current. The quadcopter has a top speed of 45 mph, a maximum wind speed resistance of 10 m/s, and a maximum flight time of about 30 minutes with its LiPo 4S battery. It can also operate in temperatures ranging from 32 °F to 104 °F. This Phantom 4 Pro has an OcuSync video transmission system with the remote controller, which means that it has a maximum range of up to 4.3 miles in ideal conditions. It also has a "return to home" feature where it reverses along the same path it took to get to where it took off from, in order to avoid obstacles it may run into if it took a straight path home. The costs of this product is $1700.

2.1.3 Existing Device #3: Starship Robot

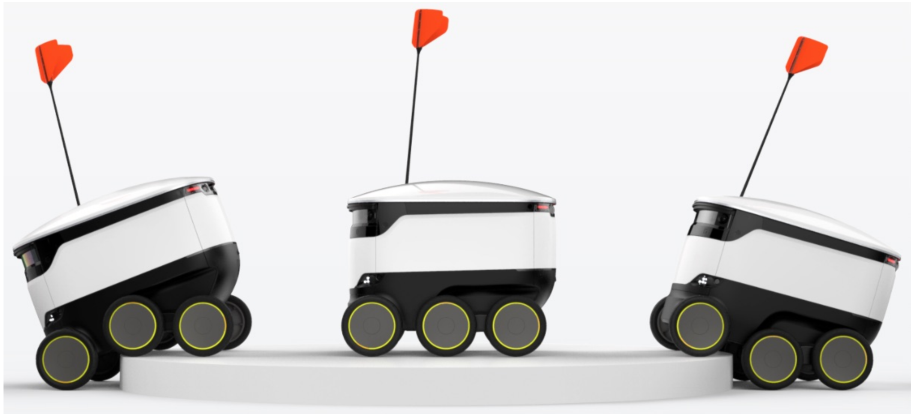


Figure 3: Starship Robot (Source: Starship)

Link: https://www.starship.xyz/
Description: The Starship Robot is an autonomous delivery robot. It can carry items within a four mile radius and the robot's location can be tracked from the smartphone that placed the order. The robots travel speed matches that of an average pedestrian walking down the street. It can also navigate around objects and people. The robot is fairly light, weighing in under 100 pounds. The cargo space is locked for security during travel and can only be opened by the person who placed the order. The Starship Robot is electronically powered, thus a green alternative to more traditional delivery services. The goal of Starship is to revolutionize food and package delivery by making these services more convenient, which in turn improve everyday life. This new technology makes local delivery faster, smarter, and more cost-efficient. These self driving robots are an alternative to delivery drones.

2.2 Patents

2.2.1 Aerial Delivery System (Patent No. 20190270522)

This patent for an aerial delivery system describes a cruciform parachute with an attached payload that can make a controlled descent towards a desired target by means of a control line and an actuator. The parachute is connected to a payload by multiple suspension lines, and a short line is also attached to the parachute. The parachute and payload are to be released from a high altitude and can move towards a desired target by either gliding or descending vertically downward. The control line can be adjusted by the actuator to be a different length of the short line, causing the parachute to rotate about its center in order to descend vertically towards a desired target. The reason for this invention was to more accurately drop supplies to targets on the ground.

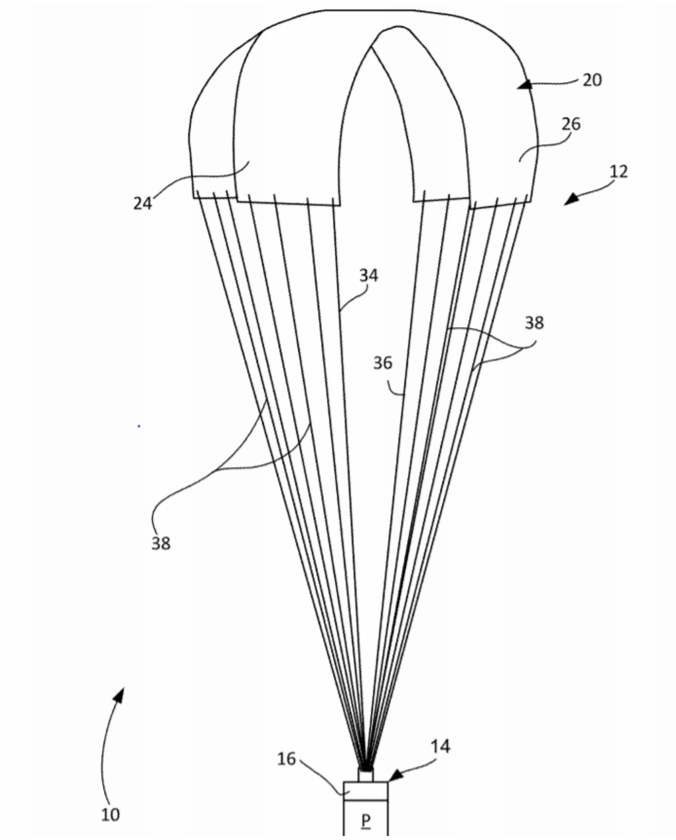


Figure 4: Patent Images for Aerial Delivery System

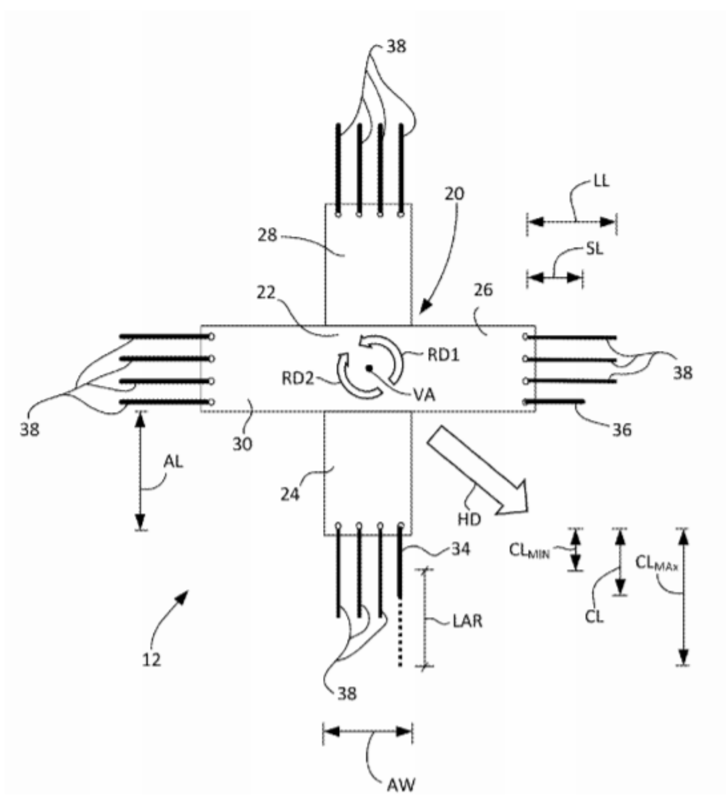


Figure 5: Patent Images for Aerial Delivery System

2.2.2 Robotic floor cleaning apparatus (Patent No. US9725013B2)

This patent describes a robotic cleaning device that uses a mobile robotic platform. The robotic platform includes two independently controlled wheels on opposite sides of the robot that are used for movement and steering. The cleaning portion of the robot is not applicable to our project, but the robotic platform is a two wheeled and piloted by a micro-controller mounted on the platform with a battery power supply.

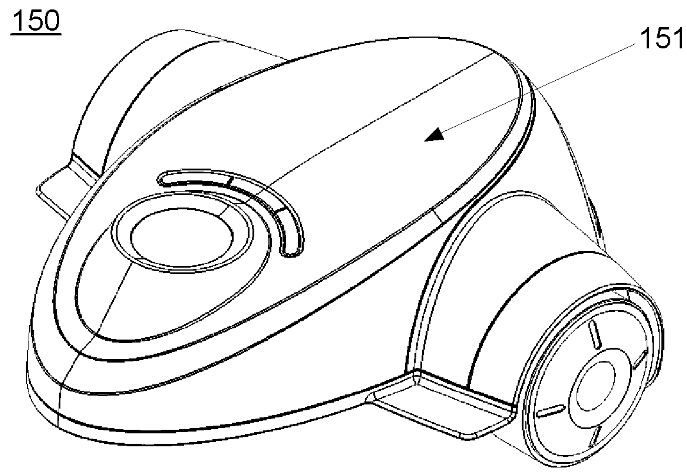


Figure 6: Patent Images for cleaning robot

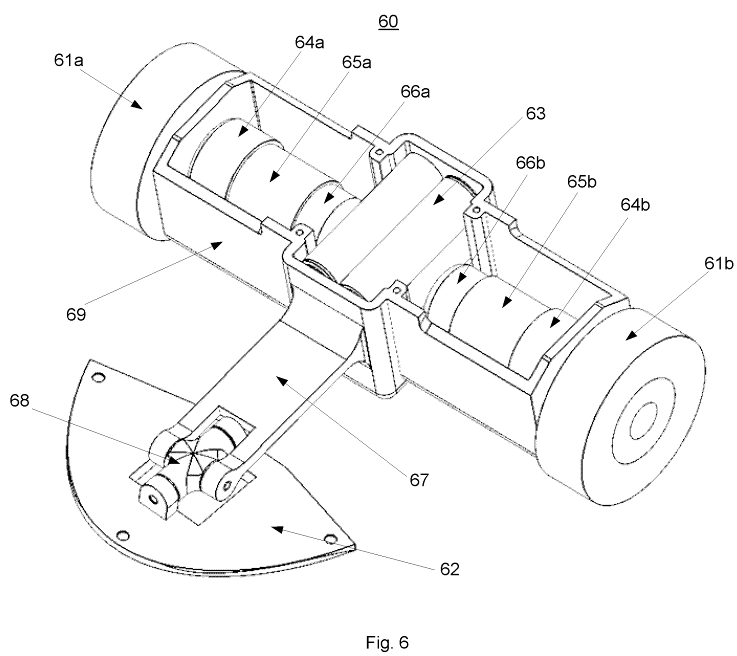


Figure 7: Patent Images for mobile robotic platform

2.3 Codes & Standards

2.3.1 Batteries - Legal Limit to Carry on an airplane (Title 49 §175.10.19)

This Federal Aviation Administration code dictates that any lithium ion battery that is to be brought on a plane must not exceed 100 Wh. Because the device is supposed to be flown to the competition, this means that the final product must use a lithium ion battery that is 100 Wh or less. Spare batteries will be permitted since the code stipulates that each passenger is allowed two spare lithium ion batteries and the device will be designed for a group of at least 4.

2.3.2 FAA Unmanned Drone usage (Section 336)

The Federal Aviation Administration regulates that all unmanned aircraft flown in United States airspace over 0.5 lbs must be registered with the FAA and must be less than 55 lbs. Since the competition mandates a weight limit of about 2.5 lbs, the 55 lb FAA weight limitation wont impact us, but, because our device is over the 0.5 weight minimum, if we build a flying device, it will have to be registered with the FAA.

2.4 User Needs

To identify specific customer needs, we interviewed them at a time and place that was convenient for them. The following is a summary of the interview.

2.4.1 Customer Interview

Interviewee: Dr. James Jackson Potter
Location: Urbauer 318, Washington University in St. Louis, Danforth Campus
Date: September 6^{th}, 2017
Setting: Dr. Potter showed us a PowerPoint presentation about his experience with the ARLISS competition and the robot he made. We received the guide lines and regulations for the competition, which identified competitors' designs as CanSats, which we will be calling rover for our design. We discussed the terrain and conditions which the rover would be subjected to as well as information on past failures of other ARLISS competitors. We asked questions about what functions Dr. Potter expected the rover to do. The whole interview was conducted in the Urbauer conference room, and took ∼50 min.

Interview Notes:
What type of device tends to work best?

- The safest design is a robot with two wheels that are as large as possible.

What does the GPS and altitude meter have to do?

- The GPS and altimeter doesn't have to control anything in the robot for this project, but both should be present on the robot and save their recorded information to an SD or micro SD at regular intervals.

How far does the robot have to travel?

- Have enough juice for 2-5 km.

How should we power the device?

- Lithium Ion batteries should hold enough charge, and solar panels are a reliable source of energy.

Can we leave the parachute behind?

- Parts of the robot, such as the parachute, can be left behind but measures should be taken to make anything that comes off of the device more visible (reflector strips and or bright coloring).

Do we have ant way to test how parts will function at low temperatures on campus?

- No, I will not expect you to have run any tests on how the device functions at high temperatures.

Should we be working toward the open class competition regulations or the 350 ml class?

- Aim for the open class because I've never actually seen an 350 ml class device fully function.

What conditions do we have to worry about the device being subjected to on the rocket?

- The forces given on the regulations sheet should be used to aim for sturdiness and should be able to deal with the high altitude conditions.

Do we have to design a way to launch the device from the rocket?

- As long as the device fits loosely within the cylinder given in the size constraints, it should eject on its own, but assume that the machine should still be going pretty fast when it is ejected.

Should we worry about the sandy conditions of the desert and that getting into the electronics

- The dusty conditions of the desert should be taken into consideration in the design, but because of how short a time the device has to work, it shouldn't be of high consideration.

Should we allow mounting space for additional sensors?

- That is not required but it would be cool if you can figure out an angle to say it is a more useful robot than it is expressly designed to be.

Do we need to worry about the heat of the desert impacting the machine?

- It's not actually that hot, but the cold at high altitudes will have a large impact on the function of the device, especially the batteries.

2.4.2 Interpreted User Needs

After identifying Dr. Potter's specific needs, we will attempt to satisfy them by sorting the needs by relative importance.

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	The rover weighs 1050g or less	5
2	The rover is 146mm or less in diameter, 240mm or less in height	5
3	The rover can has a mechanism that will reduce speed near the surface of ground	5
4	The rover can withstand shock load of 40Gs	5
5	The rover can withstand the cold temperatures that occur at high altitudes	4
6	The rover hardware can be exposed to dust and still function	4
7	The rover can move and turn by controller	3
8	The rover can move and turn by hard coded directions	5
9	The rover can make controlled decisions to get to a specified GPS location	2
9	The rover can record GPS location data	3
9	The rover can travel 2km	5
9	The rover can travel 5km	2
9	The rover components have high visibility	4
10	The rover can withstand vibrations during rocket launch	4

2.5 Design Metrics

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	1	Total weight, FAA regulations (section 2.3.1)	g	$< 24,947.5804$	< 1050
2	2	Diameter	mm	< 146	< 100
3	2	Height	mm	< 240	< 220
4	3	Velocity of descent	m/s	< 15	10
5	4	Shock load withstand-able	g	> 40	60
6	5	Temperature withstand-able	°C	< 20	5
7	6	Dust accumulated on hardware	$\mu g/m^3$	< 1000	< 100
8	7,8	maximum movement using a controller or command program	m	> 1000	5000
9	9	Obtaining GPS coordinates	Latitude & Longitude		
11		Battery capacity, Legal Limit (Section 2.3.2)	Wh	< 100	< 80

2.6 Project Management

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

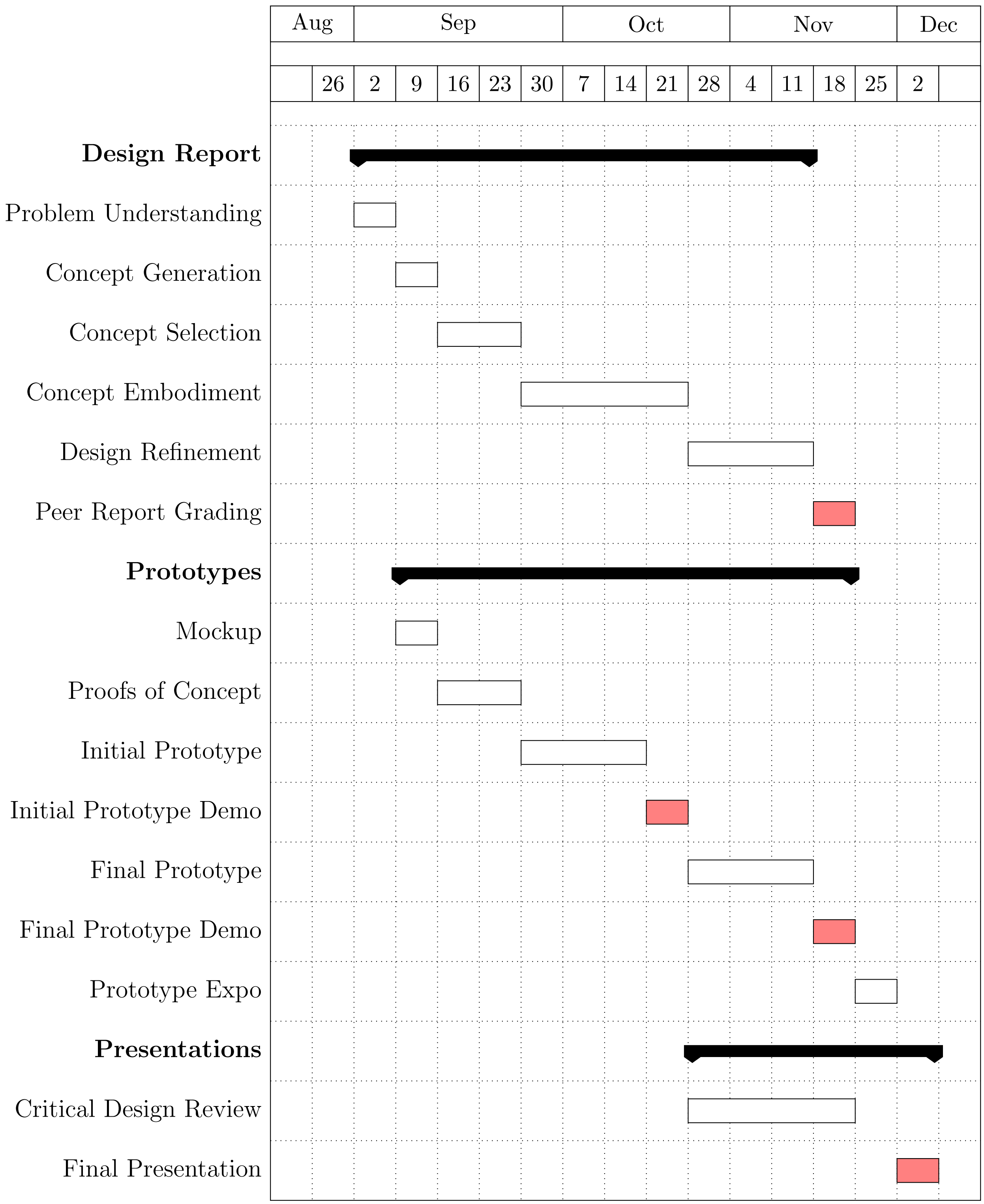


Figure 8: Gantt chart for design project

3 Concept Generation

3.1 Mockup Prototype

While creating the mockup prototype of the rover, important functions we considered were: providing housing for the electrical components, means of moving around, and contest size restriction. The solution was a platform with an axle and two 146 mm diameter wheels. The axle goes through the center of the base so that it can balance when the wheels and axle travel. During testing of the mockup we discovered that when we push the device the platform wobbles. This discovery forces us to think of different ways to make the platform more stable. When we have a power source moving the wheels, the platform should ideally balance so that it doesn't hit the ground or rotate about the axle. We will also need to re-consider platform size so that the platform is smaller than the wheel diameter.

Images of the four views of our mockup prototype can be seen on the next page in Figure 9.

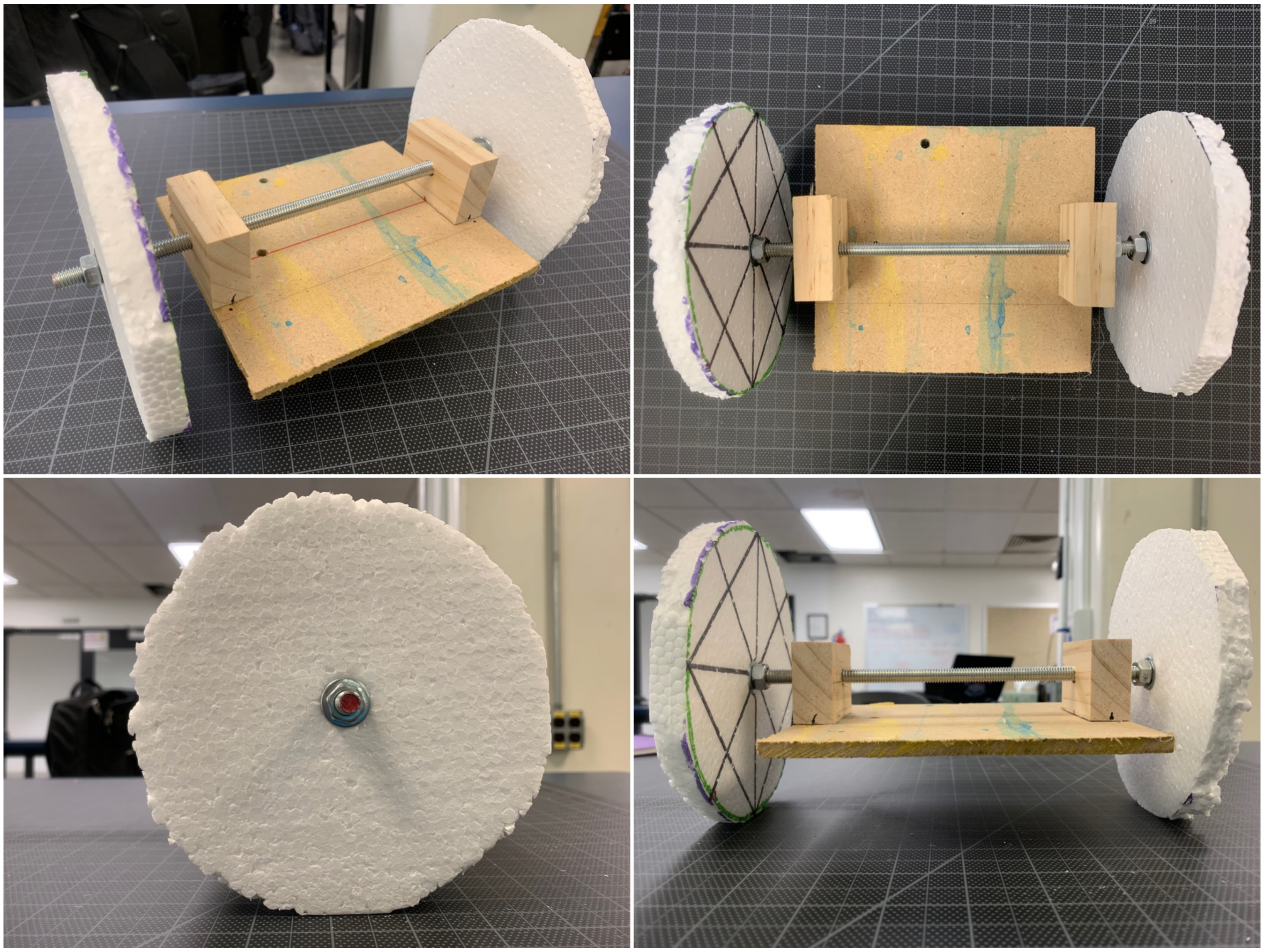
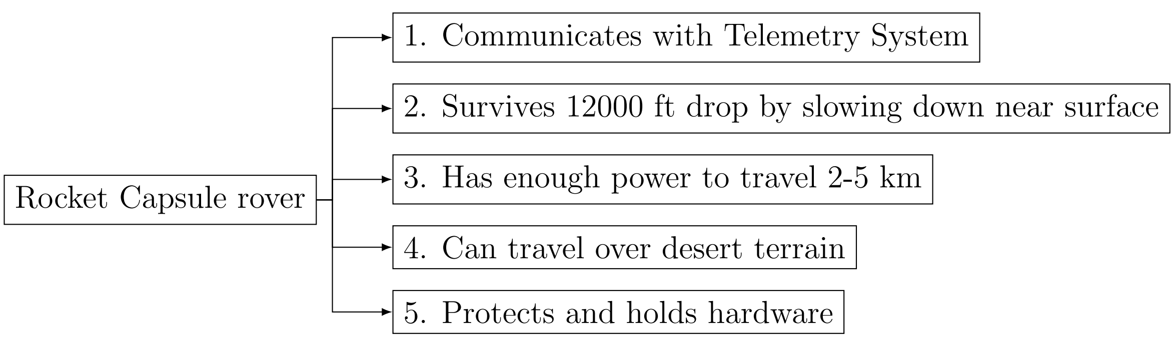


Figure 9: Isometric, top, side, and front views of the mockup prototype.

3.2 Functional Decomposition



3.3 Morphological Chart

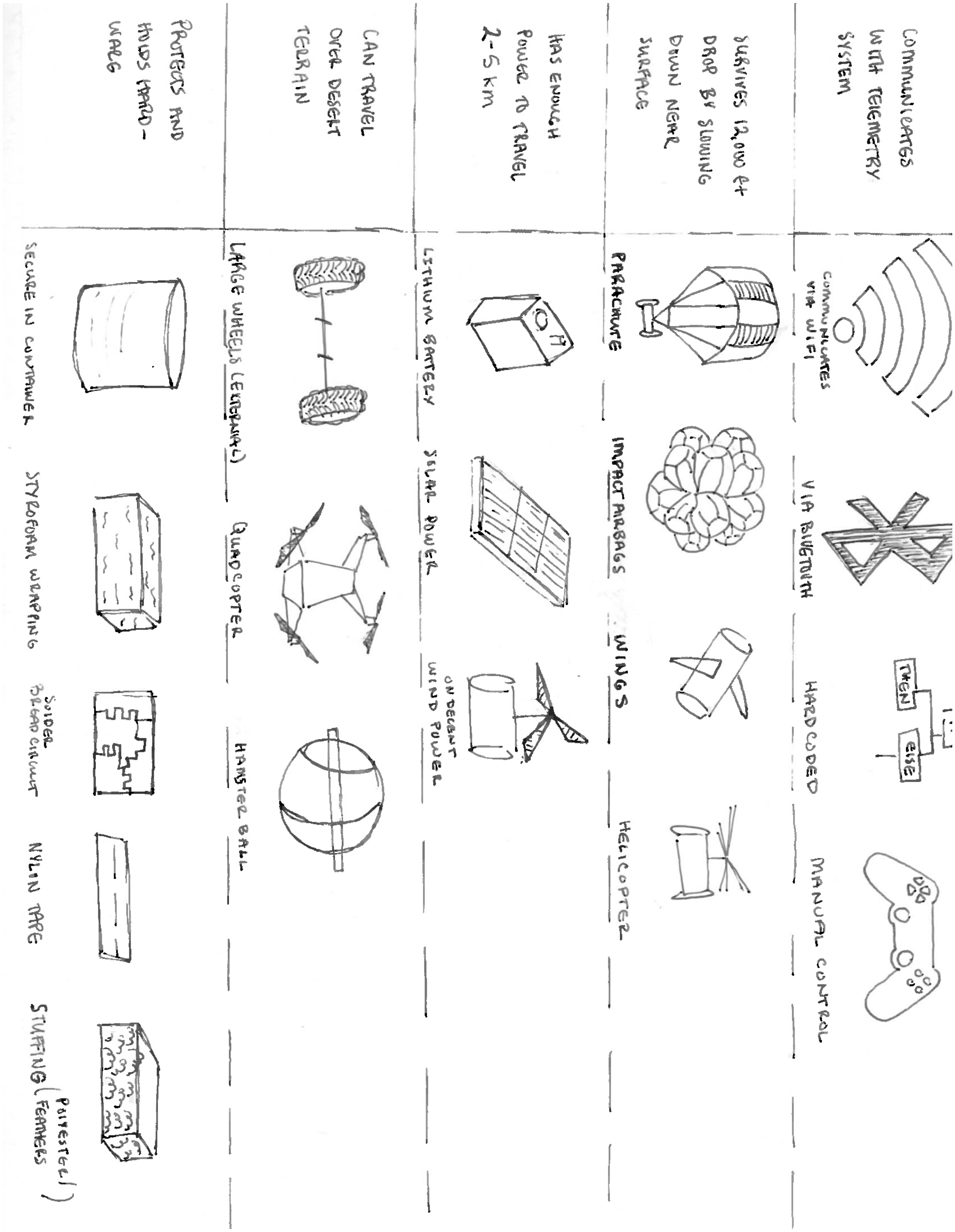


Figure 10: Morphological Chart for rover

3.4 Alternative Design Concepts

3.4.1 Falling with Style

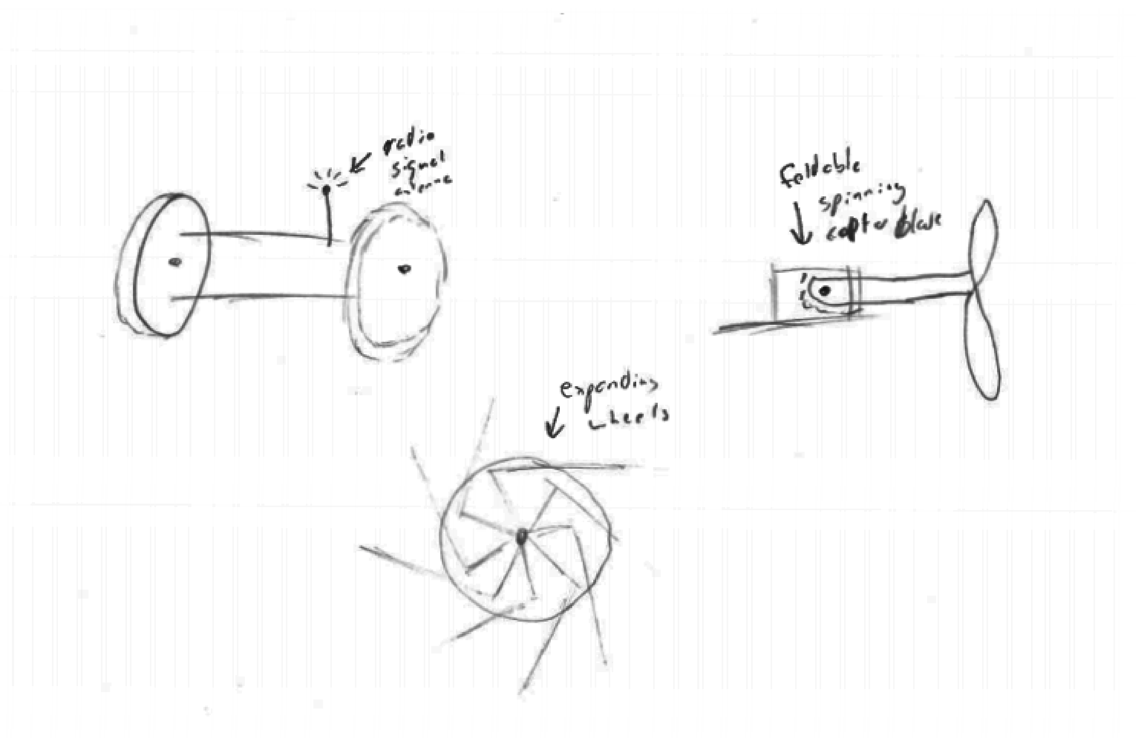


Figure 11: Preliminary sketches of Falling with Style

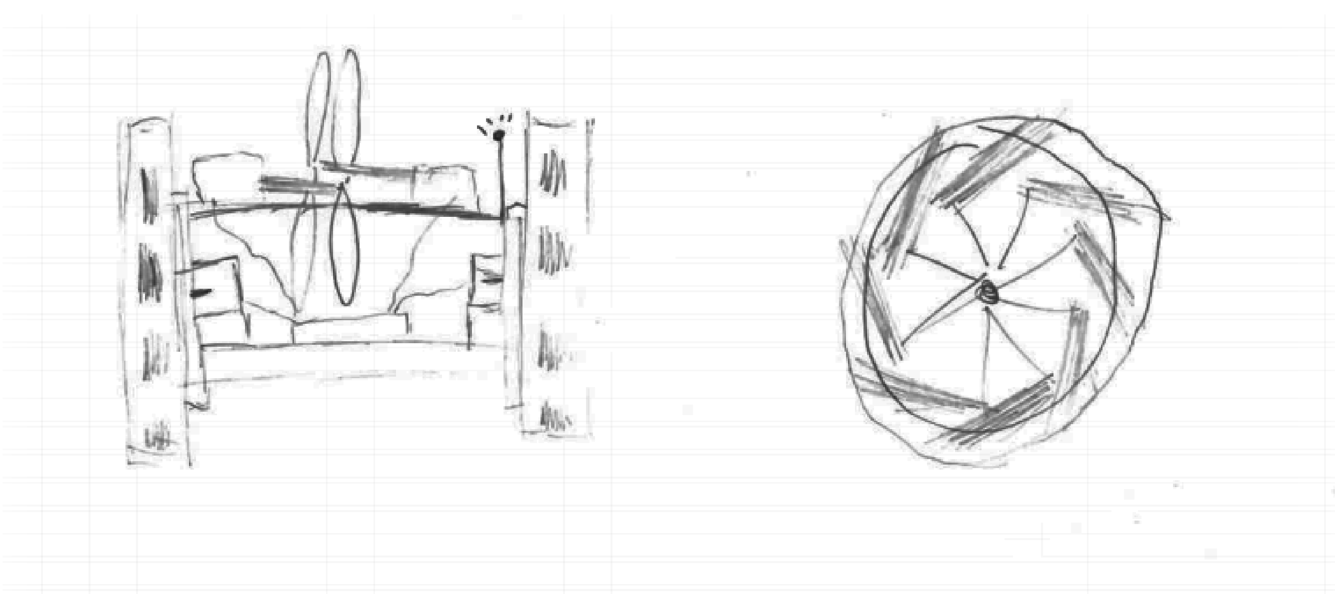


Figure 12: Final sketches of Falling with Style

Solutions from morph chart:

1. Manual Control
2. Helicopter
3. Wind power
4. Large Wheels
5. Secure in controller

Description: Two folding helicopter blades unfold during decent, spinning to slow decent (by a very small amount) and charge and internal battery that will then power the entire robot during its trip across the desert. The components are all contained within a cylinder with two large expandable wheels that help the robot roll across the desert terrain. The wheels expand when moved in one direction and retract when moved in the other, thus allowing for some control over robot movement. The robot is controlled manually via a radio link through an antenna on the robot.

3.4.2 Air Buster

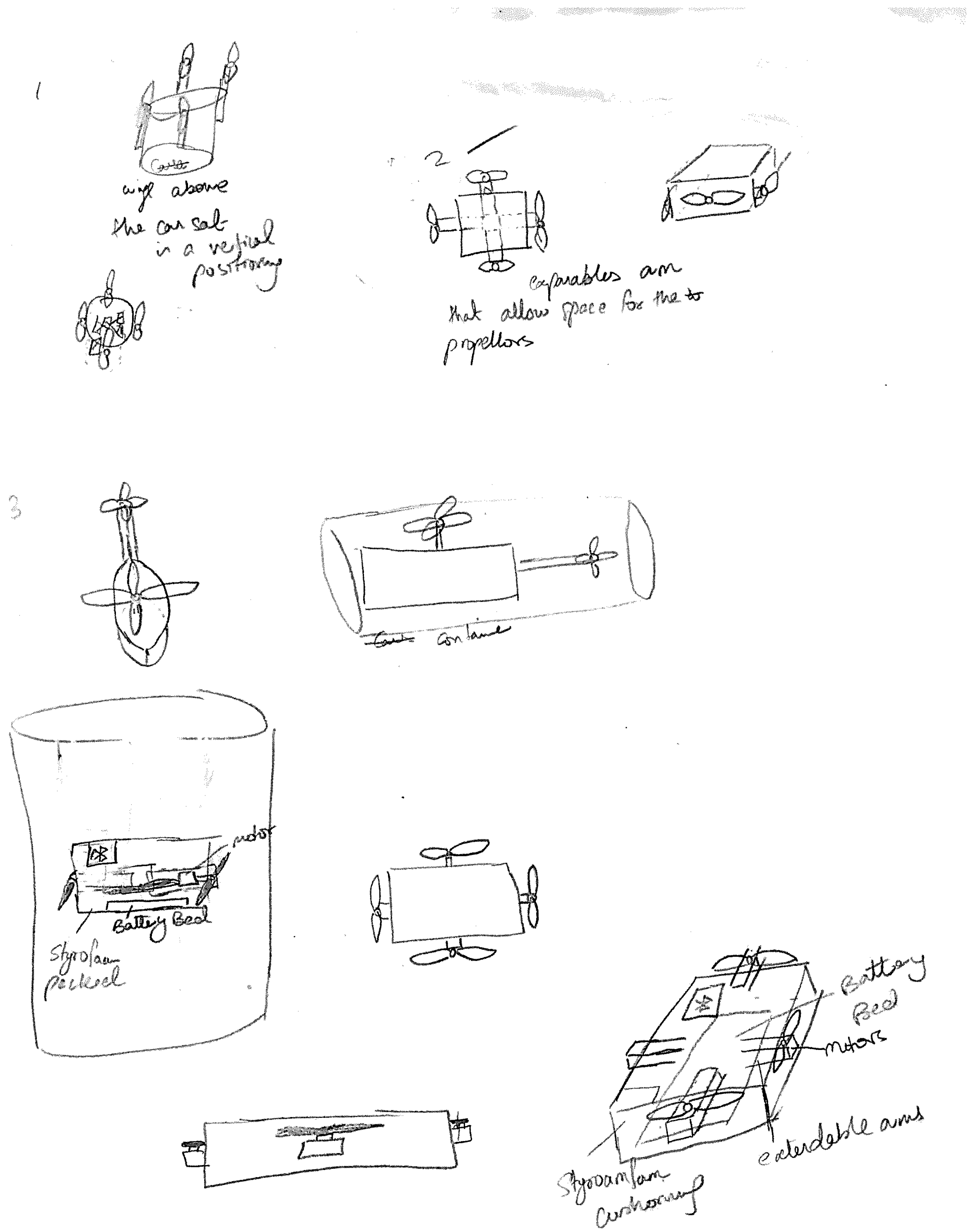


Figure 13: Preliminary sketches of Air Buster (quad-copter)

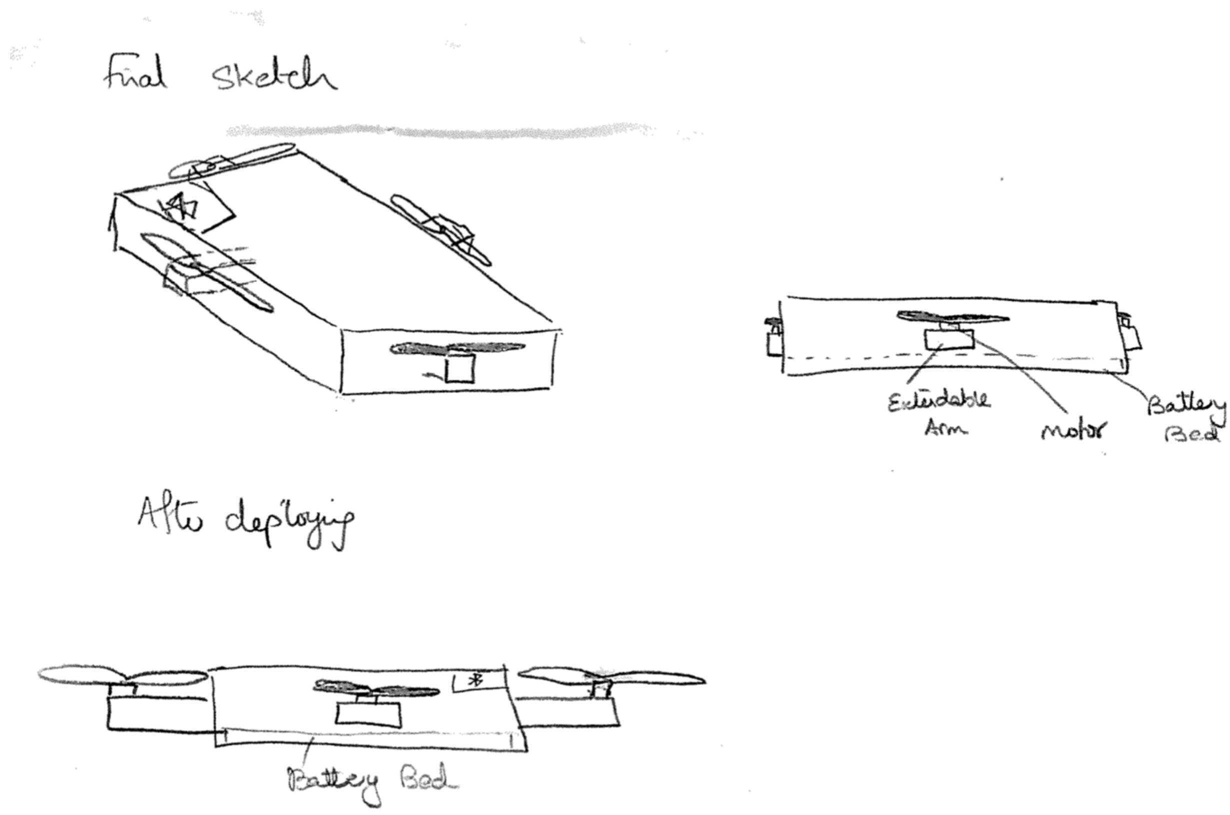


Figure 14: Final sketches of Air Buster (quad-copter)

Solutions from morph chart:

1. Has a Bluetooth module for communications with telemetry system
2. Helicopter
3. Lithium Battery bed
4. Quad-copter with extendable arms
5. Secured in a container with Styrofoam wrapping

Description: As soon as the Air Buster senses descent from its sensors it will communicate back via the Bluetooth module and inform us that it has begun to expand its arms. Once the arms are expanded a notification will be sent and the user can start the propellers to generate thrust to slow down descent speed. The design is roughly based on that of a helicopter or more accurately a quad-copter, with all the equipment stored securely inside the container packed with Styrofoam. The lithium battery sits on the bottom of the container and makes for its bed. The extendable arms have servo motors on them, on which the propellers are attached.

3.4.3 Rover Concept

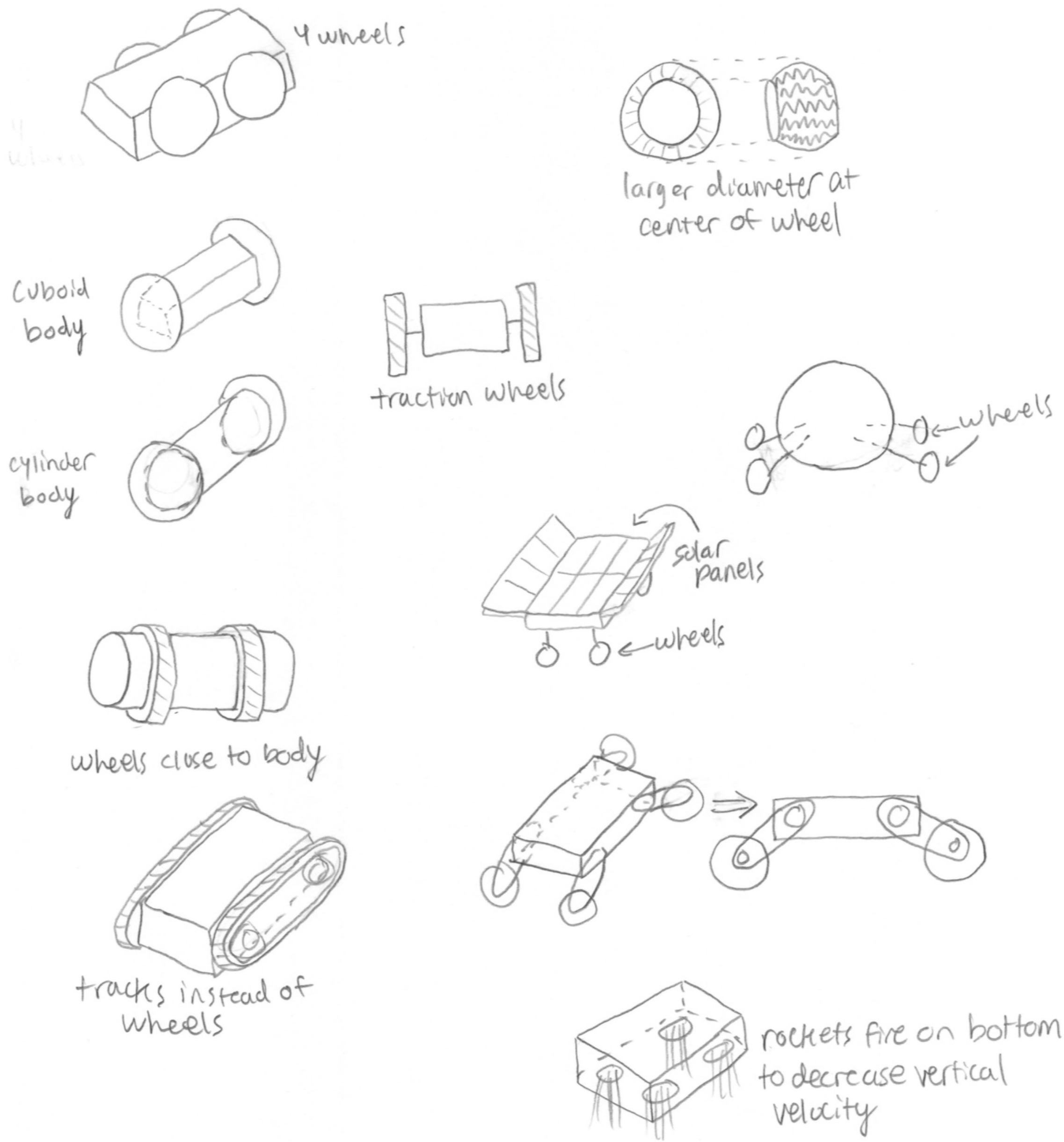


Figure 15: Preliminary sketches of Rover concept

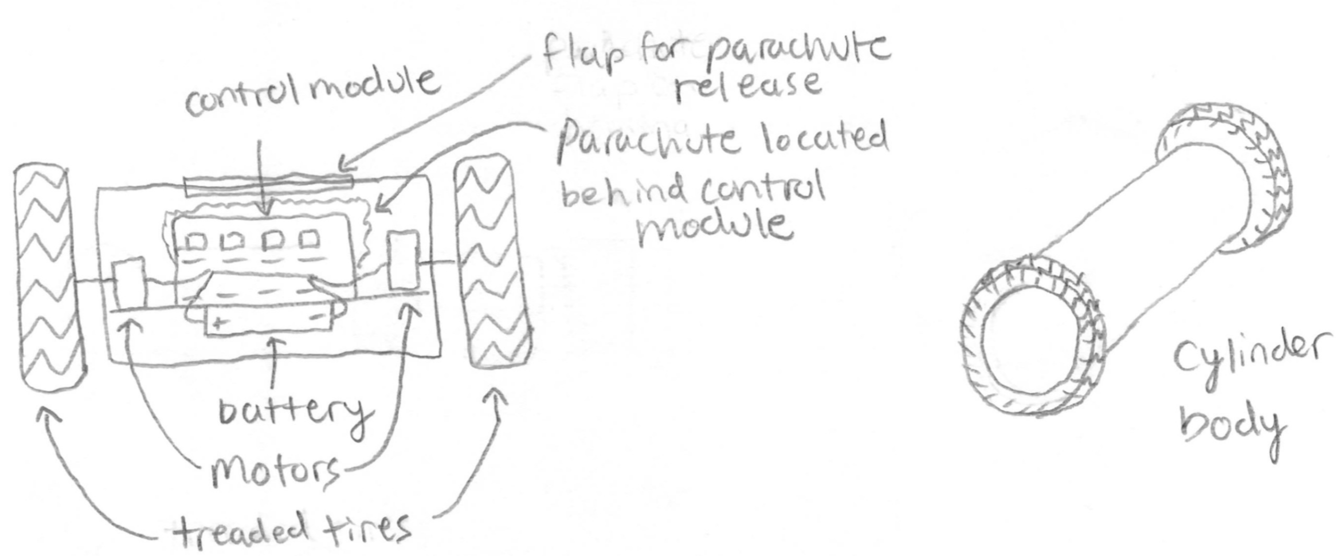


Figure 16: Final sketches of Rover concept

Solutions from morph chart:

1. Hard coded for GPS target location
2. Parachute to reduce vertical speed
3. High power lithium battery
4. Large treaded wheels
5. Enclosed container for housing electronics

Description:

The control module includes an altimeter, GPS, and code for motor control and parachute launch. The control module will read the rovers altitude and eject the parachute at a specified altitude. It also reads the rovers current GPS location and send signals to the two motors to move the wheels in the direction of the target. The powerful lithium battery should be enough to power the control module and wheel motors through the desert to the target. The enclosure for all the components is cylindrical shaped with a smaller diameter than the wheels. The wheels are also treaded for grip and stability to drive through desert terrain.

3.4.4 Hamster Ball Concept

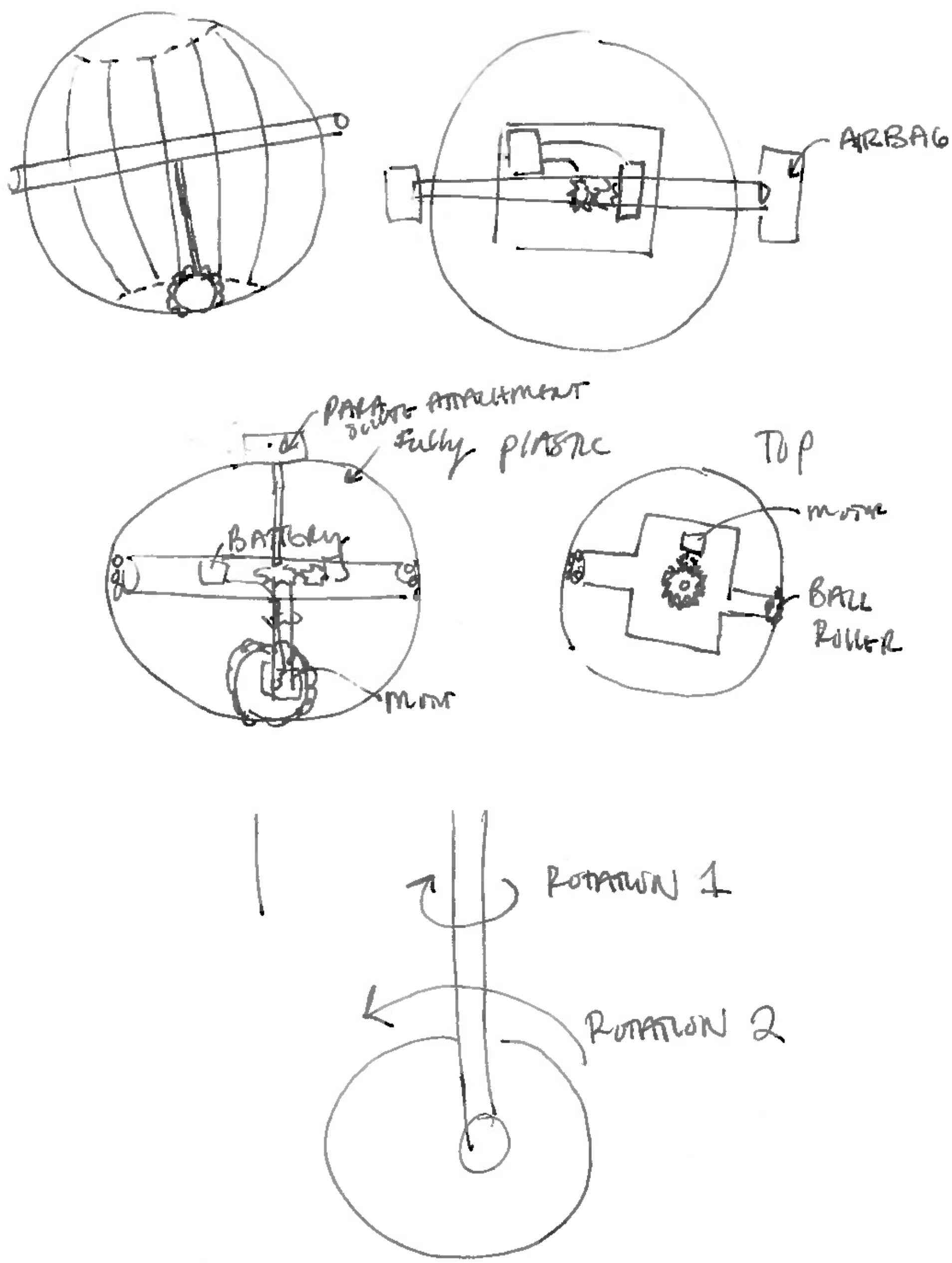


Figure 17: Preliminary sketches of Hamster Ball concept

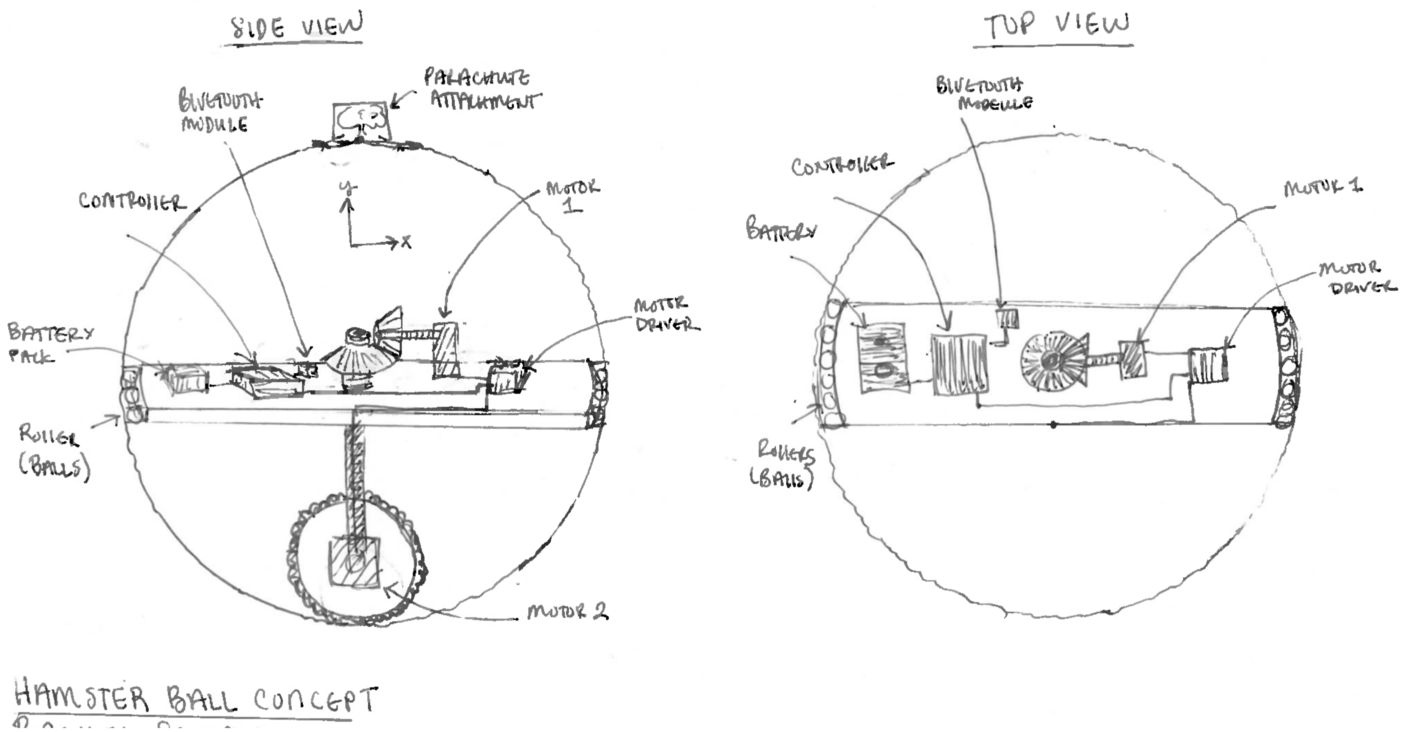


Figure 18: Final sketches of Hamster Ball concept

Solutions from morph chart:

1. Communicates with telemetry system via Bluetooth
2. Survives drop by decelerating via parachute
3. Uses power via lithium battery
4. Travels over desert terrain using hamster wheel
5. Protects and holds hardware via sealed container

Description: The purpose of Hamster Ball concept is to roll forward over desert terrain and switch directions to move towards a target GPS location. A sealed hard plastic hamster ball contains an electronic holding platform which is able to rotate freely within the hamster ball by means of roller ball contact with the sides of the largest cross sectional area. This is so that the platform stays parallel with the ground as the ball moves around it when rolling. Underneath the platform extends a wheel that is in contact with the bottom of the ball. The wheel can move about its vertical Y-axis to change direction and about its Z-axis to move forward. As the wheel rotates the ball will roll along the ground. The robot is connected to a telemetry system via Bluetooth to communicate GPS coordinates and receive directions. Two motors and all other electronics are powered by lithium battery. There is a parachute attachment on the top of the ball that will detach once the ball has landed.

4 Concept Selection

4.1 Selection Criteria

We did a Analytic Hierarchy Process to determine the weights for our scoring matrix. For each combination of selection criteria we evaluated their relative importance and then using the provided excel spreadsheet we found the weights for the scoring matrix. In the end the most important thing for our device was the resistance to impact since if the device can't survive the drop from the rocket it doesn't matter how well it works. The second most important thing was the durability of the device since it needs to survive the desert environment.

	Durability	Battery Life	Portability/Size	Maneuverability	Resistance to Impact	Ease of Manufacturing	Row Total	Weight Value	Weight (%)
Durability	1.00	6.00	2.00	1.00	0.25	4.00	14.25	0.22	22.25%
Battery Life	0.17	1.00	0.50	0.20	0.14	0.50	2.51	0.04	3.92%
Portability/Size	0.50	2.00	1.00	1.00	0.50	4.00	9.00	0.14	14.05%
Maneuverability	1.00	5.00	1.00	1.00	0.33	4.00	12.33	0.19	19.26%
Resistance to Impact	4.00	7.00	2.00	3.00	1.00	5.00	22.00	0.34	34.35%
Ease of Manufacturing	0.25	2.00	0.25	0.25	0.20	1.00	3.95	0.06	6.17%
						Column Total:	**64.04**	**1.00**	**100%**

Figure 19: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

We took our selection criteria and their weights from the AHP and used them to evaluate each of the 4 concepts we came up with. For each selection criteria we rated the concept on a scale of 1 to 5, with 1 being the worst and 5 being the best. Each rating was independent of ratings from both other selection criteria and other concepts.

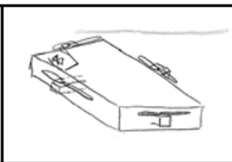
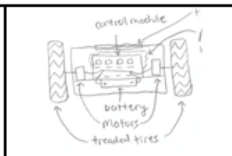
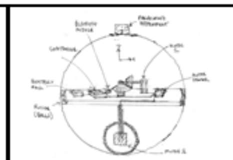
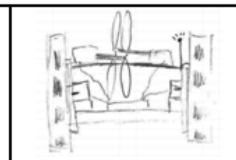
Alternative Deisgn Concepts									
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Durability	22%	2	0.45	5	1.11	4	0.89	3	0.67
Battery Life	4%	4	0.16	3	0.12	3	0.12	2	0.08
Portability/Size	14%	3	0.42	5	0.70	1	0.14	4	0.56
Maneuverability	19%	4	0.77	4	0.77	4	0.77	4	0.77
Resistance to Impact	34%	1	0.34	4	1.37	2	0.69	3	1.03
Ease of Manufacturing	6%	1	0.06	5	0.31	1	0.06	3	0.19
	Total score	**2.199**		**4.386**		**2.667**		**3.294**	
	Rank	**4**		**1**		**3**		**2**	

Figure 20: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

4.3 Evaluation Results

We now can evaluate the four different concepts based off the analytical hierarchy process and weighted scoring matrix. We found that the drone was an interesting concept, but too unreliable to select as our final concept. The hamster ball was more reliable, but was difficult to fit into the space in the rocket. Between the two dicycle designs, the first one was more resistant to impact and durable, which were the two most important criteria. It was also slightly more portable, easier to manufacture, and had better battery life than the wind powered design. Overall the first dicycle design got vastly higher score than any of the others, with the second dicycle getting the second highest score. This rover concept is similar to our mockup prototype design. The rover design will maximize use of space in the canister since the rover shape is similar, with wheels near the bases of the cylinder and components in between. The wheels are also treaded for grip and stability to drive through desert terrain. The microcontroller, other internal components, and parachute release are not included in this design concept and will have to be develop in more detail.

4.4 Engineering Models/Relationships

4.4.1 Force on parachute Joint

$$F = c_d(\frac{rV^2}{2})A + ma \tag{1}$$

Where c_d is the coefficient of drag, r is the air density, V is the velocity, A is the area of the parachute, m is the mass of the vehicle, and a is acceleration from gravity. Force on the joint is equal to the drag force plus the weight of the vehicle. This force will be a shearing force [1].

This equation calculates the force on the joint that is holding the parachute to the vehicle during descent. The joint must be strong enough to withstand the maximum force that is going to occur. The maximum force will occur at the highest velocity when the parachute is first deployed. The estimated velocity is between 0 and 17, we assume typical values of 1.75, 9.8, and 1.229 for the drag coefficient, acceleration due to gravity, and the air density respectively. The following figure shows the force on the parachute joint with varying mass and velocity.

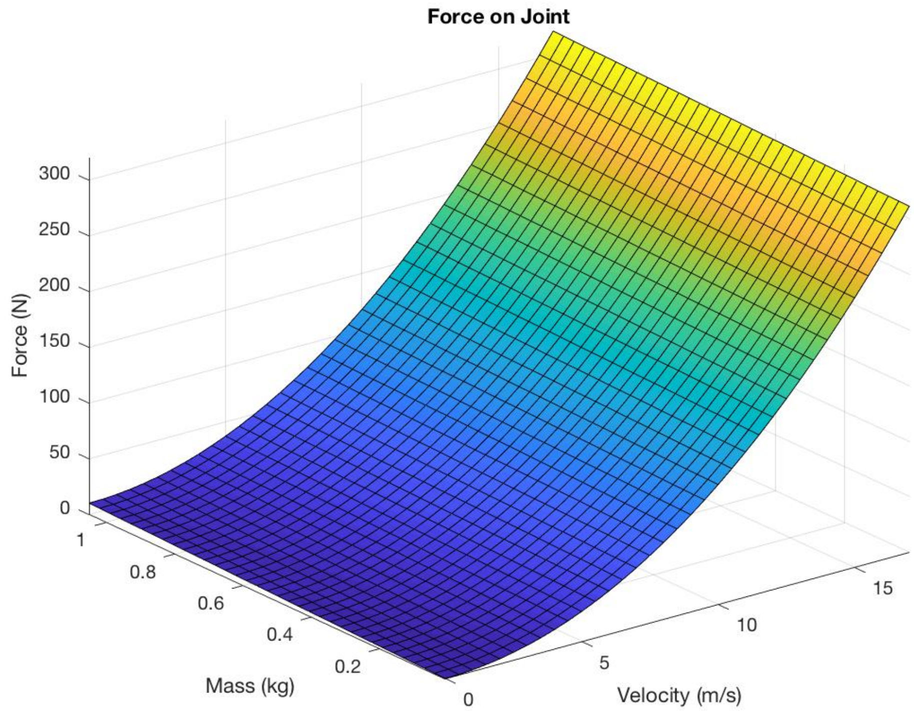


Figure 21: Force on parachute joint with varying mass and velocity.

4.4.2 Parachute Estimated Deceleration

$$V = \sqrt{\frac{2mg}{C_d r A}} \tag{2}$$

Where V is the velocity, C_d is the drag coefficient of the parachute, m is the mass of the device, g is acceleration due to gravity, r is the air density and A is the area of the parachute [1].

This equation finds the terminal velocity of our device given the mass of the device and the area of the parachute as variables. We can assume typical values of 1.75, 9.8, and 1.229 for the drag coefficient, acceleration due to gravity, and the air density respectively. Then, once we figure out how heavy our device is, we can use this equation to make sure that we order a big enough parachute. Putting this equation into Matlab we get a graph that can be used to make this selection easier, and can be used to find the terminal velocity of the device assuming the max cross sectional area of 146 mm by 240 mm. As can be seen from Fig. 22, this terminal velocity is 16.53 m/s.

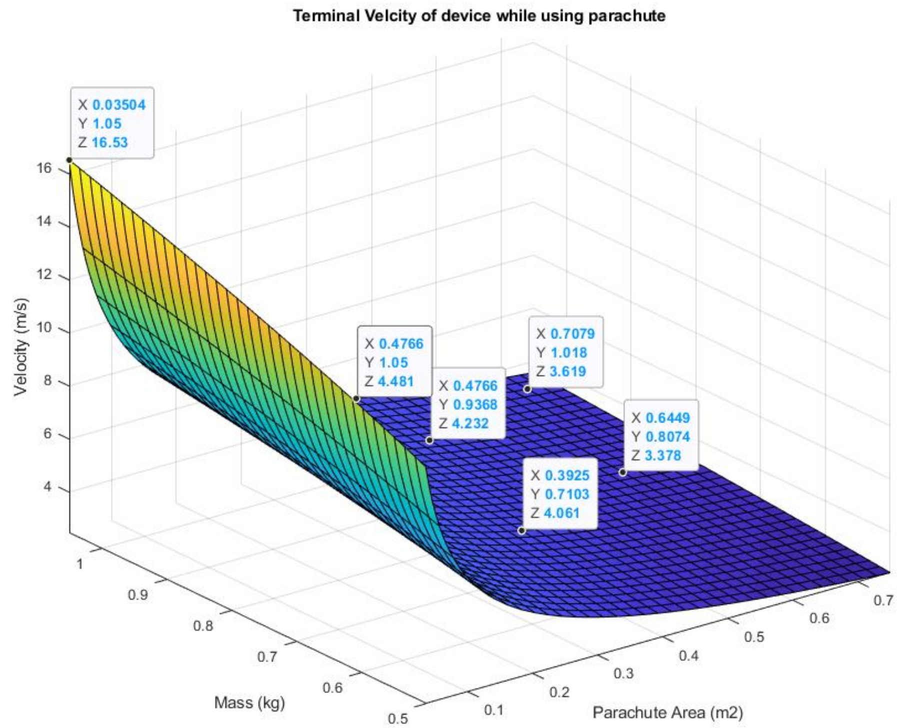


Figure 22: Matlab Graph showing potential terminal velocities with various combinations of parachute size and weight shown.

4.4.3 Torque

$$\tau = \mathbf{r} \times \mathbf{F} = Fr \sin\theta \tag{3}$$

Where τ is the torque, $\mathbf{r}$ is the position vector, $\mathbf{F}$ is the force vector, F is the linear force, r is the distance from the axis of rotation to where the linear force is applied, and θ is the angle between $\mathbf{F}$ and $\mathbf{r}$ [2].

This equation calculates the motor torque required to move the weight of the vehicle. This will help in determining the motor requirements for the two wheels of the rover. We know the maximum diameter of the wheels, $d = 146mm$, which can be divided by two to get r, $r = 73mm = 0.073m$. Also, that θ is 90 degrees, which makes $sin(90°) = 1$. This torque equation simplifies to force times moment arm. The force equation is $F = ma$, so the force depends on our rover's mass and acceleration. The figure below shows what torque would be for various forces.

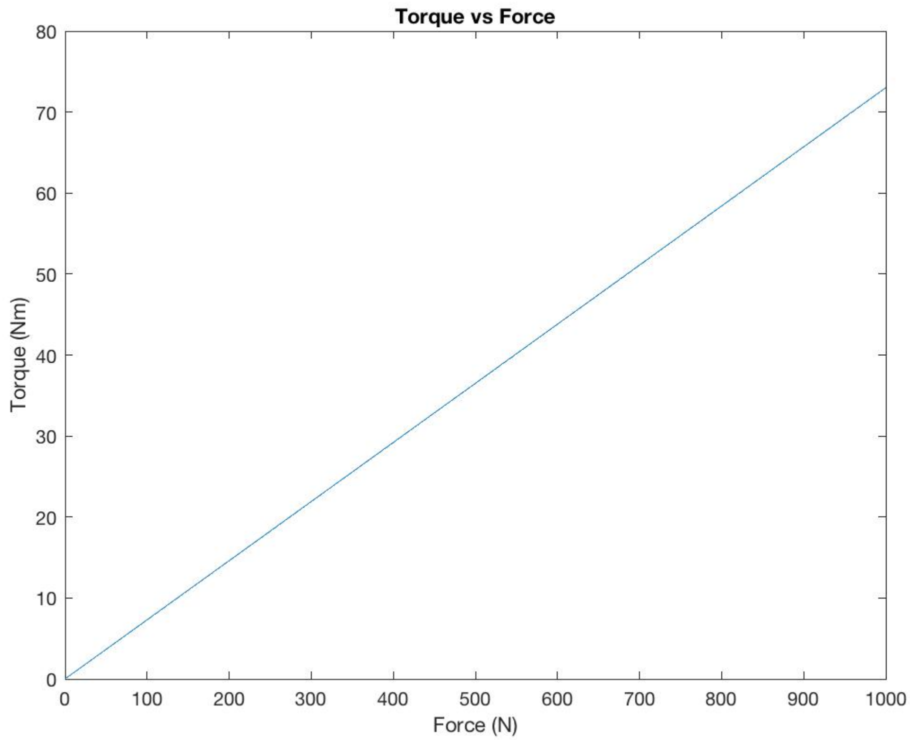


Figure 23: Torque vs Force Plot.

5 Concept Embodiment

5.1 Initial Embodiment

5.1.1 CAD Embodiment drawings of Initial Prototype

Figures 24, 25, and 26 on the following pages show the CAD drawings of our Initial Prototype with the different views and dimensions, the isometric view and bill of materials (BOM), and the exploded view with callouts to the BOM, respectively.

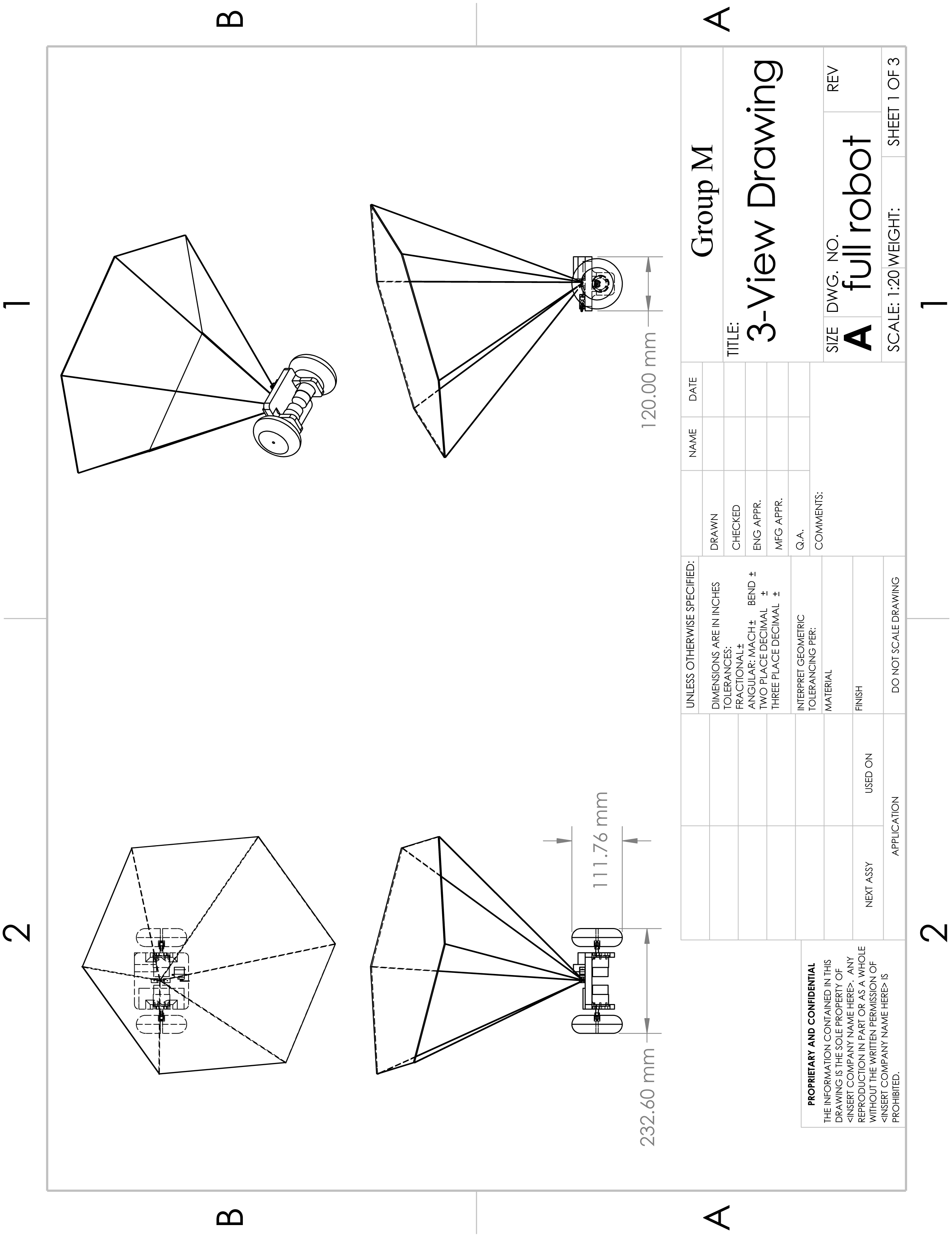
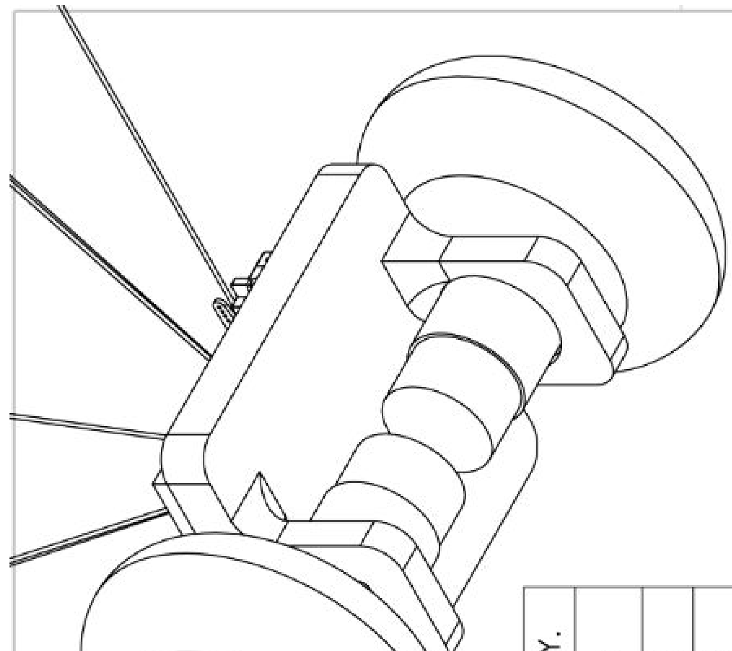


Figure 24: Assembled projected views with overall dimensions



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	base_electronic	Main Base of Device with added electronics as black box	1
2	Gearmotor_37D_100		2
3	Brass motor coupler	BRASS WHEEL TO MOTOR COUPLER	2
4	wheel		2
5	L brackets		2
6	microservoAssembly		1
7	parachute		1
8	9v	9V Batteries	2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

NEXT ASSY — USED ON — APPLICATION

Group M
TITLE:
Bill of Materials
SIZE A — DWG. NO. full robot — REV
SCALE: 1:20 WEIGHT: — SHEET 3 OF 3

Figure 25: Assembled isometric view with bill of materials (BOM)

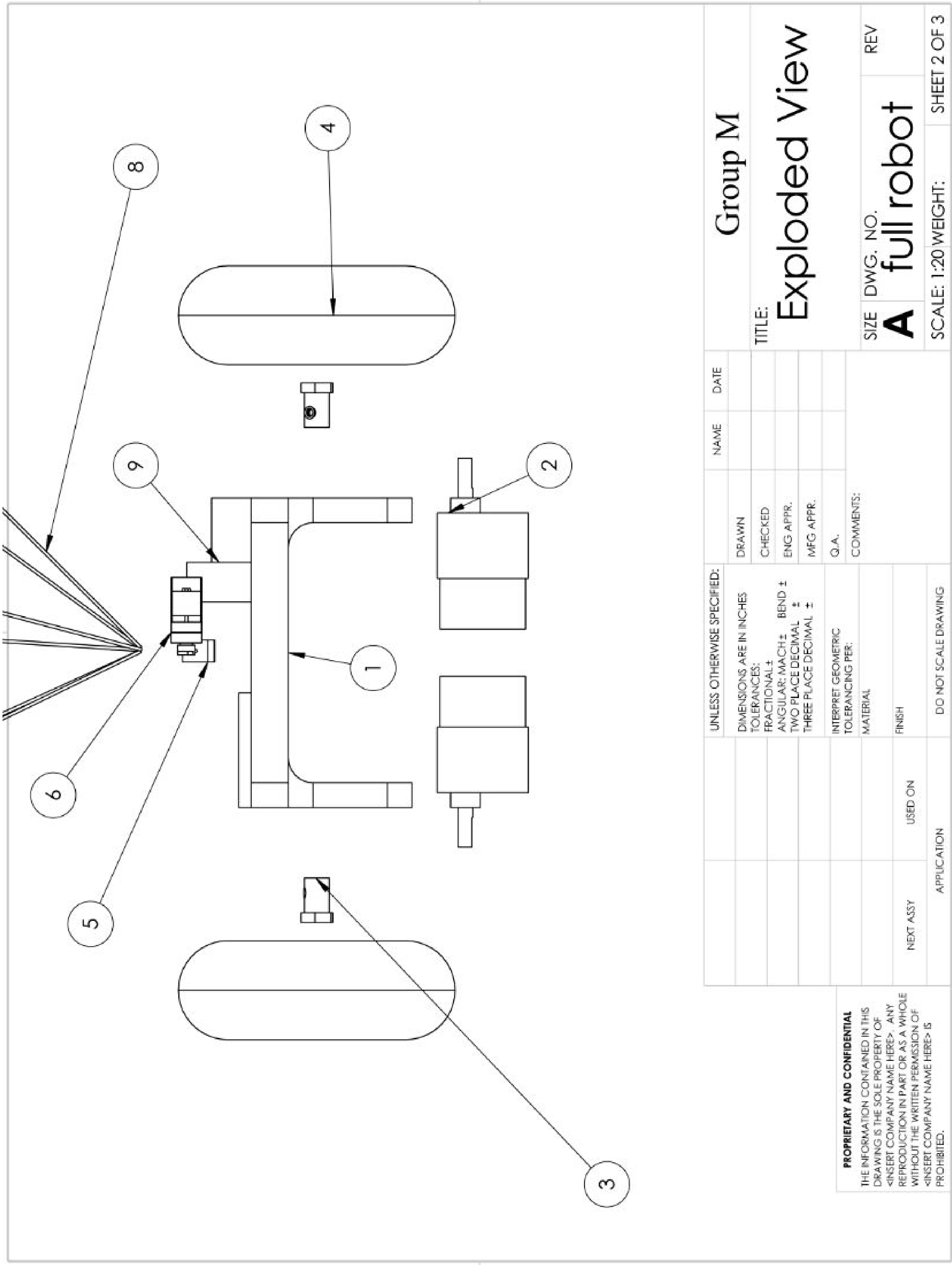


Figure 26: Exploded view with callout to BOM

5.1.2 Parts List for Initial Prototype

Below is a table of the initial list of parts for the proof of concept prototype.

Table 3: List of the Initial Prototype components

Parts List						
#	Part Name	Supplier Part #	Other Identifiers	Price	Quantity	Weight
1	Nextrox Mini High Torque DC Gear Motor	OT365-HM	12V 60 RPM	$11.99	2	5 oz
2	Estes 30" Nylon Parachute	2273	Red	$16.99	1	1.6 oz
3	HJ Garden Brass Hex Shaft Coupling 4x	NA	7mm Hex to 6mm Shaft	$8.49	1	.96 oz
4	Duratrax Deep Woods RC Tires 2x	DTXC4042	2.2in Dia., Black	$27.98	1	13.6 oz
5	Arduino Micro Controller	ATmega328P	Uno Rev 3	NA	1	0.88 oz
6	Pololu Dual Motor Driver	Pololu # 2130	DRV8833	NA	1	0.035oz
7	Power-Pro Servo motor	SGR92R	micro servo	NA	1	0.42oz
8	9V Battery	NA	NA	$1.09	2	1.58 oz
9	Bread Board	NA	NA	NA	1	NA
10	Assorted Screw and Nuts	NA	NA	NA	NA	NA
11	3-D printed Base	NA	PLA	$4.50	1	151g

5.1.3 Design Rational for PoC Components

In section 4.4 above we list three Engineering Models/Relationships that aided us in the design process. In section 4.4.2 we described a model for the parachute estimated deceleration which is shown below [1].

$$V = \sqrt{\frac{2mg}{C_d r A}} \tag{4}$$

In order to choose a parachute area we modeled the different velocities the rover would be moving at when the parachute deploys based on the mass of our rover and parachute area. The terminal velocity without the parachute deployed was calculated to be 16.53 m/s as previously stated in section 4.4.2. We decided to choose a parachute that had a 30 in diameter. Which gave a terminal velocity of 4.98 m/s with the parachute deployed. We assumed this change happened over a time of 0.1 seconds, giving a deceleration of 115.4 m/s^2. This also aided us in determining the force on the joints of the parachute, as it is directly related to the sudden velocity change from terminal velocity without the parachute to terminal velocity with the parachute.

Once the parachute area and deceleration was known we used the force on joints equation, shown below, from section 4.4.1 to choose a design for the parachute joints [1].

$$F = c_d(\frac{rV^2}{2})A + ma \tag{5}$$

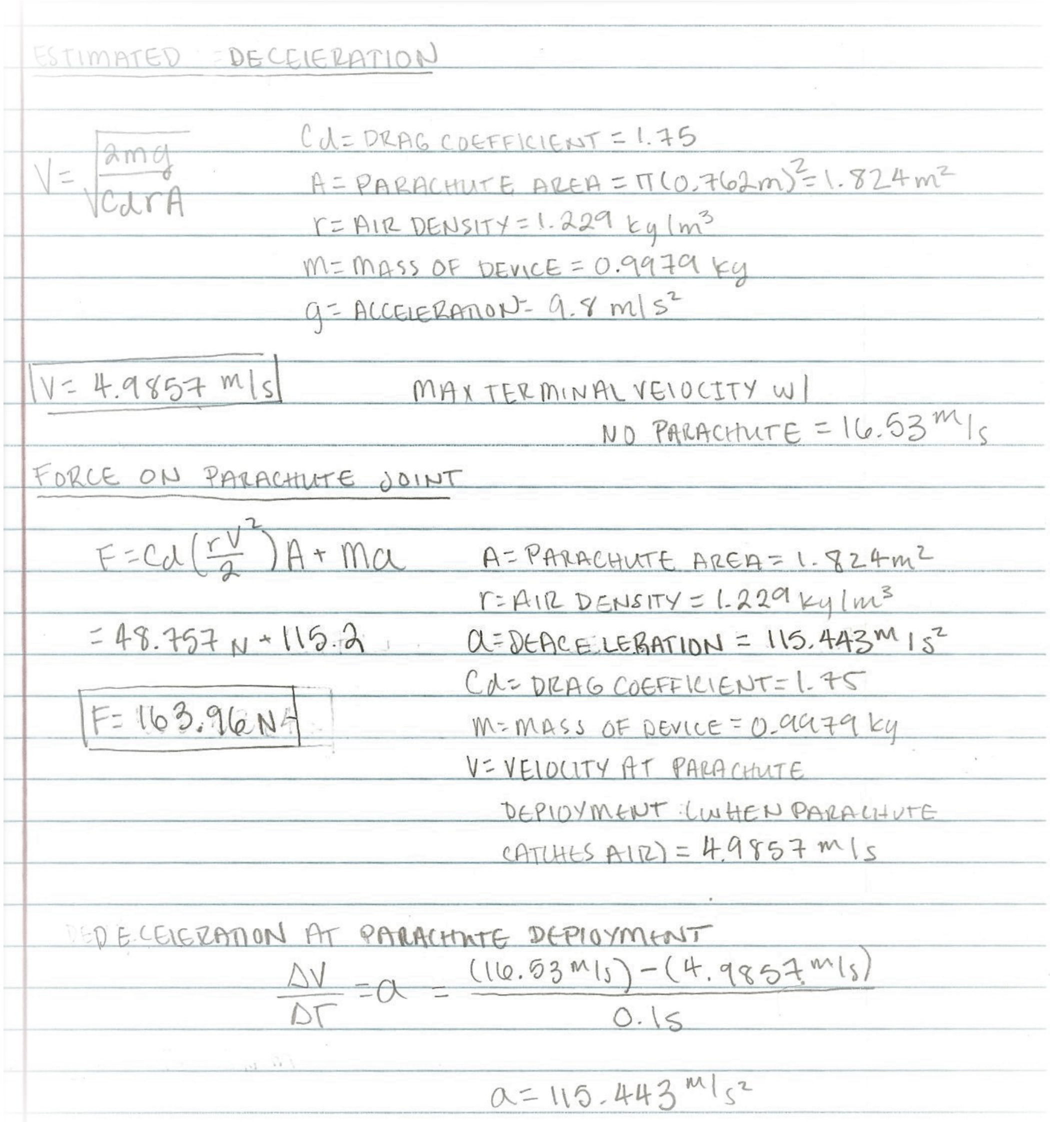
Knowing this force aided us in determine how strong the joints would need to be. In our concept embodiment we were able to choose a material and design that would be sufficient in keeping the parachute attached to the rover. The force was calculated to be 163.96 N during deceleration, calculations are shown below. This is the largest force that will occur on the joints that holds the parachute because it is when the change in velocities are the highest. In order to withstand the force we choose a steel pin that is held horizontally steel joints that were screwed into the platform.

The third engineering model described in section 4.4.3 is the torque equation which helped us determine the motor torque requirement, shown below [2].

$$\tau = \mathbf{r} \times \mathbf{F} = Fr \sin\theta \tag{6}$$

In the calculations shown in Figure 28 below, we could assume that θ is 90 degrees, which makes $sin(90°) = 1$. We knew the wheels we were ordering had a diameter of 4.4 inches so the radius was 2.2 inches. The force could be calculated by $F = ma$ and our estimated mass was 1.22lb, which when converted to kg equals 0.55 kg. We just needed a positive acceleration so an acceleration of 1 m/s^2 was assumed, meaning the force equaled 0.55N. We calculated the required motor torque to be 0.031Nm. This means the motors to be used on the rover needed to have at least 0.031 Nm torque, and we purchased high torque motors with a torque value of 30 Nm.

All calculations are shown below in Figures 27 and 28.



ESTIMATED DECELERATION

$V = \sqrt{\frac{2mg}{C_d r A}}$

C_d = DRAG COEFFICIENT = 1.75
A = PARACHUTE AREA = $\pi(0.762m)^2 = 1.824m^2$
r = AIR DENSITY = 1.229 kg/m^3
m = MASS OF DEVICE = 0.9979 kg
g = ACCELERATION = 9.8 m/s^2

$V = 4.9857$ m/s

MAX TERMINAL VELOCITY W/ NO PARACHUTE = 16.53 m/s

FORCE ON PARACHUTE JOINT

$F = C_d\left(\frac{rV^2}{2}\right)A + ma$

$= 48.757\,N + 115.2$

$F = 163.96N$

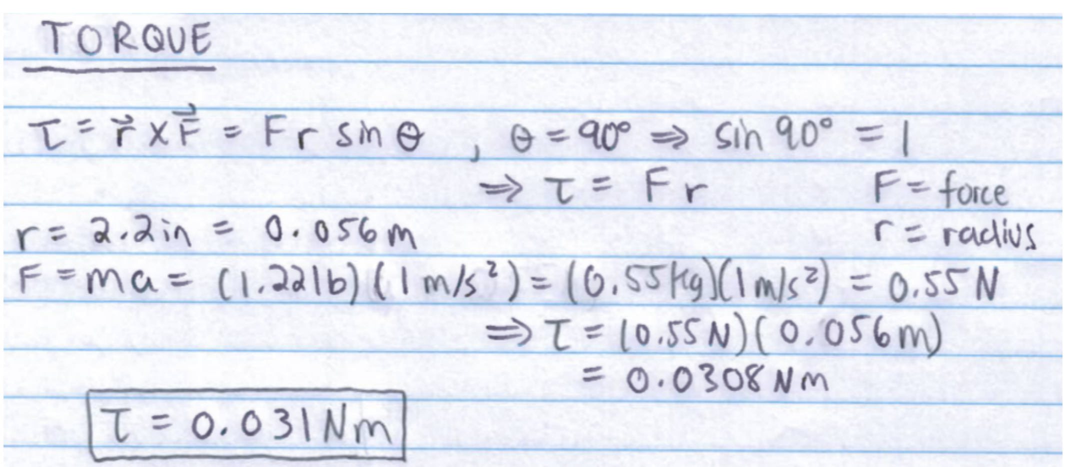
A = PARACHUTE AREA = 1.824m^2
r = AIR DENSITY = 1.229 kg/m^3
a = DEACCELERATION = 115.443 m/s^2
C_d = DRAG COEFFICIENT = 1.75
m = MASS OF DEVICE = 0.9979 kg
V = VELOCITY AT PARACHUTE DEPLOYMENT (WHEN PARACHUTE CATCHES AIR) = 4.9857 m/s

DECELERATION AT PARACHUTE DEPLOYMENT

$\frac{\Delta V}{\Delta T} = a = \frac{(16.53\,m/s) - (4.9857\,m/s)}{0.1s}$

$a = 115.443\,m/s^2$

Figure 27: Estimated Deceleration and Force on Parachute Joint Calculations



TORQUE

$\tau = \vec{r} \times \vec{F} = Fr\sin\theta$, $\theta = 90° \Rightarrow \sin 90° = 1$
$\Rightarrow \tau = Fr$

F = force
r = radius

$r = 2.2in = 0.056m$

$F = ma = (1.22lb)(1\,m/s^2) = (0.55kg)(1\,m/s^2) = 0.55N$

$\Rightarrow \tau = (0.55N)(0.056m) = 0.0308\,Nm$

$\tau = 0.031Nm$

Figure 28: Estimated Motor Torque Requirement Calculation

5.1.4 Prototype performance goals

1. Travel a certain distance (from Skinker to the History Museum) with various terrain (the gravel path with leaves and twigs).

2. Drop the rover to test for resistance to impact.

3. Drop the rover to test the parachute release mechanism and ability to drive away after the drop.

5.2 Proofs-of-Concept

5.2.1 Proof-of-Concept Prototypes

Below are images of our proofs-of-concepts for the parachute release mechanism and landing. Figures 29 to 34 are various ideas we had for the parachute release. The strings represent the parachute and the angle brackets are to hold the strings in place/attach the parachute to the rover. Figure 29 includes cutting the strings in a pinching manner while Figure 30 shows cutting the strings in a sliding manner. In Figure 31, current running between the two wires would cause a spark to light the parachute strings so they would burn off and detach from the rover. Figures 32 and 33 use a pin that once removed from the angle brackets, releases the parachute. Figure 32 shows the pin in place holding the parachute and figure 33 shows the released position. When the rover drives away, the parachute would stay behind on the ground. This is the concept we decided to move forward with because its simplistic design would make it the most reliable in execution.

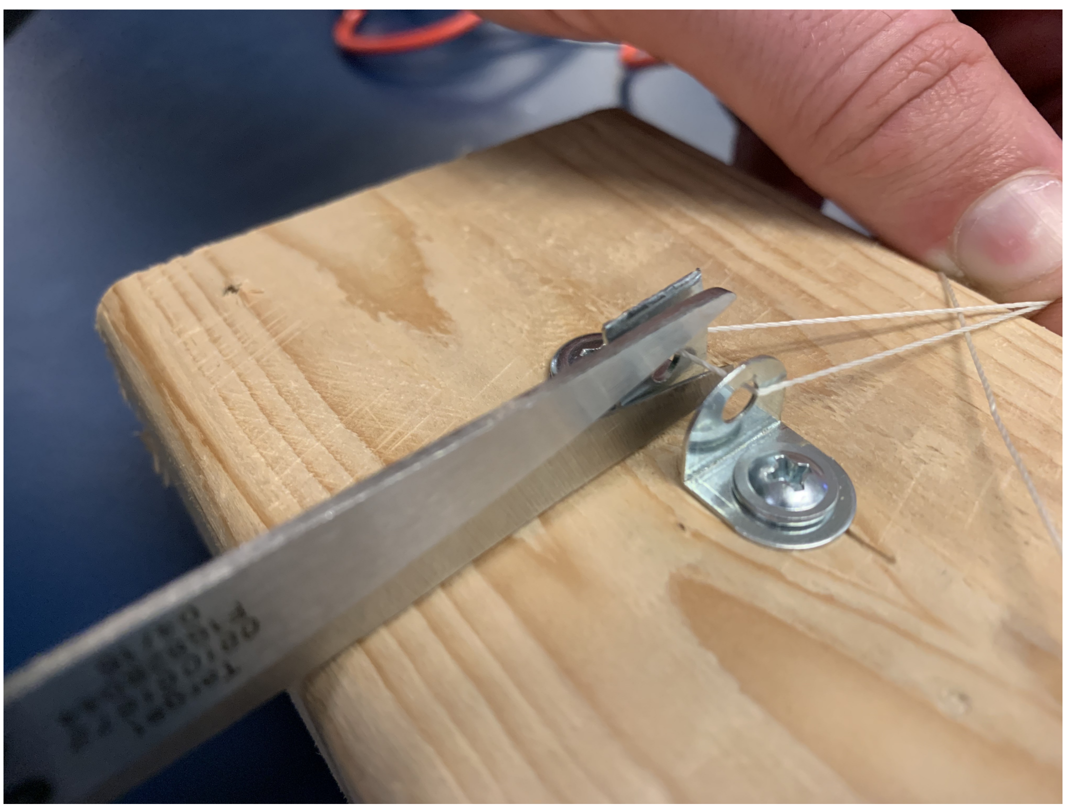


Figure 29: Proof of scissor concept.

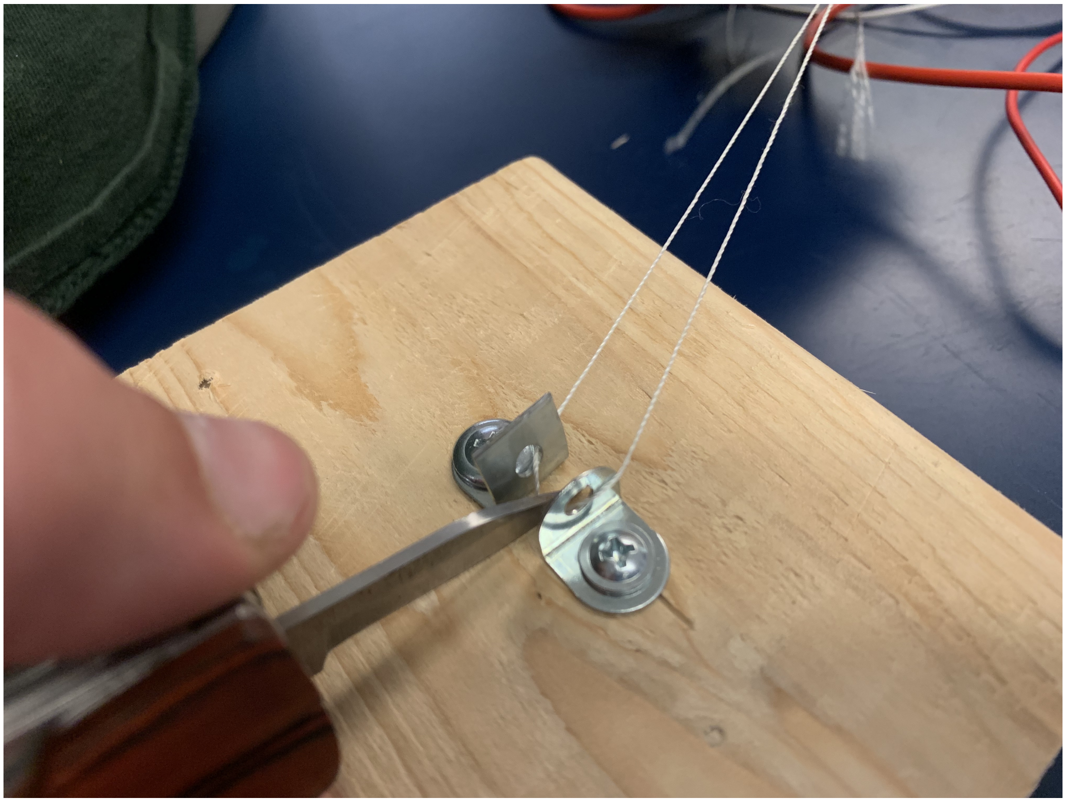


Figure 30: Proof of knife concept.

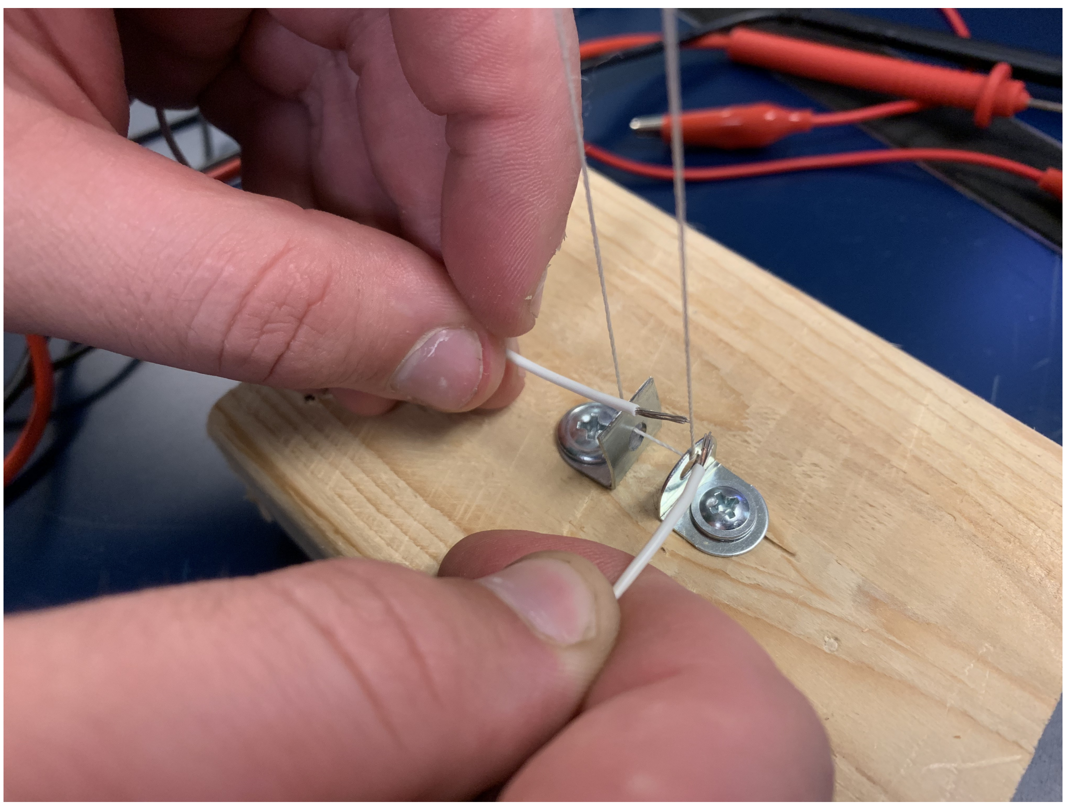


Figure 31: Proof of burn concept.

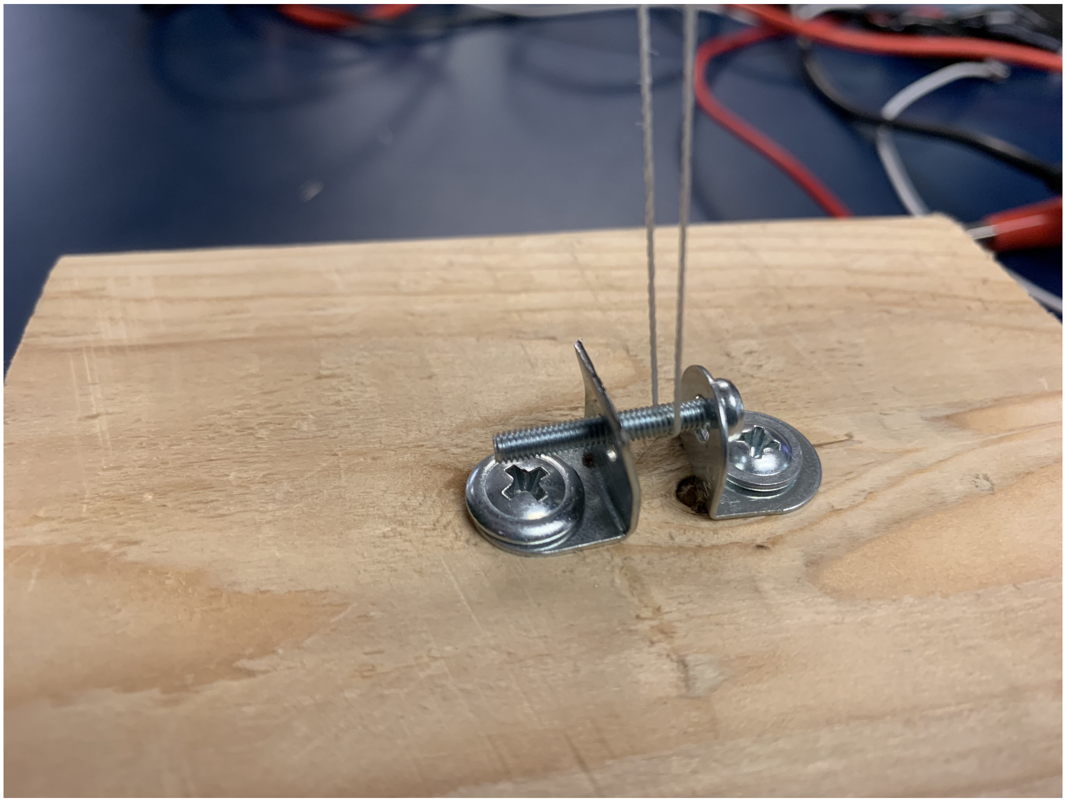


Figure 32: Proof of pin concept.

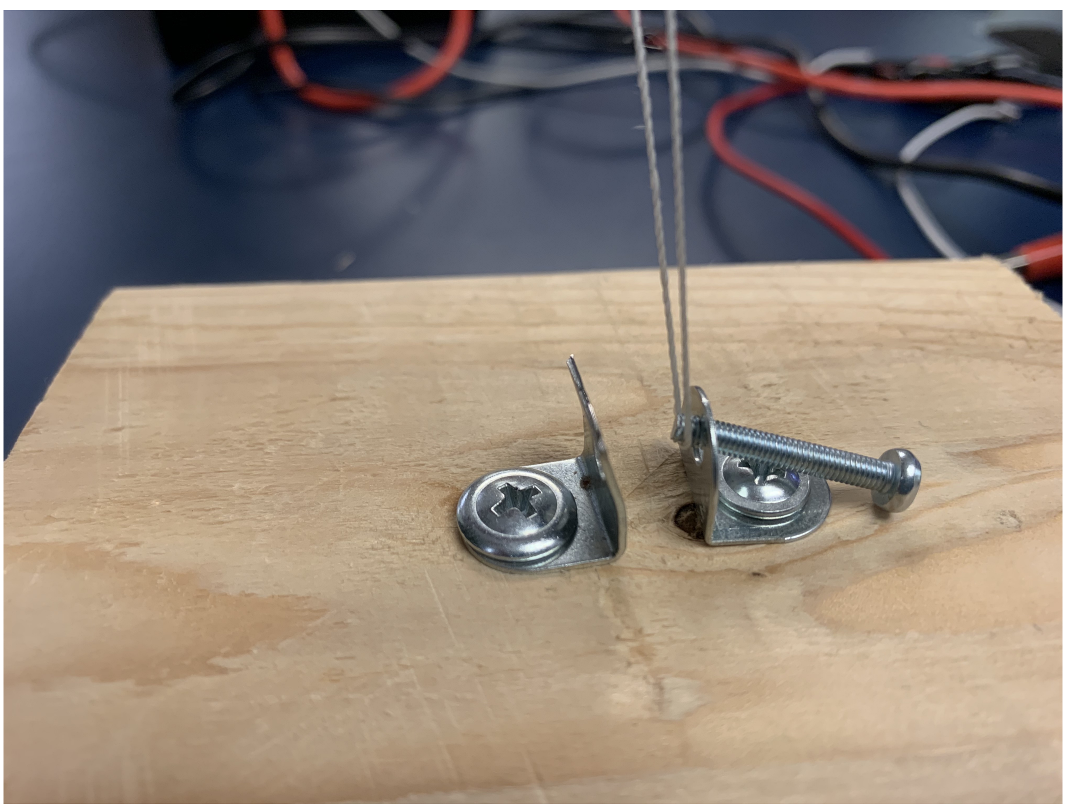


Figure 33: Proof of pin concept.

Another concept we tested was how the rover would land. The proof of concept can be seen in Figure 34 below.

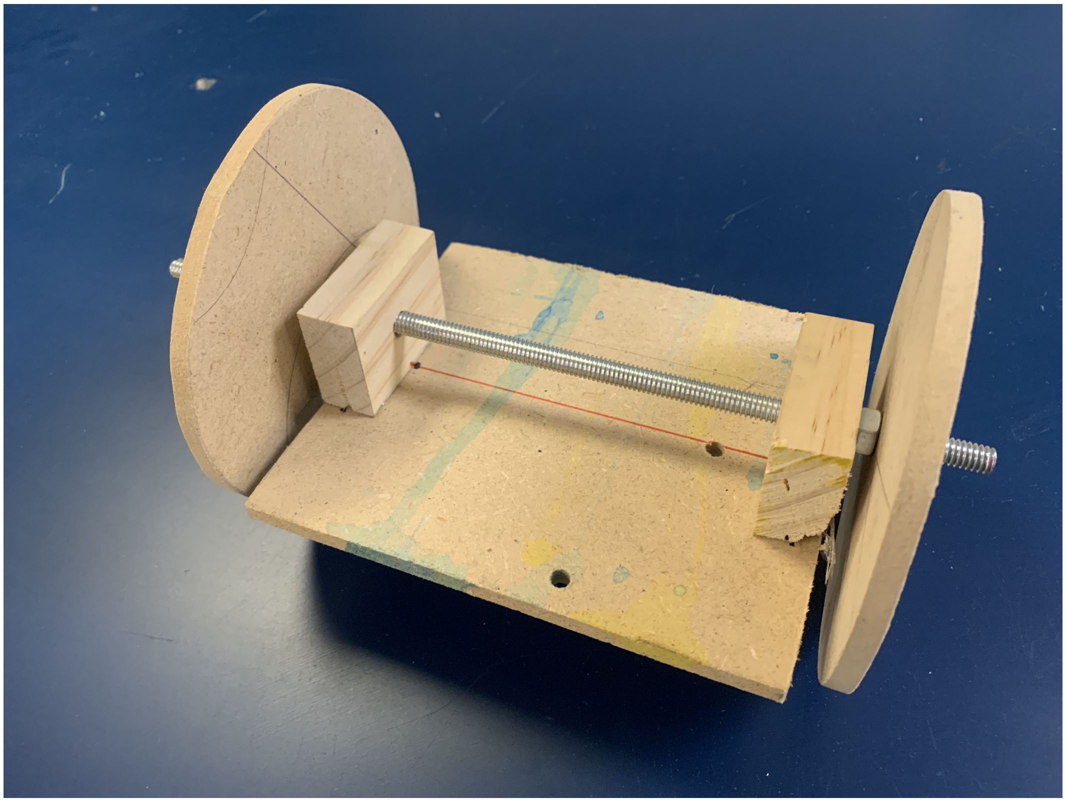


Figure 34: Proof of pin concept.

This model represented a skeleton of the rover. We dropped the unit from different angles to test if it would land in a position that could drive and navigate after landing. These tests were successful so we continued to develop this concept.

5.2.2 Selected Concept vs. Initial Prototype

During the concept embodiment phase there were some key components in the selected rover concept from section 4 that we decided to proceed with for the initial prototype rover. For example, we found airy, treaded tires similar to the ones from the selected concept, which provided excellent traction and durability during the drop test. For the motors, the general size and position stayed the same as in the selected concept.

There was some ambiguity in the selected concept that was developed more thoroughly for the initial prototype. For example, the type of control module in the concept was not specified, so we decided to use an Arduino Uno board. The quantity and type of battery was also not specified in the selected concept. We did some initial testing and discovered that one 9V battery was not enough to power the microcontroller, servo, and 12V motors so we added a second 9V battery.

There were some changes from the selected concept to the initial prototype. For example, in the selected concept, there was a cylindrical housing to contain all the components, but this was changed to a plate with side mounts for the motors. The idea was to contain all the components so they would survive the drop but we decided that if the components were secured to the platform well enough then they would remain intact after the drop. The parachute in the selected concept was to be contained in a flap and ejected after the rover was ejected from the canister. For our testing purposes, we were releasing the rover with the parachute already out and the problem to consider was that it would not be ideal to navigate the rover with the parachute still attached. To solve this, we added a release mechanism that was not in the selected concept. This included a servo motor attached to a pin that holds the parachute onto the rover and when rotated 180 degrees, releases the strings so that the rover can drive away and leave the parachute behind. We also added a tail which was not included in the selected concept. This was to keep the rover body from spinning in place because when the motors turn on, there was more force on the body than on the wheels, so instead of moving the wheels, the body moved. The tail kept the body upright forcing the wheels to turn and therefore the rover could navigate forward. Figures 35 to 37 below show our initial prototype.

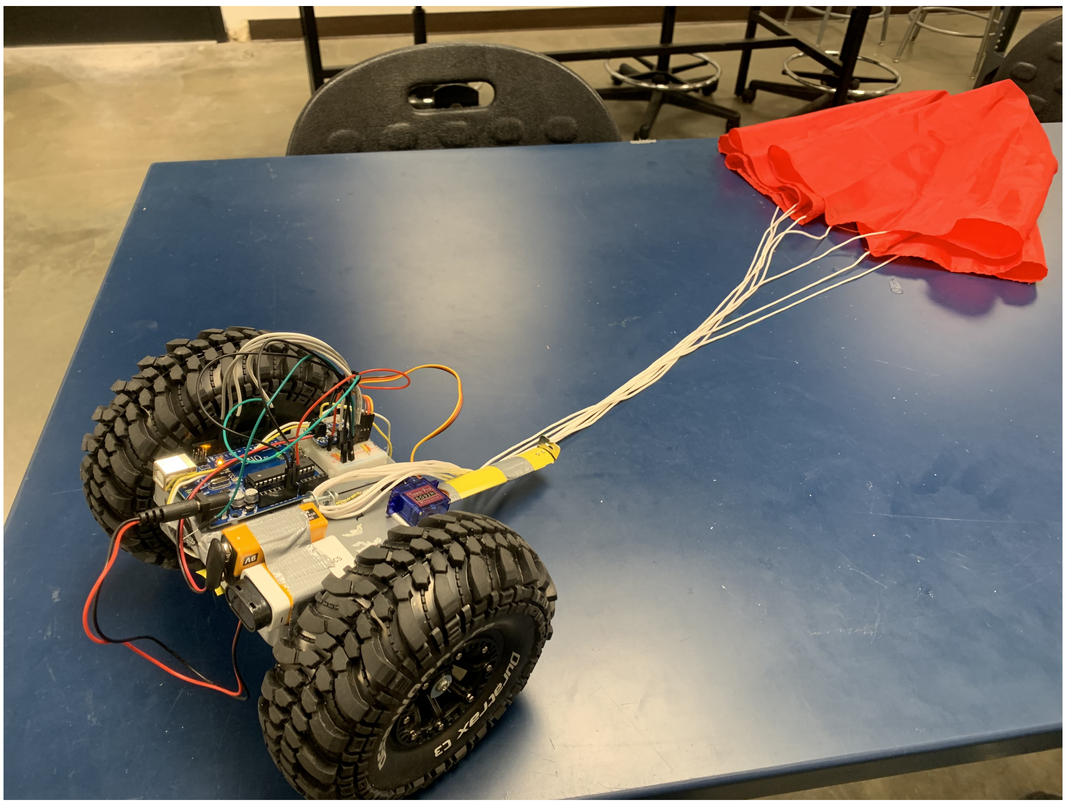


Figure 35: Initial Prototype Isometric View

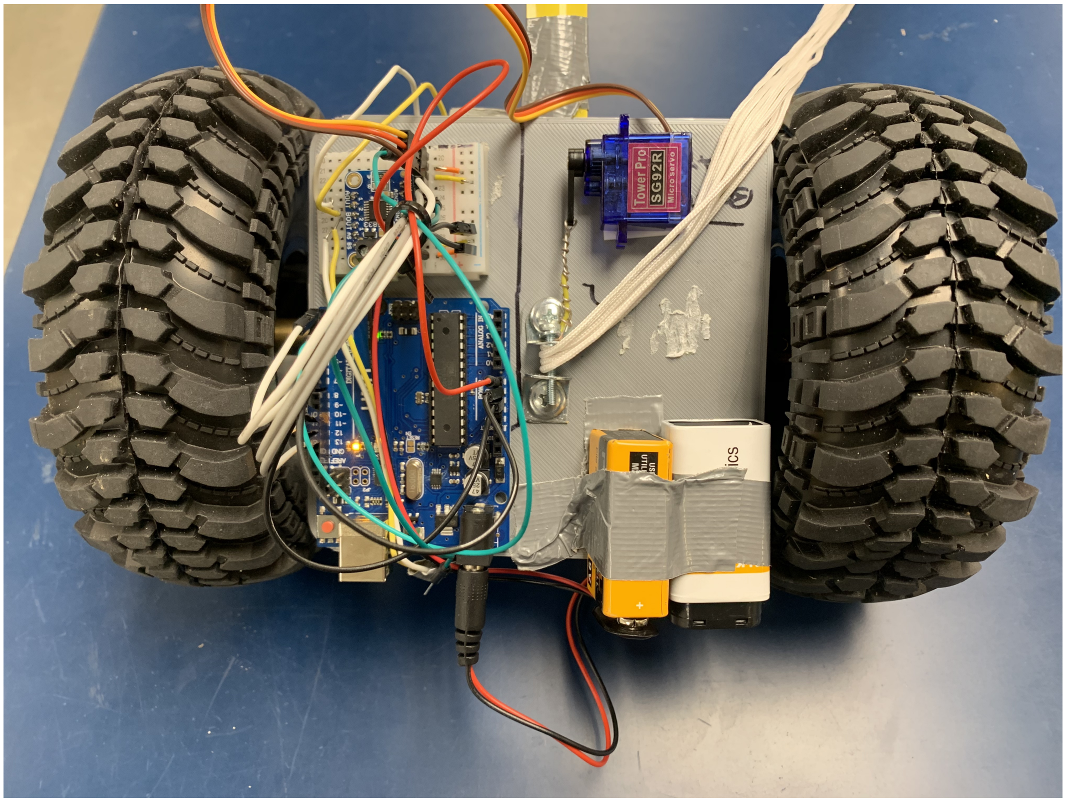


Figure 36: Initial Prototype Top View

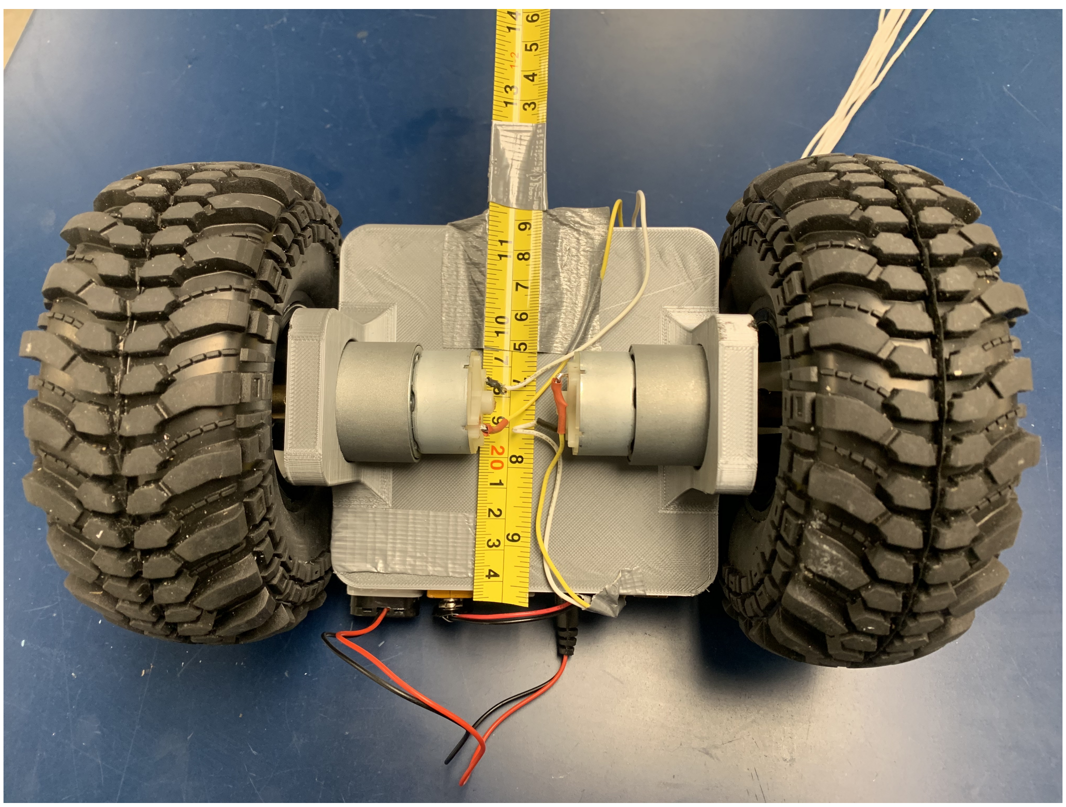


Figure 37: Initial Prototype Bottom View

6 Design Refinement

6.1 FEM Stress/Deflection Analysis

For our FEM Stress and Deflection Analysis, We looked at the PVC pipe that forms the main support for our device. We approximated the stresses by assuming that our device would go from terminal velocity to stand still in about a tenth of a second. We used our model for terminal velocity with the parachute size we chose, and assumed that our device weighs 1.05 kg since this would give us our maximum force, about 42.7396 N. We then assumed that this force would be spread across the body of the PVC pipe and that the sides of the pipe would remain fixed due to the wheels impacting the ground. We used a mesh that was part way between average and fine with about 100,000 degrees of freedom. These forces, fixtures, and the mesh can be seen in Fig. 38 below.

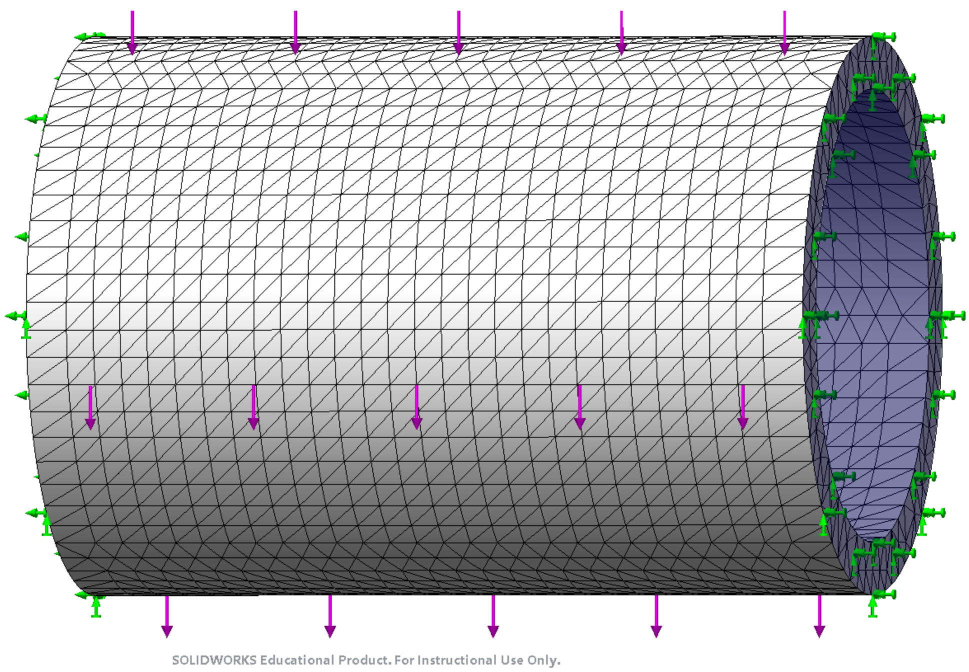


Figure 38: Mesh, Fixtures, and Forces on Pipe

Upon running our FEM analysis, we found that the stress was highest next to the wheels, getting up to 127.8 kN/m^2. The placement of the motors inside the pipe at these points should help dissipate some of the Stress, but as we do not have accurate models for the motors with all their small parts, we elected not to include them in this analysis. The stress plot can be seen in Fig. 39 below.

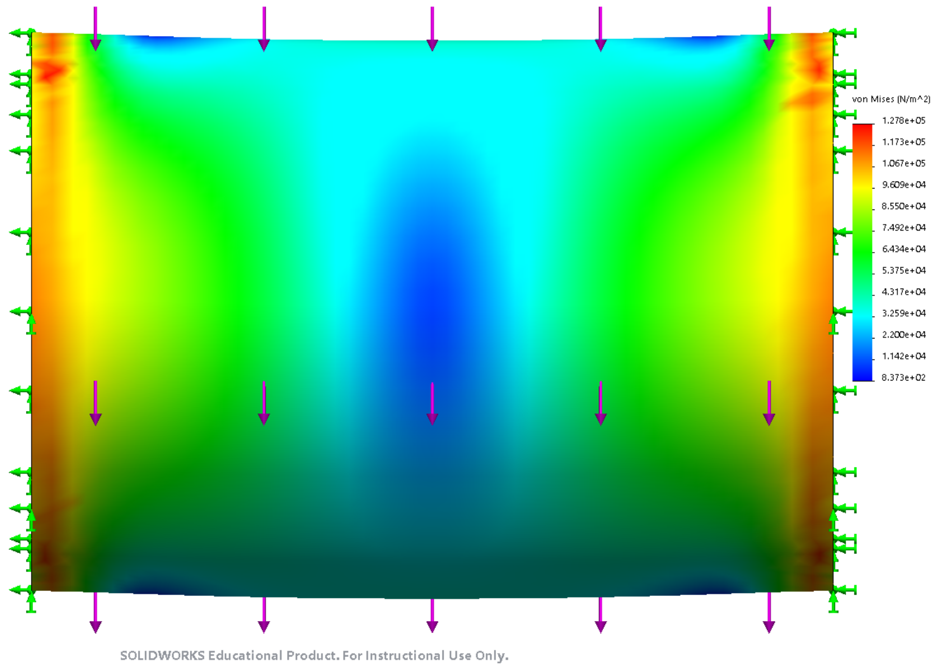


Figure 39: Stress Results of FEM analysis

The deflection analysis of our pipe showed that the max deflection occurs near the center of the pipe, which is what we expected, but that the deflection was only .6599 mm at its maximum. As this is a very small deflection, we are not concerned with trying to correct for it. The deflection plot of the results can be seen in Fig. 40 below.

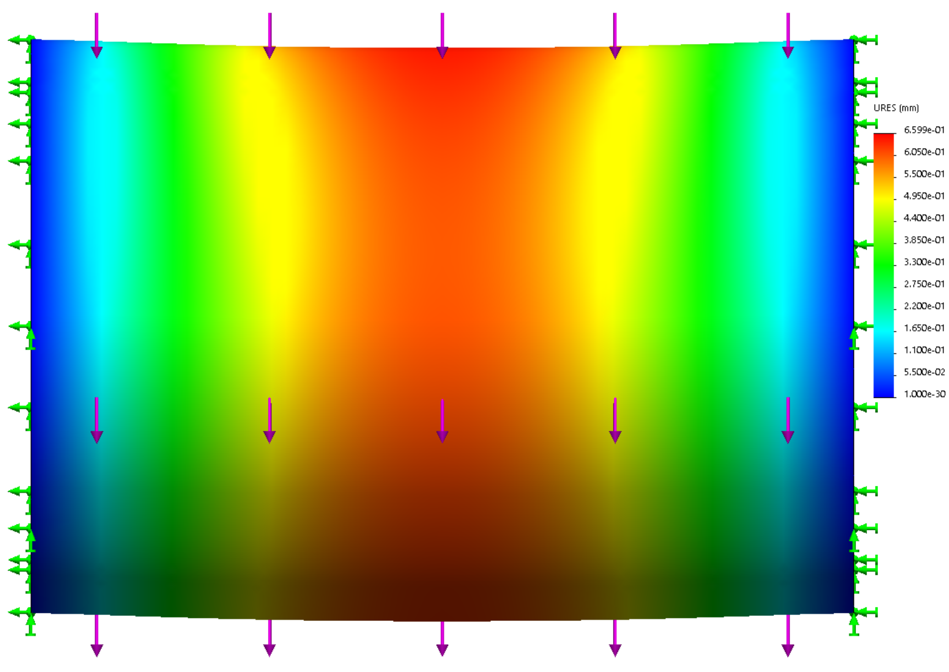


Figure 40: Deflection Results of FEM analysis

6.2 Design for Saftey

As a responsible design engineer, it is important to consider how safe a product is in terms of the severity of risk and the probability that something will go wrong. Devices can be hazardous with or without the presence of a part failure, which can result in physical harm to people and/or damage to property. In this section, we identify potential risks of our prototype and their corresponding priority relative to each other.

6.2.1 Risk #1: Contact with motors

Description: A person touching any part of the motors while they are running can cause injury.
Severity: Marginal.
Probability: Likely.
Mitigating Steps: Design a casing around the motors to protect them from the environment.

6.2.2 Risk #2: Lands on person

Description: The prototype is free falling with a parachute and could land anywhere.
Severity: Critical.
Probability: Seldom.
Mitigating Steps: Clear the drop zone before launch and add an alarm to the prototype.

6.2.3 Risk #3: Shock

Description: A person touching the electrical wiring of the components could cause them to receive a shock.
Severity: Marginal.
Probability: Occasional.
Mitigating Steps: Design a housing to cover the wiring components.

6.2.4 Risk #4: Fire hazard

Description: Too much current through electrical components could cause the system to overload and start an electrical fire.
Severity: Catastrophic.
Probability: Seldom.
Mitigating Steps: The microcontroller has a built in current regulator to reset if current reaches peak value.

6.2.5 Risk #5: Battery exploding

Description: The lithium ion battery could short circuit while charging, causing overheating and thus an explosion.
Severity: Catastrophic.
Probability: Unlikely.
Mitigating Steps: Keep a close watch on the batteries while they are charging and keep them in a cool, controlled environment.

Probability that something will go wrong

Severity of risk: 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
Catastrophic				Fire hazard	Battery exploding
Critical				Lands on person	
Marginal		Contact with motors	Shock		
Negligible hazard presents a minimal threat to safety, health, and well-being of participants; trivial					

Figure 41: Risk Assessment Heat Map

As recommended by the heat map, the highest priority risk is the fire hazard. This is due to the fact that if the prototype were to catch on fire, the severity would be catastrophic, yet the probability of an electrical fire is only seldom. The next highest priority is the battery exploding because an explosion also has a catastrophic impact, but is less likely to occur than the fire hazard. The third highest priority is the rover landing on a person because the severity is critical and probability is seldom. The next highest priority is contact with motors since the severity is marginal and probability is likely since the person operating the device will be handling the rover and picking it up. The lowest priority risk is risk of shock. Severity of receiving a shock is also marginal but the probability of receiving a shock is only occasional.

6.3 Design for Manufacturing

In this section we looked at different process of manufacturing and analyzed two different parts in our prototype to observe whether or not they are within the guidelines of the manufacturing technique.

6.3.1 Draft analysis

The draft analysis in particular relates to the manufacturing technique injection molding. We ran the draft analysis with a simpler part of our design which was the pvc pipe. After the initial analysis, we observed how the outer surface was at an angle of about 90% to the top and bottom openings, which would had stopped the flow in injection molding. So we decided to add a draft of about 2% to outer curved surface from one end to another. Which made the top opening of relatively higher radius as compared to the lower opening. This allowed a draft of about 2% percent and this was done through the help of one solid work's feature. Below is a picture with draft analysis of the pvc pipe before and after the addition of draft.

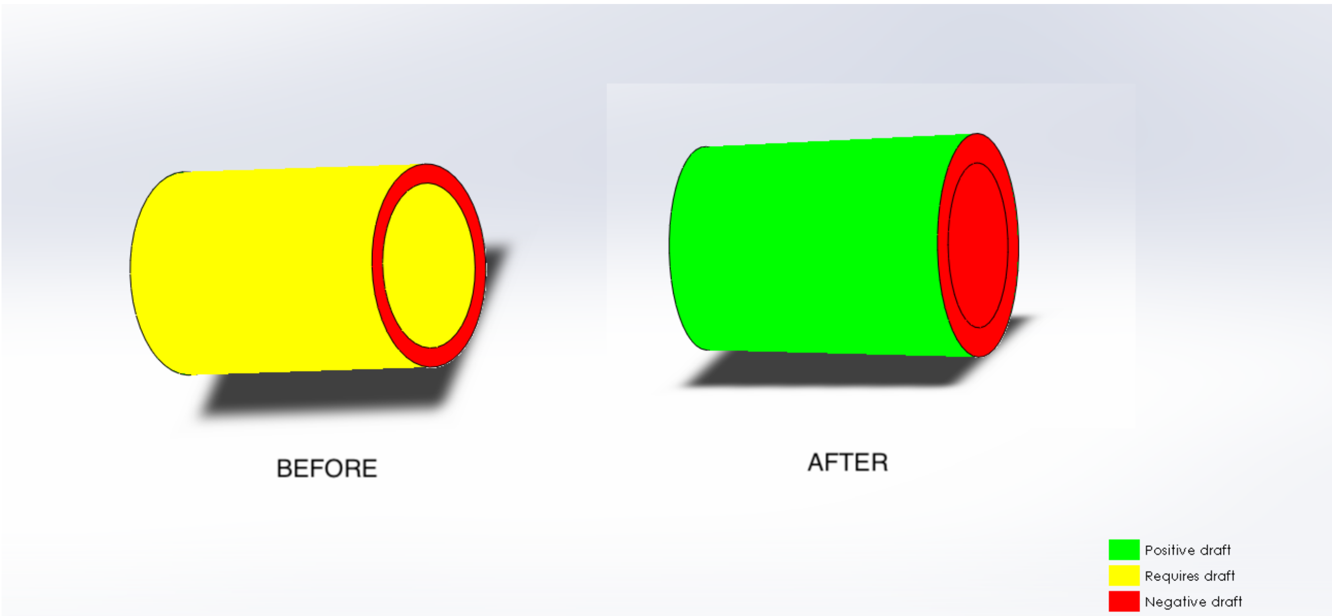


Figure 42: Draft analysis of the PVC pipe

6.3.2 DFM Analysis

The complicated part that we choose for our DFM analysis was the base plate. The first analysis was ran with the manufacturing technique milling/drilling only. We found through the analysis that there were about 5 errors in the design that didn't satisfy the guidelines of the mill/drill technique. The first one is for the arc as show below in the image, where the arc that supports the pvc pipe has an area of about 50% whereas according to the guidelines it should be at least 75%. The other 4 errors corresponded to the size of holes we had on our design, which didn't match the standard size of holes that are used with mill/drill. However the standard size was within the tolerance limit of the manufacturing technique so we weren't worried too much about the mill/drill technique since it would had worked.

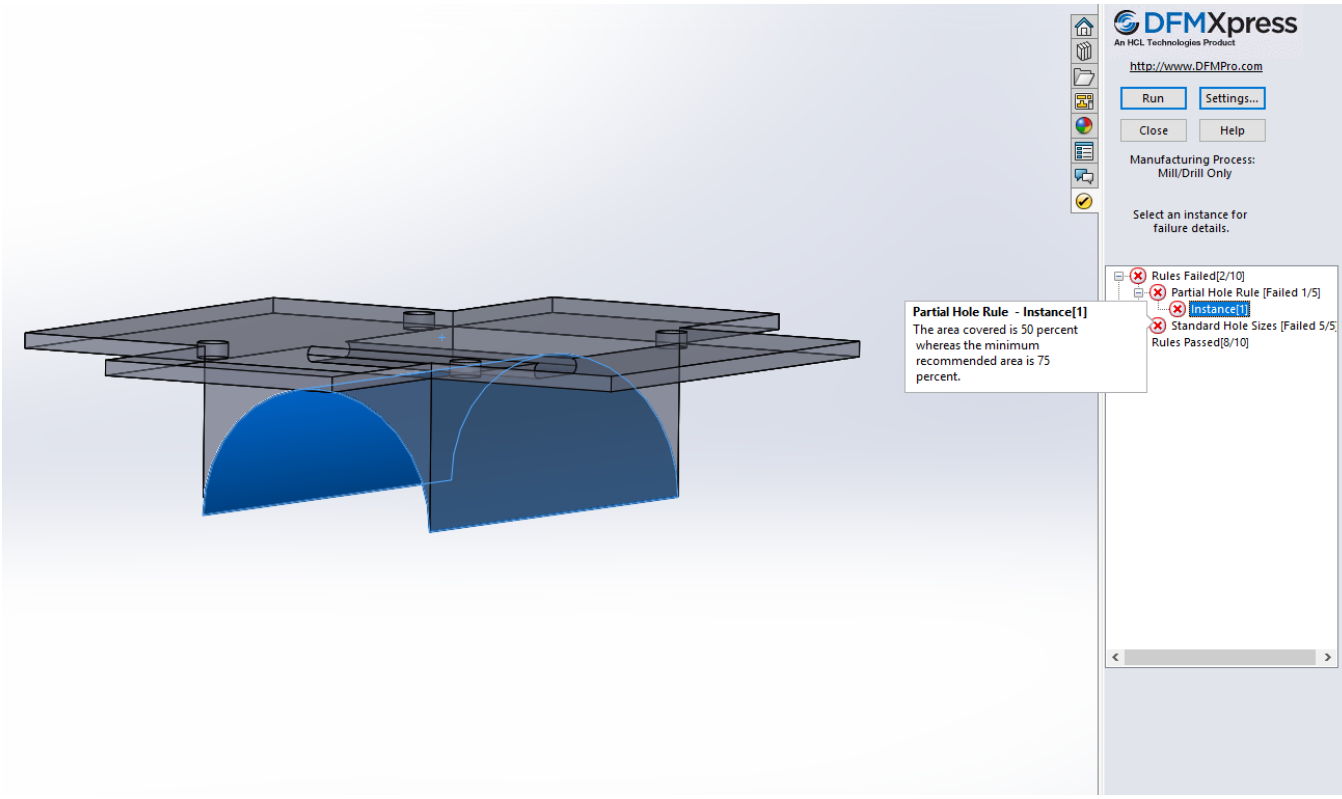


Figure 43: DFM analysis for the mill/drill analysis

The second analysis was ran with injection molding technique for the same base plate. There were multiple error with the injection molding technique which made us believe if anything injection molding was far from the right manufacturing choice. The error in this manufacturing technique corresponded to the thickness of different components in this part, where some components are above the maximum thickness and some are below the minimum thickness. This can be seen in the diagram beneath.

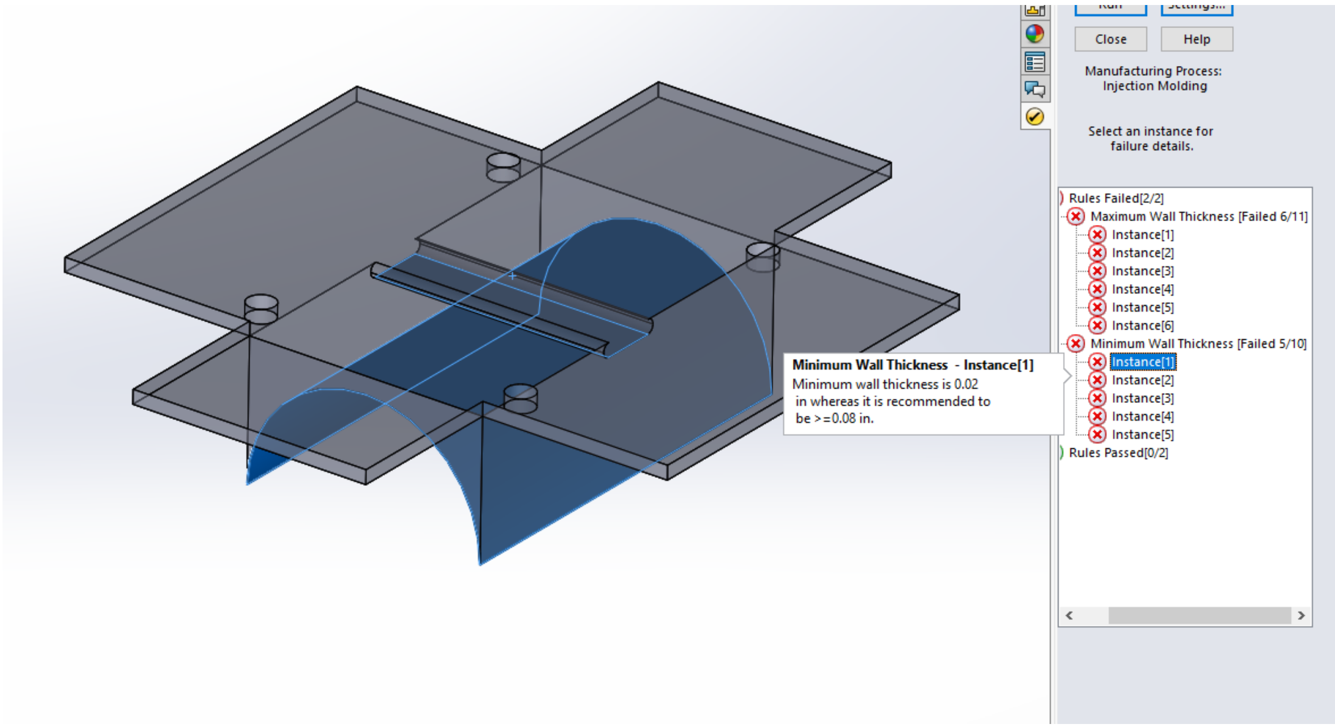


Figure 44: DFM analysis for the injection molding technique

6.4 Design for Usability

In this section we looked at making our rover as usable as possible for a variety of people, factoring in those who may have vision, hearing, physical, or control disabilities. We evaluated our design to look at how those factors may influence usability, and suggest ways to modify the design to improve the usability for those planning to use this device in the ARLISS challenge or just introduce themselves to robotics.

To make the rover usable for a person with vision impairment such as red-green color blindness or presbyopia (difficulty focusing), we consider the ways color influences the development of the rover and its use in ARLISS competition. Confusion with wiring may become an issue while developing the rover for someone with color blindness, as wiring is often tracked by colors. To counter obstacle we may use wires that have labels on them. Second, during the competition, once the rover detaches the parachute it is up to the user/users to drive around and locate the parachute. To make the parachute as visible as possible we used bright color.

To make the rover usable for those with a hearing impairment such as presbyopia, which makes hearing higher frequencies or quieter sounds difficult, we looked specially at obstacles that would arise during testing and development. During programming/testing the servo release it may be difficult to hear the sound of the servo initiation. To counter this, we would include a noise making device that would sound at a low frequency when the servo releases. Other then the servo initiation, most cues that the device it working properly are signifigantly visually apparent

To make rover usable for someone with physical impairments such as arthritis, muscle weakness, or limb immobilization, we looked at obstacles that may occur during testing and development. Specifically, de-tangling the parachute lines multiple times may become irritating or impossible as the small lines require lots of dexterity. To counter this, we would add small rubber or silicone tubing around the lines of the parachute to allow them to be more handle-able. otherwise, our rover in total is under 1kg and shouldn't be an issue to lift.

Finally, to make the rover usable for those with distraction, excessive fatigue, or medication side effects we looked at how the rover operated during use. To make it more usable we would modify it play a sound (of lower frequency) while moving so that the user does not lose track of the device where it could become a hazard to others or be damaged itself. If the rover was left on with the battery's in, we would have the rover play a alarm after a minute of non use to remind the user to disengage the batteries.

7 Discussion

7.1 Project Development and Evolution

Does the final project result align with its initial project description?

- Our final project is very close to our initial project description, with two main exceptions. The first is that in our initial project description, our main body took the brunt of the impact during the fall, attaching directly to the mounting points on the motors while the revised device used a PVC pipe that holds the motors in place by compressing around the sides of the motors. The second main difference is that, in part due to the change in the distribution of stress through the device, the original device had a very thick upper surface, while in our final device the upper surface was much thinner.

Was the project more or less difficult than expected?

- The project was much more difficult than expected, as we faced multiple issues with different parts of the device. For example, we had trouble finding parts that matched our project specifications for everything from the right size wheels to the battery voltage used to power the microcontroller and motors. In addition, we had some trouble meeting up to work on the project together since our studio session for the course was only 1 hour. We met on weekends when we were unable to complete everything we needed to during studio.

On which part(s) of the design process should your group have spent more time? Which parts required less time?

- Our group should have spent more time working on the circuitry on the device since that turned out to be a lot more difficult than we expected it to be. It required a lot of trial and error and help from both the TA and Dr. Potter to help find faults. We also had issues getting the microcontroller to work and communicate with all of our computers. In the end, only two of us were able to upload code so this along with finding the right microcontroller slowed us down, especially when not everybody could meet at one time. We should have spent less time working on the release of the parachute. We came up with the idea of pulling a pin pretty early, but spent a lot of time trying to figure out a more creative way to get the parachute to come off with no success. In hind sight, we should have just stuck with the simple solution and spent our time on more tedious problems.

Was there a component of the prototype that was significantly easier or harder to make/assemble than expected?

- The microcontroller proved to be a lot more difficult than we expected it would be. We had to go through several different iterations of microcontrollers, with problems with every one we tried. Some didn't work with our computers, while others randomly stopped working.

In hindsight, was there another design concept that might have been more successful than the chosen concept?

- Using small metal bars and a single motor was an idea we saw another group using that might have worked better for us in conjunction with some of our other design choices. In particular, this design would have helped us cut down on weight which was one of our biggest constraints that we had difficulty planning around.

7.2 Design Resources

How did your group decide which codes and standards were most relevant? Did they influence your design concepts?

- Since our design was for a competition, rather than regular production, most of the codes and standards we decided were relevant had to do with our capacity to bring the device to competition. We put some consideration into our design based on the restriction of the size of batteries we can bring on an airplane. We didn't wind up using the code about registering drones because we didn't use a drone for our device.

Was your group missing any critical information when it generated and evaluated concepts?

- When we started generating the concepts, none of us had much experience with building robots like this so additional information about how to handle circuitry and check for weak points in the system would have been helpful.

Were there additional engineering analyses that could have helped guide your design?

- An analysis of how much force would be caused by the impact with the group would have been helpful for guiding our design choices. We tried to figure this out on our own later on in the process, but the information we found seemed to be overestimating how hard the impact would be.

If you were able to redo the course, what would you have done differently the second time around?

- If we redid the course, we would start our modeling and build processes earlier. We waited until the assignments were going to be due to start building, which was later than we should have started. We did not leave enough time to address inevitable problems we would run into.

Given more time and money, what upgrades could be made to the working prototype?

- Given more time and money we would incorporate the GPS and make the device autonomous, along with improving the organization of the circuitry. We would also try to cut down on the weight of the prototype and record flight data.

7.3 Team Organization

Were team members' skills complementary? Are there additional skills that would have benefited this project?

- Our team's skills were fairly complementary with some of us being more proficient with things like 3D printing while others were better with the wiring and circuitry. This worked out because we could divide up the work based on what different people already knew how to do. It would have been nice to have some information on building circuit boards in order to remove the need for the bread board.

Does this design experience inspire your group to attempt other design projects? If so, what type of projects?

- This experience has gotten some of us interested in trying to design a device for the ARLISS 350ml class competition. We're going to be meeting with Dr. Potter to explore the possibility of doing so next semester.

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