Pitt

ROCKETRY TEAM

PER ARDUA AD ASTRA

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Preliminary Design Report
NASA Student Launch 2018-2019
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1 Summary

1.1 Team Summary

The University of Pittsburgh's Rocketry Team, or the Pitt Rocketry Team (PRT) consists of approximately 50 members that contribute to one of four sub-teams: systems, mechanical, avionics, and payload. Team members either build and design the rocket or rover, control the on-board electronics, or manage the team's finances, logistics, and community presence. To aid students the team is working with Tripoli Pittsburgh, TRA Prefecture #001, and Pittsburgh Space Command, NAR Chapter #473. The Pitt Rocketry Team can be contacted at 3700 O'Hara St, Pittsburgh, PA 15213.

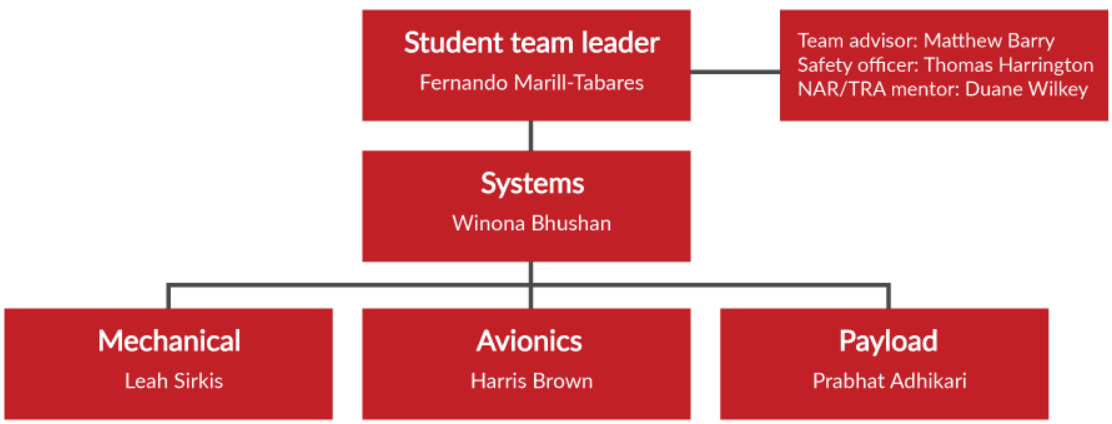


Figure 1.1a: Team Organization.

Name	Team Role	Contact Information	Additional Information
Professor Matthew Barry	Team Advisor	mmb49@pitt.edu	(412) 624-9031
Fernando Marill-Tabares	Student Team Leader	fjm17@pitt.edu	(412) 313-1133
Thomas Sullivan Harrington	Safety Officer	tsdh25@pitt.edu	N/A
Duane Wilkey	NAR Mentor	duane@velocity.net	NAR Level 3 #6342

Table 1.1b: Important Contact Information.

1.2 Launch Vehicle Summary

Title: **PRT-1**

Mass	Length	Diameter	Motor choice	Target altitude	Recovery system
18.5 lbs	95in	4in	CTI P54 K570 Classic	4750 ft	Dual deploy

Table 1.2: Launch Vehicle Summary.

1.3 Payload Summary:

Title: **WALL-E**

Experiment: Autonomously travel at least 10 feet away from the launch vehicle and collect 10 mL of soil.

2 Changes Made Since Proposal

2.1 Changes Made to Vehicle Criteria

Mechanical	
Change:	**Reason:**
Motor choice changed from Cesaroni Pro54 K590-15A to Cesaroni P54-5G Classic (K570)	After updating our mass estimate, we found that the K590 motor provided more thrust than we needed to reach our goal apogee
Fin shape changed from Trapezoidal to Clipped Delta	We want the ability to angle our fin; this can be more easily done if the fins have a clipped delta shape

Table 2.1a.

Avionics	
Change:	**Reason:**
Gyroscope and accelerometer removed from avionics bay	Mechanical subteam no longer requires data logs for orientation and acceleration during flight, recovery altimeter logging will suffice
Only one GPS unit will be used on the rocket in addition to the GPS unit in payload	The PDR Q&A session hosted by NASA clarified the amount of required GPS units

Table 2.1b.

2.2 Changes Made to Payload Criteria

Payload	
Change:	**Reason:**
Rover retention and deployment mechanism changed from springs to a powered threaded rod	An off-axis threaded rod design provides better retention, stability and reliability during launch and deployment
Soil collection mechanism changed from robotic arm to integrated wheel-scoop design	Simpler and more reliable, easier to prototype and test using 3D printing

Table 2.2.

2.3 Changes Made to Project Plan

Change:	Reason:
Timelines for design and fabrication teams were reworked	Gantt charts were suggested for the PDR and the proposal timeline was deemed an inefficient summary of the project

Table 2.3.

3 Vehicle Criteria

3.1 Mission Statement and Success Criteria

3.1.1 Mission Statement

PRT's launch vehicle will fly to an apogee of 4,750 feet while carrying a rover payload, safely land, and deploy a rover that achieves the tasks specified in the NASA SL Handbook. Through the research, design, and fabrication of our rocket, we will learn the art of rocketry teamwork.

3.1.2 Success Criteria

PRT will meet all the success criteria stated in the NASA SL 2018-2019 handbook. To achieve this, PRT's launch vehicle will be ready for launch and able to stay on the launch pad fully functioning for 2 hours on launch day. A 12V direct current will be able to ignite the motor for launch without any outside circuitry. The motor selected will be commercially available and able to use ammonium perchlorate composite propellant (APCP) with an impulse less than 5120 Ns. Our launch vehicle will have a stability margin of greater than 2 and accelerate to greater than 52 fps at the point of rail exit. PRT's rocket will fly to an apogee of 4750ft through the use of a single stage launch vehicle. PRT's launch vehicle will be recoverable and reusable through careful design. The launch vehicle design will include less than 4 separate sections with couplers and shoulders at least one body diameter in length. A subscale version of PRT's rocket will be created and launched.

3.2 Selection, Design, and Rationale of Launch Vehicle

3.2.1 Vehicle Body Design Review

As a first year team, we do not yet have the resources to manufacture our own air frame. Therefore, we have chosen to use and modify the Wildman Darkstar Extreme air frame for our launch vehicle. This kit uses a 94 inch airframe with spiral wound G12 Fiberglass as the material. This particular kit was chosen because G12 Fiberglass is a lightweight, strong material. Carbon fiber bodies were also considered. As illustrated in table 3.2.1a below, carbon fiber is stronger than fiberglass, but significantly more expensive, so ultimately the fiberglass kit was chosen.

Fiberglass	**Carbon Fiber**
Price: 24.3-34.4 USD/kg	*Price*: 37.4-41.6 USD/kg
Strength: 138-241 MPa (T) 128-207 MPa (C)	*Strength*: 550-1050 MPa (T) 440-840 MPa (C)

Table 3.2.1a.

The dimensions of each piece of the rocket were measured in order to: 1. Satisfy NASA's requirements, and 2. Purchase the correct-sized parts. These dimensions (in mm) can be seen below in the following figures, which were taken from a SolidWorks Drawing. The mass of each component was also calculated and can be seen in Tables 3.2.1g.

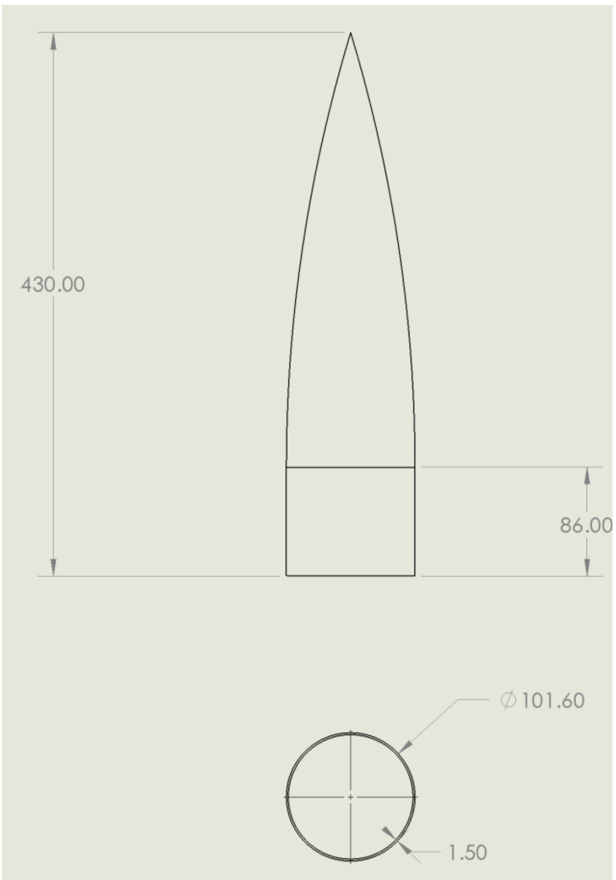


Figure 3.2.1b: Nosecone

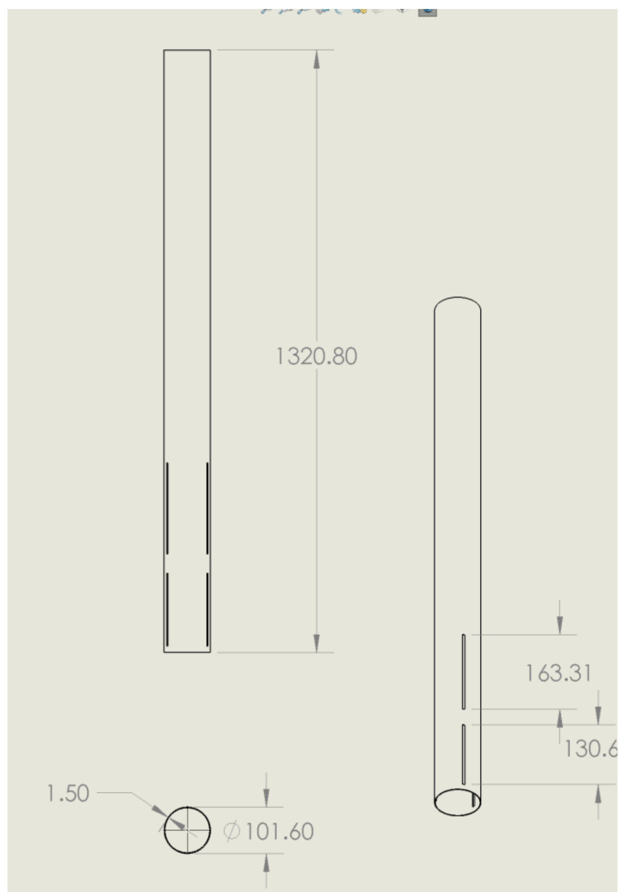


Figure 3.2.1c: Booster

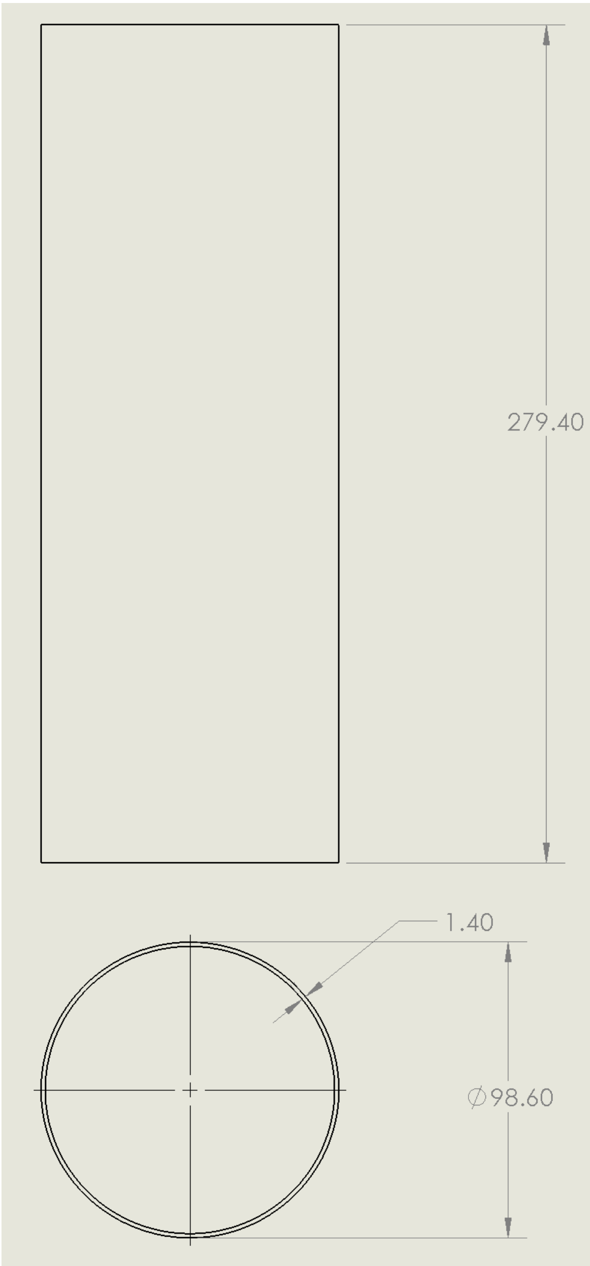


Figure 3.2.1d: Coupler

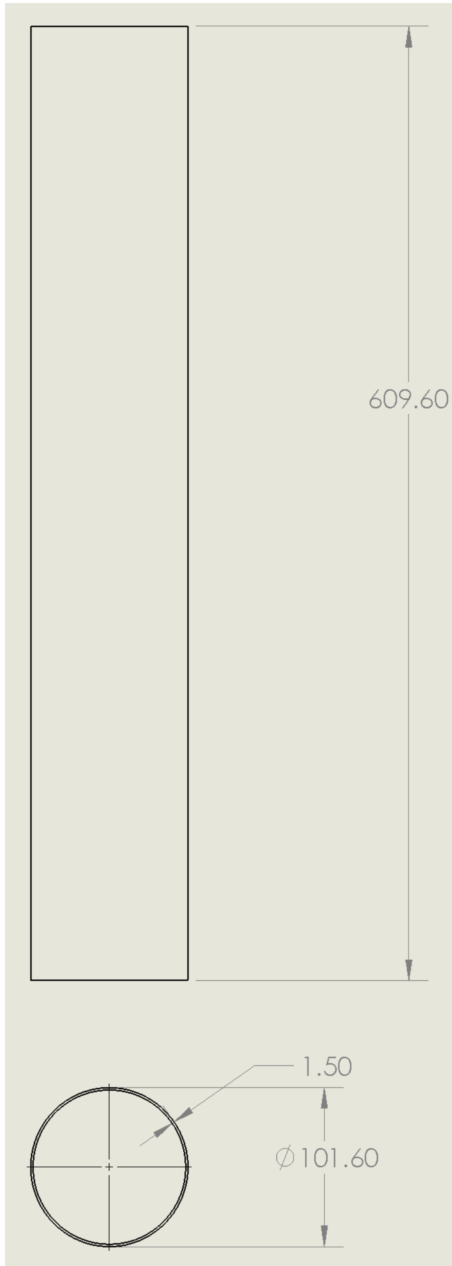


Figure 3.2.1e: Payload Section

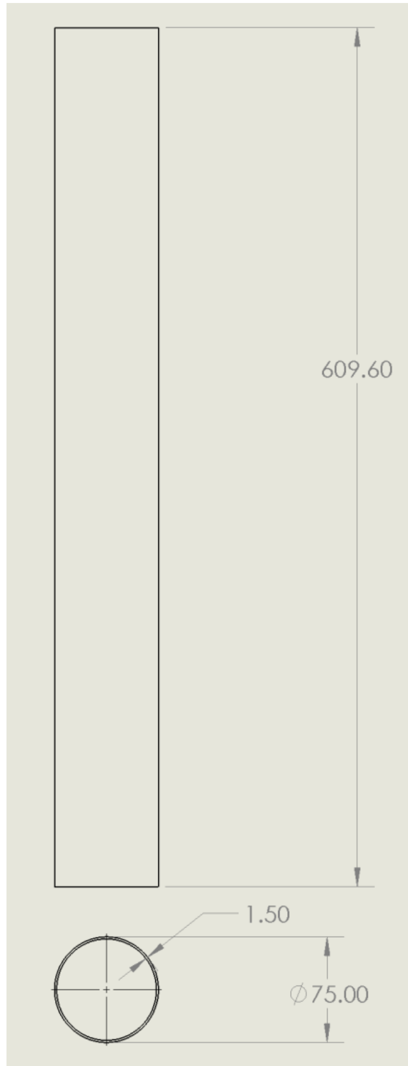


Figure 3.2.1f: Motor Mount

	Booster	Payload Section	Motor Mount	Coupler	Nosecone
Mass [g]	1284	499	367	337	353

Table 3.2.1g: Mass of each part of the rocket.

3.2.2 Fin Design Review

The fins lower the center of pressure in order to keep the rocket upright during flight. The fins also counteract any non-parallel forces during flight with a corrective lift force. This creates a system where the rocket will automatically correct itself to the proper orientation.

Because the center of pressure depends on cross-sectional area and not fin shape, any shape will work provided it has enough area. However, for aerodynamic purposes, some fins are better suited than others. The decision making process is as follows in table 3.2.2. Note that the qualitative representation of the colors in all forthcoming decision matrices are outlined within the appendix of this report in section 7.2.

Criteria	Trapezoidal	Clipped Delta	Elliptical	Rectangular
Aerodynamic (60%)	9	9	10	4
Ease of Manufacturing (10%)	8	8	4	10
Durability (30%)	8	8	7	6
Total	8.6	8.6	8.5	5.2

*Assumes all fins are of equal surface area and made of the same material

Table 3.2.2: Decision Matrix Results with Scoring Breakdown of the Fin Design.

Each criteria was given a weight based on its importance to the mission. Aerodynamics is most important, however durability was a large concern as well because the rocket must be relaunched, and therefore cannot sustain damage upon landing. Ease of manufacturing was the least important, but still factored into our decision making process. In the end, we tied between trapezoidal shaped wings and clipped delta wings.

In addition to the fin shape, we have decided to angle our fins slightly. This is done primarily for two reasons. Angled fins increase stability due to rotation and conservation of angular momentum. This is very important to the flight of our rocket because without enough stability it may deviate from the planned course or crash.

Angled fins also give us a way of controlling the final altitude of the rocket. Because of the angle, a component of the thrust from the motors goes into making the fins spin. Therefore, we can angle the fins in such a way to limit the amount of vertical thrust, allowing us to reach a specific altitude. For this reason, the clipped delta wings are the best option for our fins, as they are most easy to angle.

The dimensions of the fins must satisfy a 2.0 static margin. This is defined as 2 diameter's length separation between the center of mass and center of pressure. The static margin is for the current fins are given by the following equation and modeling in OpenRocket:

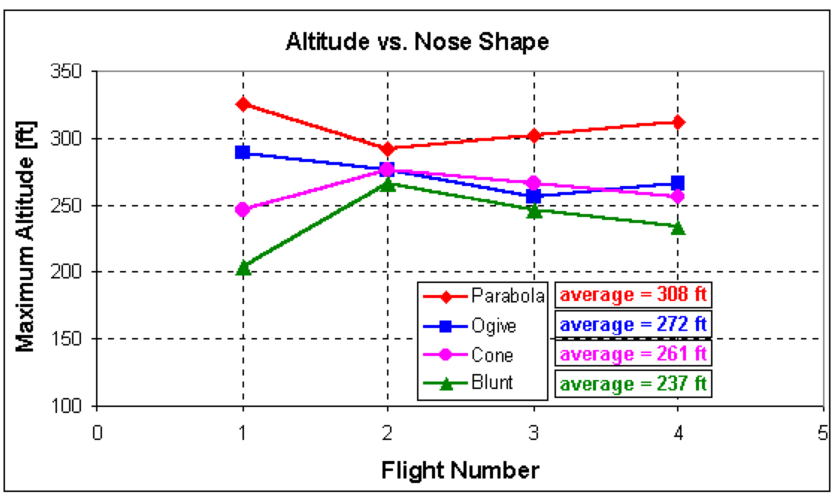
$$\frac{(CP - CG)}{d} = \frac{(197 - 149)}{10.16} = 4.7$$

3.2.3 Nose Cone Design Review

PRT looked into many different possible nose cone shapes, and ultimately decided to use a fiberglass Von Karman Ogive (LD-Haack) nose cone with an aluminum tip.

Nose Cone Shape:

For subsonic high speeds, the top nose cone options that provide low coefficients of drag include Parabolic, Cone, and Von Karman (Ogive). We have been provided with a Von Karman nose cone with our airframe, so the Von Karman shape is the most cost effective option. The performance of different nose cone shapes on the same rocket type were tested by AeroSpaceWeb, and the data is shown in figure 3.2.3 below:



Altitudes achieved using different nose shapes on the same rocket

Figure 3.2.3.

From the chart above, we can see that the parabolic nose cone shape allows the rocket to reach the highest altitude of all the shapes tested, so it is the most efficient option. The ogive shape has the second highest average altitude, but also is the most cost effective and easiest to manufacture since we already have this nose cone and therefore do not need to purchase or manufacture it. We have chosen the Von Karman nose cone shape because it has a low coefficient of drag while also being cost effective, as it is provided with our air frame.

Material Selection:

We have chosen a fiberglass nose cone to maintain the same material as the airframe for ease of use. We have selected a nose cone with an aluminum tip to give the tip extra strength so that if it hits the side of the airframe or ground the tip is not damaged. We considered using a nose cone without an aluminum tip, as it would be lighter, but the extra strength provided by the aluminum tip is important to ensuring our rocket is durable enough to be reusable.

3.2.4 Motor Selection and Retention System Design Review

Motor Selection:

We have selected the Cesaroni Technologies P54 K570 Classic Reusable Motor. This has changed from our original decision of a Cesaroni Technologies Pro54 2398K590-15A motor chosen in our proposal. We chose Cesaroni Technologies as the company for our motor because their motors are readily available, come in many sizes, and in our simulations have held up better under strong wind conditions than other motor brands. We chose a reusable rocket because while single use motors would make motor mounting easier, the single use motors are more expensive based on the number of times we plan to launch our rocket. Different CTI rockets that we looked at include:

CTI Pro54 K570
CTI Pro54 K600
CTI Pro54 K1200

We eliminated the K600 motor because it brings our rocket to an apogee that is too high given our current mass, even with full ballast. The K1200 motor brought our rocket to the right apogee, but was eventually eliminated because the K570 motor brought our rocket to the same apogee while having a much longer burn time than the K1200 with similar impulse. The K570 motor has an acceleration of 83 m/s^2 while the K1200 has an acceleration of 140m/s^2. The K570 acceleration provides more than enough velocity at rail exit to be stable, but puts less stress on the rocket components than the K1200. Therefore, the CTI P54 K570 motor was chosen as the best option.

Motor Retention:

The motor retention system, or motor retainer, of our rocket design was carefully chosen based on three main factors: cost, weight, and ease of application. Each of these factors was given a weighted percentage to quantitatively define its importance. The most important factor was the weight of the motor retainer, with a value of 50%. This was given highest priority because it's essential to not overload the rocket with excess weight. Next highest was the cost, with a value of 30%. This was ranked second because it is not ideal to spend more than necessary on our final design. Lastly was the ease of application, at 20%. This was given its value because it was assumed prior to the purchase that the method to apply would be done with ease.

The weighted importance of the three criteria were applied to three different manufacturers' motor retainers: Apogee Components, Rocketarium.com, and Giant Leap Rocketry. The results and how the importance of factor affected each motor retainer can be seen below in Table 3.2.4:

Criteria	Apogee Rockets	Rocketarium	Giant Leap Rocketry
Weight (50%)	9	6	4
Cost (30%)	5	7	9
Ease of Application (20%)	10	10	6
Total	8.0	7.1	5.9

Table 3.2.4: Results from Decision Matrix of Motor Retainer along with Weighted Percentages and Scoring Breakdown.

Based on the decision matrix, it was was concluded that the 75mm motor retainer from Apogee Rockets is the best option for our rocket because it has the highest total weighted score. While it is the most expensive of the three and it has the same method of applying it to the rocket, the weight played the largest role in the final calculation because it held the lightest weight.
Since the motor mount sections of the rocket (75mm) is larger than the diameter of the chosen rocket (54mm), a motor adapter must be used. The Aeropak 54/75mm Motor Adapter was chosen from Apogee Rockets.

The centering rings, which act as a complement to the motor retention system, are fiberglass centering rings that were included with our rocket kit. We looked at options such as plywood and fiberglass as centering ring materials but we decided that the centering rings provided with our kit are the best option based on the criteria of strength, cost, ease of manufacturing, and mass. They were premade and provide a perfect-fit inside the 75mm tube. These will be used to maintain the motor retainer's position in the appropriate tube and transfer force from the motor to the airframe, which will ultimately allow the motor itself to be remain stationary as needed in our design.

3.2.5 Avionics Bay System Design Review

After carefully reviewing all avionics bay construction methods and commercially available avionics bays, we have determined that manufacturing our own with 3D printing is the optimal solution. The ability to construct an avionics bay specific to our components is crucial in the decision. This will eliminate any wasted space within the avionics bay, reducing its mass. This mass can then be allocated to other areas of the vehicle which may need the added mass allotment to meet their design requirements.

Furthermore, 3D printing permits us to design an avionics bay using geometries that would otherwise be impossible for us to achieve using the more traditional construction methods and materials that we have available to us. Another added benefit to 3D printing our bay is that we can make changes to the design and simply print a new one with minimal effort. This greatly speeds up the prototyping process as compared with typical manufacturing methods. While the print itself may take longer to complete than various other methods, it can be printed while the designer is working on other tasks, thus freeing up a substantial amount of manpower that typically would be lost to manufacturing.

Table 3.2.5a depicts the decision matrix that concludes that a 3D printed avionics bay, produced using NylonX filament, is the ideal solution to our problem. Table 3.2.5b is a compilation of all the material properties used to determine the values assigned to each material for the categories of the decision matrix. This particular filament was chosen based off of its high strength to weight ratio, combined with its ease of manufacturing and its moderate cost. For this matrix, density was assigned the highest weight due to the need to reduce the mass of the avionics bay as compared to commercially available options while achieving a similar or higher level of strength. Even though wood was the clear winner in the density department and has been used successfully for years in commercially available units, it leaves much to be desired in the strength category. This realization lead us to believe we could substantially reduce the mass of this assembly by using a material with a higher density, but with better strength characteristics. Since NylonX has an ultimate tensile strength that is approximately three times higher than that of plywood (14,500 psi vs. 5,000 psi) and a density that is double (1200 kg/m^3 compared to 600 kg/m^3) we feel we can design a more trim avionics bay while actually improving the strength of the design.

For our overall design, we have considered using threaded rods, but ultimately decided on a design that does not require threaded rods. Threaded rods running through the avionics bay provide strength to prevent flexural and tensile strain, but are very massive. The NylonX 3D printing material is strong enough to withstand the forces on the avionics bay to minimize flexural and tensile strain, while minimizing mass by eliminating threaded rods.

In order to exclude the threaded rods from our design and still maintain the ability to remove our avionics bay from the vehicle body, we will print the board and one of the bulkheads as a single unit. The side of the board not permanently attached to the bulkhead will have a flared base with a total of four (two on either side) holes to accommodate small nuts receiving bolts passing through the fixed bulkhead. The nuts will be epoxied in place to prevent them from falling out while the bolts are being tightened. The second bulkhead will be printed separately and contain a series of through holes which will match the the hole pattern of the board.

		Density	Strength	Ease of Manufacturing	Cost	Total
	Wood	10	2	10	10	7.6
	Aluminum	3	10	3	9	6
3-D Printed Filaments	ABS	9	5	8	9	7.65
	Polycarbonate	8	9.5	5	8	8
	Nylon	7.5	8	8	8	7.8
	NylonX	8.5	9	9	6	8.35
	PLA	8	7	8	9	7.85

Table 3.2.5a: Decision matrix for possible materials for avionics bay construction and each categories assigned weight.

	Ultimate tensile strength (MPA/psi)		Yield Strength (MPA/psi)		Density (kg/m^3)
Plywood	Na	Na	13.8	2001	600
aluminum	310	44961	270	39160	2700
ABS	46	6671	42	6091	1010
Polycarbonate	70	10152	59	8557	1300
Nylon	76	11022	45	6526	1700
NylonX	100	14503	NA	NA	1300
PLA	60	8702	NA	NA	1250

Table 3.2.5b: Material Properties for all of the materials considered for the avionics bay.

3.3 Avionics System Design

3.3.1 Objectives

The rocket's avionics can be split into two systems: the recovery avionics system and the main avionics system. The recovery avionics system is entirely independent from the main avionics system and is discussed in the following section. Its purpose is to ensure the safe recovery of the rocket following apogee. The main avionics system is comprised of the onboard and ground avionics systems. The purpose of the main avionics system is to locate the rocket after landing and to deploy the rover following a successful landing. Both the main avionics system and the recovery avionics system log all data collected from the GPS unit and altimeters for use in both competition judging and future analysis.

3.3.2 Success Criteria

The avionics system will be considered successful if the rocket is successfully recovered. The recovery avionics system must ensure that the rocket makes a safe descent following apogee and the main avionics system must ensure that the rocket is located following landing. The recovery avionics system must fire ejection charges at the correct time to deploy the drogue and parachute. The main avionics system must transmit GPS coordinates to the ground system so the rocket can be found following landing. The main avionics system must also release the rover when commanded to do so.

3.3.3 Design Alternatives

Figure 3.3.3a demonstrates the block diagram for the entire avionics system including the main avionics system, the avionics recovery system, and the avionics ground system.

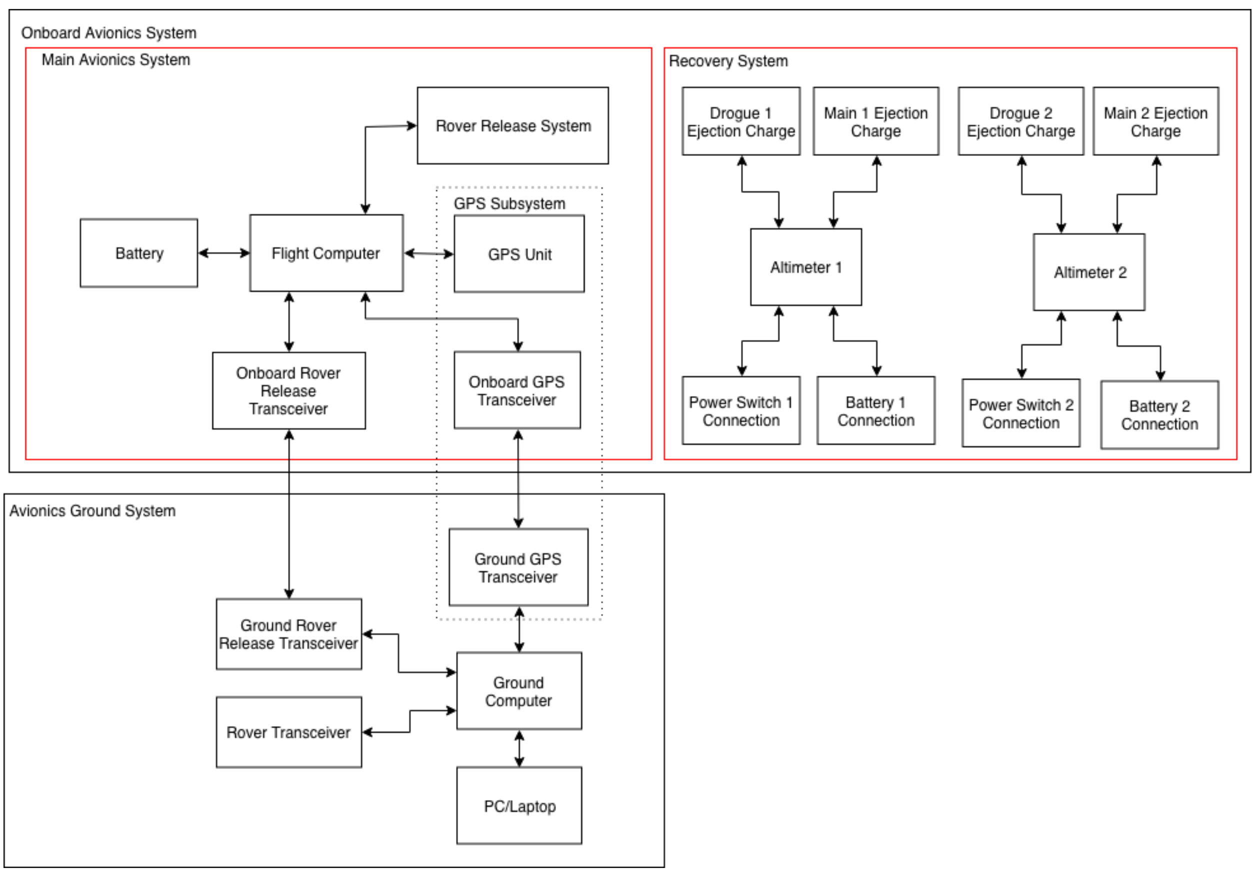


Figure 3.3.3a: The block diagram for the avionics system.

The first constraint the block diagram captures is the independence of the avionics recovery system from the main avionics system as per the Student Launch Handbook. The second constraint is the requirement that the vehicle must transmit GPS data to the ground system. The third constraint is that the main avionics system be able to send a signal to deploy the rover upon receiving a command from the ground system. With these three constraints captured, the block diagram was used to derive a network diagram for the main avionics system. Due to the simplicity of the design of the main avionics system, once the block diagram was created there were three design decisions to make. The first design decision was whether to have two separate transceiver pairs (one of the rover release command and one for GPS telemetry) or one transceiver pair with a custom data framing scheme to determine whether telemetry received is for the rover release system or for the GPS system. These two network design options are shown in Figure 3.3.3b.

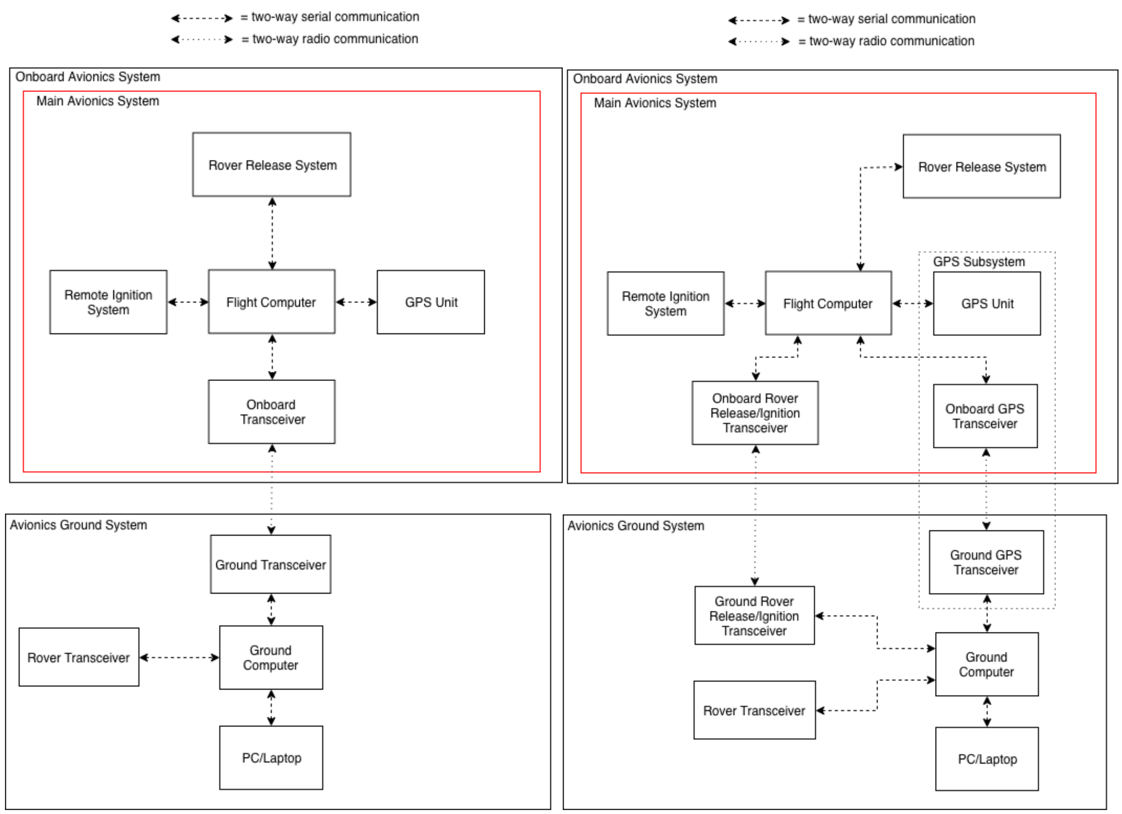


Figure 3.3.3b: Network diagram with one transceiver pair (left) and two transceiver pairs (right).

The two-transceiver-pair design was ultimately chosen for two reasons. The first is to minimize data framing complexity. There were concerns that if the data framing scheme somehow failed that this could result in either the rover not being released or the GPS data being corrupted, both of which are unacceptable. The second reason is because the transceivers that were ultimately chosen in the design (HC-12 transceivers) are very inexpensive. The cost of doubling the number of transceivers in the system is minimal compared to the risks to both the rover deployment and GPS functionality incurred with designing a single transceiver pair system. The risk incurred with this design, however, is that the two transceiver pairs could interfere with each other. This was deemed a more avoidable risk than that imposed by the complexity of the single transceiver pair system because the transceivers will already be RFI-shielded.

The second design decision was whether or not to have an altimeter in the main avionics system. At first, the team was interested in having the main flight computer log both GPS data and altimetry data to a dedicated non-volatile data logger. As a first year team, any data we can collect from each launch is extremely valuable. However, in making component decisions, it was discovered that both the GPS unit (the Adafruit Ultimate GPS Breakout) and the altimeter (the StratologgerCF) chosen have built-in logging functionality. For this reason, it was decided that it is sufficient to use each device's built-in logging functionality and therefore having an additional altimeter and a dedicated logger in the main avionics system is unnecessary.

Another decision the team faced was whether or not to rely on the GPS unit in the rover as the primary GPS for the entire vehicle. While this would reduce the number of GPS units required and therefore the overall cost of the vehicle, it was decided that it is bad practice to rely on the performance of a non-critical component (namely, the payload) for such critical functionality as the ability to locate the rocket after landing. If something were to happen to cause the rover to fail it would adversely affect not only the rover's operation but the ability to track the rocket after landing. For this reason, the main avionics system has its own GPS unit.

Once these decisions were finalized, a wiring diagram for testing purposes, shown in figure 3.3.3c, was created.

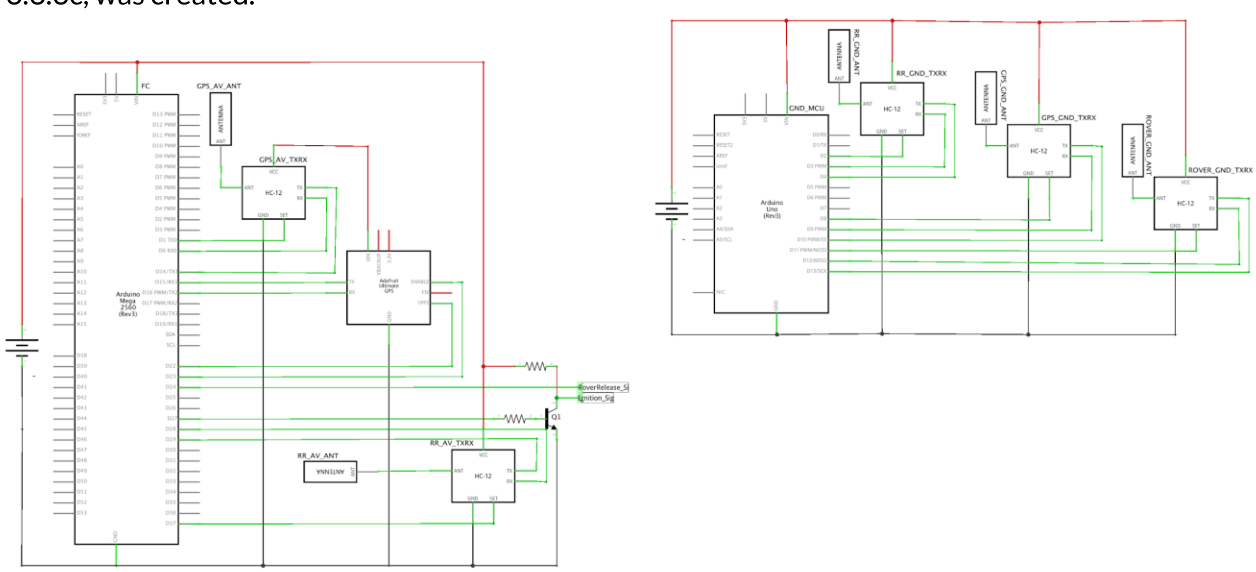


Figure 3.3.3c: The wiring diagrams for the onboard main avionics system (left) and the ground system (right) with the main avionics system in its test configuration with an Arduino Mega instead of a Teensy 3.6.

3.3.4 GPS Subsystem

Criteria	Eggfinder GPS Tracking System	BigRedBee Beeline 70 cm GPS	Custom GPS unit from Adafruit Ultimate GPS
Cost (40%)	6	2	9
Position Accuracy (40%)	3	5	7
Ease of Use (20%)	6	8	4
Total	4.8	4.4	7.2

Table 3.3.4a: GPS unit decision matrix.

When selecting a GPS system, two different approaches were considered: purchasing a complete GPS-radio system or designing and building our own GPS system. As research on viable GPS systems progressed, it became clear that most COTS GPS systems are very expensive. Even the Eggfinder, the least expensive system available, costs $100 and requires surface mount soldering to assemble the board. Without sufficient technical expertise in surface mount soldering, this option is not favorable which is reflected in its low “Ease of Use” score. Another option considered, the BigRedBee Beeline 70 cm GPS, appears from component research to be a very popular option for both model and high power rockets. The price of the BigRedBee Beeline 70 cm GPS, however, is entirely prohibitive; the lowest price found was $259 which is far more than the team is willing to spend. After much consideration, the team came to the conclusion that the best option was to design and build a custom GPS system. A detailed comparison of these GPS systems is shown in Table 3.3.4b.

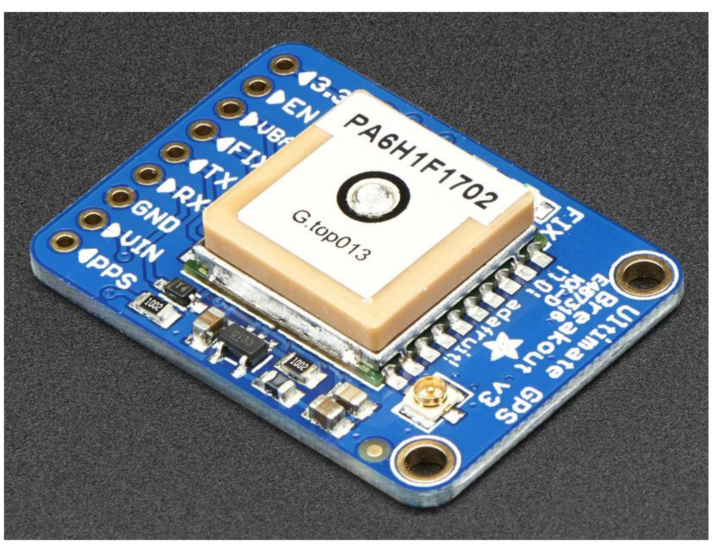


Figure 3.3.4a: Adafruit GPS breakout board.

Manufacturer & Model	**Eggfinder GPS Tracking System**	**BigRedBee Beeline 70 cm GPS**	**Custom GPS Unit (Adafruit Ultimate GPS + HC-12 Transceivers)**
Cost	$100	$259	~$60-$80
HAM License Required?	No	Yes	Yes
Transmitter Power	100 mW	100 mW	100 mW
Mass of onboard component (excluding battery)	25 g	55 g	~10 g - 20 g
Min. tube size	24 mm	38 mm	24 mm
Position Accuracy	2.5 m	2.5 m	1.8 m
Frequency	900 MHz	440 MHz	440 MHz
Transceiver Range	~3 km	> 64 km in air	1 km in FU3 mode; 1.8 km in FU 4 mode
RX/TX included?	Yes	Extra $26 for TX/RX	N/A
Antenna?	Integrated; ¼ wave "stick" antenna included but extendable	Integrated	Non-integrated; flexible
GPS data format?	NMEA	NMEA	NMEA
TX/RX packet format?	APRS data format	APRS data format	Flexible
Misc. info	Comes as a kit; requires SMD soldering		Requires more engineering effort

Table 3.3.4b: Detailed comparison of GPS options; green label indicates a favorable aspect, red label indicates an unfavorable aspect.

The custom GPS system consists of a ground component and an onboard component. The ground component is comprised of a transceiver with an antenna connected to a microcontroller connected to a laptop so GPS data can be received to the ground station for vehicle recovery. The onboard component is comprised of a transceiver with an antenna connected to a microcontroller which is in turn connected to a GPS breakout. To design the GPS system, two new components needed to be chosen: a transceiver and a GPS breakout board. Ultimately, due to familiarity with these components, the 443MHz HC-12 Wireless Serial Port Communication Module transceiver and the Adafruit Ultimate GPS Breakout were chosen.

There were several considerations made when choosing the HC-12 transceiver. A comparison of various other transceivers considered are shown below in Table 3.3.4c.

Model & Manufacturer	**HC-12 Wireless Serial Port Communication Module**	**XBee-PRO 900HP**	**Adafruit RFM95W LoRa Radio Transceiver Breakout**	**Digi XBee S2C Digimesh 2.4**
Cost	$6	$39	$19.95	$17.50
Mass	2 grams	3.91 grams	3.1 grams	2.7 grams
Maximum power during transmission	100 mW	100 mW	100 mW	63 mW
Max range (assuming lowest baud rate and best antenna)	1 km (FU3 mode); 1.8 km (FU4 mode)	Up to 45 km	Up to 20 km	Up to 3.2 km(Outdoor RF line-of-sight range)
Operating frequency	433.4 MHz to 473.0 MHz	902 MHz to 928 MHz	868 MHz or 915 MHz	2.4 GHz
Expected operating baud rate	1.2 kbps (FU4 mode)	Up to 200 kbps	Up to 300 kbps	115 kbps
Supply voltage	3.2 V to 5.5 VDC	2.1 V to 3.6 V VDC	1.8 V to 3.7 V	2.1 to 3.6V
Quality of documentation	Fair	Fair	Fair	Poor

Table 3.3.4c: Comparison of transceivers for use in GPS system.

The HC-12 transceiver is the choice we made as the low mass and cost are favorable to get it working in the initial test phases. While the HC-12 has a few drawbacks compared to its more expensive contemporaries, it should still prove suitable for our specific needs. In the situation that the HC-12 fails to achieve its purpose, we will instead opt for a more expensive transceiver in its place.

The first consideration is that because the HC-12 transceiver operate in the 433.4 MHz to 473 MHz frequency band (which falls within the 70 cm HAM band), we had to ensure that at least one member of the team has the necessary HAM Technician's license to operate the transceivers. Fortunately, this turned out to be trivial since a team member does have a HAM Technician's license. The second consideration is related to the range of the HC-12 transceiver. Without any modifications, the base range of the transceiver is 1 kilometer (about 3280 feet) which posed some concerns considering our target apogee is 4750 feet and the the recovery area is limited to a 2500 foot range from the launch pads. Without extending the range of the transceivers, they are guaranteed to disconnect prior to achieving apogee. This means two different problems need to be tackled: first, the range of the transceivers needs to be extended; second, the transceivers will need to be able to reconnect if and when they disconnect. Since the recovery area is within the transceiver base range, as long as the transceivers can reconnect upon landing, there will be no problems recovering the vehicle. Upon researching the HC-12 transceiver further, it was discovered that the transceiver actually has an FU4 mode which supports a 1200 bps baud rate at a 1.8 kilometer (about 5900 foot) range. Since this mode's range exceeds our target apogee and the low baud rate is sufficient for transmitting GPS data (capable of transmitting 60-byte packets with a minimum transmission time interval of at least 2 seconds), this option adequately addresses this consideration.

Figure 3.3.4b: The HC-12 transceiver unit.

The next consideration in designing the custom GPS system is choosing a suitable antenna for the transceivers. Ultimately, the SMAKN 433MHz 11 cm Omnidirectional Antenna was chosen.

Yet another consideration in designing the custom GPS system was whether to have the HC-12 transceiver pairs perform a handshake transmission to initiate data transmission or frequency hopping. Both handshaking and frequency hopping can be used to resist interference and make data transmissions more difficult to intercept. However, since the transceivers already pair using handshaking, it was decided that handshaking will be used to initiate data transmission.

The final consideration in designing the custom GPS system was which antenna to choose. The HC-12 transceivers chosen can accommodate a number of different kinds of antennae. While the module has a PCB antenna pedestal, it can also accommodate an external 433 MHz frequency band antenna. While the standard configuration of the HC-12 transceiver only contains the communication module and the aforementioned standard RF socket, there's an additional option to purchase a 433 MHz frequency band spring antenna and matching 433 MHz omni-directional rubber antenna. Upon researching external antennae for the HC-12, four options emerged: the 237-SREI038-S9P, the SMA Male Straight Rubber Duck, the SMAKN 433MHz 11 cm Omnidirectional Antenna, and the ISM 433 MHz Helical Antenna. A decision matrix for these antennae is shown in Table 4.4.3d.

Criteria	237-SREI038-S9P	SMA Male Straight Rubber Duck	SMAKN 433MHz 11 cm Omnidirectional Antenna	ISM 433 MHz Helical Antenna
Cost (30%)	8	5	8	2
Gain (40%)	6	7	7	4
Weight (20%)	2	4	3	8
Versatility (10%)	7	6	4	2
Total	5.9	5.7	6.2	4

Table 3.3.4d: Antenna decision matrix.

Figure 3.3.4c: SMAKN 433MHz 11 cm Omnidirectional antenna.

A more detailed overview of the pros and cons of each antenna is shown in figure 3.3.4h.

Manufacturer & Model	237-SREI038-S9P	SMA Male Straight Rubber Duck	SMAKN 433MHz 11 cm Omnidirectional Antenna	ISM 433 MHz Helical Antenna
Cost	$10.11	$6.00	$5.60	$1.68
Gain	-2.90 dBi	3 dBi	3 dBi	-2.90 dBi
Mass	21 g	4.5 grams	9.07 grams	1.8 grams
Frequency	432-434 MHz	400-450 MHz	NA	433-435 MHz
VSWR	1.65	1.5	1.5	1.5
Impedance (Ohms)	50	50	50	50

Figure 3.3.4e: Comparison of antennae considered for the GPS system.nnn

3.3.5 Main Control Unit

Criteria	Teensy 3.6	Raspberry Pi 3 – Model B+	Texas Instruments TI MSP430
Capabilities (25%)	7	9	7
Ease of Use (25%)	9	6	3
Dimensions (20%)	9	7	3
Power Usage (15%)	9	4	9
Cost (15%)	8	7	9
Total	8.35	7.2	5.8

Table 3.3.5a: Decision matrix comparing main control unit candidates.

Figure 3.3.5a: A Teensy 3.6 microcontroller.

The most important factor when deciding which main control unit (MCU) to use for the launch vehicle was its capabilities. The device we picked ultimately had to be capable of interpreting all of the data from the individual sensors the launch vehicle was utilizing. Additionally, the ability to do floating point calculations with values from sensors such as the altimeter could prove to be useful. With all this in mind, it was decided that a microcontroller would satisfy all the requirements and a full computer would not be necessary. This made any Raspberry Pi model less attractive than other MCU options. Although they are much more powerful than any microcontroller, they are bulkier in design and more difficult to use.

The Teensy 3.6 is the best microcontroller choice as it meets all the required specifications and is best in terms of ease to program and familiarity. Teensies are similar to Arduinos except they have even more capabilities and are perfect for final products as they can be directly soldered to printed circuit boards (PCB). Arduinos such as the mega will be used for testing all sensors on the launch vehicle, and the Teensy will be on the final product. Teensies run off code from the Arduino IDE just like Arduino microcontrollers, this is much easier to use and setup than other advanced microcontrollers such as those produced by Texas Instruments. Those require more intricate coding and have less accessible example files and documentations. The Teensy 3.6 also had the smallest area and mass of all the microcontrollers that were up for consideration. In the end, the teensy was chosen because of its satisfactory capabilities, familiarity and ease of use, and compact dimensions.

3.4 Recovery Subsystem

3.4.1 Dual-Deploy Recovery System

In order to increase the success rate of our launch vehicle, our team decided to use a dual-deploy recovery system (DRS). The dual-deploy recovery system will require the launch vehicle to release a drogue parachute at apogee to prevent excessive acceleration upon main deployment, while the main parachute will be deployed at a lower altitude to ensure the minimization of kinetic energy and drag upon landing. Two independent sections allowing for separation via two ejection charges will hold the drogue parachute and the main parachute. It is critical that the nose cone air frame and the Avionics bay booster section separate when the two ejection charges go off. The first ejection charge will separate the nose cone air frame releasing the drogue parachute at apogee. The second ejection charge will separate the Avionics bay from the booster section releasing the main parachute at our estimated height of 550 ft.

The nose cone and air frame are tethered together by 1500# Kevlar shock cords to ensure strength in attachment. Both parachutes have Nomex parachute protectors to allow for protection against the hot gasses created by the ejection charge. The main parachute will be held in a deployment bag to ensure for proper release and minimize the chance of entanglement. As a first year team, we will be purchasing Kevlar shock cords, parachutes, and recovery system components (swivels, quick links, etc.) from outside vendors due to the difficulty of fabricating the essential components. For proper deployment of both the drogue and main parachutes, steel quick links, swivels, and eye bolts will be used to prevent tangling and twisting of shock cords and shroud lines.

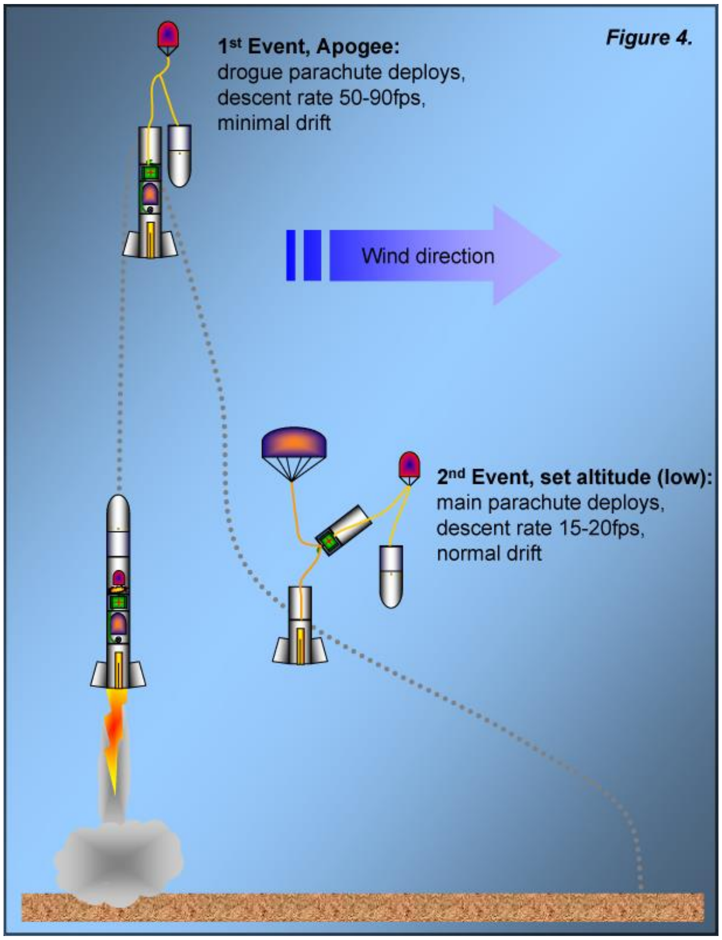


Figure 3.4.1 Plan for descent (courtesy West Rocketry).

3.4.2 Recovery Avionics System

Criteria	StratologgerCF	Adafruit BMP280	Adafruit MPL3115A2	Missleworks Rocket Recovery Controller 3
Cost (10%)	1	8	8	1
Weight (10%)	1	8	9	1
Accuracy (50%)	9	5	5	8
Ease of Programming (30%)	9	3	5	8
Total	7.4	5	5.7	6.6

Table 3.4.2a: Altimeter decision matrix.

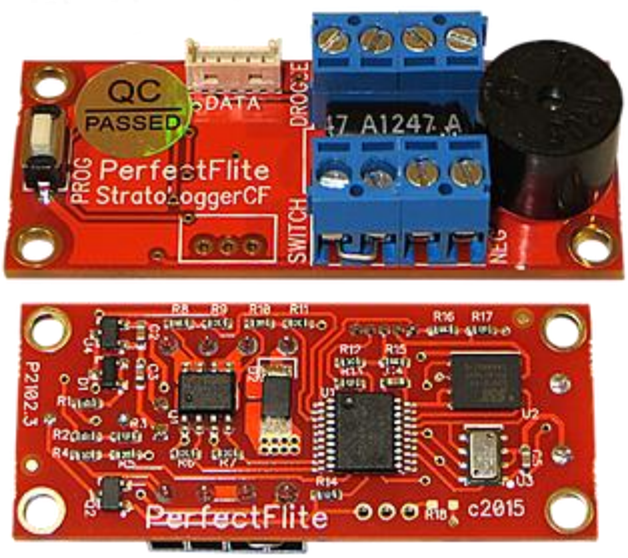


Figure 3.4.2a: StratologgerCF.

Altimeter	Pros	Cons
StratologgerCF	• $54.95 • Wide operating temperature from -40°F to 185°F • Recommended by mentor • Weighs only 10.77282 grams • Stores 16 flights of 18 minutes each • Sample rate is about 20 samples per second for all variables • Operational up to 100,000 feet MSL	• Output current does not exceed 5 A • Quieter post flight locator and siren help locate everything

	• Measures only 2 inches by 0.84 inches by 0.5 inches • The main chute deployment altitude is adjustable by 1 ft increments	
Rocket Recovery Controller 3	• 8 Mbit SST Flash memory • Operational up to 100,000 feet MSL • Output current only to 3 A • The main chute deployment altitude is adjustable by 1 ft increments • Extra-loud 85 dB magnetic buzzer	• $84.62 • High current consumption (6 mA at 9 V) for alternative only (1.5 mA at 9 V) • Weights about 17 grams • Stores 15 flights with 28 minutes each • Only 20 Hz for altitude, velocity and only 1 Hz for temperature, battery voltage • Measures 3.92 inches by 23.5 inches by 0.5 inches

Table 3.4.2b: Pros and cons of considered altimeters designed for dual deploy recovery

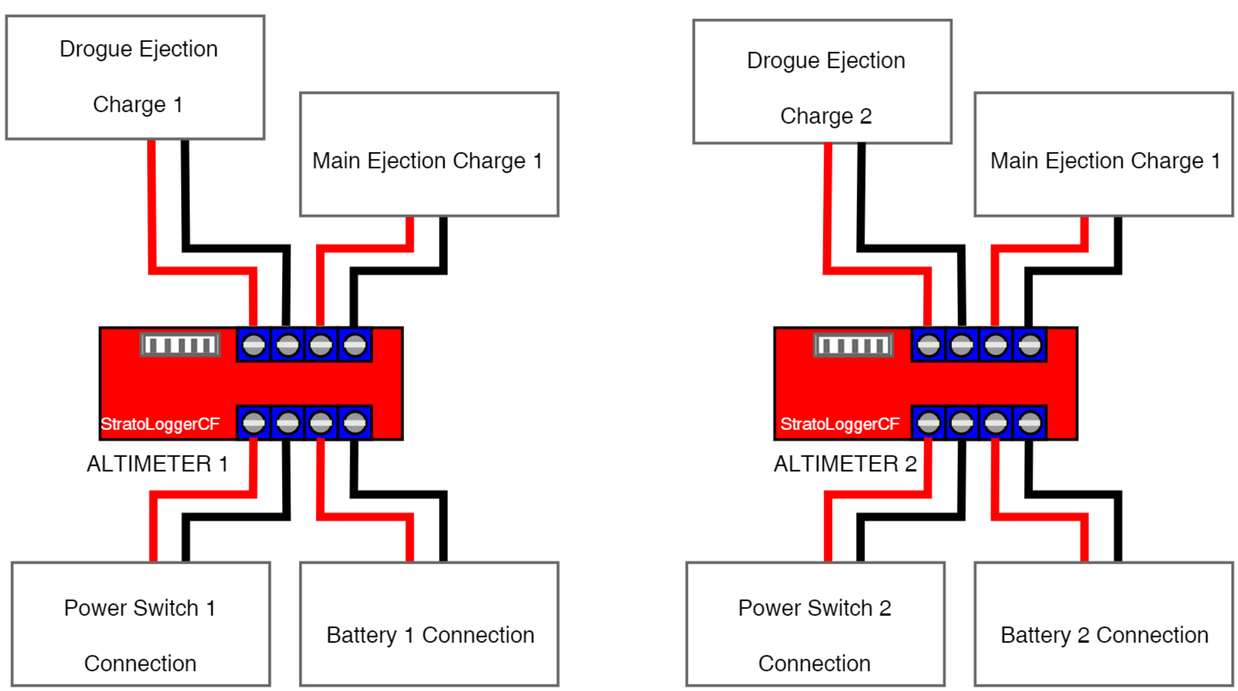


Figure 3.4.2b Redundant recovery system design.

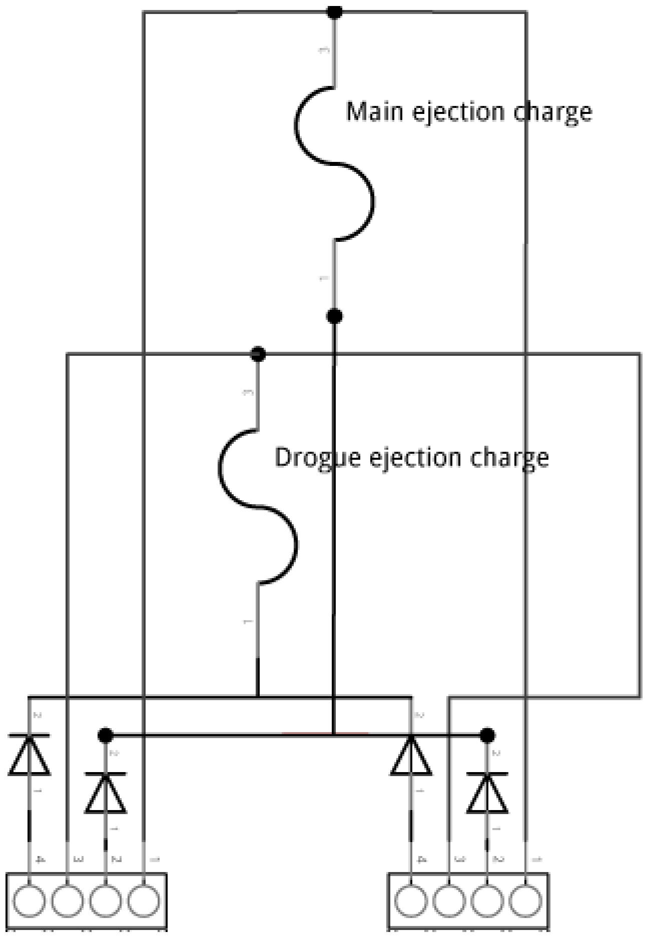


Figure 3.4.2c Wiring diagram for ejection charges.

The StratologgerCF combined altimeter/flight computer was chosen as the altimeter for the avionics recovery system per the justification provided in Table 3.4.2a and Table 3.4.2b. The StratologgerCF altimeter offers capabilities of reading flights up to 100,000 ft MSL. It can log data at a rate of 20 samples per second throughout the flight. This data can be stored and downloaded later on a computer. In addition, it also has the capacity to store up to 16 flights, even when power is removed from the system.

The primary purpose of the altimeters is to deploy the vehicle's drogue and parachute. The altimeters will deploy the drogue parachute no more than two seconds after apogee and the main parachute. The ejection charges are to be lit by electric matches connected to both altimeters. Diodes will restrict current to exclusively flow out of the altimeters to protect them when the match is expended and opens the circuit. This allows the altimeters to operate redundantly while protecting the electronics for reuse.

3.4.3 Parachute Choice

Parachute Location:

The drogue parachute will be placed between the nose cone and the avionics bay. Between the avionics bay and motor mount will be the location of the main parachute.

Main Parachute Selection:

In our current rocket design, we have chosen the Iris Ultra Fruity Main Parachute (72" diameter model). After thorough research for main parachute options, the Iris Ultra Fruity parachute was chosen for many reasons. In our selection process we compared two SkyAngle Classic models of varying dimensions and one Apogee model. The three parachutes are made out of ripstop nylon material. The final selection was made according to dimension and carrying capacity after thorough analysis of simulations and numerous calculations. The Apogee Iris Ultra Fruity Parachute is a multi-gore chute with a toroidal shape when inflated. Due to a toroidal shape, it will be able to create more drag compared to an elliptical shaped parachute. The parachute has attached suspension lines, a heavy bridle, and barrel swivel to ensure maximum strength and security.

Criteria	SkyAngle Classic Main Parachute 52"	SkyAngle Classic Main Parachute 60"	Apogee Iris Ultra Fruity 72" Nylon Main Parachute
Cost (15%)	8	8	7
Material (25%)	9	9	9
Dimensions (15%)	6	8	9
Carrying Capacity (20%)	6	9	8
Weight (25%)	6	6	8
Total	7.05	7.95	8.25

Table 3.4.4a Main parachute decision matrix.

Drogue Parachute Selection:

For the drogue parachute, we have chosen the Apogee Fruity Drogue Parachute (18" diameter model). Without a drogue parachute, there would be significant drift away from the point of apogee. In order to slow down our launch vehicle, we must have a drogue parachute deployed at apogee so the main parachute can be deployed at the lowest elevation point possible. In the process of selecting the drogue parachute, the three factors we are concerned with are the material, weight, and dimensions. The Apogee Fruity Drogue Parachute (18") is not only bright in color, but it has an elliptical shape which is considered optimal for high drag and minimum weight and material. The typical drag coefficient is 1.5-1.6 which fits the estimated drag coefficients tested in our simulations. The strong nylon cloth material used for the parachute and the suspension lines that attach to a nylon bridle and a barrel swivel ensure for maximum strength and minimization of twisting. The 18" diameter is the proper size to minimize drift between its deployment at apogee and the deployment of the main parachute. Additionally, it will maintain a factor of safety in the force applied to the main parachute shroud lines and shock cords.

Criteria	Apogee Fruity Drogue 18"	SkyAngle Classic 24"	Apogee Dino Drogue 18"
Cost (15%)	7	8	8
Material (25%)	9	7	6
Dimensions (15%)	9	6	9
Carrying Capacity (20%)	8	8	6
Weight (25%)	8	6	7
Total	8.25	6.95	7

Table 3.4.4b Drogue parachute decision matrix.

To calculate the kinetic energy at landing, the system is defined as the rocket and parachute. Once we know the total mass of our rocket, and the cross sectional area of the parachute, we can calculate the kinetic energy with the following equations:

$$p\Delta = F_{net} \cdot \Delta t$$

$$0 = F_{gravity} - F_{drag}$$

$$F_{gravity} = F_{drag}$$

So,

$$g \cdot M = \frac{C_d \cdot \rho \cdot V^2 \cdot A}{2}$$

Where C_d is the drag coefficient, M is the mass of the system, g is the acceleration due to gravity, ρ is the air density, V is terminal velocity, and A is the cross sectional area of the parachute. The minimum cross sectional area of the parachute is calculated in the next section using the maximum allowable kinetic energy to ensure the KE at landing of all sections of the rocket is below this value.

Numerical Analysis of Main Parachute Selection:

Utilizing the maximum allowable kinetic energy upon landing, 75 ft-lbs (101.686 J), we solved for the greatest possible terminal velocity of the rocket.

$$KE = \frac{1}{2}MV^2$$

$$V_t = \sqrt{\frac{2KE}{M}}$$

$$V_t = \sqrt{\frac{2(101.686\,J)}{7.42}}$$

$$V_t = 5.23\ m/s = 17.17\ ft/s$$

Using this max velocity, we can use a rearranged equation from above to solve for the minimum area of the main parachute that would allow us to reach this speed.

$$A = \frac{2Mg}{\rho C_d V^2}$$

In our calculations we utilize an estimated coefficient of drag of 1.6, a reasonable number for a high powered rocketry main parachute to attain an estimate of the parachute's area.

$$A = \frac{2(7.42kg)(9.81m/s^2)}{(1.225kg/m^3)(1.6)(5.23m/s)^2}$$

$$A = 2.71\ m^2 = 29.17\ ft^2$$

Relating the area of the parachute to its radius,

$$A = \pi r^2$$

Solving for r, we find the minimum possible radius for a parachute with this coefficient of drag.

$$r = \sqrt{\frac{A}{\pi}}$$

$$r = \sqrt{\frac{(2.71)m^2}{\pi}}$$

$$r = .9287\ m = \ 36.56in$$

This corresponds roughly to a diameter of 73.1”. However, our selected parachute has a coefficient of drag of 2.2 while this calculation used a coefficient of 1.6 to add a measure of factor of safety. Using the above equations with the greater coefficient of drag value, we found a minimum parachute diameter of 62”. Therefore, using a 72” parachute will be sufficient to slow our launch vehicle to under the specified 75 ft-lbs for each part of the rocket upon landing. We utilized the entire mass of the rocket in this calculation, so this guarantees that each section of the rocket (which holds only a fraction of the entire weight) not land with a kinetic energy exceeding 75 ft-lbs. Thus, our choice of a main parachute of with a diameter of 72” in conjunction with the contribution of the drogue parachute is valid based on the above calculations.

We ruled out the other two parachutes illustrated in Table 3.4.4a above as the Apogee 60” parachute would not withstand the change in momentum our rocket would experience upon parachute deployment. Additionally as shown below, the final velocity achievable with the 52” parachute is too high for the mass of our rocket.

$$V = \sqrt{\frac{2Mg}{\rho C_d A}}$$

Using the manufacturer provided information,

$$V = \sqrt{\frac{2(7.42kg)(9.81m/s^2)}{(1.225kg/m^3)(1.46)(1.37m^2)}}$$

$$V = 7.66\ m/s$$

This value exceeds the maximum allowable velocity which led us to purchase the 72” parachute. Though the 72” parachute keeps us within the kinetic energy constraint, we are considering using a larger parachute for an increased safety factor.

3.5 Mission Performance Predictions

Given the nature of the rail system, ignition and the first few meters of ascent will be a period crucial to mission success. The launch vehicle performance during the ascent phase can be accurately predicted perfected through testing and running simulations. Given this ability to mitigate the potential of failure through the design and testing process makes this stage of the mission relatively risk free. With proper engineering, design, and testing, we can ensure with a high degree of certainty that ascent will not be the greatest potential point of failure. The aspect of our mission profile and launch vehicle that is paramount to a successful launch and recovery is the recovery system. Any failure of the recovery system renders all other mission criteria unobtainable. The largest probability of recovery system failure will occur during parachute deployment, as numerous events must occur simultaneously, without hesitation, and reliably.

3.5.1 Target Altitude

The Student Launch guidelines require a launch vehicle to reach a maximum altitude between 4000 and 5,500 feet to receive points for altitude. To minimize the chances our launch vehicle is outside this range, we have chosen a target altitude of 4,750 feet, the center of the provided range.

3.5.2 Flight Simulations

<u>Flight Profile Simulations:</u>

The rocket's design was recreated in the flight simulation program OpenRocket by using the dimensions, component shapes and properties, and mass distribution of the actual launch vehicle.

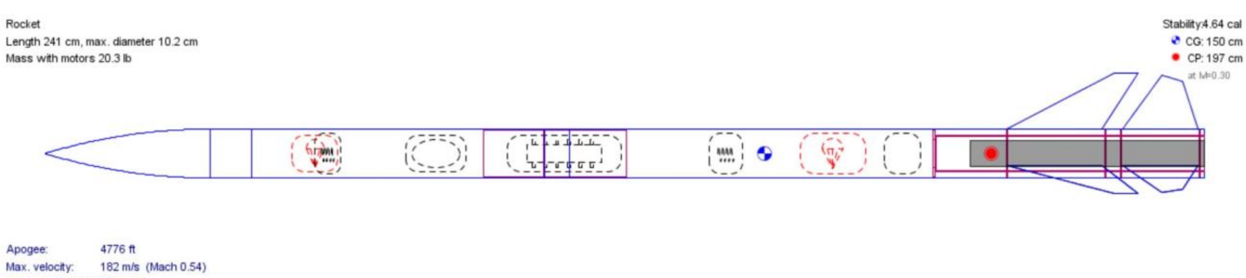


Figure 3.5.2a: Side view of the assembled vehicle model in OpenRocket

The simulation was configured with the coordinates and elevation of the launch site in Toney, Alabama to improve accuracy. We found that the mean wind speed at the launch location in April is 6 mph, and this was incorporated into the simulation to determine the mass of the ballast needed to achieve our target altitude. The total mass of the rocket without ballast is 8.411 kilograms, and our simulations showed that adding a ballast of 720 grams would result in our target apogee of 4750 ft when the wind speed was set to 6 mph. This brought our launch mass up to 9.164 kg, with room to increase or decrease the ballast mass as needed.

Using a launch rail height of 12 ft, the expected rail exit velocity of the rocket is 25 m/s or 82 ft/s. The vehicle will experience a peak acceleration of 82.9 m/s^2. The maximum velocity of the rocket is 181 m/s and occurs 3.25 seconds into flight, at an altitude of 1155 ft. The rocket is expected to reach apogee 17.2 seconds into flight, and land at a lateral distance of approximately 250 ft from the launch site, with a terminal velocity of 5.03 m/s. The total descent time from apogee to ground hit is expected to be 85.8 seconds.

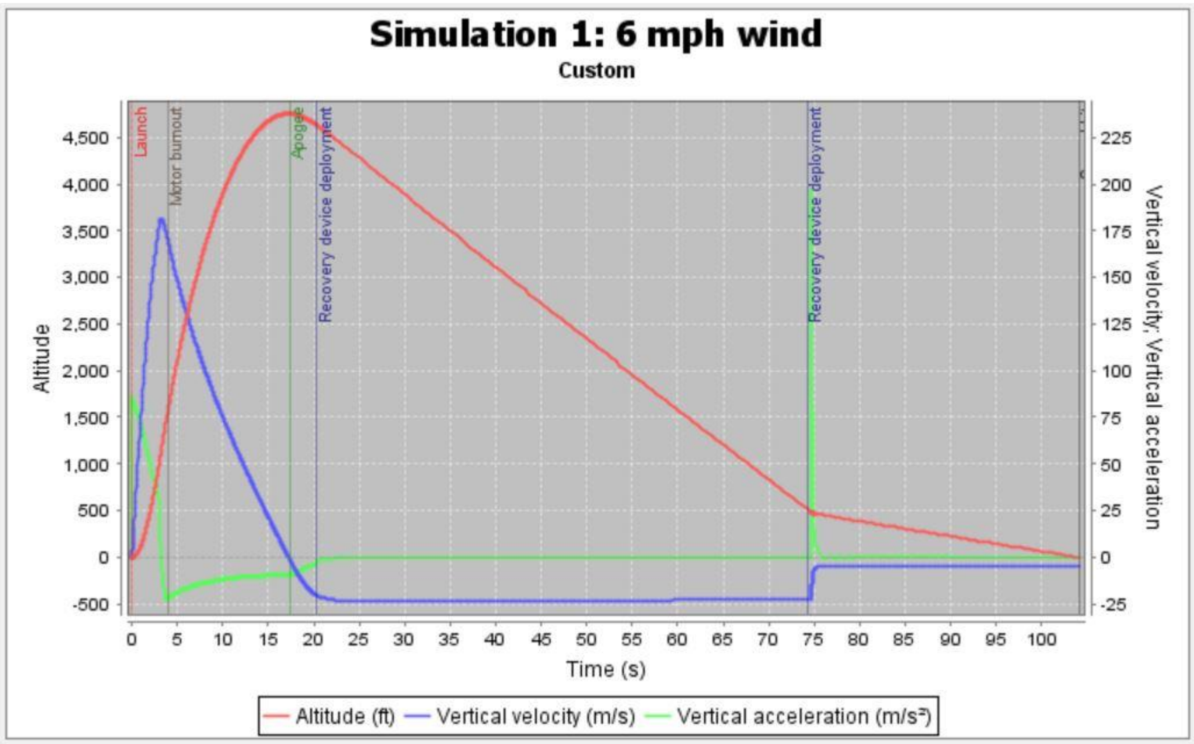


Figure 3.5.2b: Simulated plot of altitude, vertical velocity and acceleration at a wind speed of 6 mph

Component	Mass (g)
Avionics Sled	180
Centering Rings	216.3
Airframe total	3175
Motor Fuel	990
Motor	695
Motor Retainer	139
Motor Adapter	127
Avionics Equipment	230
Fins	115
Rover	890.2
Rover Release Mechanism	443.6
Chute Protectors	60.1
Ejection Canisters	9
Quick links	39.7
Swivels	23.2
Drogue parachute	56.1
Main parachute	380
Eyebolts	47.4

Shock Cord Protectors	20
Shock Cord	47.4
Bulkheads	514.8
Total:	8411.5g 18.54lbs

Table 3.5.2a: Component masses.

<u>Motor Thrust Curve:</u>

The thrust curve of the K570 motor is shown in figure 3.5.2. The motor has a total impulse of 2070 Ns. The launch mass of the motor is 1685 g and the burnout mass is 652 g. The liftoff thrust of this motor is 900 N, resulting in a Thrust-To-Weight ratio of 10.01.

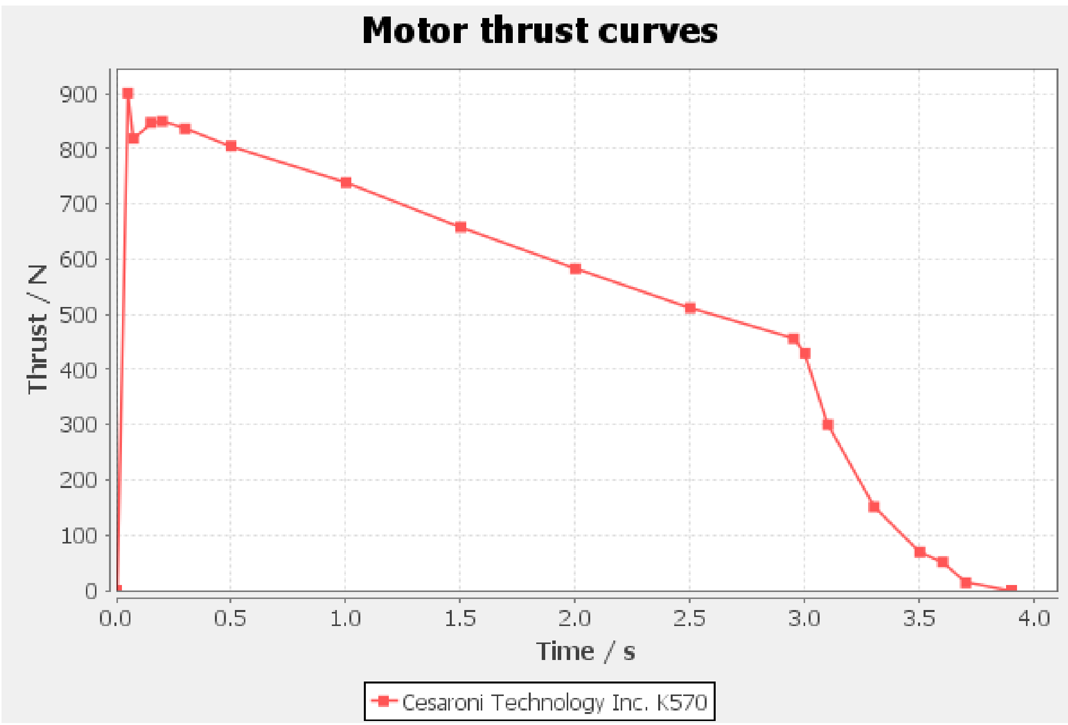


Figure 3.5.2c: Expected Thrust Profile of the Cesaroni Technology K570 motor. Source: OpenRocket Motor Database

3.5.3 Stability Data

<u>Stability Margin:</u>

As simulated, the Center of Gravity (CG) of the rocket lies at 149 cm from the top of the nose cone and the Center of Pressure (CP) lies at 197 cm. This results in a stability margin of 4.7 cal. This meets the NASA requirements for a stability margin. We may take measures to decrease the stability margin through a decrease in fin size to prevent against weathercocking after further research.

Stability margin was also calculated using the equation shown below.

$$S = \frac{x_{cp} - x_{cg}}{d}$$

Where x_{cp} is the location of the Center of Pressure, x_{cg} is the location of the Center of Gravity, and d is the diameter of the rocket. Using our values listed above, we found the stability margin to be 4.6 cal, which corresponds with the simulation value found in OpenRocket.

3.5.4 Recovery Calculations and Simulations

Vehicle Drift and Altitude Predictions:

The following results were obtained for the landing site lateral distance at different wind speeds.

All simulations were run in OpenRocket multiple times.

Drogue parachute diameter: 18 in

Drogue parachute drag coefficient: 1.6

Main parachute diameter: 72 in

Main parachute drag coefficient: 2.2

Burnout mass of the rocket: 8.13 kg

Wind speed (mph)	Lateral Distance from launch site with ballast (ft)	Apogee with ballast (ft)	Apogee without ballast (ft)
0	7.1	4834	5290
5	250	4772	5289
10	520	4728	5043
15	725	4694	4816
20	1140	4520	4632

Table 3.5.4: Flight Simulation Results for Varying Wind Speeds

From this table it is clear that the motor selected for the rocket will allow us to reach our intended apogee and stay within the required drift radius of 2500 feet even in adverse weather conditions. Ballast can be adjusted based on weather conditions to ensure we reach the correct height. A sample plot from one of our calculations of no wind condition for full ballast is shown in the figure below.

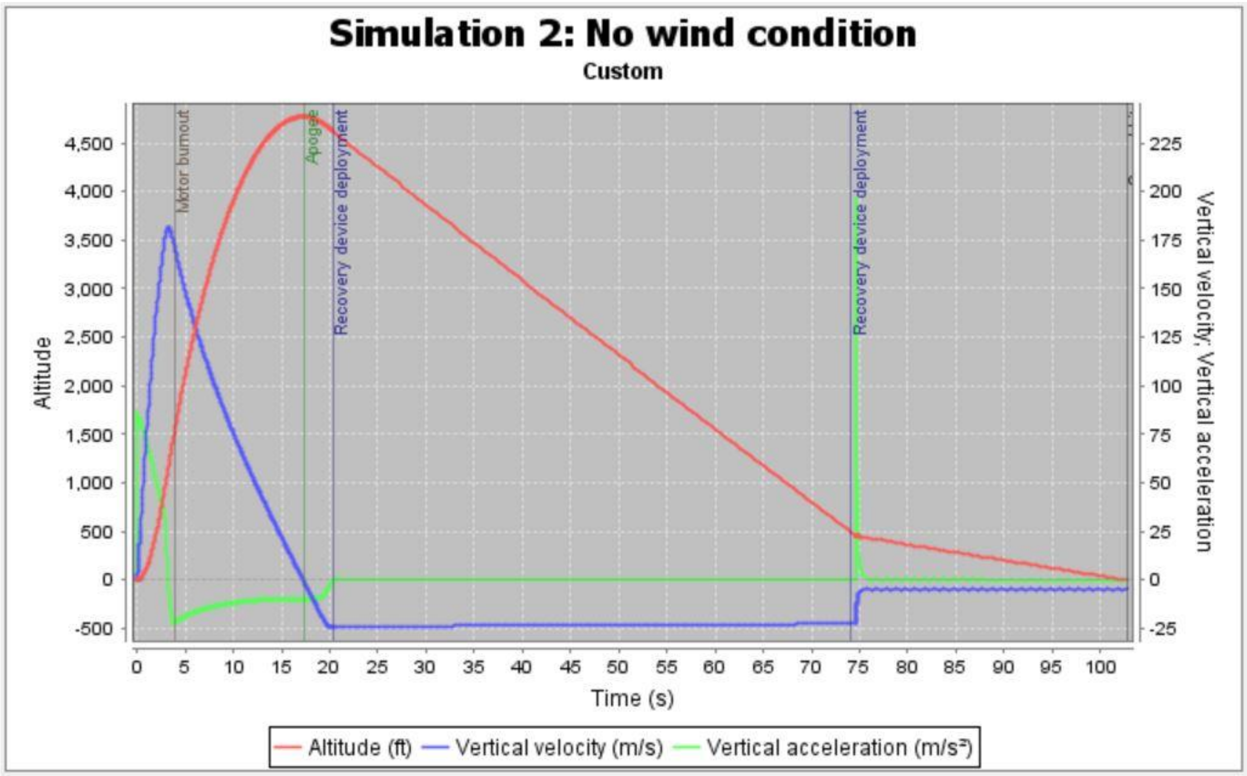


Figure 3.5.4: Sample Simulation Graph with ballast and no wind

4 Safety

Personnel hazard and failure mode analysis is performed by evaluating risks with the risk assessment code (RAC) matrix as shown in Table 4a. This table is adapted from the RAC used by the Glenn Research Center. Risk levels are evaluated by their frequency and severity with relation to the Pitt Rocketry Team's success in the NASA SL competition. Risks will be attended to in different ways depending on their assessment according to table 4b.

RAC	A Frequent	B Probable	C Occasional	D Remote	E Improbable
1 - Catastrophic	1	1	2	3	4
2 - Critical	1	2	3	4	5

3 - Marginal	2	3	4	5	6
4 - Negligible	3	4	5	6	7

Table 4a.

Risk level	**Necessary action**
1-2 - Highly undesirable	Documented approval from NASA SL officials, faculty advisor, team mentor, and safety officer is required before imposing the risk.
3 - Undesirable	Documented approval from faculty advisor, team mentor, safety officer, and team leads is required before imposing the risk.
4-7 - Acceptable	Documented approval from relevant team leads and facility supervisors is required before imposing the risk.

Table 4b.

Designated severity	Personnel Illness and Injury	Equipment Loss	Project Plan	Environmental
1 - Catastrophic	Permanent disability or death.	Irreparable damage to system, machinery, or equipment.	Delays or budget overruns resulting in failure to complete project.	Long-term or irreversible damage (>5 years)
2 - Critical	Severe injury or illness temporarily preventing normal activities.	Major damage to system, machinery, or equipment resulting in prolonged non functionality.	Delays or budget overruns that severely limit project performance.	Medium-term (1-5 years)
3 - Marginal	Minor injury or illness without effect on daily activities.	Minor damage to system, machinery, or equipment resulting in temporary non functionality.	Minor delays or budget overruns that impact non-critical project performance factors.	Short-term (<1 year)

4 - Negligible	Insignificant injury treated through basic first aid.	Minor damage to system, machinery, or equipment that can be immediately fixed.	Minor delays in non-essential components.	Minor damage, readily repaired.

Table 4c.

Designated Probability	Qualitative Definition	Quantitative Definition
A - Frequent	Likely to occur repeatedly during life of project.	Probability $> 10^{-1}$
B - Probable	Likely to occur several times during life of project.	$10^{-1} \geq$ Probability $> 10^{-2}$
C - Occasional	Likely to occur sometime within life of project.	$10^{-2} \geq$ Probability $> 10^{-3}$
D - Remote	Not likely to occur within life of project.	$10^{-3} \geq$ Probability $> 10^{-6}$
E - Improbable	Occurrence is not expected during life of project.	$10^{-6} \geq$ Probability

Table 4d.

4.1 Preliminary Personnel Hazard Analysis & Risk Analysis

Table 4.1 shows the preliminary personnel hazard and risk analysis performed by the Pitt Rocketry Team.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification Plan	Post-RAC

Injury from machinery	Mishandling of machines, fatigue, failure to comply with safety guidelines, or machine malfunction.	Bodily harm to team member(s); Damage to machine and/or rocket	2C	Safety guidelines and instructions will be carefully observed with all machines used. Certification tests for SCPI and the SSoE Makerspace must be passed before using the facilities.	Access to machinery will be limited to those with certification; Powered machinery will be operated only while another certified user is present.	2E
Chemical Injury	Mishandling of chemicals, failure to comply with MSDS guidelines and warnings	Bodily harm to team member(s); Damage to rocket or rocket parts.	2C	MSDS guidelines will be carefully observed with all chemicals used.	Chemicals will only be available to members who have read and understand the MSDS guidelines; Chemicals will only be used when there is at least one other member present.	2E
Injury from erratic rocket flight	Poor rocket stability; Rail system malfunction.	Injury to team members and/or bystanders resulting from rocket impact.	1D	Accurately calculate the center of pressure and center of mass; Perform simulations before fight.	Calculations and simulations will be performed multiple times and reviewed by team advisor Matthew Barry.	1E
Premature rocket ignition	Ignition malfunction; Failure to follow safety procedures.	Injury, including severe burns, to team members and/or	1D	Conduct briefings at pre launch meetings; Ensure reliability of	Launch day operations will be supervised by safety officer Thomas Harrington and NAR mentor.	1E

		bystanders.		ignition safety switch.		
Premature black powder ignition	Recovery system malfunction; Faulty testing procedures; Failure to follow safety procedures.	Injury to team members form explosion and resulting shrapnel.	2C	Perform black powder tests within a testing enclosure; Follow launch day safety procedures.	A safety officer or mentor will be present for all black powder tests; Launch day operations will be supervised by safety officer Thomas Harrington and NAR mentor.	2E
Free falling rocket sections	Recovery system fails to deploy.	Damage to rocket and/or injury to team members on the ground from free-falling projectiles.	1D	There will be ground and subscale testing of the entire recovery system and its components. Test launches will be carried out on days with optimal weather conditions and minimal clouds below projected apogee. All persons present during launch will be notified to remain attentive.	The recovery system will be declared as functional before test launch. All members at the launch will be reminded to stay attentive during the entirety of the flight, from launch to landing.	1E
Lithium battery fire	Overcharge, over-discharge,	Heat and/or	2D	All lithium cells will be in	Test battery enclosure to	2E

or explosion	overheating, puncture, or physical impact to lithium cells	chemical burns to team members, damage to rocket.		parallel with a LiPO low-voltage alarm. Additionally, each battery will be fully charged with a balance-charger prior to launch. Maximum current draw will fall within official discharge rate of battery. Batteries will be secured-down and located away from potential points of impact.	ensure it is sufficient to protect batteries from a hard crash. Cycle batteries at typical charge and discharge rates while measuring temperature with IR thermometer. Test low-voltage alarms with lab power-supply.	
$PM_{2.5}$ emitted during production of parts	Fumes of material created during laser cutting might contain $PM_{2.5}$	$PM_{2.5}$ can penetrate deeply into the lungs and affect respiratory system	2D	Turn on the ventilator and make sure people does not work alone	Use materials that creates less $PM_{2.5}$ and make sure only trained members have access to 3D printing	3E

Table 4.1.

4.2 Preliminary Failure Modes and Effects Analysis

Table 4.2 shows the preliminary failure modes and effects analysis performed by the Pitt Rocketry Team.

Hazard	**Cause**	**Effect**	**Pre-RAC**	**Mitigation**	**Verification Plan**	**Post-RAC**

Altimeter failure	Loss of power to altimeter; software bug(s); hardware malfunction.	Recovery system is not deployed resulting in an uncontrolled free fall possibly leading to injury or death.	1C	Perform rigorous testing of recovery system altimeter; purchase reliable altimeter.	Test the recovery system and altimeter during the subscale launch.	1E
GPS failure	Loss of power to GPS; software bug(s); hardware malfunction.	Difficult or impossible to locate the vehicle after landing.	1D	Perform rigorous testing of GPS system; purchase reliable GPS.	Test the GPS system prior to and during the subscale launch.	1E
Transceiver failure	Transceiver exceeds range and is unable to operate upon returning to range; software bugs; hardware malfunction; transceiver interference.	Failure to receive GPS coordinates and therefore failure to locate the vehicle after landing. Failure to receive rover deployment command and therefore failure to deploy the rover.	1C	Test transceivers at multiple ranges within and exceeding maximum expected range; purchase reliable transceivers; test transceiver pairs in range of each other (with RFI shielding) and ensure no interference occurs.	Test transceivers independent of system and during subscale launch.	1E

Fin detachment	Structural weakness at fin attachment point.	Fin falls from vehicle mid-flight causing potential injury or death; loss of fin causes vehicle to lose stability.	1D	Take special precaution when attaching fins to airframe to ensure quality of attachment.	Perform structural tests on fins to ensure proper attachment.	1E
Rocket motor explodes	Manufacturing anomaly.	Vehicle is destroyed and explosion could cause injury or death.	1D	Consult NAR advisor Duane Wilkey on reliability of rocket motor.	Test the viability for use of the motor	1E
Premature parachute deployment	Altimeters not properly calibrated; faulty deployment logic.	Parachutes deploy prior to apogee causing the vehicle to lose stability, rendering its flight path off-nominal and unpredictabl e.	1D	Verify and test altimeter calibration procedure; verify and test deployment logic.	Test the recovery system during subscale launch.	1E
Premature rover release	Failing avionics	Recovery does not work	1D	Ensure that rover release mechanism adheres to rules outlined in Student Launch Handbook.	Test the rover release mechanism and the altimeters before flight	1E
Kevlar	Excessive force	Vehicle	1C	Appropriate	Develop tests	1D

shock cord snaps	on cord upon parachute deployment.	separates into untethered components ; certain components have no parachute or safety mechanism, turning them into potentially deadly projectiles.		calculations simulation, and testing can demonstrate that our choice of shock cord significantly reduces the likelihood of this event.	and simulations to ensure that the risk of this occurring is at least remote but preferably improbable.	
Power Failure	Insufficient battery voltage; voltage ripple from 5v switching voltage-regulator	Failure of the on board electrical component(s).	1C	Fully charge all batteries prior to launch. Choose batteries with capacities suited for devices' power draw and expected run time. Choose a switching voltage-regulator designed for use with sensitive electronics.	Measure power draw of all components during typical use. Endurance test switching regulator with corresponding electronic devices.	1D

Table 4.2.

4.3 Environmental Concerns

Table 4.3 shows the environmental concerns analysis performed by the Pitt Rocketry Team.

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification Plan	Post-RAC
Water pollution with perchlorate	Perchlorate from the ammonium perchlorate composite propellants release to air	Perchlorate inhibits NIS-Sodium Iodide symporters in thyroid, which NIS is essential for Iodine transport, which is needed for synthesizing T3(thyroxine) and T4 (triiodothyronine) hormones	2C	Change to other alternative of fuels or use exact amounts of fuels needed.	Try to calculate and control the amount of perchlorate released	4E
Parts of rover break off from system	Rover is poorly assembled.	Pieces of rover are littered into the environment.	4C	Verify quality of rover assembly and minimize number of separate, small (potentially detachable) components on rover.	Inspect rover for lose pieces prior to flight.	4E
Drive wheel parts detach while spinning	Drive wheel material is fragile and drive wheel parts are liable to detach while the rover is roving.	Debris might be left in the environment.	4C	Verify quality of drive wheel parts after production.	Perform quality assurance tests on drive wheels by testing drive wheels on various surfaces and inspect drive wheels prior to flight.	4D

Parts detached and become projectiles	Parts experience impact force from moment of vehicle acceleration until vehicle is stable after landing.	Debris might be left in the environment.	3D	Pay close attention to potential detachment points during fabrication.	Thoroughly test potential detachment points	3E
Battery rupture that spreads hazardous chemicals	Battery is punctured by a hard crash or by general mishandling.	Hazardous chemicals are spread into the environment.	3D	Protect the batteries and locate them away from potential points of impact on launch vehicle.	Test battery enclosure to ensure it is sufficient to protect batteries from a hard crash.	3E
Hot motor exhaust damaging grounds around launching area	The motor blow hot air at the ground during launching.	The land is scorched.	3B	Use device to redirect the exhaust into different direction.	Examine the ground condition after every test launch.	3C
Affecting birds and other animals around the launching area	Birds might get hit by the rocket.	Birds might get killed and the vehicle's trajectory is might be affected.	1D	Visual inspection of vehicle during launch to ensure no bird are hit.	Visually inspect number of bird in area prior to launch to validate risk is low.	1D
Noises created damaging to the ear	The rocket launching create large noises due to the friction with the air	Disrupt people living around the launching area	3C	Measure and monitor the noises during test launches. Provide hearing protection to team.	Make sure the noise level is not over 85 db, which is damaging to hearing.	3D
Shrapnel of	Parts might	Emit large	4C	Use less	Test parachutes	4D

sparks from material cause fire	explode and cause fire	amount of CO_2 and burn people around		flammable material for rovers and use waddings for parachutes to make sure they do not catch on fire after landing	and rovers to make sure they do not explode	

Table 4.3.

4.4 Project Completion Risks

Table 4.4 shows the project completion risks analysis performed by the Pitt Rocketry Team.

Hazard	**Cause**	**Effect**	**Pre-RAC**	**Mitigation**	**Verification Plan**	**Post-RAC**
Project fails to progress according to the projected timeline	Arisal of unexpected circumstances that delay the project. Failure to adhere to work schedules.	Team members fail to produce a completed project.	2C	Even distribution of work between members of the project by the sub team leads. Proper communication between all sub teams as well as team members and their team leads.	Continue holding weekly subteam meetings and bi-weekly general body meetings. Use of online services such as Trello to assign and keep track of individual assignments.	2E
Decreasing team size	Failure to keep team members engaged and interested in the project. Neglecting members by not assigning them work.	Too much work for too few members could lead to failure to complete the project.	2C	Ensure that every willing participant feels included. Keep members busy with the right amount of work which suits their abilities and	Sub team leads will keep up with all their members and keep them engaged in interesting work. Continued project success	2E

				interest.	will lead to continued interest and desire to see the project to completion.	
Budget limitations	Project significantly exceeds budget or funding is withdrawn.	Hinders acquisition of mission critical parts potentially resulting in failure to complete the project.	2C	Secure significant funding beyond expected needs; Maintain a strict budget to track expenditures.	Systems team and team leader leader, Helena Richie, will enforce budget restraints on the project and subgroups.	2E
Parts Procurement limitations	Inability to procure desired parts due to unavailability or unacceptably high cost.	Significant project delays; Inability to thoroughly test parts and system.	2C	Research multiple alternatives for each part; Purchase extra parts to ensure spare parts are on hand in case of damage.	Team leaders will ensure that their respective subgroups have acquired all the necessary parts and will provide alternative part selections to the systems team if necessary.	2E

Table 4.4.

5 Payload Criteria

5.1 Payload Objective

Deployable Rover System:

There are three main criteria for determining the success of payload deployment. First, the rover must be secured within the launch vehicle for the entirety of the flight. Second, the rover must be deployed from the launch vehicle only after landing and only when the team sends a signal to the main avionics system to trigger rover release. Lastly, the rover must autonomously move 10 feet away from the launch vehicle and recover and store a soil sample of at least 10 milliliters. A successful payload deployment will be achieved when and only when these three criteria are met.

5.2 Current Leading Design and Rationale

5.2.1 Frame and Form Factor

The primary constraint for the physical design of the rover is the limited dimensions inside the rocket's airframe -- in our case an internal diameter of 98.6 millimeters. The rover's body will be 3D printed from nylon due to its optimal mechanical properties including high strength, chemical resistance, impact tolerance, and durability.

The three major frame options considered are:

- Two wheel bar
- Three wheel tail dragger
- Four wheel drive

<u>Two wheel bar design:</u>

In this design, the rover body has two wheels on the same axis and the body with all components in the middle. The body has a center of mass that is offset from the wheel axis, and the moment from the off-axis CG allows the rover to move.

Pros:

- Orientation at deployment does not matter as the rover will always right itself automatically.
- Efficient use of space; permits the largest wheel size of any design.

Cons:

- Obstacle avoidance is more challenging since the body wobbles around during normal movement, making sensors less reliable.
- Severely limits the torque that can be applied at the wheels since too much torque would cause the body to spin on its axis.
- Soil collection method is limited to the wheel scoop design and the low available torque limits the effectiveness of the excavation.

<u>Three wheel tail dragger design:</u>

In this design, there are two larger drive wheels up front with a single passive wheel in the middle of the body that trails behind the rest of the rover.

Pros:

- Better stability of the body during movement which helps with the use of obstacle avoidance sensors.
- Permits higher torque to be applied to the drive wheels.

- Easier to design soil collection mechanism for this design; the wheel scoop design benefits from the higher torque capability.

Cons:

- Sensitive to initial orientation. Can be solved by adding a gyroscope to determine if rover is upside down. In that case, a rod mounted on a servo can be actuated to flip rover over if gyroscope determines that rover is upside down.

<u>Four wheel drive:</u>

Pros:

- Four drive wheels provide better traction and stability.

Cons:

- Still sensitive to orientation but much more difficult to flip over.
- Most designs would be too large to fit inside the airframe.
- Retention and deployment mechanisms would be more challenging to design.

Leading Design choice: Three wheel tail dragger. This design offers the best combination of desired properties and minimizes the quantity and quality of disadvantages.

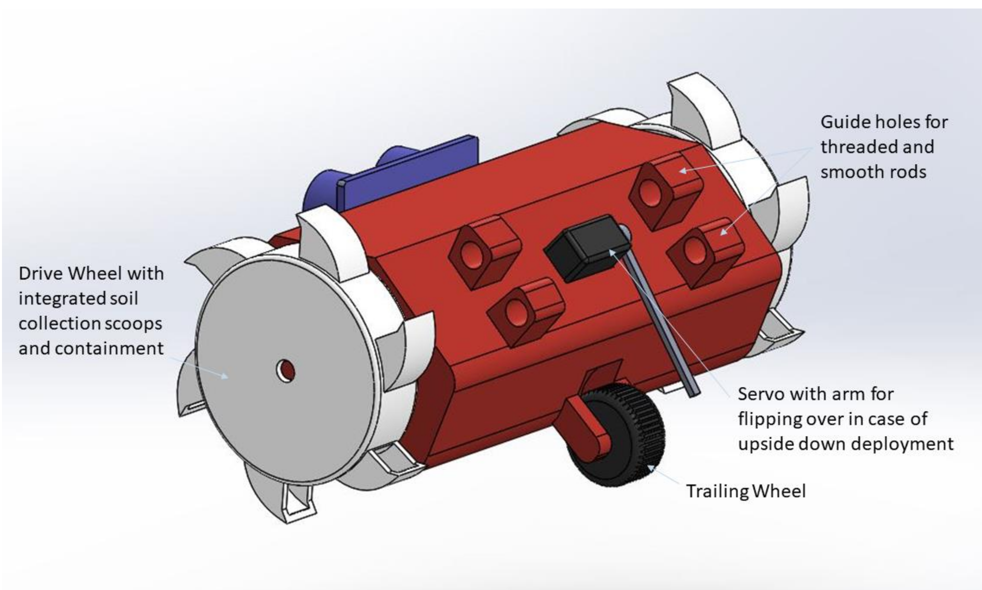


Figure 5.2.1: Preliminary CAD of the rover with certain critical components labeled.

Figure 5.2.1 shows several key features of the rover's design. The body of the rover houses all the critical components including the battery, microcontroller, motors, radio transceiver, and sensors. The main wheels are driven by two independent geared DC motors and double as the soil collection and containment system. Each wheel has six scoops that will dig the soil under the rover as it drives so the soil sample is collected in the hollow inner chamber of the wheel.

The length of the rover including wheels is 140 millimeters, and the width at the widest part is approximately 90 millimeters. The total mass of the rover, excluding the interface is expected to be around 950 grams or 2.1 pounds.

On the exterior of the rover body are two pairs of protrusions with holes. These are structural elements that will be used to expel the rover out of the rocket body with the help of a threaded rod and a smooth rod. One of each pair contains a threaded brass sleeve and the other is a smooth through hole. More details about the deployment mechanism are presented in the Payload Interface section below.

A servo motor also protrudes out of the body, to which a long arm is attached and can be actuated up to 180 degrees. The purpose of this arm is to conduct a flip maneuver if the rover's internal gyroscope detects that it has been deployed in an upside-down orientation.

5.2.2 Soil Collection Mechanism

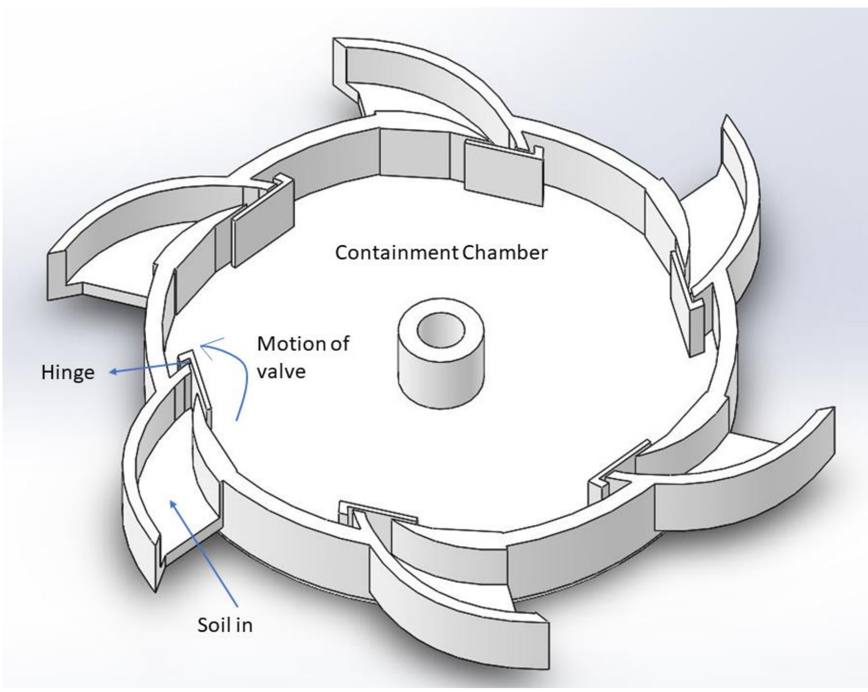


Figure 5.2.2: A cutaway of the preliminary wheel-based soil collector design.

The soil collection and containment system is integrated into the wheel as shown in the Figure 5.2.2. The wheel will be 3D printed with clear PETG material which offers suitable mechanical properties for this application. The translucent material will also help with visual confirmation of a successful sample collection during testing. The collected sample will be accessible by removing one side of the wheel.

As the wheels spin, the sharp edge of the scoop digs into the soil and the soil is channeled into the interior of the scoop. Once the scoop approaches the top of the wheel, the gravity-controlled one-way valve rotates on its hinge and allows the soil to fall into the hollow interior. On its way down, the valve closes automatically as it turns due to its own weight, preventing the soil sample collected in the chamber from escaping.

The internal volume of each wheel is approximately 40 milliliters, which provides ample margin for collecting and storing at least 10 milliliters of soil across the two wheels. The design of the hinges, shape, and size of the scoops and other details will be refined and optimized after prototypes are fabricated and tested.

This design for the soil collection system was selected primarily due to its relative simplicity compared to a robotic arm excavator which would involve multiple actively controlled elements which therefore increase the likelihood of failure. This design is entirely passive, and only requires the rover to drive over soil. We believe that through extensive testing, refinement, and optimization of the design this system will prove to be successful and reliable.

5.2.3 Drivetrain Design

To fulfill the rover's requirement of being able to autonomously drive at least 10 feet away from the rocket, the payload team was tasked with selecting a drive motor that has the optimal properties for our purpose. Different options were compared based on the criteria of size, weight, cost, torque and ease of tracking the motion. In particular, three kinds of motors were studied:

- Stepper Motor
- Geared DC motor
- Continuous Servo

<u>Stepper Motor:</u>

Stepper motors work by sequentially turning on and off electromagnets in discrete steps which correspond to the angle by which the rotor turns.

Pros:

- Can provide full torque at standstill.
- Accurate in position control.
- Good for low speed and acceleration applications.

Cons:

- High current draw and high holding current requirements.
- Heavier than similar geared DC motors.
- Small ones which would be used for this application are susceptible to skipping steps and losing position tracking.

Geared DC Motor:

Geared DC motors are small DC brushed motors with the shaft attached to a reduction gear system and the output can range from as low as 30 rpm to 600 rpm and above.

Pros:

- Cheap and readily available in different sizes.
- High torque without a high current draw from holding.
- Position can be tracked easily by adding an encoder.

Cons:

- No built-in position tracking.
- Shorter lifespan due to wear of gears and the motor's brushes.

Continuous Servo:

Very similar to geared DC motors, continuous servos contain a small DC motor with reduction gears leading to the output shaft. Continuous servos lack the precise feedback control of regular servos.

Pros:

- Easy to control with a microcontroller.
- Good low-speed torque.

Cons:

- No position tracking.
- Much slower than alternatives.

After careful consideration of design criteria, it was decided that geared DC motors would be the best option for our purpose. The preliminary motor of choice is the "Uxcell 12V geared DC motor with encoder". It comes with an integrated hall-effect encoder which will make tracking the distance covered by the rover possible.

5.3 Electronic Components and Schematic

Preliminary selection of electronic components that will be used in the rover are as follows:

Component	Details	Quantity

Battery	Turnigy 11.1V 2200mAh LiPo battery pack	1
Microcontroller	Arduino Nano	1
Motor controller	L298N dual H-bridge driver	1
Motor	Uxcell DC 12V DC gear motor with encoder	2
Obstacle Sensor	HC-SR04 Ultrasonic sensor 2 I/O pins	1
Radio Transceiver	HC-12 long range serial radio	1
Gyroscope for orientation	GY-521 breakout for the MPU 6050 module	1
Servo for flipping rover	TowerPro SG90 micro servo	1

Table 5.3a: List of electronic components that will be used in the rover.

Figure 5.3b shows a wiring schematic of all electronic components for the rover. The Arduino Nano was selected as the microcontroller for the rover due to its small size, low cost, adequate number of I/O pins, and compatibility with the Arduino programming language. The two motors will be controlled through the L298N dual H-bridge motor controller, which was chosen due to its ease of use, low cost and high power rating. The HC-12 radio transceiver was selected to keep cross-compatibility and streamline the programming, since the Avionics subteam is using the same transceiver. The rover will sense its orientation with the help of the MPU 6050 accelerometer and gyroscope module. This module is available as a breakout board that easily interfaces with an arduino through the I^2C protocol. Open source libraries are also available for this board, which makes it easy to read and process the data. A TowerPro SG90 micro servo will be used for flipping the rover in case it is deployed in a non-optimal orientation. This servo is cheap, compact, decently powerful and efficient.

	MPU-6050	MPU-9250	BNO055	FXOS8700 + FXAS21002	LSM9DS1	L3GD20 H
Fusion Calculation s (30%)	10	0	10	0	0	0
Zero Rate (15%)	3	6	8	10	1	7
Price (30%)	5	7	3	7	7	10

Power (15%)	5	6	4	7	7	4
Total	5.7	3.9	5.7	4.65	3.3	4.65

Table 5.3b: Decision matrix for gyroscope selection.

The rover will navigate using the HC-SR04 ultrasonic sensor to detect obstacles, using an algorithm to stop, back up and turn at an angle to avoid hitting them. The encoder will keep track of the distance travelled without encountering an obstacle, which the rover will use to determine if it's at least 10 feet away from its starting point.

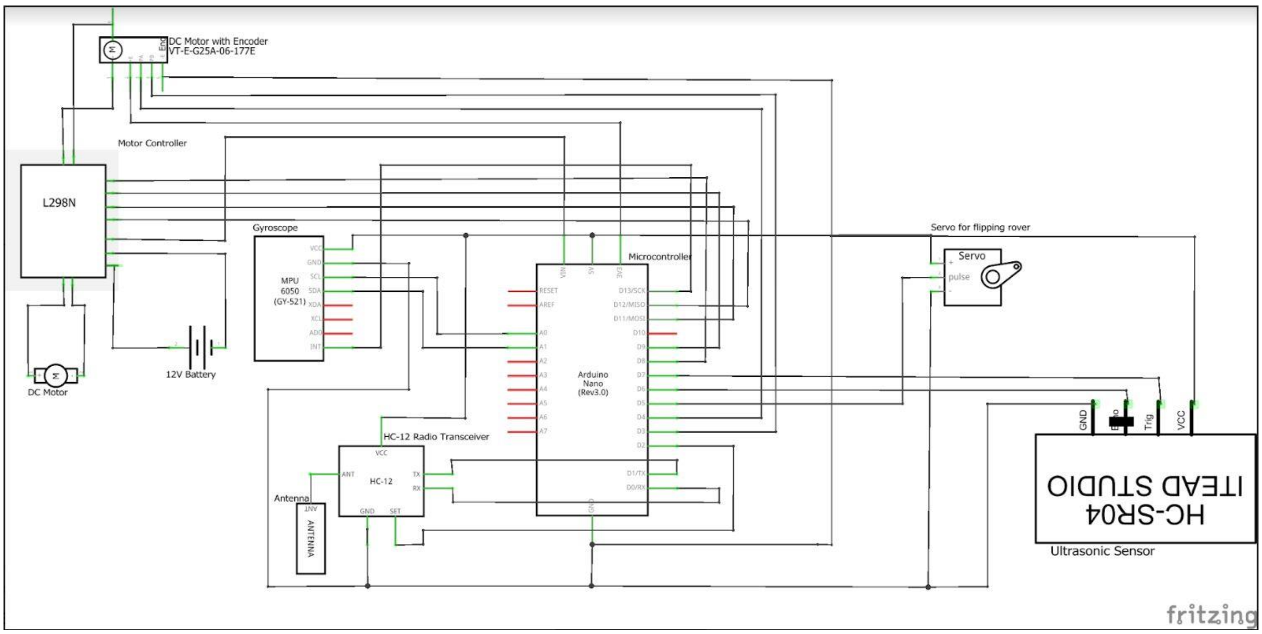


Figure 5.3b: Schematic showing the microcontroller pins that will be used.

5.4 Preliminary Payload Interface

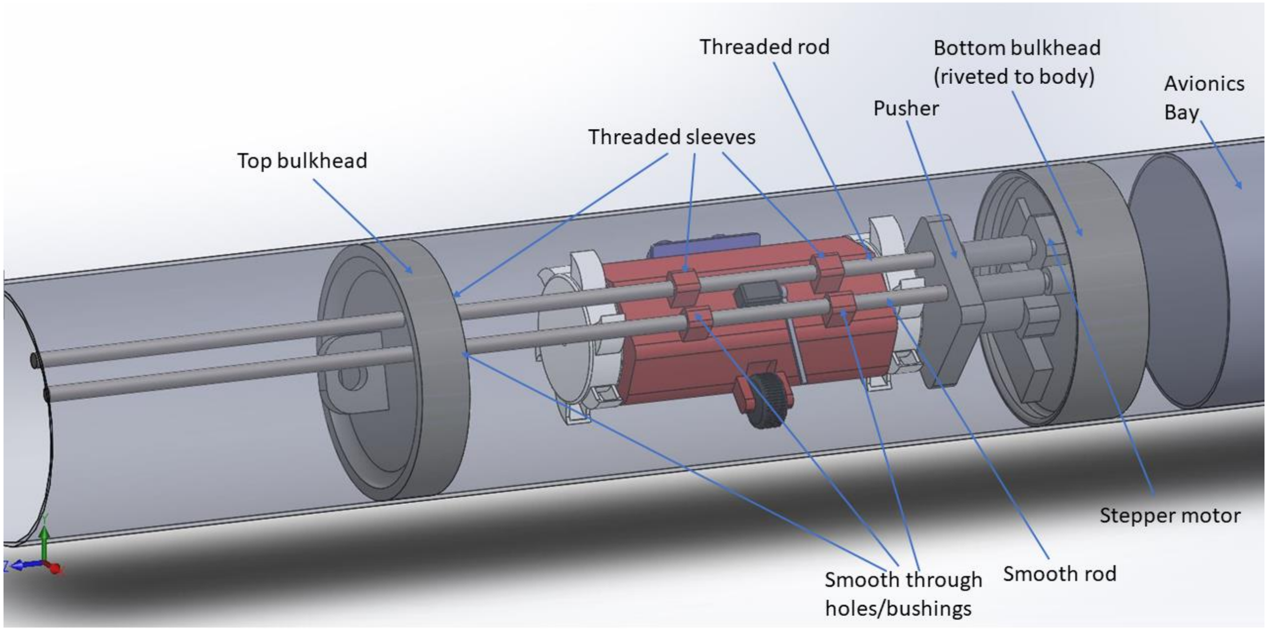


Figure 5.4: Preliminary CAD image showing the payload retention and deployment mechanism.

The rover will be housed in the payload section of the launch vehicle, below the nose cone. A 3D printed bulkhead is riveted to the rocket body near the avionics bay, and it holds a stepper motor with a threaded 6061 Aluminum rod and a smooth rod for rigidity. The stepper motor can be powered through the Avionics bay. The rover, top bulkhead, and the pusher all have a threaded sleeve and a smooth bushing. The drogue parachute and the ejection charge will be placed above the top bulkhead, with the drogue parachute being tethered to the top bulkhead through the hole shown in Figure 5.4.

When the payload deployment signal is received, the stepper motor begins turning the threaded rod, which causes the top bulkhead, the rover and the pusher to be gradually pushed out of the payload bay. The top bulkhead will be ejected first, followed by the rover. The pusher is there to make sure that the rover fully exits the vehicle and also to provide structural support to the rover during launch. Once the stepper motor has completed enough turns so that the rover has fully ejected the body tube, the avionics bay flight controller sends a signal to the rover so it can begin its operations.

6 Project Plan

6.1 Requirements Verification

6.1.1 Rules Based Requirements

Requirement	Verification
General requirements	
Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor).	Demonstration will be used to verify that students on the team will do 100% of the project by recording all members involved any given task.
The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	This is demonstrated with the Gantt charts below, the recorded work of the systems team, the personnel hazard analysis, and the failure modes and effect analysis.
Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during certain activities.	This will be demonstrated by performing appropriate actions to allow foreign national team members join us at the competition.
The team must identify all team members attending launch week activities by the Critical Design Review (CDR). Team members will include: ● Students actively engaged in the project throughout the entire year. ● One mentor ● No more than two adult educators.	All PRT members actively engaged in team activities starting September 2018 through the CDR, our mentor Duane Wilkey, our advisor Matthew Barry, and up to one other adult educator will be recorded as being a part of the Pitt Rocketry Team from 2018-2019 by the CDR.
The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the STEM Engagement Activity Report, by FRR. To satisfy this requirement, all events must occur between project acceptance and the FRR due date and the STEM Engagement Activity	As described in our proposal, through collaboration with Pitt's Society of Physics Students, PRT will present to 2-3 schools about the technical information regarding rocketry as well as opportunities in STEM fields. The details of each presentation are currently being developed and the meeting of this requirement will continue to be

Report must be submitted via email within two weeks of the completion of the event.	demonstrated through each report.
The team will establish a social media presence to inform the public about team activities.	Our team's Instagram account can be found at https://www.instagram.com/pittrocketryteam/ where we post about team activities.
Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient.	All team deliverables will be sent to NASA by the deadline as requested.
All deliverables must be in PDF format.	Before submitting any deliverable, it will be converted to PDF format.
In every report, teams will provide a table of contents including major sections and their respective sub-sections.	This will be demonstrated at the beginning of each report.
In every report, the team will include the page number at the bottom of the page.	This will be demonstrated at the bottom of report pages.
The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.	PRT will reserve all necessary space and computer equipment to teleconference with the review panel prior to each design review.
All teams will be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted on the launch field. Eight foot 1010 rails and 12 foot 1515 rails will be provided. The launch rails will be canted 5 to 10 degrees away from the crowd on launch day. The exact cant will depend on launch day wind conditions.	PRT will not create a custom pad for the launch. The launch vehicle will be compatible with the launch pad provided by the Student Launch's launch services provider.
Each team must identify a "mentor." A mentor is defined as an adult who is included as a team	The PDR demonstrates that Duane Wilkey, a level 3 certified NAR member is our team's

member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to launch week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attend launch week in April.	mentor. Duane possesses evidence of the necessary requirements to assist our team as the designated mentor.
Vehicle requirements	
The vehicle will deliver the payload to an apogee altitude between 4,000 and 5,500 feet above ground level (AGL). Teams flying below 3,500 feet or above 6,000 feet on Launch Day will be disqualified and receive zero altitude points towards their overall project score.	The mechanical subteam will design the rocket to reach an apogee of 4,750 feet, and the result will be demonstrated by the readout of the altimeters during test flights and on launch day.
Teams shall identify their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team's altitude score during Launch Week.	Our target altitude is 4,750 feet.
The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the Altitude Award winner. The Altitude Award will be given to the team with the smallest difference between their measured apogee and their official target altitude on launch day.	There will be at least one commercially available, barometric altimeter on the launch vehicle.
Each altimeter will be armed by a dedicated	Inspection will show that our recovery system

mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad. Each altimeter will have a dedicated power supply.	has been designed including these specifications.
Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	Our choice in arming switches will adhere to this guideline.
The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	There will be no expendable components on the vehicle. The vehicle will be re-armable following a launch.
The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	The PRT-01 will consist of three sections: A nose cone, the body tube (which contains the avionics bay) , and the booster section
Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length.	The lengths of the airframe shoulders were measured and compared to that of their respective diameter and it was found that the lengths are indeed at least their diameter. These values can be seen in figures 3.2.1a-e.
Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.	The length and diameter of the nose cone shoulder were measured and it was proved that the length was at least ½ its body diameter. These values can be seen in figure 3.2.1a.
The launch vehicle will be limited to a single stage.	The only motor used will be a single stage refuelable motor.
The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	The rocket will be capable of going through preflight preparations within two hours.
The launch vehicle will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board	All sensitive (namely electronic) components will be left idle in flight configuration for a minimum of two hours to ensure that the launch vehicle is capable of remaining in

components.	launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components.
The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider	The motor in use will be able to be launched with a standard 12-volt DC firing system. This will be verified by inspection.
The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).	The motor in use will require no external circuitry or special ground support to be launched. This will be verified by inspection.
The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	The motor used is a commercially available APCP fueled motor. APCP purchased will be certified by the NAR or TRA.
Final motor choices will be declared by the Critical Design Review (CDR) milestone. Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO) and will only be approved if the change is for the sole purpose of increasing the safety margin. A penalty against the team's overall score will be incurred when a motor change is made after the CDR milestone, regardless of the reason.	Motor has already been chosen through research. Further tests and research will ensure that the correct motor is chosen before the CDR milestone. If motor needs to be changed after this, the NASA RSO will be notified for approval.
Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria: ● The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews. ● Each pressure vessel will include a pressure relief valve that sees the full	Our final rocket design will not be utilizing a pressure vessel.

pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank. • Full pedigree of the tank will be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.	
The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).	Motors with impulses greater than 5,120 Ns will not be considered for our rocket.
The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	Masses within the launch vehicle and fin surface area will be adjusted as necessary throughout design process to ensure stability margin is greater than 2.0
The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	The motor will be chosen to ensure that the launch vehicle will accelerate to a velocity greater than 52 fps at the point of rail exit.
All teams will successfully launch and recover a subscale model of their rocket prior to CDR. Subscales are not required to be high power rockets.	A subscale rocket will be manufactured and launched prior to the CDR deadline.
The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale will not be used as the subscale model.	The subscale rocket has same design as the full-scale model but smaller to ensure the subscale performs as similarly as possible to the full scale rocket. The subscale rocket is not full-scale size.
The subscale model will carry an altimeter capable of recording the model's apogee altitude.	Two Perfectflite StratoLoggerCF altimeters will be used on the subscale model.
The subscale rocket must be a newly constructed rocket, designed and built specifically for this year's project.	Our team will have designed and fabricated the subscale rocket starting September 2018.
Proof of a successful flight shall be supplied in the CDR report. Altimeter data output may be used to meet this requirement.	This altimeter output from the subscale flight will be included in the CDR.

An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA required Vehicle Demonstration Re-flight after the submission of the FRR Report.	If PRT requires a NASA required Vehicle Demonstration Re-Flight or a Payload Demonstration flight, an FRR addendum will be submitted to NASA after the FRR report.
Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline will not be permitted to fly the vehicle at launch week.	PRT will complete a Vehicle Demonstration Re-Flight if necessary, in a timely manner to ensure FRR Addendum is submitted by the correct deadline.
Teams who successfully complete a Vehicle Demonstration Flight but fail to qualify the payload by satisfactorily completing the Payload Demonstration Flight requirement will not be permitted to fly the payload at launch week.	The Pitt Rocketry Team will complete all tasks by their deadlines.
Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload at launch week. Permission will not be granted if the RSO or the Review Panel have any safety concerns.	The Pitt Rocketry Team will complete all tasks by their deadlines.
Any structural protuberance on the rocket will be located aft of the burnout center of gravity.	All structural protuberances such as fins will be located aft of the center of gravity after burnout.
The team’s name and launch day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.	This information will be listed on the fins of the rocket, verifiable by inspection. Additionally, it will be listed on the top of the rover.
Vehicle demonstration flight	
All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown must be the same rocket to be flown on launch day. The	Our final, full-scale design of the rocket will be tested prior to FRR in its final flight configuration. This will be done at local launchings in an audience and supervision of

purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.).	trained and accredited rocket specialists, as well as general rocket hobbyists.
The vehicle and recovery system will have functioned as designed	The vehicle and recovery system will be thoroughly researched and tested to ensure it functions as designed.
The full-scale rocket must be a newly constructed rocket, designed and built specifically for this year's project.	The full scale rocket is a newly constructed rocket built and designed by PRT for the NASA 2019 Student Launch competition.
The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply: ● If the payload is not flown, mass simulators will be used to simulate the payload mass. ● The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.	If payload is unable to be flown on Vehicle Demonstration flight, a mass will be added to simulate the mass of the payload and located in the same area as the payload.
If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale Vehicle Demonstration Flight.	The PRT payload is not designed to change the external surface of the rocket, but if payload design changes to affect the external rocket surface the external systems will be active during the full-scale Vehicle Demonstration Flight
Teams shall fly the launch day motor for the Vehicle Demonstration Flight. The RSO may approve use of an alternative motor if the home launch field cannot support the full impulse of the launch day motor or in other extenuating circumstances.	The launch day motor will be used during the Vehicle Demonstration Flight. If launch field cannot support full impulse of launch day motor on Vehicle Demonstration Flight, an alternative motor will be used with the approval of the RSO.
The vehicle must be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the launch day	A check will be performed to verify that the vehicle flown during the full-scale test flight is in its fully ballasted configuration.

flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.	
After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).	Following the successful completion of the full-scale demonstration flight, the launch vehicle and its components will not be modified without the concurrence of the NASA Range Safety Officer.
Proof of a successful flight shall be supplied in the FRR report. Altimeter data output is required to meet this requirement.	The recovery altimeters will collect and store flight data in their on-board loggers. The flight data will be recovered following the flight for use in the FRR report.
Vehicle Demonstration flights must be completed by the FRR submission deadline. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. This extension is only valid for re-flights, not first-time flights. Teams completing a required re-flight must submit an FRR Addendum by the FRR Addendum deadline.	The team will ensure that the Vehicle Demonstration flights are completed by the FRR submission deadline. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary and an extension is granted, the team will submit an FRR Addendum by the FRR Addendum deadline.
Payload Demonstration Flight	
The payload must be fully retained throughout the entirety of the flight, all retention mechanisms must function as designed, and the retention mechanism must not sustain damage requiring repair	The retention mechanism will be designed such that the payload is always supported and rigid during flight. The deployment stepper motor will be powered and apply a holding torque so any of the components don't move inadvertently.
The payload flown must be the final, active version.	The final version of the rover will be ready before the payload demonstration flight.
If the above criteria is met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required.	If the payload is ready by the Vehicle Demonstration Flight, it will be flown during that flight.
Payload Demonstration Flights must be completed by the FRR Addendum deadline. No	The team will ensure that the Payload Demonstration Flights are completed by the

extensions will be granted	FRR Addendum deadline.
Vehicle Prohibitions	
The launch vehicle will not utilize forward canards. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.	The vehicle will be designed to not contain any forward canards or camera housings. This is verifiable by inspection.
The launch vehicle will not utilize forward firing motors.	The vehicle design will not utilize forward firing motors. This is verifiable by inspection.
The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	The vehicle design will not utilize that expel titanium sponges. This is verifiable by inspection.
The launch vehicle will not utilize hybrid motors.	The vehicle design will not utilize hybrid motors. This is verifiable by inspection.
The launch vehicle will not utilize a cluster of motors.	The vehicle design will not utilize a cluster of motors. This is verifiable by inspection.
The launch vehicle will not utilize friction fitting for motors.	The vehicle design will not utilize friction fitting for motors. This is verifiable by inspection.
The launch vehicle will not exceed Mach 1 at any point during flight.	The motor utilized and the overall final design of our rocket will be incapable of producing enough thrust force to achieve Mach 1.
Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad (i.e. a rocket with and unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast).	The ballasted weight of our rocket design will be checked prior to launch and made sure not to exceed 10% of the unballasted weight. This will be done by calculating and summing the individual weights of the parts, then comparing it to the weight expected to be used for unballasting purposes.
Transmissions from onboard transmitters will not exceed 250 mW of power	The transceivers and antenna used will be incapable of transmitting a signal of 250 mW of power.
Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but	Only the desired and appropriate amount of metal needed for our design will be used. Likewise, dense metal will not be used.

limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	
Recovery System Requirements	
The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the RSO.	The recovery system is designed to stage the deployment of the drogue and main parachutes, with the main to be deployed at a lower altitude.
Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full-scale launches.	This test will be performed before both initial launches.
At landing, each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.	Appropriate parachute sizes to reduce the kinetic energy of the rocket below 75 ft-lbf have been calculated and will be used in the recovery system.
The recovery system electrical circuits will be completely independent of any payload electrical circuits.	The recovery system electrical circuits have been designed to be completely independent of all other electrical circuits on the vehicle. The recovery system will be tested and verified independent of the rest of the vehicle.
All recovery electronics will be powered by commercially available batteries.	The recovery system design includes only commercially available batteries.
The main parachute shall be deployed no lower than 500 feet.	The altimeters will be tested to confirm that they can precisely deploy the main parachute at a height greater than 500 feet. Analysis of the flight logs will verify that this requirement is satisfied.
The apogee event may contain a delay of no more than 2 seconds.	The altimeters will be tested to confirm that they can precisely deploy the drogue within 2 seconds of reaching the apogee. Analysis of the flight logs will verify that this requirement

	is satisfied.
The recovery system will contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.	The design of the recovery system includes two Perfectflite StratologgerCF altimeters, both able to activate the charges for the parachutes.
Motor ejection is not a permissible form of primary or secondary deployment.	The motor will not be ejected during flight.
Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Removable shear pins are used in the design of the parachute compartments.
Recovery area will be limited to a 2,500 ft. radius from the launch pads.	The recovery area will be limited to a 2,500 ft. radius from the launch pad based on the subscale design and simulations, as well as initial testing of the rocket.
Descent time will be limited to 90 seconds (apogee to touch down).	The descent time will be limited to 90 seconds. This will be done so based on simulations, the subscale design, and mathematical calculations.
An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver	All sections of the rocket are to be tethered to each other, allowing the GPS system in the avionics bay and the GPS system on the releasable payload to satisfy this requirement. The tethers will be chosen to withstand the tensile forces that may be imposed on them during flight.
Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic tracking device.	The rocket and payload will be the only two separated components.
The electronic tracking device(s) will be fully functional during the official flight on launch day.	The GPS units will be powered and sending data at a constant frequency during launch and recovery. The batteries chosen for the rocket will have enough power to sustain this.
The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	The recovery system electronics will be in a separate compartment from all other on-board electronics.

The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	The recovery system electronics will be in a separate compartment from all other on-board electronics.
The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.	The compartment housing the recovery system electronics will be protected with radio frequency shielding.
The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	Any device that may create enough magnetic waves to affect the recovery system will be surrounded with a high permeability metal to prevent the waves from reaching the recovery electronics compartment. As of the current design, it is highly unlikely that this would be necessary, but proper magnetic protection can be verified through appropriate testing.
The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	Proper testing can verify that the recovery system will be unaffected by other onboard devices.
Payload Experiment Requirements	
Each team will choose one experiment option from the following list: • Option 1: Deployable Rover/Soil Sample Recovery • Option 2: Deployable UAV/Beacon Delivery	The team will build a deployable rover that will recover a soil sample after landing
An additional experiment (limit of 1) is allowed, and may be flown, but will not contribute to scoring.	The team will be flying any additional experiments so there is no verification plan in place.
If the team chooses to fly an additional experiment, they will provide the appropriate documentation in all design reports so the experiment may be reviewed for flight safety.	The team will not by flying any additional experiments so there is no verification plan in place.
Deployable Rover / Soil Sample Recovery Requirements	

Teams will design a custom rover that will deploy from the internal structure of the launch vehicle.	The team will develop a custom rover and a deployment mechanism inside the launch vehicle to deploy the rover upon landing and meeting deployment conditions.
The rover will be retained within the vehicle utilizing a fail-safe active retention system. The retention system will be robust enough to retain the rover if atypical flight forces are experienced.	The rover will be threaded into an aluminum rod and supported on both sides by solid surfaces. For active retention, the deployment stepper will be powered on during the flight and set to hold torque to avoid any movement.
At landing, and under the supervision of the Remote Deployment Officer, the team will remotely activate a trigger to deploy the rover from the rocket.	The avionics bay will be able to receive a remote signal to deploy the rover.
After deployment, the rover will autonomously move at least 10 ft. (in any direction) from the launch vehicle. Once the rover has reached its final destination, it will recover a soil sample.	The rover is designed to carry out these actions which will be verifiable by inspection.
The soil sample will be a minimum of 10 milliliters (mL).	The rover soil sample containment device and mechanism will be operated prior to launch and the containment device will be inspected following operation to ensure that a soil sample of at least 10 milliliters was collected. This test will be performed a statistically significant number of times to ensure that the rover reliably collects an adequate sample size.
The soil sample will be contained in an onboard container or compartment. The container or compartment will be closed or sealed to protect the sample after collection.	The rover soil sample containment device and mechanism will be operated prior to launch and the containment device will be inspected following operation to ensure that the device closed or sealed to protect the sample as intended.
Teams will ensure the rover's batteries are sufficiently protected from impact with the ground.	The rover's batteries will undergo stress tests to ensure that they are capable of withstanding impact with the ground. The tests will be performed such that the batteries are in as close to the same encasing and environment as will be present on vehicle landing.
The batteries powering the rover will be	The batteries on the rover will be covered in a

brightly colored, clearly marked as a fire hazard, and easily distinguishable from other rover parts.	bright non flammable material and marked with warning signs indicating a fire hazard.
Safety Requirements	
Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.	The team will develop a launch and safety checklist to be included in the FRR report and used in the Launch Readiness Review and any launch day operations.
Each team must identify a student safety officer who will be responsible for the following requirements: ● Monitor team activities with an emphasis on Safety during: Design of vehicle and payload, Construction of vehicle and payload, Assembly of vehicle and payload, Ground testing of vehicle and payload, Subscale launch test(s), Full-scale launch test(s), Launch day, Recovery activities, STEM Engagement Activities ● Implement procedures developed by the team for construction, assembly, launch, and recovery activities. ● Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data. ● Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	Thomas Sullivan Harrington has been identified as the student safety officer and will perform the listed requirements.
During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or	The team will not launch the vehicle designed for the NASA Student Launch at any NAR or TRA launch unless allowed by the local President or Prefect and RSO. If the team wishes to launch the vehicle at any NAR or TRA launch, a member will contact the President or Prefect and RSO for permission.

TRA launch.	
Teams will abide by all rules set forth by the FAA.	The team will read the rules set forth by the FAA and ask any necessary questions to ensure that the rules are fully understood.

Table 6.1.1.

6.1.2 Team Derived Requirements

Requirement	Verification
Vehicle	
Ensure that avionics bay is accessible	Bulkhead at access point will be removable such that the avionics bay can be removed from launch vehicle.
Outside of airframe is smooth	Airframe will be sanded and a clear coat will be added on top of sticker used to identify rocket.
Ensure fins are properly spaced and attached	Create and utilize a jig for fin attachment
Recovery	
Safely install black powder	Our NAR Level 3 certified mentor will handle and load the black powder.
Break shear pins during recovery deployment	Simulation and testing will confirm that the black powder is able to appropriately break the shear pins.
Prevent parachute from tangling with itself	Parachute ejection tests and simulations of parachute placement will verify that the parachute does not tangle during recovery
Payload	
Ensure rover is rigid when held in its enclosure	Extensive testing will confirm that the rover stays secured under various loads
Ensure rover egress is not hindered by any launch vehicle components such as bulkheads or shock cords.	Simulate landings and test rover deployments. Adjust stepper motor power and speed until reliable deployment is confirmed

Wheel scoops should work in a variety of soil conditions	Test and refine scoop design to make it work in different soil conditions
Wheel scoop valves should open to allow maximum soil contaminant for a given internal volume	Build various prototypes with different valves and hinge angles to choose the best design
Ensure that the obstacle avoidance system works reliably	Test the rover with simulated obstacles

Table 6.1.2.

6.2 Testing

After determining which tests are required, component and system test procedures are being developed. For the avionics team, these procedures are being created by team members unassociated with the design of the relevant component or system. This preserves the validity and rigor of these tests, which will be carried out by a third party not involved with development of a given system or its test. Figure 6.1 shows a diagram included in the test procedure for the altimeters. For the mechanical and payload teams, testing procedures will be developed by members working on that system, as they have the most knowledge of the system and what aspects of it need to be tested. These tests will be reviewed by other members of the team and our mentor to ensure their validity.

Required Test	Objective	Success Criteria	Reason for Necessity	Potential Outcomes or Alterations
Black Powder Sectioning Test	To ensure that the black powder does not prematurely ignite and appropriately separates rocket sections	Black powder is secured and able to ensure separation of rocket sections by breaking the shear pins	The recovery system will either fail by becoming active too early or not becoming active (if the black powder fails to ignite only from the electric matches)	Change security method Create an auxiliary match ignition option Choose different shear pins
Shock Cord Durability Tests	To ensure that the shock cords we purchase can survive flight and prevent sections	Shock cords can withstand the forces predicted from simulations	Having sections of the rocket separate during the flight without a recovery system	Reevaluate choice in shock cords

	from separating		for each separable component is highly dangerous	
Wire Connection Tests	To ensure that wires do not detach from shock or any outside force	Wires do not disconnect avionic components under arduous stress testing	Wires that disconnect would lead to safety hazards during flight and would prohibit avionic function	- Redesign of wire connections
Computer Connection Tests	To ensure that the PC/laptop connects to the ground computer	PC/laptops connects to the ground computer	Without connection to the ground computer, the ground GPS transceiver will not work and the rocket might not be found after landing	- Purchase a new ethernet cable with a reliable connector that will not fall out of the laptop/PC port
Computer Battery Tests	To ensure that the PC/laptop has sufficient battery percentage to complete the launch	PC/laptop has sufficient battery to complete the launch or is connected to a powers source during launch process	Without battery, the ground GPS transceiver will not work and the rocket might not be found after landing	- Reevaluate PC/laptop power cord length so that it is sufficient enough to connect to the computer
Ground Ejection Test for Drogue and Recovery Parachutes	To test the the active function of the recovery system	Parachutes are properly ejected on ground	The tests are required by the rules. It is important to have a recovery system that functions properly for safety purposes	- Redesign of parachute containment - Modification of recovery system
Recovery Altimeter Precision Verification (shown in figure	To test the precision of the barometric altimeters used to deploy the	Signals are sent to the drogue charges at apogee and main parachute at	The electronics of the recovery system are necessary to precisely deploy	Main parachute may need to be triggered at a slightly

6.2b)	parachutes	specifically set heights	the parachutes for a swift and safe recovery	greater height depending on the error of the device
Recovery Shielding Tests	To ensure that the recovery system is not exposed to interference from the rest of the electronics	Radio waves, magnetic waves, and electronics from the payload or avionics bay do not affect recovery altimeters	This is necessary for a safe flight and required by the rules	Additional shielding will be added
Avionics Bay System Test	To ensure that none of the components interfere with each other when operated from the same controller	Avionics system functions as desired	The avionics bay is necessary to satisfy the electronic tracking requirement to deploy the payload	Software may need to be redesigned Components may need to be reoriented on bay
GPS Tracking	To test our ability to track the rocket's position via received GPS information	The rocket can be tracked over 1.5 miles away	The vehicle cannot be re-launched if it cannot be recovered	- Reworking of transmission hardware or software
HC-12 Range Verification	To ensure that the rocket can transmit messages from its recovery range	The transceivers can send messages up to 1.5 miles away.	The vehicle should be able to be recovered even in the event of landing outside the recovery area	Change transceiver module
Flight Preparation Practice	To ensure that our team can get the rocket ready for launch quickly and efficiently	The rocket is flight ready from storage within one and a half hours	The rocket must be capable of being prepared for flight at the launch site within 2 hours of the time the Federal	Change how components are stored Develop tools and software to speed up the process

			Aviation Administration flight waiver opens	i.e. a fast reset program for the payload
Flight Delay Readiness	To ensure that the vehicle can stay prepared for launch for up to two hours and still function properly	Vehicle remains flight ready and can have a successful launch two hours after being prepared	This is required by the rules	Batteries with more power can be added Potentially set up a remote power switch for the avionics bay and rover

Table 6.2.

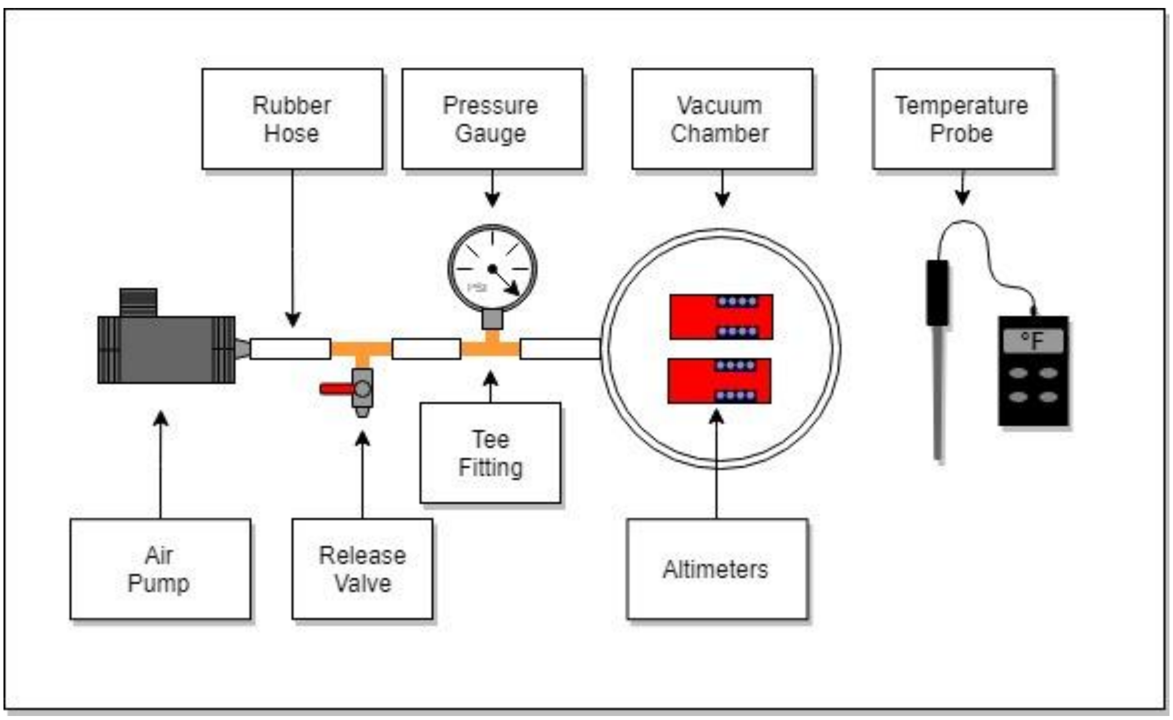


Figure 6.2.

6.3 Budgeting and Funding

Our team has procured multiple sources of funding from within our university and is working towards the acquisition of additional funds from other sources. Our first donor is the mechanical engineering department at the Swanson School of Engineering, which has granted us

$5,000. The Swanson School of Engineering itself will also be providing a further $5,000 for our team. One of the makerspaces located on campus has also supplied us with some materials that can be used in the production of our rocket. Other opportunities on campus that we are pursuing include fundraisers and a grant provided by the Student Government Board, which is a student run organization that can allocate funds to student groups on campus through an application process. Both of these sources can be used to supplement any travel or manufacturing expenses.

We are also making an effort to contact and establish relationships with local companies in order to secure funding, materials, sponsorship, and mentorship. Pittsburgh features a thriving community of engineering firms and our main focus will be on those that have good ongoing relationships with the faculty and students here at the University of Pittsburgh. Our research into this is being conducted mainly with the University of Pittsburgh Alumni offices, as well as with other clubs regarding what companies are likely to sponsor Pitt engineering teams. Lastly, we have considered collecting dues from team members in order to create an emergency fund that will only be used should a major incident occur. These funds will be transferred into the budget of future teams should it not be necessary for the current team.

Whilst our current funding brings us close to our funding goal, we are anticipating for unexpected costs throughout the process therefore we will continue to establish funding even after our goal has been reached.

Description	Cost
K motor	$200
Subscale motor (x3)	$200
Rocket kit	$1,100
Parachutes	$200
GPS Receiver/Transmitter	$100
Microcontroller (x2)	$80
Altimeter (x2)	$130
Radio Transmitter	$90
Battery System	$150
Ejection System	$400
Building Materials	$550

Miscellaneous	$500
TOTAL	$3,700

Table 12: Vehicle budget.

Payload Budget

Description	Cost
Chassis	$500
Wheels	$300
Motor	$80
Battery System	$50
Miscellaneous	$300
TOTAL	$1,230

Table 13: Payload budget.

Business and Travel

Description	Cost
Advertisement	$70
Website Hosting	$40
Travel	$1,700
Lodging	$2,500
Model Launch (Falcon 9)	$50
Outreach	$250
Emergency Fund	$600
TOTAL	$5,210

Table 14: Business and travel budget.

Total Expenses

Description	Cost
Vehicle	$3,700
Payload	$1,230
Business and Travel	$5,210
TOTAL	$10,140

Table 15: Total expenses for competition.

6.4 Timeline

The updated timelines for the subteams responsible for design and fabrication are shown in Figures 6.4a-d. We believe that these are more realistic projections for the design process than what was originally shown in our proposal. So far, all subteams are either on track with their timeline or slightly ahead.

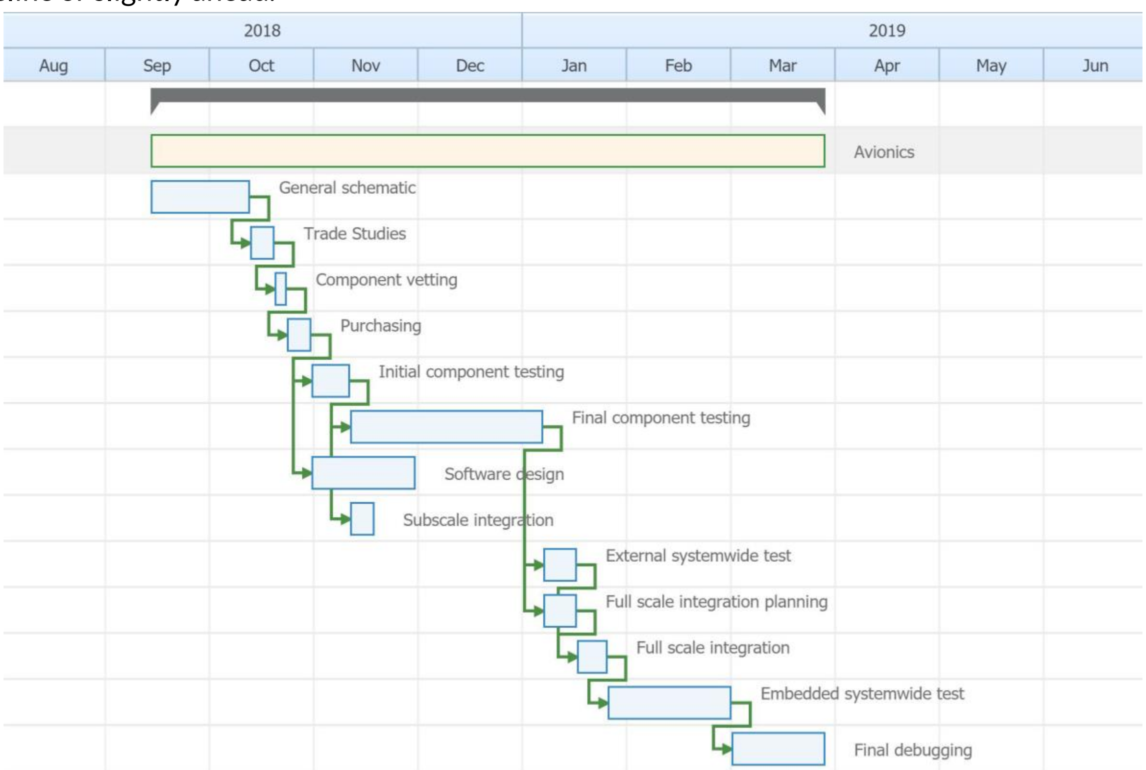


Figure 6.4a: Avionics subteam timeline.

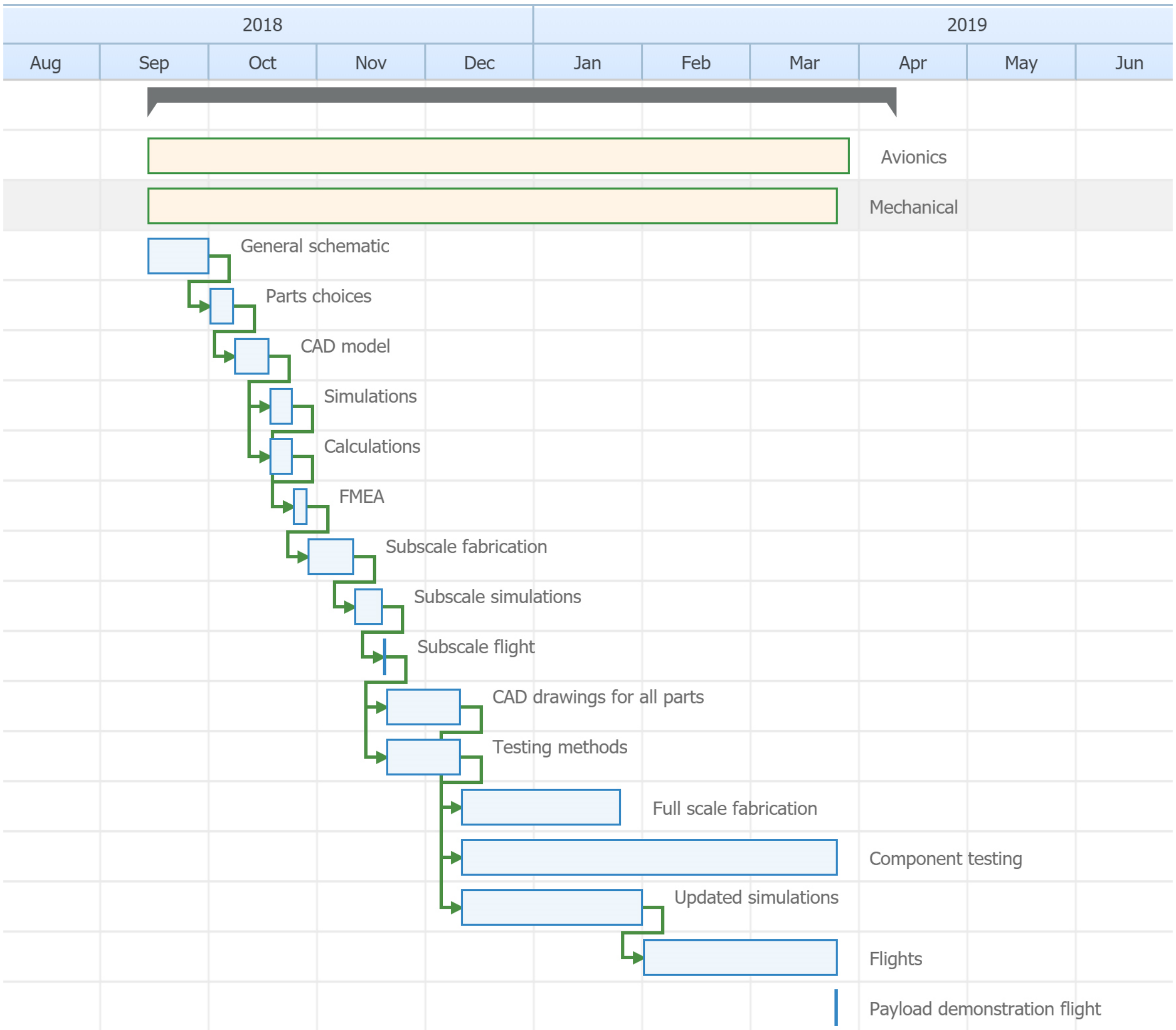


Figure 6.4b: Mechanical subteam timeline.

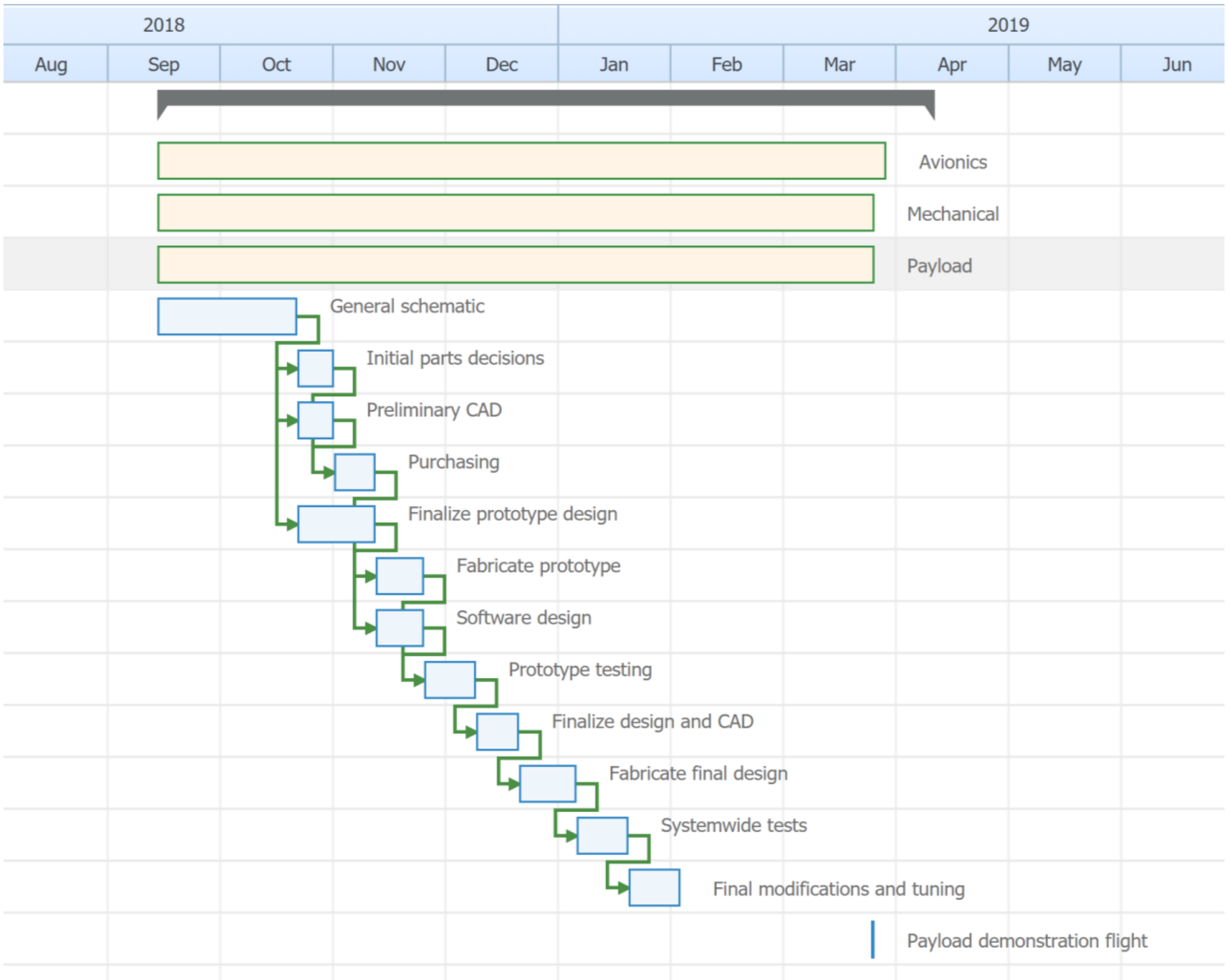


Figure 6.4c: Payload subteam timeline.

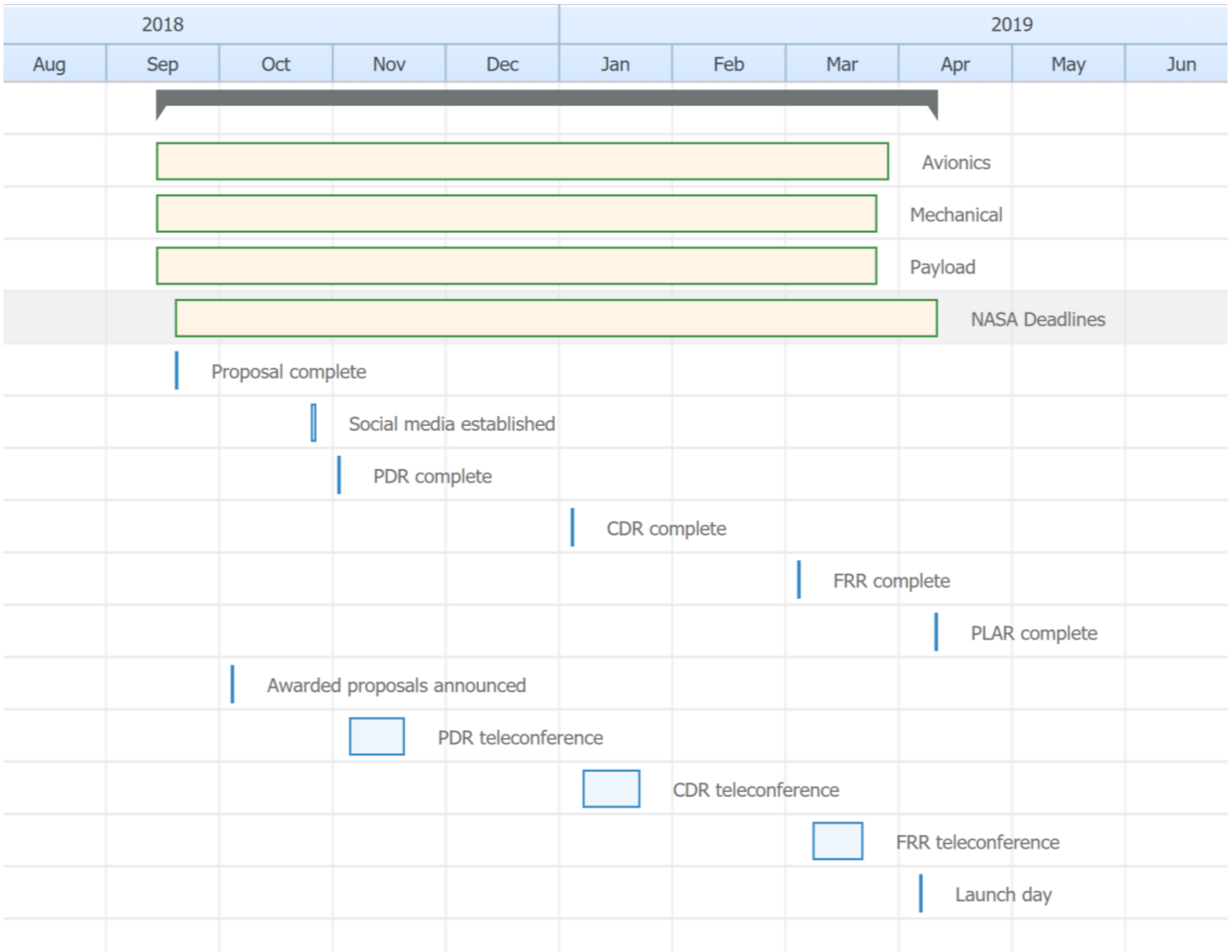


Figure 6.4d: NASA deadlines.

The projected STEM education timeline has not changed since the proposal as shown in Table 6.4e.

School	Event Date	Expected Attendees
Norwin Senior High	To Be Determined - Late November	250
New Brighton Elementary	03/14/2019	60
Bethel Park High School	To Be Determined -Late January to Early February	75

Table 6.4e: Projected STEM education timeline.

7 Appendix

7.1 References

Glenn Safety Manual – Chapter 1A from NASA - Glenn Research Center https://www.grc.nasa.gov/wp-content/uploads/sites/82/chapter_01a.pdf

7.2 Decision Matrix Criteria

All decision matrices follow the following score classifications unless otherwise stated.

Score (S)	Qualitative descriptor
$S \leq 2$	Very Poor
$2 < S \leq 4$	Poor
$4 < S \leq 6$	Fair
$6 < S \leq 8$	Good
$S > 8$	Excellent