Rocket Team at UCSC

NASA Student Launch 2018-2019
Preliminary Design Review (PDR)
November 2nd, 2018

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1 Summary

1.1 Team Summary

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1.2 Launch Vehicle Summary

Table 1.1 describes the general vehicle characteristics as determined from the SolidWorks CAD model, online information and the OpenRocket simulation software.

Length (feet)	Diameter (inches)		Mass (lbs)	Motor Selection	Recovery System		Predicted Altitude (feet)	Vehicle Material	CG	CP
	Outer	*Inner*			*Drogue (in)*	*Main (in)*				
7.75	5.52	5.36	14.38	AeroTech K560W	15	58	5280	Carbon Fiber	40	27

Table 1.1 General launch vehicle information

1.3 Payload Summary

Payload Title: *Slim Sammy*

Slim Sammy is the team's answer to the soil sample collection payload challenge. The rover has been designed to be safely and securely housed within the rocket's air frame during flight, deploy upon landing with the proper orientation correction, drive a minimum of 10ft from the landing sight taking into account the vast range of possible terrains, collect at least 10mL of soil, and seal the sample. The rover features a 3D printed unibody chassis driven by two independently driven silicone tracks. This enables the rover to traverse a majority of the expected terrains and perform obstacle avoidance maneuvers. Once the rover has reached a minimum of 10ft from the landed rocket airframe, the bull-dozer like soil sample collection scoop will deploy. The rover will then drive forward (further away from the rocket) and collect the soil sample. The scoop will then be returned to the closed position, pressed up against the sealing lid to complete the collection task.

2 Changes Made Since Proposal

Tables 2.1 to 2.4 document a number of changes that have been made to proposed designs in order to increase efficiency and safety, and decrease cost and build complexity.

2.1 Vehicle Changes

Change	Rationale
The air frame has been expanded from 4” OD to the 5.5” OD standard.	Preliminary payload designs indicated that a larger airframe was need for accomodation.
A single recovery separation point is planned rather than the proposed two. This change also requires the transition back to the black powder charge drogue parachute deployment followed by the Jolly Logic Chute Release main deployment.	In order to house and deploy the rover from a segment not affected by a charge, the new separation scheme was adopted.
The rover deployment method has changed such that the payload section is separated from the airframe via a black powder charge on the ground followed by the rover driving through a door to exit the ejected payload section.	This method best isolates the rover from the ejection charge by featuring a hinged firewall which the rover will pass through when deployed and eliminates any chord or structural pass through the rover housing.
Inclusion of rover orientation correction device when vehicle has landed and received deployment signal.	The team determined that the payload’s landing orientation must be controlled so an active correction system was developed to deploy the rover upright..

Table 2.1 Changes made to the airframe and launch vehicle

2.2 Payload Changes

Change	Rationale
A single sided soil sample collection device has replaced the proposed dual sided scoop.	Given the new design change to control the orientation of the rover upon landing, a single scoop will maximize the collection volume.
A bulldozer-type scoop has replaced the rubber seal design.	A bulldozer will be able to penetrate more dense soil.
The soil sample collection scoop has been moved to the front of the rover as opposed to the middle location shown in the proposal.	This configuration makes better use of the available volume.
The rover will be using an ultrasonic rangefinder for obstacle avoidance, rather than a bumper sensor.	Detecting a bump, calculating where to back out, and re-calculating distance traveled is more complicated than avoiding obstacles before encountering them.

Table 2.2 Changes made to the payload and its associated systems

2.3 ADaptive Aerobraking System (ADAS)

Change	Rationale
Motor changed from NEMA-17 to NeveRest 40 12V Gearmotor	Higher torque motor 350oz-in with lower weight for updated minimum torque threshold
Battery changed from Tau 3s LiPo Battery Pack 45C (11.1V/850mAh) to GOLDBAT (14.8V/1300mAh)	A stronger battery was needed to power ADAS
Time for full deployment of ADAS fins reduced from 2.1s to 0.375s	0.375 seconds for full deployment (1 rotation = full deployment, 60s/160RPM = 0.375s)

Table 2.3 Changes made to ADAS

2.4 Project Plan Changes

Change	Rationale
Set proactive deadlines for sub-documents	The team has been struggling to meet deadlines.

Table 2.4 Changes made to the team's project plan

3 Vehicle Criteria

3.1 Mission Statement

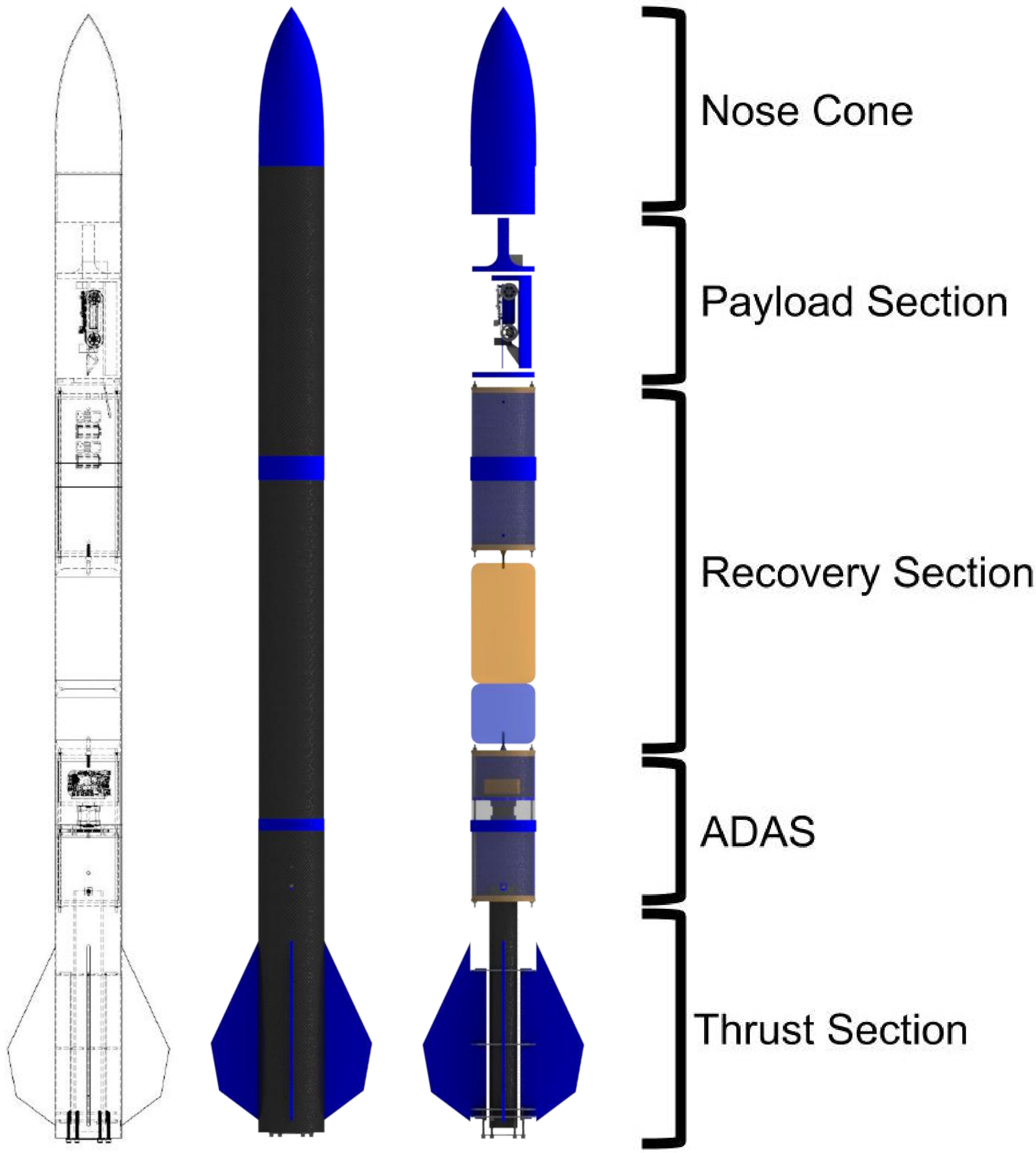
The launch vehicle, Aeolis, will successfully reach the predicted apogee, land safely without damage, and deploy the soil sample collection rover, Slim Sammy. The Adaptive Aerobraking System (ADAS) will guide the rocket to the predicted apogee.

3.2 Mission Success Criteria

Paramount to mission success, the rocket must land safely in a condition fit for reuse. However, should any aspect of the recovery fail, the mission will be considered a failure. The deployment of the soil sample collection rover is mission critical, while the failure of the rover to collect a sample shall be evaluated as an error in design, or abnormally harsh landing terrain and obstructions. If ADAS does not deploy, the mission shall be considered a partial failure.

3.3 Vehicle System Level Design

Figure 3.1: Overall Rocket Design



3.3.1 Airframe

The airframe is the primary structure of the rocket. It provides mounting rigidity and the aerodynamic shielding to the rocket's numerous other components. A lightweight airframe is preferable to minimize overall vehicle mass, but not at the cost of structural integrity. A number of options were considered in the following design matrix:

		Options									
		Carbon Fiber (Cloth Roll)		Carbon Fiber Donation		Fiberglass		Blue Tube		Carbon Fiber (Winding)	
Selection Criteria	W	S	WS	S	WS	S	WS	S	WS	S	WS
Strength	5	5	25	5	25	4	20	3	15	5	25
Weight (density)	4	5	20	5	20	2	8	4	16	5	20
Cost	5	3	15	5	25	3	15	5	25	5	25
Construction Complexity	3	3	9	2	6	4	12	4	12	3	9
Coolness factor	2	5	10	5	10	4	8	3	6	5	10
Safety	3	4	12	4	12	3	9	5	15	4	12
Availability	3	4	12	2	6	4	12	4	12	4	12
Total Score		105		104		84		101		113	

Carbon fiber in general seems to be the leading option, with Blue Tube as a close second, but Fiberglass will no longer be considered as an airframe material due to is low score. While Blue Tube scored low in the primary strength category, it has numerous other features that raise its score to be competitive. The team is pursuing the option of winding our own airframe, leveraging a donation of carbon fiber filament and newly gained access to an X-Winder.

The selection of the proper diameter is also crucial to a good airframe design. After much consideration and debate, the following design matrix informed the team's decision:

		Options (by interior diameter)							
		3 inches		4 inches		5 inches		5.5 inches	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Cost	2	5	10	4	8	3	6	3	6
Weight	2	4	8	3	6	2	4	2	4
Size for cargo (Volume)	5	1	5	3	15	4	20	5	25
Ease of construction	2	5	10	4	8	3	6	2	4
Total Score		33		37		36		39	

The 5.5 inch airframe provides the largest payload segment volume at a slight weight penalty and increased drag. A transitioning vehicle diameter was also considered, but rejected for manufacturing complexity and concerns about aerodynamic stability. The 5.5 dimensions, specifically the 5.52 inch OD and 5.36 inch ID were selected to match commercially available airframe materials. This enables compatibility with off the shelf components and allows for the purchase of standard airframe material as a last resort.

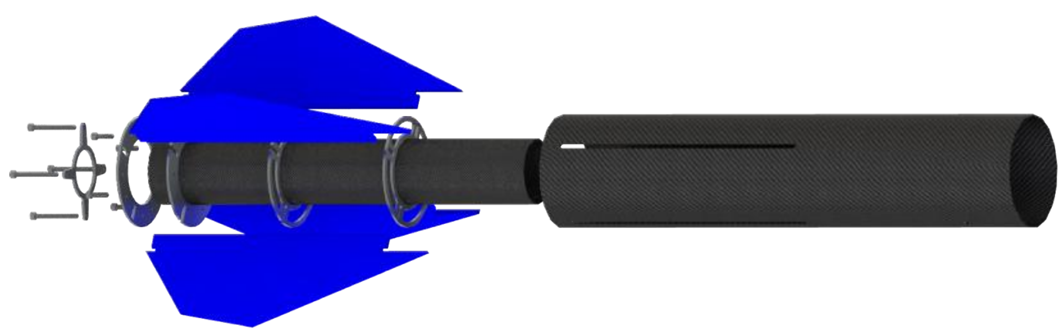


Figure 3.2: Fin section of the Rocket

The airframe also includes the thrust section of the rocket. While numerous other materials are available and were considered, a carbon fiber motor tube and aluminum centering rings are the leading design options for this segment. These materials can provide the strength necessary to handle the thrust load and leveraged to implement a removable-fin feature.

The area of the fins is determined to yield an acceptable CP value and thus a stability margin greater than 2.0. The sloping shape is selected to reduce drag.

The selection of the proper nose cone is also critical to air frame design. The following options were explored:

		Options					
		Ogive		Parabola		Cone	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Drag	4	3	12	5	20	2	8
Weight (density)	3	4	12	3	9	4	12
Cost	3	2	6	5	15	2	6
Coolness factor	1	4	4	5	5	3	3
Availability	4	4	16	1	4	4	16
Total Score		50		53		45	

The parabolic-shaped nose cone was strongest in drag but scored lowest in availability. To implement a parabolic nose cone shape, the component would need to be manufactured in-house. While potentially cost saving, this option strains the team's limited resources. The ogive shape was strongest in the availability, its commercial availability, and also performed decently on drag and weight. Thus it is the favored alternative to a parabolic nose cone. The conic shape was strong in the availability and weight aspects, similar to the ogive shape, but lacks in the drag aspect.

3.3.2 Payload

3.3.2.1 Landing Correction

When our rocket lands, it is necessary for the rover to deploy in an upright position. Therefore, a device or system is needed to house the rover and correct its orientation after landing. The system must be able to secure the rocket in-flight to mitigate CoG shifts and ensure that the rover deploys correctly upon landing. As the rover itself is not invertible, the deployment orientation of the rover upon landing must be guaranteed to be correct. Attention was needed for the design of the payload housing compartment within the rocket to ensure stability and guaranteed safe delivery.

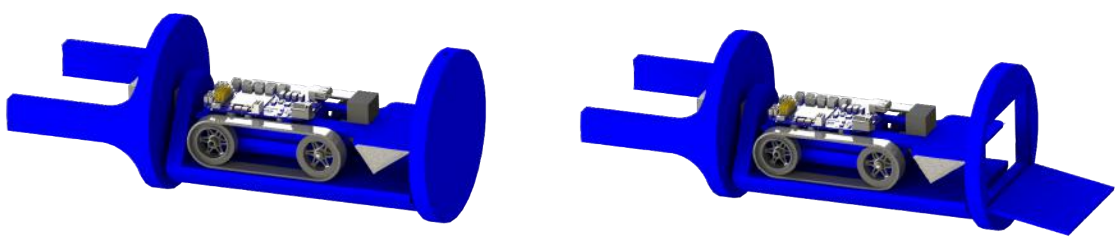


Figure 3.3: Payload deployment bay

3.3.2.1.1 Weighted Bearings

The weighted bearing system is an apparatus in which the rover and a weight is attached to a rotating bearing to correct the rover's orientation. While the weighted bearing system is a strong choice for its simple design and ease of integration into the rocket, the weight it adds to the rocket makes its implementation potentially infeasible. The weight imbalance it would introduce puts the in-flight stability at risk due to the underlying principle of one side needing to be heavy enough to shift orientation.

3.3.2.1.2 Ball Bearings

This system uses ball bearings to correct the orientation of the rover stored in a tube inside the body of the rocket. Although this system adds less weight to the rocket than the weighted bearing system, it is overall more complicated to design and integrate into the rocket. The design would also decrease the already limited space for the rover.

3.3.2.1.3 Trade Study Matrix

The highest-priority factors in choosing the landing correction design were integration, alignment, and complexity. The integration category indicated the complexity of installation of the system within the rocket. The alignment category combined accuracy and reliability (reduction in risk of failure) of orientation correction. Complexity referred to the difficulty of designing and constructing the alignment system itself. The cost and added weight of each system were also considered but deem of lower priority than the other parameters.

		Options					
		Weighted Bearings		Ball Bearings		Computer Controller	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Design complexity	2	5	10	3	6	1	2
Weight	4	1	4	4	16	3	12
Size	5	3	15	4	20	4	20
Accuracy	4	3	12	1	4	5	20
Cost	1	4	4	5	5	2	2
In-flight stability	3	1	3	3	9	5	15
Total Score		48		60		71	

3.3.2.1.4 Computer Controller (Leading Choice)

The computer-controlled system is the best option to correct the orientation of the rover after landing. While this system is more complex to design and more difficult to integrate, its accuracy and reliability in aligning the rover paired with the space it provides compared to other systems makes it the preferred option. In addition, the in-flight stability and inherent braking mechanism with a DC motor make it the optimal choice.

3.3.3 ADaptive Aerobraking System (ADAS)

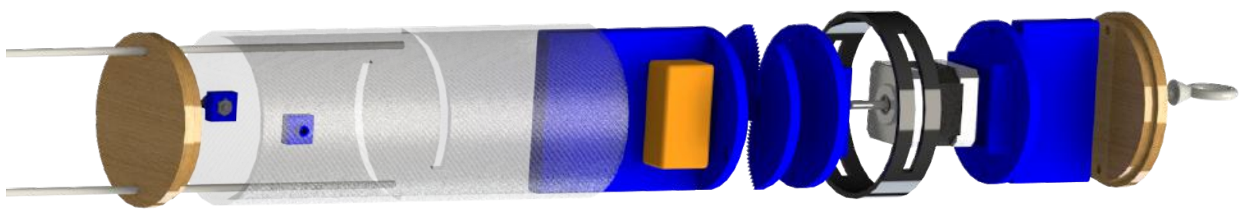


Figure 3.4: Exploded view of ADAS

Our models show that Aeolis may reach a maximum height of 5607ft, a 6.1% overshoot of the goal height of one mile AGL. ADAS is designed to attenuate the rocket's apogee to the desired altitude of 5,280ft (1609.34m) with arbitrary accuracy and minimal added turbulence. The deployment of two semi-circular fins from the interior of the rocket, perpendicular to the rocket's velocity vector, increases the rocket's cross-sectional area by 25%, thus increasing drag and reducing the vertical acceleration of the rocket in accordance with the drag-force equation,

$$F_D = ½ \rho(z) v^2 C_D A,$$

where ρ is the air density which depends on vertical position z, v is the rocket's vertical velocity, C_D is the drag coefficient (which will require numerical simulations to determine), and A is the reference area which increases as the fins are deployed.

The fins, depicted in Figure 3.5, are composed of 3D printed PLA material and are mounted between two plates by all-threads that run through the entire ADAS unit. Their shape was selected as that which maximized drag while minimizing turbulence in fluid simulations. The fins' deployment is controlled by a single 20-toothed gear between the fins. The gear is rotated by a shaft connected to a motor/encoder pair that is chosen to generate sufficient torque (350oz-in) to open and adjust the fins mid-flight at ~20Hz.

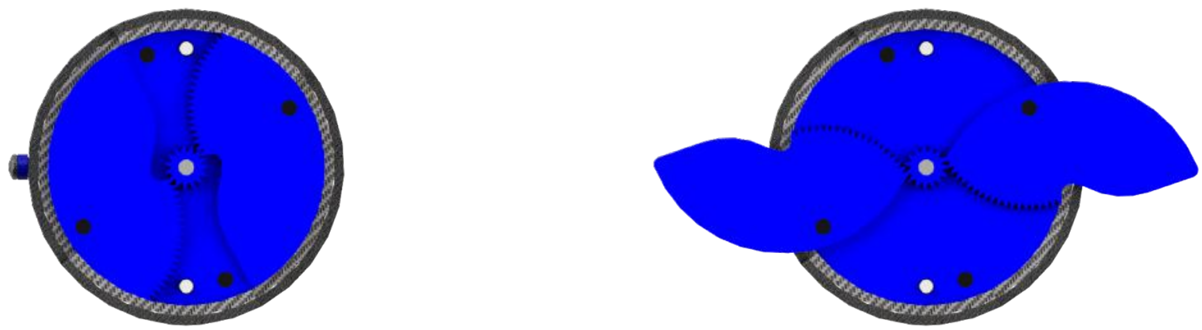
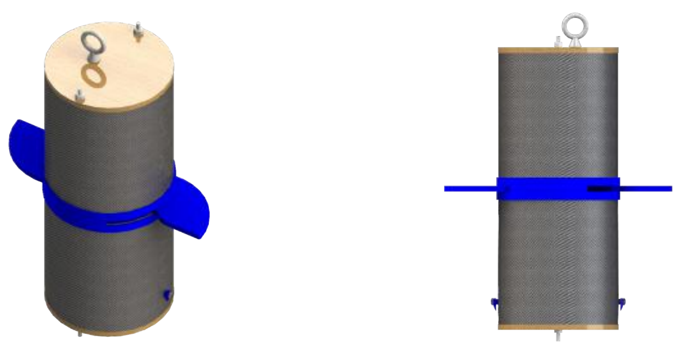


Figure 3.5: (Clockwise starting from upper left) ADAS closed, ADAS open, Angled 3D outer view, side on outer view



A deployment function for the fins is determined pre-flight and is adjusted by a control algorithm for the actuation of the motor which adjusts the fins' deployment angle in order to rectify deviations from the desired thrust-curve profile. This requires detection of several flight characteristics: launch, MECO, and apogee.

Launch is detected in order to conserve battery power and data storage space. It is determined as the instance where the accelerometer first detects acceleration greater than 8 times the g-force. This threshold ensures that pre-flight rocket movements are not misinterpreted as the launch event.

MECO, which indicates the initialization of the ADAS deployment protocol, is determined by the accelerometer as the point at which the acceleration of the rocket is only that of gravity — in other words, when the acceleration changes sign from positive to negative.

Once apogee is achieved, the ADAS fins will be fully retracted so that they are safely housed in the rocket when the rocket reaches Earth's surface. This point is calculated from the barometer measurements as the point at which the pressure begins to increase. As an additional safety measure, the fins will retract 20s after launch, a time which is guaranteed by simulations to be between the time of apogee and the landing time, if they have not done so already.

Mid-flight verification of successful deployment/retraction of the fins is necessary to ensure ADAS performs as simulated. Monitoring how the fins deploy at varying positions on the flight curve will indicate how closely the control algorithm and hardware are following ideal simulations. Performing testing and taking readings during the flight will also give insight about parameters that might be changed to achieve higher accuracy in the braking system.

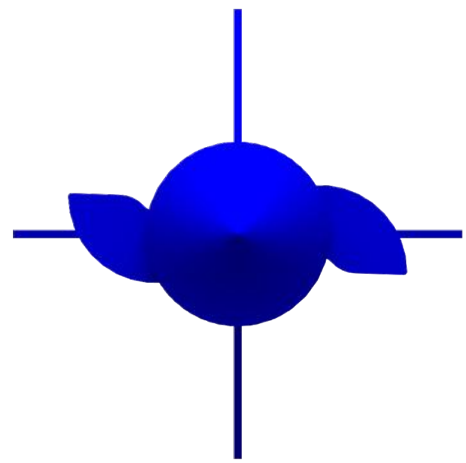


Figure 3.6: Top-down cross section of ADAS

The derived requirements set by the team to assess the system's performance rely on gathering a second set of feedback data outside the pre-established channels so as to verify the system and measurements. In order to test that the rocket reached the correct apogee a cross-verification of all onboard sensors will be performed. The deployment of the fins will also be monitored with an optical sensor feedback loop separate from the encoder that actuates the motors. This entails an optical sensor on the fins that measures the deployment angle as a function of counted pulses and will determine successful action of ADAS. This will deliver independent second check data on fin deployment.

Finally, flight curve analysis will be done by statistical measurement of the deviation between the simulated, ideal flight curve and the realized physical performance. Adjustments for inaccurate flight curves or a high margin of error will increase the accuracy of ADAS and will provide valuable feedback on the performance metrics.

3.3.3.1 Materials

The housing of the rocket will be created with the same material choice as decided for the entire airframe itself. The case around the housing unit will also be reinforced to improve strength. Due to the slots necessary for the fins' emergence from the rocket, the section near the ADAS system is inherently weak and experiences high stress, necessitating the reinforcement.

3D printed material was chosen as the fin material for its extremely high prototyping ability. Due to the necessity for the fins to be custom made, a feasible manufacturing process was needed with a high enough level of accuracy.

Figure 3.7: ADAS unit with support ring

3.3.3.2 Microcontroller

A microcontroller is needed to run the algorithm that determines when to deploy the aerobraking fins. It needs to: obtain and log data from sensors, perform calculations based on that data, and finally tell the motor to physically deploy and retract the fins.

3.3.3.2.1 Raspberry Pi 3 Model B+

The Raspberry Pi 3 is a strong choice due to its price, performance, and ample documentation but unfortunately it lacks onboard storage and has minimal features making it an unfavorable option.

3.3.3.2.2 Arduino Mega 2560 Rev3

The Arduino Mega, while cheap, suffers from poor performance. The lack of speed and RAM is made up for by EEPROM and onboard flash memory making this option better than the Raspberry Pi 3 but still not the optimal one.

3.3.3.2.3 Trade Study Matrix

Clock frequency and core count were combined in the speed category, this will dictate the ceiling that our algorithm is capable of achieving, therefore it has been given highest priority. Not much RAM is needed but it could potentially bottleneck the system if not sufficient giving it the second highest priority. The microcontroller is the lightest component in ADAS so weight is a low priority. Size is significant as the allocated space for

ADAS is compact. Storage is important but, as the code will be light and storage is cheap, it has low priority. Price is important because other components in ADAS such as motors and sensors will use a large fraction of the budget. Finally, connectivity (e.g., motor control, buses, peripheral, GPIO) contributes to ease of use but is not a requirement, so its weight in the trade study matrix is not as high as that of the other criteria.

		Options					
		Raspberry Pi 3 Model B+		Beaglebone Blue		Arduino Mega 2560 Rev3	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
SPEED	5	5	25	5	25	3	15
RAM	4	5	20	4	16	2	8
SIZE	3	5	15	4	12	4	12
WEIGHT	2	3	6	5	10	4	8
STORAGE	2	1	2	5	10	3	6
PRICE	4	5	20	2	8	5	20
CONNECTIVITY	3	2	6	5	15	3	9
Total Score		88		96		78	

3.3.3.2.4 Beaglebone Blue (Leading Choice)

The Beaglebone Blue is the strongest microcontroller option for ADAS. It is fast and has ample RAM to run the system. The board has a number of ports specifically for interfacing with the motor and sensors. The dedicated real-time CPU cores alongside a traditional dual-core CPU allow an operating system to be run on the board in addition to embedded software. This allows easier utilization of the CPU's multiple threads while maintaining the accurate timing that running embedded software affords. Although the Beaglebone Blue is the most expensive option on the list, the time it will save our programers will make up for the extra cost.

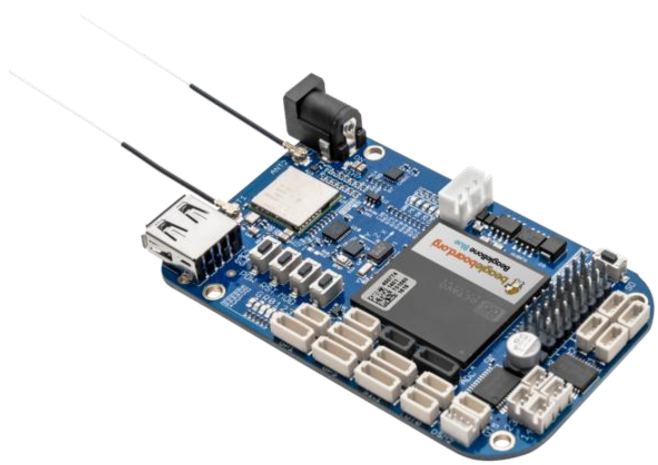


Figure 3.8: Beaglebone Blue board

3.3.3.3 Motor

A motor is necessary for mid-flight deployment, adjustment, and retraction of the ADAS fins. The choice of motor is critical because it must be strong enough to overcome the drag forces experienced by the fins and it must have adequate accuracy in its adjustment of the fin deployment angle in order to slow the rocket's ascent so that it reaches the desired apogee. It was decided that a minimum torque of 350oz-in is needed for successful mid-flight deployment of ADAS.

3.3.3.3.1 NEMA-17 Stepper Motor

The NEMA-17 Stepper Motor was considered because of its exceptional torque (566oz-in) and precision (0.035deg per step). In addition, it has a relatively small size in comparison with motors that have similar torque output and its power draw is low. The disadvantages of this motor are its high weight (620g) and high cost ($51).

3.3.3.3.2 Pololu DC Gearmotor

The Pololu DC Gearmotor was chosen to contrast the NEMA-17 Stepper Motor. Unlike the Stepper Motor, the Pololu Gearmotor has a low weight (235g), but it also has a low torque output (250oz-in). It is important to note that the torque of this motor is lower than the optimal torque of 350oz-in. As for cost, speed, precision, and dimensions, both motors performed similarly.

3.3.3.3.3 Trade Study Matrix

The driving motivation for the motor choice was in the motor's control of the position and deployment of the air-drag fins. Ideally, the motor will reliably implement a precisely-calculated deployment angle from the control algorithm without need for external monitoring. This means torque, speed, and precision in the motor are priorities to alleviate any overhead concerns.

In addition, the motor is projected to be one of the larger and also heavier components in ADAS. Due to this concern the weight and dimensions are heavy factors in the motor decision, with larger scores equating to smaller weights and dimensions. Since the projected length of ADAS is 10in and the total weight is 851g it was important to factor in these constraints when determining a motor choice from the candidates.

Lastly, the cost of any motor with the required torque, precision, speed, and size rarely exceeded $100, with the most costly motor in this study being half of that. In relation to the team's budget these prices are inexpensive, thus cost received the lowest weight.

		Options					
		Geared Stepper motor		Geared linear DC motor (1)		Geared Linear DC motor (2)	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Weight	5	2	10	4	20	5	25
Torque	3	5	15	4	9	2	6
Cost	1	2	2	5	5	3	3
Speed	2	2	4	4	8	3	6
Precision	3	5	15	3	9	4	12
Dimensions	4	4	16	4	16	5	20
Total Score		62		67		72	

3.3.3.3.4 NeveRest Gearmotor (Leading Choice)

The reigning motor option is the NeveRest 40 12V, 160RPM Geared DC Motor with a built-in encoder. Though this motor was not the top scoring motor in the trade study, the implications of its higher torque rating outweigh its lower scores for weight and dimensions in comparison with the top scoring motor. Calculations show that the weight and dimensions of this motor fit acceptably within the allocated space and weight for ADAS with the other ADAS components considered. Reliability in deployment is therefore prioritized over the smaller dimensionality for the motor choice.

3.3.3.4 Battery

A battery is needed to power all of the electrical components of ADAS, including the sensors, microcontroller, and motor. The battery needs to supply sufficient voltage and ampere hours to all of the components which was estimated to be within a range of 1000-2500mAh.

3.3.3.4.1 Gens Ace 2200mAh

The Gens Ace 2200mAh battery has the highest ampere hour rating of the three batteries considered in this study. It also has a low weight and low cost. However, these attributes are accompanied by a lower voltage than that of the other two, as well as a larger volume. Although it has the highest ampere hour rating, its lower voltage and higher volume justify not choosing this battery.

3.3.3.4.2 Turnigy Nano 1600mAh

The ampere hour rating of the Turnigy Nano 1600mAh battery falls between that of the GOLDBAT and Gens Ace batteries. Its voltage is the same as that of the GOLDBAT and is higher than the Gens Ace's. However the Turnigy Nano has a higher weight and cost than the others which makes the Turnigy Nano a less-desirable option.

3.3.3.4.3 Trade Study Matrix

The battery's voltage, ampere hour rating, and weight are important for the design of ADAS. It is critical to ensure that the battery has enough voltage for all of the components; calculations indicate that 12V will be sufficient. Voltage is given a weight of 2 because it is not anticipated that more than 11 or 12V will be needed. The most important aspect for choosing a battery was the ampere hour rating because all components must be powered for a sufficient amount of time. The weight of the ampere hour rating is 5 for this reason. The size of the battery was taken into consideration because it must fit into the housing for ADAS. Size is weighted at 2 because most of the batteries considered had small volume. The weight of the battery was important to consider because the weight of ADAS should be minimized, so it was weighted by 4. The cost was also a factor, but all considered batteries were so inexpensive that it was of less importance than the other aspects of the batteries, justifying its weight of 1.

		Options					
		GOLDBAT1300mAh		Gens Ace 2200mAh		Turnigy Nano Tech Plus 1600mAh	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Voltage	2	5	10	3	6	5	10
Ampere Hour	5	3	15	5	25	4	20
Weight	4	5	20	4	16	3	12
Cost	1	5	5	5	5	4	4
Size	2	5	10	2	4	5	10
Total Score		60		56		56	

3.3.3.4.4 GOLDBAT 1300mAh (Leading Choice)

The GOLDBAT 1300mAh battery fits ADAS's needs best because its voltage meets the required 12V minimum to power the components of ADAS and its weight and size are smaller than those of the Gens Ace and Turnigy Nano batteries. Though its ampere hour rating is the lowest, it is still sufficient to run ADAS for as long as is necessary. Thus the GOLDBAT battery was determined to be the most well-rounded battery for implementation in ADAS.

3.3.3.5 Inertial Measurement Units (IMU)

An IMU is important because it allows for easy implementation of sensor fusion. This saves the team time that would otherwise be spent programming the sensor fusion and troubleshooting the system. There are a wide variety of IMUs available on the market, each featuring varying levels of sensitivity, cost, and integration with microcontrollers and other electronic components. Only IMUs with larger levels of documentation and integration were considered for the purpose of ease of use.

3.3.3.5.1 Adafruit BNO055 9DOF IMU

The BNO055 is notable for its widespread use in a large number of applications, and as such the large prevalence of references on its usage. The IMU also comes with various sensors built in, so the team has to spend less time troubleshooting the functions of each sensor.

3.3.3.5.2 Raspberry Pi Sense HAT

Like the Adafruit BNO055 9DOF IMU, there is a significant amount of documentation for the Sense HAT's usage. The HAT, however, also comes with several features that are irrelevant to the function of ADAS. The HAT also requires the usage of a Raspberry Pi as a microcontroller which is somewhat limiting.

3.3.3.5.3 Trade Study Matrix

A much larger emphasis is being placed this year on ease of use. This is prioritized over accuracy because of several troubleshooting issues last year. Cost was also ranked as a high priority due to budget constraints. The scoring for cost was unintuitive because the three products in question also have varying amounts of prerequisite components. It was determined that weight was of minimal importance to the function of ADAS and the stability of the rocket.

		Options					
		Beaglebone Blue		Sense HAT		BNO055 9DOF	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Ease of Use	5	5	25	3	15	2	10
Cost	4	4	20	5	20	2	10
Weight	1	3	3	3	3	5	5
Accuracy	4	4	12	5	15	3	12
Total Score		60		53		37	

3.3.3.5.4 Beaglebone Blue (Leading Choice)

The team chose to use the IMU integrated into the Beaglebone Blue microcontroller because of several factors. Due to the fact that the microcontroller comes with the IMU and other components already built into it, the Beaglebone will save the team a significant amount of time that would otherwise be spent properly connecting the components and troubleshooting their functionalities. The team also recognized the Beaglebone Blue as an excellent choice as a microcontroller in comparison to its other competitors, and as such it would be troublesome to utilize an IMU that requires some other microcontroller to operate.

3.3.3.6 Motor Driver

The motor driver board will function as an intermediary interface between the microcontroller board and the physical motor. By abstracting this interface and delegating the control to a dedicated intermediary it provides two important gains:

1. Mitigated risk of blowing electronics by wiring high current outside of the microcontroller
2. Improved control and speed modulation with specialized electronics.

It was decided that all motor drivers need to be able to withstand at a minimum the stall current draw of our motor (11A), therefore only drivers meeting this sustained current output were considered.

3.3.3.6.1 30A High Current Dual Motor Module Full-bridge Driver for Arduino

The 30A High Current Dual Motor Module Full-Bridge Driver for Arduino is a breakout IC board that functions as a wrap-around for the VNH2SP30 IC driver chip. The chip itself is a full H-bridge module that integrates several MOSFETs along with input control signal correction and filtering. The driver chip is designed to handle large currents with a small voltage and input current and functions well in terms of its max output and peak current at 14A and 30A respectively. The size and weight were both the smallest of considered drivers. This small profile was not enough to overcome the deficiencies namely, the largest issue is with the ease of control. The board is adapted specifically for the Arduino, which makes it simple to integrate with Arduino boards but difficult to make work with other boards. For this reason this option was not used.

3.3.3.6.2 Cytron 13A, 5-30V Single DC Motor Controller

The Cytron 13A, 5-30V Single DC Motor Controller is designed by the same company as the optimal final choice with similar input and output characteristics, however with several important caveats. The board itself was more geared towards high precision industrial use and as such had much more onboard components. Because of this, the overall component weight and cost were higher. The combined detraction of these two characteristics took this component out of the running. The input characteristics were as straightforward as those of the final choice, with three pins controlling the speed and direction of the output. There were additional benefits in the control methods such as coupled PWM input and a higher frequency resolution. However, the motor in ADAS does not need such precise control, and these additional benefits were not enough to sway the decision in favor of this option.

3.3.3.6.3 Trade Study Matrix

The decision for a DC motor driver for ADAS was motivated by the need for a controller that will be easy to use and will have a minimal footprint in the overall system. In addition to this the component must be able to handle the maximum peak current pull of the motor at stall (11A) and not be too expensive. Since this component will be used solely for a single motor as an interface with the main control board, it must remain as a component role and not as a major resource drain in the overall design.

The plug-and-play mentality was deemed most important and a range of possible candidates fell on a range polarized between two sides: smaller highly modular component boards and larger boards that offered much more control and precision for a larger size and weight tradeoff. Candidates from both specialty providers and general purpose wholesale vendors were considered. Filtering out the minimal criteria, it was apparent that specialty providers guaranteed the needed details and specifications which narrowed the selection and ensures good documentation for the options.

		Options					
		30A Dual Motor Module Full-bridge Driver for Arduino		Cytron 13A DC Motor Drive		Cytron 13A, 5-30V Single DC Motor Controller	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Max current	1	5	5	2	2	2	2
Cost	2	5	10	4	8	2	4
Weight	5	4	20	5	25	1	5
Dimensions	3	5	15	3	9	3	9
Ease of Control	5	1	1	5	25	5	25
Total Score		51		69		42	

3.3.3.6.4 Cytron 13A DC Motor Driver

According to the trade study, the strongest choice for a motor driver is the Cytron 13A DC Motor Driver. This motor driver was the highest scoring component in the study by a comfortable margin. The reason being that the performance in two key categories, weight and ease of control, were the best out of all the considered options. While the dimensions of the chip are suboptimal, its performance in the two other key categories were more than enough to outweigh this small oversight, a finding supported by the trade study matrix. This motor driver will comfortably control the motor with minimal external monitoring and extra weight.

The other two options were ruled out due to their respective lower performances in ease of control and weight. Because of these performance detriments in these two key areas, coupled with the fact that the prime choice performed best in these two areas, the Cytron 13A DC motor driver was determined to be the best option.

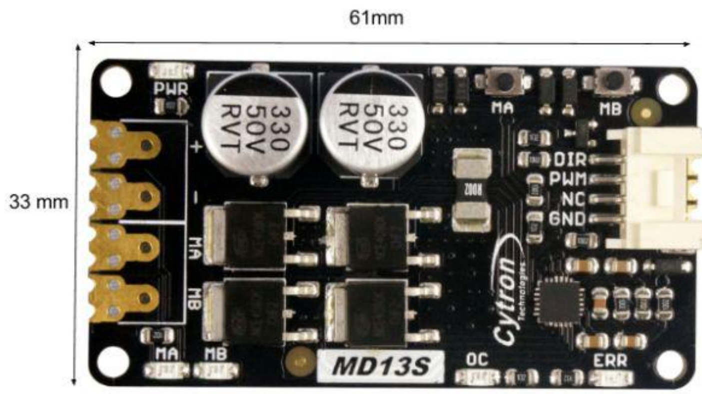


Figure 3.9: Cytron 13A DC motor driver

3.3.3.7 Software

The PID (proportional-integral-derivative) control algorithm will be hosted by the ARM processor and will be written in either C or Python. The algorithm manipulates real-time, Kalman-filtered sensor data to obtain values including the rocket's current acceleration, velocity, position, Euler angles, and pressure gradient. The data is stored onboard for post-flight analysis. The current state of the rocket is compared against a predetermined trajectory and the according adjustments are communicated to the motor. Additional programming is required for communication between the sensors, processor, and motor driver. Github will be utilized for all software for its version control and code management.

3.3.3.8 Testing ADAS

Several tests will be completed in an effort to verify the design choices and the overall effectiveness of ADAS. These tests are outlined in the following Table 3.1

ADAS Testing

ADAS Test	Test Details	Success Criteria	Failure Analysis
Fins and Gear	Finite element analysis (FEA) of the fins and gear will be necessary to ensure avoidance of slippage between and breaking of the parts during flight.	The fins are able to deploy when the rocket has high velocity without components breaking or slipping.	A detailed analysis of the failure mode will be completed. A design change will then be researched and discussed in the form of a Trade Study.
Structural Stability of Rocket at Fin Slots	The structural stability of the rocket at the fin slots — a potential weak point — upon landing will be tested with real-life drop tests with simulated weights.	The rocket does not break or bend at the fin slots upon impact.	A detailed analysis of the failure mode will be completed. A design change will then be researched and discussed in the form of a Trade Study.
Friction between Bearings and Plate	A test to verify that the bearings don't stick entails simulating a load on the bearings while deploying the fins.	The fins are able to fully deploy and retract without any issues	A detailed analysis of the failure mode will be completed. A design change will then be researched and discussed in the form of a Trade Study.

Table 3.1: ADAS testing Criteria

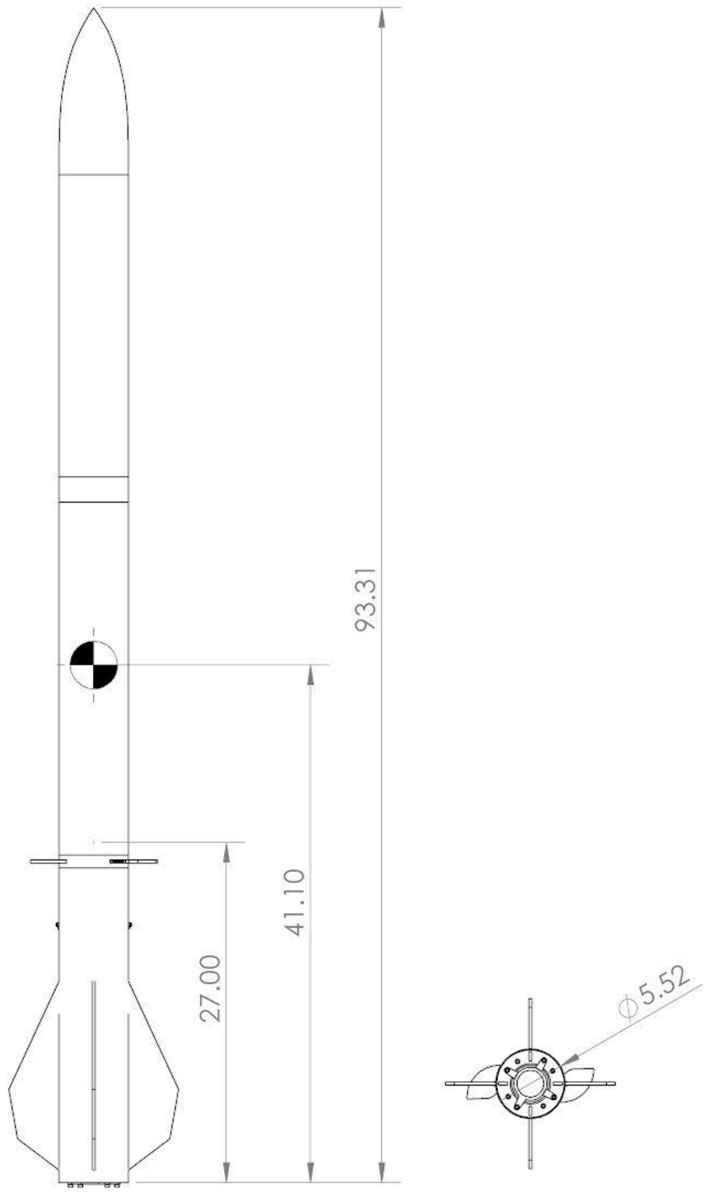
3.4 Preliminary Vehicle Design

Figure 3.10: Internal view of rocket

The vehicle is optimized to meet the challenges posed in this year's student launch initiative. The vehicle is divided into the following design sections:

- Thrust section
  - Designed to house the motor necessary to propel the vehicle to 1 mile and transfer the load to the airframe.
- ADaptive Aerobraking system (ADAS)
  - An active aerobraking system capable of correcting the vehicle's flight to most accurately reach the 1 mile apogee target.
- Recovery Section
  - Redundant systems ensure that the vehicle will land safely.
- Payload Section
  - Retains and deploys the soil sample collection rover payload, including active landing orientation correction.

Following are dimensional drawing of each system including the overall expected subsystem mass:



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL: CF Airframe

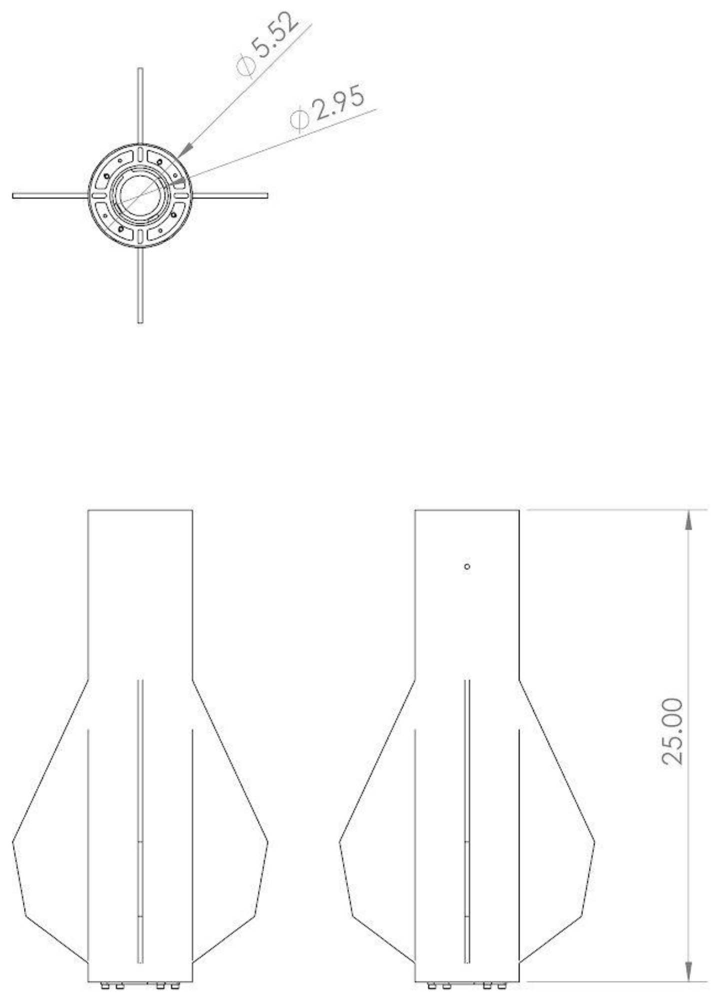
WEIGHT: 14.4lb

DWG NO. Rocket

A4

SCALE:1:24

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL: CF Airframe Al CRs

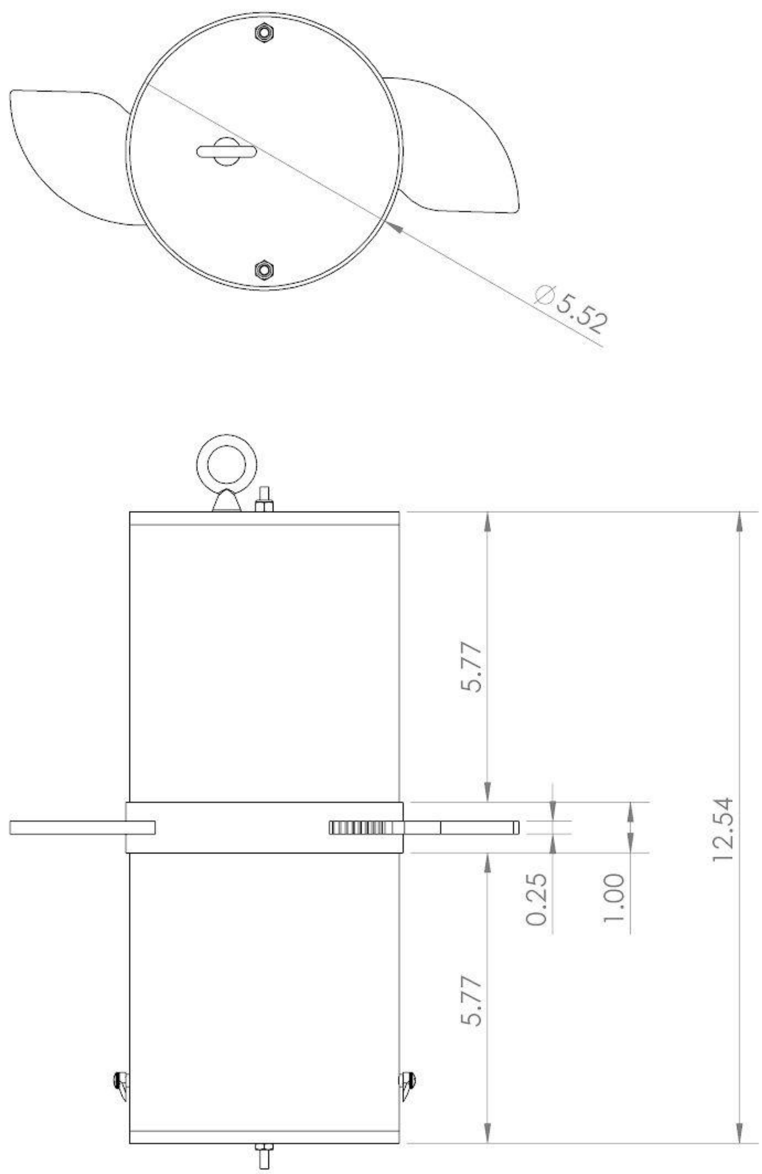
DWG NO. Thrust Section

A4

WEIGHT: 3.25 lb

SCALE:1:8

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

WEIGHT: 3.3lb

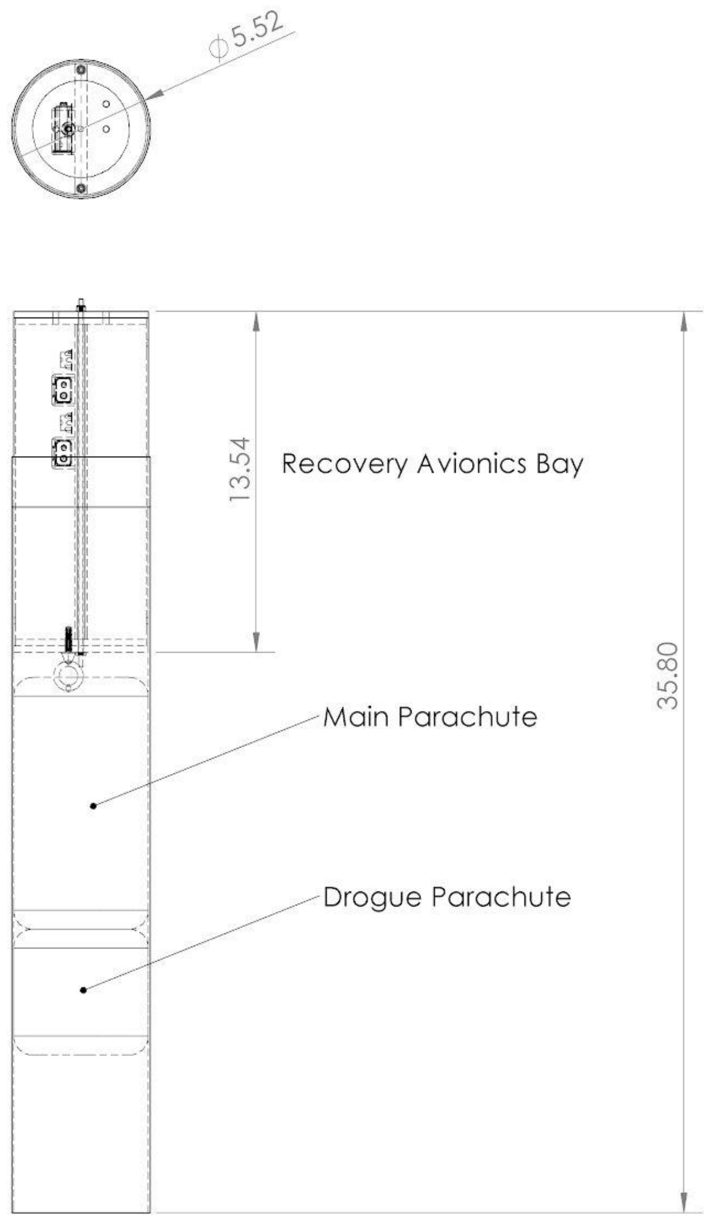
DWG NO.

ADAS

A4

SCALE:1:8

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

WEIGHT: 3.47lb

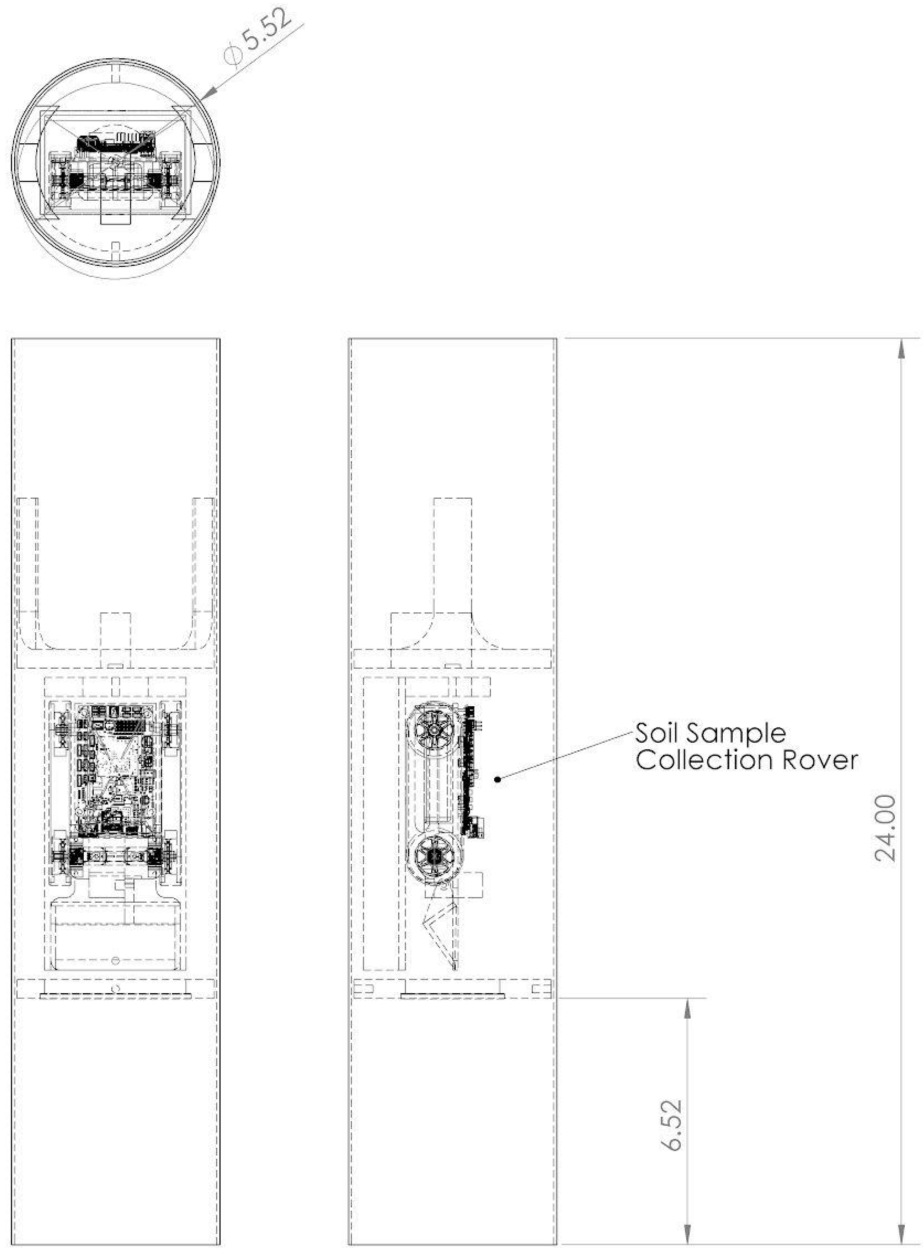
DWG NO.

Recovery

A4

SCALE:1:8

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

WEIGHT: 3.39lb

DWG NO.

Payload Section

A4

SCALE:1:8

SHEET 1 OF 1

3.5 Recovery Subsystem Design

3.5.1 Recovery Subsystem Overview

The recovery system features a two stage deployment system. The drogue is deployed at apogee, and the main is tied along the line and contained with Jolly Logic Chute releases. The main parachute is deployed at 500ft in an effort to minimize drift and landing energy in accordance with the following equation for kinetic energy,

$$KE = \frac{1}{2}mv^2.$$

The recovery subsystem utilizes two altimeters to deploy the parachute combo. This is to ensure that the parachutes are properly deployed and to minimize any risk.

3.5.2 Recovery Configuration Design

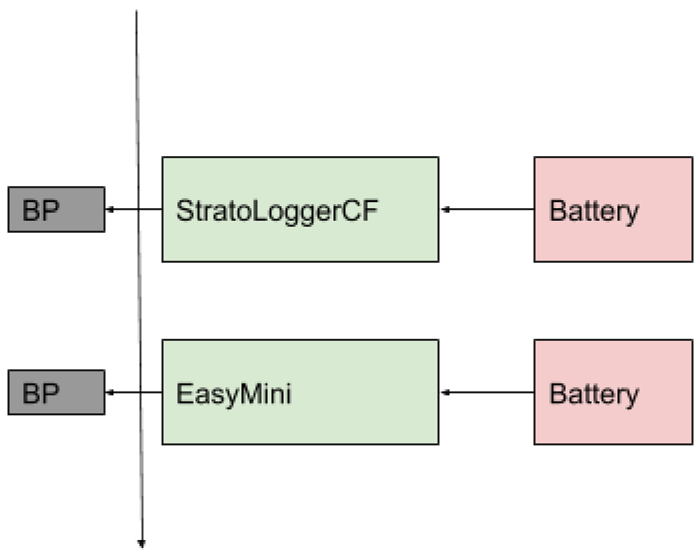


Figure 3.11: Altimeter wiring

3.5.3 Parachute Design

3.5.3.1 Main Parachute

From OpenRocket Simulations we have decided to use a 58in main parachute that will deploy at 500ft. We chose this parachute size based on the landing velocity and drift requirements.

3.5.3.2 Drogue Parachute

OpenRocket simulations let us to decide on a 15in drogue parachute deployed at apogee. This parachute keeps the vehicle within the drift requirements and landing energy requirements.

3.5.4 Parachute Deployment

At apogee, the drogue and main parachute are deployed. The drogue parachute unfurls, but the main parachute is contained using Jolly Logic Chute releases. Once the vehicle reaches 500ft, the chute releases open, allowing the main parachute to unfurl.

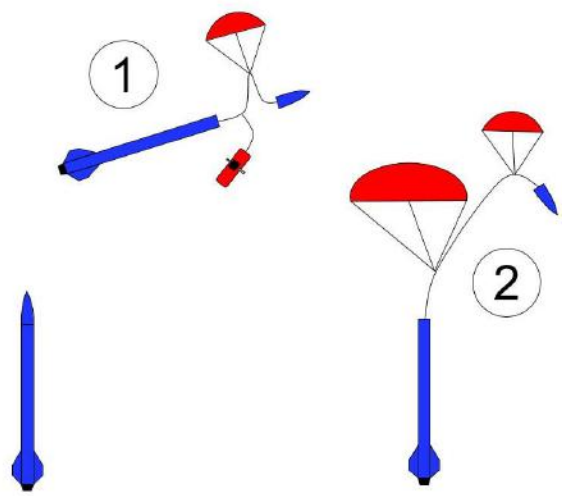


Figure 3.12: Chute deployment

3.5.5 Recovery Avionics

Recovery features two altimeters to deploy the parachutes, an EasyMini and StratoLoggerCF. We use two altimeters in an effort to increase redundancy and minimize catastrophic failures. Each altimeter has its own dedicated power supply and is wired separately from all other systems.

3.5.6 Safety and Redundant Systems

Through use of the dual deployment system and dual altimeter design, we hope to minimize risk and increase redundancy. Should one altimeter fail, the other is there to keep the mission from failing. The main parachute will be contained with two Jolly Logic Chute releases in series. If one fails, it does not prevent the other from activating.

3.6 Mission Performance Predictions

The OpenRocket modelling software is used for all mission performance predictions and analysis. Table 3.2 details the simulated drift values from OpenRocket.

	0 MPH	5 MPH	10 MPH	15 MPH	20 MPH
Main Parachute (58in)	8.2 ft	164 ft	387 ft	1150 ft	2400 ft
Drogue Parachute (15in)					

Table 3.2: Drift values from OpenRocket

Table 3.3 details the drift using the flight time provided by OpenRocket.

	0 MPH	5 MPH	10 MPH	15 MPH	20 MPH
Main Parachute (58in)	0 ft	246 ft	658 ft	1523 ft	2345 ft
Drogue Parachute (15in)					

Table 3.3: Drift using flight times from OpenRocket

Based on these values, we have decided to use a 58in main parachute and 15in drogue parachute. The parachutes also keep the vehicle within the landing energy requirement of 75ft-lbs. The most massive tether portion of the vehicle is 3.18kg and has a landing velocity of 7.68m/s. Using the equation for kinetic energy, the landing energy is calculated to be 93.78J (69 ft-lbs). This is under the requirement of 75ft-lbs, therefore the parachute sizes are acceptable.

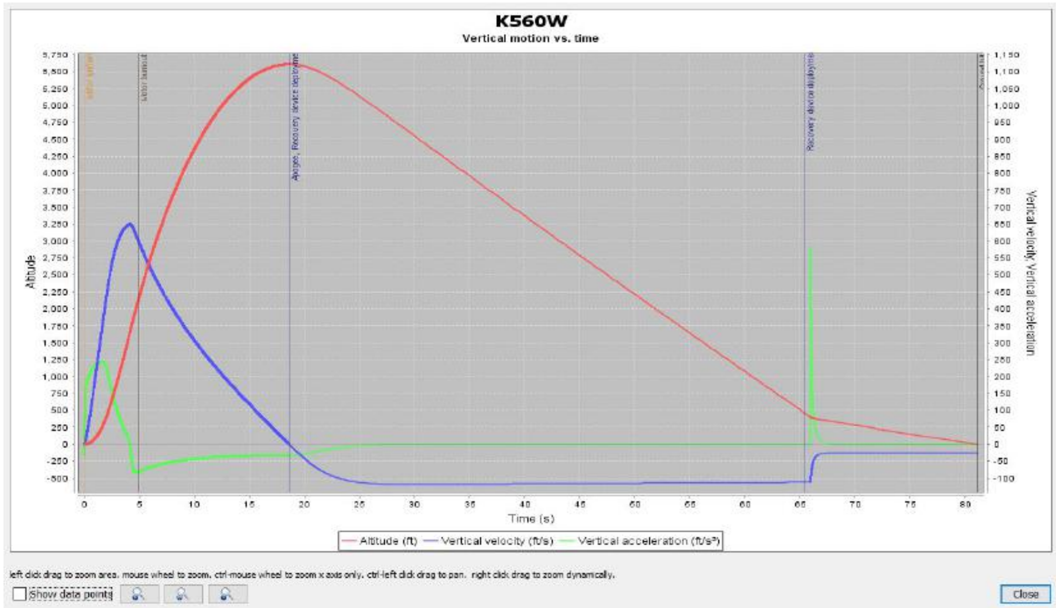


Figure 3.13: Flight profile

Figure 3.13 shows the altitude, velocity, and acceleration profile of the vehicle with the K560W motor. The predicted apogee is greater the the desired apogee in order to allow ADAS room to work properly.

4 Safety

The Rocket Team at UCSC is committed to ensuring a safe environment for all personnel responsible for building, testing, and observing the launch vehicle and its interior contents. It is therefore necessary to analyze potential hazards, risks, and interactions between the rockets and surrounding locations to establish precautionary measures and prevention methods. The safety documentation will be accessible to all team members to follow project development, testing of subsystems or the vehicles, and understand potent materials. Launch personnel will have access to necessary information regarding the safety of the rocket when preparing for launches, as per NAR and government standards. Verification of SLI safety requirements is given in Section 6.1.1.

4.1 Safety Officer

The Safety Officer position for Rocket Team at UCSC for the 2018-2019 SLI competition will be fulfilled by Richard Alves. He will be responsible for keeping all personnel involved with constructing and launching the rockets safe from injury, ensure laws applicable to rocketry are being followed at all times, as well as preventing unwanted damage to the environment where possible. In the case where the Safety Officer will be unable to complete their duties due to personal or unforeseen reasons, an immediate replacement must be made to fill the vacancy.

4.1.1 Responsibilities

Specific responsibilities of the Safety Officer include the following:

- Be fully competent in the known laws and regulations of NAR/TRA, the FAA, the state of California, and UC Santa Cruz with regards to building and launching the vehicle and its on-board components.
- Ensure the team's compliance with local, state, and federal law.
- Provide the team with a Safety Manual detailing the necessary steps to gain access to lab workspaces, handle tools and devices, understand the laws and regulations in rocketry, identify hazards, risk assessment and analysis, failure mode analysis, PPE requirements, materials safety data sheets, lab inventory spreadsheet, and emergency procedures.
- Oversee the design, construction, and testing of the rockets and rocket subsystems.
- Create and enforce checklists for each launch of the vehicle that meet safety and operation standards as per launch needs.

- Attend the following activities to ensure that checklists requirements are met, safety protocol is followed, and guests are educated on the procedures involved:
  -- Building sessions
  -- Launch tests
  -- Ground testing of vehicle and payload
  -- Recovery activities, including design and installation of recovery components
  -- Educational/Outreach events
  -- Logistical meetings with the rest of the Board
- Provide a Safety Acknowledgement Form that members must read and sign to certify that they have read and understood all sections in the Safety Manual and have met lab access requirements.
- Maintain a list of all students and their contact information who have signed the Safety Acknowledgement Form such that campus administrators may cross-check and verify that students working in lab have met school requirements for access.
- Cooperate with the team's NAR mentor, David Raimondi, to handle and prepare electric matches, charges, ignitors, and the motors used on the launch vehicles.

4.1.2 Safety Manual

A team safety manual was created to educate and introduce new members to the team's policies and applicable laws surrounding amateur rocketry, on school property and at launch sites. It is located on the team's Google Drive used by active student participants. The manual contains the following information:

- On-campus and off-campus lab access requirements
- General lab safety training
- Risk assessment and hazard analysis
- Launch site safety
- NAR safety code
- Hazardous material handling
- Checklists
- Data sheet information
- Federal laws and regulations on amateur rocketry
- Instructions for hand and power tools

4.1.3 Launch Procedures

As stated in Section 4.1.1, the Safety Officer will be required to create launch procedures in the form of checklists to ensure a safe event for all personnel. These checklists will be thorough in their description to properly set-up the rocket's interior systems, prepare the vehicle on the launchpad, launch the rocket, and track and recover the rocket safely. See Appendix A for a preliminary checklist example.

Launches will occur only at designated locations approved and operated by the National Association of Rocketry (NAR). Possible sites where the team may launch rockets from include the following:

- **Snow Ranch**: A remote, private farmland east of Stockton, CA that is an approximate 3 hour drive from UC Santa Cruz, thus being the closest alternative.
- **Northern Nevada Salt Flats:** The ROCKONN Northern Nevada Rocket Club hosts a major NAR launch site, and the second closest by car (4 to 5 hour drive).
- **Holtville Airport:** Located near San Diego, this airport serves as a TRA launch site, but is significantly farther away (about 8 hour drive) and would require overnight accommodations, along with additional expenses for travel.
- **Tucson, Arizona:** In cases where the team cannot launch within more convenient circumstances, the launch site operated by Southern Arizona Rocketry Association would be the farthest yet best weather location during winter launch tests.

4.2 Material Handling

Only personnel with certified safety training in labs or otherwise will be allowed to use potent compounds and chemical devices. The Safety Officer will also be available during times when such materials are being used in lab or at launch sites.

4.2.1 Hazardous Materials

Table 4.1 details a variety of materials that the team may use during construction of rocket vehicles and systems. All of the items pose potential threats to personnel safety if handled improperly. Each material is given a description of its purpose, the hazard it may pose, a form of mitigation to avoid such risks, and advised/required PPE.

Material	Description	Use	Hazard	Mitigation	PPE
Batteries	5 - 18 Volts, LiPo, Li-ion, NiMH, etc.	Powers on-board electronics	Electric shock, burns	Check for faulty equipment	N/A
Black Powder	Pyrotechnic charge	Separates rocket body, ejects parachutes	Highly flammable, explosive	Stored in secure and low-temps, handling restricted to	N/A

				certified personnel	
Epoxy	Polymer resin	Structural adhesive	Corrosive, toxic, irritant	Use in well-ventilated area	Nitrile gloves
Fiberglass Resin	Polyester resin	Structural adhesive	Corrosive, flammable, toxic, irritant	Use in well-ventilated area	Nitrile gloves
Liquid Hardener	Polyester resin	Resin casting and curing	Corrosive, flammable, toxic, irritant	Use in well-ventilated area	Nitrile gloves
Solder	Low-melting alloy, usually made of tin, lead, etc.	Electrical connections, join fusible metals	Severe burns, irritant	Use at a soldering station, well-ventilated area	Safety glasses, breathing mask
Superglue and Hot Glue	Thermo-plastic, Cyano-acrylate	Basic adhesives	Burns, irritant	Use in well-ventilated area	Nitrile gloves

Table 4.1 Hazardous Material Analysis

4.2.2 Motor and Pyrotechnical Safety

David Raimondi, the team's mentor, will be responsible for the purchase, storage, transportation (by car), and general handling of any and all motors to be used on launch vehicles. Any team members who have achieved a Level 2 High Power Rocketry Certification will also be able to assist in motor preparation if needed. Other items that Mr. Raimondi will be responsible for include the ignition charges, electric matches, and any other pyrotechnical items necessary to launch and recover the vehicle.

4.3 Hazard Analysis

4.3.1 Risk Assessment

In order to quantify the magnitude with which certain hazards may occur for the team during the project, it is necessary to create a risk assessment matrix. This tool can then be used to identify and prioritize issues that could arise, as well as how to mitigate them. Each hazard is studied and analyzed by its impact to human health, environmental damage, and importance to the launch vehicle and payload.

Each risk will have a severity and probability value given to it. Severity is identified as numbers 1 - 4 with 1 being ranked most severe. It is used to gauge how devastating the effects of an incident would emerge on the team's goals. Table 4.2 describes the severity levels and details. The probability, or likelihood, an event will occur is also taken into account, and is designated by capital letters A - E, with A representing the most frequent or likely event to happen. Table 4.3 shows the details on risk probability and its levels. Together, the severity and probability can form a Risk Assessment Code (RAC) which can rank the dangers jeopardizing the team's participation in the competition, from direct physical harm to monetary losses. Table 4.4 and Table 4.5 break down the RAC and each risk's color legend and the associated penalties.

Description	Value	Properties
Catastrophic	1	May cause life-threatening injury or death, irreversible environmental damage, complete loss of onboard systems. violate at least one major regulation, and/or mission failure.
Critical	2	May result in serious injury, major but reversible environmental damage, and major damage to onboard systems. May violate at least one law/regulation, and most of the mission is severely impacted.
Marginal	3	May result in minor injuries, minor damage to the environment, and minor damage to onboard systems. Does not violate a law/regulation, and the mission is not critically affected by the outcome.
Negligible	4	May result in little to no injuries, minimal damage to the environment, and at most partial damage to a non-critical onboard system. Does not violate any law/regulation, and its impact on the mission is barely noticeable.

Table 4.2 Hazard Severity Levels and Criteria

Description	Code	Properties
Frequent	A	Expected to occur with >90% probability; happens almost immediately or very soon.
Common	B	Expected to occur between 50% - 90% probability;

		usually happens in the near future, if not more than once over a set period of time.
Occasional	C	Expected to occur between 10% - 50% probability; possible to happen once over a longer period of time.
Unlikely	D	Expected to occur between 1% - 10% probability; a remote chance that it happens at some point much farther in time.
Improbable	E	Expected to occur with <1% probability; almost certainly will never happen and will not be expected at any time.

Table 4.3 Hazard Likelihood Designation and Criteria

Likelihood	**Severity**			
	Catastrophic (1)	**Critical (2)**	**Marginal (3)**	**Negligible (4)**
Frequent (A)	1A	2A	3A	4A
Common (B)	1B	2B	3B	4B
Occasional (C)	1C	2C	3C	4C
Unlikely (D)	1D	2D	3D	4D
Improbable (E)	1E	2E	3E	4E

Table 4.4 Risk Assessment Codes (RAC)

Risk Level	**Penalties/Response**
Extreme	Unacceptable. Will cause complete project failure. Immediate mitigation required.
Moderate	Undesirable. Will cause major loss in competition points and project status. Mitigation required soon.
Low	Acceptable. Will cause minor loss in points and project completion. Mitigation needed on case by case basis.

Table 4.5 Risk Level Color Codes

4.3.2 Personnel Hazard Analysis

Throughout the competition project, there exist certain dangers to personnel safety present in either the construction, testing, or launching of equipment. In order to minimize the possibilities of injury or loss of life, it was imperative to list potential sources of hazards to human health, as well as the ideal methods to mitigate and avoid such situations. Hazards posed by launches and tests are analyzed in Table 4.6, and the risks involved with building the rocket are investigated in Table 4.7.

Hazard	Cause	Effect	RAC	Mitigation
Motor detonation	1. CATO 2. Improper installation 3. Damaged motor canister	Injury or death of personnel, loss of vehicle and on-board systems	1D	Motor will be purchased from reputable vendors, strict oversight will occur at the launch pad, and NAR or other qualified personnel may help with installation, as well as there being strict zoning limits at takeoff
Recovery system	1. E-match and/or black powder charges fail to deploy 2. Parachutes not ejected from detonation due to being stuck in vehicle 3. Parachutes become entangled while vehicle descends	Injury or death of personnel, loss of vehicle and on-board systems	1C	Trained personnel will ensure that cords and risers are not tangled during installation, e-matches and electronics will be tested for continuity, and sizing of parachutes will come from numerous tests before launch
Pyrotechnic charges	1. Stray voltage 2. Installation of e-match while battery on 3. Altimeter	Severe burns, electric shock, limb damage, death, loss of recovery system	1C	Installation of pyrotechnics restricted to Safety Officer and launch personnel; batteries

	powered on ground	hardware		and altimeters will be powered off when charges placed
Unstable rocket trajectory	1. Unexpected winds 2. ADAS deploys too early in flight 3. Damaged or improperly prepared motor housing	Personnel and bystanders injured or killed by high velocity impact from rocket, loss of vehicle and on-board systems, rocket may not reach intended apogee	1D	1. Range safety officer has final say of when to launch, and team may cancel if winds are stronger than expected on launch pad 2. Rigorous tests will be performed such that ADAS will remain idle while in the burn phase and its deployment will not harm flight path if opening early 3. All couplers and motor retainers will be inspected and tested thoroughly before installation
Extended exposure to RF signals	Use of radio antennas for RF communications on rover deployment and GPS tracking	High frequency electromagnetic waves may cause cancer or other disease	2D	Any use of antennas or testing of telemetry systems will be done in short periods of time to avoid over exposure
Ground testing	1. Falling objects from vehicle or its systems 2. Getting hit by rover while it moves autonomously	Minor cuts and bruises	3D	Personnel will be held accountable for injuries and accidents that could be avoided by being reprimanded; team will be told to watch out for others' health and safety

Table 4.6 Launch and Test Conditions Hazard Analysis

Hazard	Cause	Effect	RAC	Mitigation
Electric Shock	Exposed wiring, improper connecting of batteries	Severe burns, electrocution, damage to equipment	2D	All personnel who must work with high voltage equipment must be trained on the lab's materials and design, and will ground themselves when appropriate
Power and hand tools (sander, hammer, drill, dremel, etc.)	Improper training or handling	Cuts, bruises, damage to equipment, damage to vehicle components	2C	Team members are required to watch and learn how to operate tools before being used on the vehicle, and verify their expertise with the Safety Officer
Shop tools and machines (automatic saws, grinders, CNC, drill press, etc.)	Improper training, improper use of PPE	Severe cuts, limb damage, death, damage to equipment and components worked on	1D	More specialized machinery will require operation by certified personnel who must demonstrate their ability to the Safety Officer, and no operation of such devices will happen if the Safety Officer is directly unavailable
Soldering iron	Improper training, improper use of PPE, distracted from task	Severe burns, damage to equipment and work environment, inhalation of toxic solder/circuit fumes	2B	Soldering tutorials will be presented to untrained personnel, and they will be required to verify their understanding with demonstration to the Safety Officer
Liquid or solid chemical reactions	Improper training or handling,	Burns, skin damage or irritation,	2B	All volatile compounds will be stored in secure

(epoxy, glass hardener, cutting fluid, motors, etc.)	improper use of PPE	inhalation leading to respiratory problems like congestion or lung damage		locations in the lab, and only certified personnel may handle the compounds in a controlled environment with proper attire
Carbon fiber/ fiberglass	Involuntary inhalation while sanding or fabricating vehicle	Congestion, lung damage, cuts	2C	Team members will be required to wear breathing masks and other PPE to avoid inhalation of toxic materials
Rechargeable batteries (LiPo, Li-Ion, etc.)	Improper training or handling	Electric shock, severe burns, damage to components	2B	No sharp or hot object will be allowed within close proximity of batteries, and they will be handled according to product specifications
Non-affiliate personnel working near team members and components	The on-campus lab space is shared by other engineering teams performing their own potentially hazardous tasks, and may not inform or warn our team about their actions.	Team members may encounter non-team students operating machinery unsafely, or otherwise might be hurt by non-personnel actions beyond Safety Officer control.	1C	All team members will be required to cooperate with non-team students and plan ahead for building work, as well as reporting hazardous interactions with the Safety Officer or Captain immediately

Table 4.7 Lab and Workshop Hazard Analysis

4.3.3 Failure Modes and Effects Analysis

Various hazards exist in developing the rocket, including possible injury during building, testing, installment, and launching, as well as there being risks to mission success through technical failures while performing a launch. Table 4.8 analyzes the dangers present in the vehicle design, such as its construction and launch. Possible risks associated with ADAS design and its integration in the vehicle system are written out in Table 4.9. Recovery system concerns are described in Table 4.10, and it is important to note that the writing can apply to more than one parachute within the vehicle. The hazards associated with operation of the rover payload and its housing within the vehicle are described in table 4.11. Finally, Table 4.12 covers the issues which may arise as the rocket prepares for launch, while launching, or after launch.

System/ Device	Failure Mode	Cause	Effect	RAC	Mitigation
Motor	CATO	Fractured motor, improper fuel packing	Explosion occurs ejecting shrapnel	1E	Ensure motors are purchased from licensed vendors and inspect before installation, report all CATO accidents to manufacturer
	Defective ignition	Defective motor or igniter system	Drastically reduced launch velocity	2E	Check ignition electronics and connections to motor
Motor retention	Centering ring failure	Centering ring is not secured properly	The rocket will not fly straight upward, possibly flying in erratic directions	1D	Check to ensure that center ring is secured
	Motor retainer fails	Motor retainer is not secured properly	The rocket will not fly straight upward, possibly flying erratically in random directions	1D	Routinely check to make sure the retainer is securely fastened and test to make sure it can withstand the forces of launch
Fins	Fin retainer fails	Damaged or unsecured	The rocket's flight path	2D	Routinely check to make sure the fins

		retainer installed and used	becomes erratic		are securely fastened and test to make sure they can withstand the forces of launch
	Fins sheared off in flight	Fin material not strong enough to resist drag forces	The rocket's flight path becomes erratic.	2D	Routinely check to make sure the fins are not damaged and test to make sure they can withstand the forces of launch
	Vehicle landing fractures fins	The fins are not strong enough to bear the forces during the rocket's landing	The fins must be repaired before the next launch and the broken pieces of the fin must be cleaned.	2C	Routinely check to make sure the fins are not damaged and securely fastened and test to make sure they can withstand the forces of landing
Upper airframe	Premature separation of vehicle in flight	faulty sensors or powder charge/the airframe was not secured together well enough	The rocket becomes unfit to fly, potentially dangerous ejecta is emitted from rocket	1D	Routinely check to make sure all sections of the vehicle are securely fastened and test to make sure the rocket can withstand the forces of launch
	Centering ring failure	Centering ring is not secured properly	The rocket will not fly straight upward, possibly flying erratically in random directions	1D	Routinely check to make sure the centering ring is securely fastened and test to make sure it can withstand the forces of launch

Table 4.8 Launch Vehicle FMEA

System/ Device	Failure Mode	Cause	Effect	RAC	Mitigation
Drag fins	Fins shear off in flight	Fin material not strong enough to resist drag forces	Vehicle reaches higher than desired apogee	2C	Routinely check to make sure the fins are not damaged and test to make sure they can withstand the forces of launch
	Fins rotate too far	Improper signal sent to ADAS motor	The rocket will not be able to retract its fins	3D	Limit rotation of motor by sending optical signals to microcontroller
ADAS Electronics	Loss of power	Improper battery charging, launch forces separate electrical connections	The fins will stop reacting to the rocket's situation and the rocket's flight path will not be corrected properly	3D	Routinely check to make sure the battery is not damaged and run diagnostic checks on the microcontroller and its systems
	Sensor error	Runtime error, signal error from other system electronics, improper circuit wiring	Incorrect data is recorded and the fins will not deploy in the necessary ways to correct the rocket's flight path	4D	Routinely run diagnostic tests on the sensors and microcontroller
	Software bugs	Faulty code uploaded to system	The fins will not deploy in the ways necessary to correct the rocket's flight path	4D	Test for run time errors thoroughly, perform on-ground test conditions first

Mechanical retention	Broken gear mechanisms	Excess load on the system/the material is damaged or too weak	The fins will not deploy or retract properly	4D	Routinely check to make sure the gear and fins are not damaged and test to make sure motors are not trying to push the fins past their mechanical limits
	Weakened point of airframe	Fin cavities not designed and constructed properly	The airframe breaks during flight	1C	Routinely check to make sure the airframe is not damaged and test to make sure it can withstand the forces of launch
	Fracture of hinge pin	Excessive drag forces beyond pin capabilities	Fins detach from vehicle,	2D	Routinely check to make sure the pin is not damaged and test to make sure it can withstand the forces of launch

Table 4.9 ADAS FMEA

System/ Device	Failure Mode	Cause	Effect	RAC	Mitigation
Parachutes	Ejection charge damage	Black powder detonation burns or destroys part of parachute	Higher than expected landing velocity, unstable descent	1C	Perform adequate testing of black powder charge ignition before any launches
	Entangling	Improper packing of parachute	Parachutes fail to deploy correctly, fast uncontrolled descent	1C	Have recovery team members practice correctly packing parachute and perform multiple checks on

					launch
	Failure to deploy	Improper packing or parachutes too large	Parachutes fail to deploy correctly, fast uncontrolled descent	1C	Have recovery team members practice correctly packing parachute and perform multiple checks on launch. Tests to ensure parachutes correct size
	Shock cord snaps	Cord is damaged or is otherwise not strong enough to bear the tension	Parachutes fail to deploy correctly, fast uncontrolled descent	1E	Perform adequate testing to ensure that parachute is strong enough to withhold forces placed on string by chutes
Ejection charges	E-matches disconnects from altimeter	Wiring between E-match and altimeter is not secure	Charges do not detonate and parachute does not deploy	1C	Perform tests to ensure wiring can withstand forces experienced in flight
	Failed detonation	Charges fail to deploy	Charges do not detonate and parachute does not deploy	1C	Purchase reliable charges
	Charge well not vented properly	Design for ejection charge is insufficient	Structural integrity of rocket is compromised and shrapnel is dispersed	1C	Thorough design and testing process
Recovery electronics	Altimeter failure	Altimeter loses power or experiences fatal bug	Ejection charges not activated, thus recovery system compromised	1D	Purchase reliable altimeter and ensure wiring is secure and tested for continuity

	GPS failure	GPS loses power or experiences fatal bug	The rocket becomes very difficult to find after flight	3E	Purchase reliable GPS and ensure wiring is secure
Airframe	Separation of recovery system from vehicle	The recovery systems are not attached to the the body of the rocket well enough	The rocket's descent is too rapid	1D	Routinely check to make sure the recovery system is securely fastened and test to make sure it can withstand the forces of launch
	Vehicle sections fail to separate	The powder charge is not strong enough	Parachutes do not deploy and the rocket's descent is too fast	1C	Check for e-match continuity and test to see that the charges can indeed open the rocket
	Rocket descends too rapidly	Parachutes are not large enough	The rocket exceeds the safe velocity limit and is at risk of breaking	1D	Test the parachutes sufficiently in advance
	Rocket descends too slowly	Parachutes are too large	The rocket could drift faraway from the launch site due to the wind	3D	Test the parachutes sufficiently in advance
	Airframe zippering	Shock cord tears into rocket from undesired angle of deployment	Severe damage to airframe, onboard systems	1D	The rocket is designed to avoid zippering. Sufficient testing should be done to make sure.

Table 4.10 Recovery System FMEA

System/ Device	Failure Mode	Cause	Effect	RAC	Mitigation
Payload housing	Deployment signal fails to be detected	RF signal attenuated by landscape or carbon fiber frame	Entire payload mission compromised	1D	Debug the software that sends the signal thoroughly; test to make sure the payload can deploy
	Rover caught in housing	Rover or housing damaged during flight or landing event	Rover cannot deploy	1D	Test to make sure the rover can deploy
	Housing fails to rotate	Landing causes deformation in housing structure	Rover cannot deploy or leaves housing at wrong angle	1D	Test to make sure the housing can bear the forces of landing and can rotate smoothly
ALC	Insufficient motor torque	Not enough electronic power supplied by battery or motor	Housing cannot rotate, causing stuck rover	1E	Routinely check the battery of the rover to make sure it has no damages and enough power to operate the rover.
	Sensor cannot determine orientation	Sensor data corrupted or broken by landing; bugged code	Housing cannot rotate, causing stuck rover	1D	Perform shock test on the ground with sensors before flight
RDM	Black powder charge fails detonation method	Improper design and/or amount of black powder	Payload section fails to separate, causing stuck rover	1D	Sufficient ground testing of charges to ensure they can separate rocket
	Black	Excessive	Payload	1C	Sufficient ground

	powder charge damages vehicle	detonation power from black powder	section and other systems damaged considerably		testing of charges to ensure they are not damaging vehicle systems
RMS	Damaged treads	Landing or black powder charge detonation	Rover unable to move considerably well, possibly stuck	2C	Ground testing and factors from launch events will determine strength of treads needed
	Insufficient motor torque	Not enough electronic power supplied by battery or motor	Rover unable to move considerably well, possibly stuck	2D	Ground testing determines how much additional motor power would be required if current alternative fails
ODAS	Faulty sensor data	Damaged hardware or poor integration	Rover cannot travel 10 feet away from rocket	2B	ODAS will be tested sufficiently to ensure functioning capability with most field terrain
SCM	Insufficient servo torque	Not enough electronic power supplied by battery or servo	Rover cannot collect 10 mL soil sample	1D	Ground testing determines how much additional servo power would be required if current alternative fails
	Scooper cannot reach low enough to collect soil	Ground is lower than expected during rover travel	Rover cannot collect 10 mL soil sample	1D	SCM will be tested to see its limits in mobility
	Soil falls out of scooper during collection	Rover travels across uneven land	Rover cannot collect 10 mL soil sample	1C	Scooper and rover must act slow enough to not disturb already

		or scooper moves sporadically			collected soil
	Rover travels back toward rocket	Controller fails to balance object detection with movement requirement	Mission is compromised if rover moves to back within 10 feet of rocket	1C	Test the object detection algorithm and design it so the robot always ends up away from the rocket.
Payload Electronics	Excess current enters controller	High motor demand of power	The controller gets damaged	2D	Use diodes and current limiting hardware, or restrict motor usage; test for upper limits of current needed
	Damaged components	Landing or detonation forces	Signals aren't sent properly in between the rover's components, battery could catch fire	1D	Properly protect the rover's internal components and build the rover sturdily
	Software errors	Untested bugs and poor code writing	The rover does not properly maneuver away from the rocket; the rover does not properly collect the soil sample	2B	Test the rover's code and debug thoroughly

Table 4.11 Payload FMEA

System/ Device	Failure Mode	Cause	Effect	RAC	Mitigation
Launch pad issues	Launch vehicle fails to fit rail	Rail buttons not correct size	Delayed or scrubbed launch	2D	Use compatible equipment and check ahead for rail/button sizing
	Exit rail velocity is less than 75 feet/second	Incorrect motor impulse or high friction between rail and vehicle	Unstable vehicle flight by having larger banking angles	1D	Selection of a large and strong enough motor, as well as ensuring proper fit between rail and vehicle
	Launch vehicle fails to lift off rail	Damaged launch rail or buttons	Damage to vehicle, lost motor	2E	Launch rail and buttons inspected for proper fit before launch
	Launch vehicle shears rail buttons	Lower than required rail velocity at takeoff	Vehicle enters steep angle after launch	2D	Launch rail and buttons inspected for proper fit before launch
Auxiliary issues	Inaccurate flight simulations	Program errors, or incorrect data used	Undesired apogee and launch characteristic s	4C	Ensure that the simulations use up-to-date information and test sufficiently for bugs and errors
	Rocket dropped by personnel	Improper handling	Damage to vehicle systems	3B	Multiple people must carry the full vehicle and should not have slippery hands or shoes
	Failure to pass RSO inspection	Rocket systems not working or secured as determined by RSO	Delayed or scrubbed launch	1C	Pre-launch checklists will detail all aspects of the rocket before RSO inspection

Table 4.12 Launch Operations FMEA

4.3.4 Environmental Hazard Analysis

Table 4.13 records the factors the environment could impose upon the launch vehicle during its construction, testing, or at launch. Should a potentially moderate or extreme risk level arise due to the environment, and if they are beyond the control of the team, any rocket will be prevented from launching until undesired conditions disperse over a convenient period of time. Hazards the launch vehicle or its systems affect the environment with are listed in Table 4.14.

Hazard	Cause	Effect	RAC	Mitigation
Low-flying clouds/low visibility	Weather	Restricted or lost time waiting for clearer skies.	2B	Before launch dates are set, the forecast for that location will be checked prior to leaving and/or reserving launch time slot.
Rain	Weather	1. Restricted or lost time waiting for clearer skies. 2. Damage to avionics and flight systems.	2C	1. Before launch dates are set, the forecast for that location will be checked prior to leaving and/or reserving launch time slot. 2. When traveling, the team will ensure all electronic devices are kept safe in bags.
Wet ground	Weather, terrain	Damage to avionics and onboard systems, including payload	2E	Electronics will be stored in waterproof bags and are designed to be sealed within the rocket, and also will be tested after a wet landing. The rocket will not be launched if wet areas exist within the drift radius.
High wind speeds	Weather	Unsafe flight trajectory after launch, possible	1C	Weather will be monitored days in advance of flight

		landing in trees or out of drift radius		location, and the Range Safety Officer will also determine when safe to directly launch while the rocket is at the pad.
High temperatures	Weather	1. Damage to electronics, potentially causing on-board fires 2. Loss of adhesive strength, causing on-board components to become free 3. Metals thermally expand, losing strength or damaging vehicle	2B	Temperatures will be monitored before launches, and suitable shelter from the Sun, such as a foldable tent, will be brought if needed.
Low temperatures	Weather	1. Rocket cannot separate easily 2. Batteries will not discharge properly, causing black powder charge events to fail	1D	1. Testing of continuity for black powder charges will be used if temperatures are below operating/manufacturer conditions. 2. All batteries will be checked for charge before installation and flight.
Uneven/rough landing terrain	Topograph y	Failure of rover to deploy due to landing angle	1B	The flight radius and scouting of the launch area will determine if the payload can fly with the rocket, if not, equivalent ground tests will be made in response.
Humidity	Weather	Oxidation to metals, electronics damaged by water, black powder charges fail to ignite	2C	All explosive and pyrotechnic devices will be stored in dry, secure areas prior to launch.

Table 4.13 Environmental Effects on Launch Vehicle Analysis

Hazard	Cause	Effect	RAC	Mitigation
Hazardous chemical or compound spills or leaks onto ground	Improper handling, disposal, or storage of epoxy, carbon fiber, LiPo batteries, etc.	Possible loss of wildlife, damage to equipment, pollution	2C	Data sheets will be referred to before any personnel uses hazardous materials for the first time, and disposal of such compounds will be carried out properly.
Release of toxic fumes into atmosphere	Burning of ammonium perchlorate motors	Contribution to atmospheric pollution, possible harm to wildlife via decomposing	3D	Although unavoidable due to the rockets requiring motors, the amount of ammonium perchlorate is negligible in the course of the season.
Electronic waste or pollution	1. Soldering 2. Wire and circuit components not properly put into e-waste	1. Toxic fumes released near personnel, soldering compounds damage equipment 2. Improper labels and waste areas	2A	1. Soldering will be performed at designated soldering stations, and only done by experienced personnel, with clean up afterwards being mandatory. 2. Waste bins will be provided during construction of the rocket.
Fire	1. Motor ignites nearby grassland or sets onboard systems on fire due to launch failure 2. Rechargeable battery ignites due to improper charging or	1. Damage to launchpad and launch field area, leading to loss of wildlife and unwanted emissions 2. Explosion of battery, injury to personnel, toxic	1D	1. Ensure fire control equipment will be available, clear launch area of flammable material, and report damaged motors to manufacturers. 2. Qualified personnel will only

	storage	compound emission		be allowed to handle rechargeable batteries, all data sheets will be followed on handling.
Spray painting	Rocket will be painted with decals, aesthetic themes	Contamination of water from liquid paint seeping into sewage systems, and emission of paint fumes	3D	All spray painting will be done outside the lab building in an area with no drainage pipes and away from campus forestry.
Travel	Team will need to use internal combustion cars and planes throughout the project season	Release of CO_2 and other greenhouse gases into atmosphere	4A	Negligible amounts of fossil fuel emission by team activities.
Loss of launch vehicle	1. Recovery system fails to deploy parachutes on descent 2. CATO 3. Unexpected flight trajectory from winds or ADAS failure	Injury or death to bystanders and equipment, damage to vehicle and systems, possible loss of wildlife, excretion of vehicle materials onto ground	1C	Checklists will be provided to operate and initiate recovery systems, motors will be checked for damage, and no launches will occur if monitored winds are too high a speed

Table 4.14 Launch Vehicle Effects on Environment Analysis

4.3.5 Project Risk and Delay Analysis

NASA SLI presents myriad challenges, both technical and logistical, to be completed thoroughly by set dates, or teams face penalties and losses towards the project. The Rocket Team at UCSC recognizes that it faces unique challenges: no mechanical or aerospace departments, limited lab and machine shop resources, relatively unheard of around campus, etc., however, the team has faith in its second returning year to the competition. In order to better understand the limitations that might arise for the team's administrative duties, Table 4.15 has been compiled to determine the major impact of risks involved with the SLI project as a whole for the remainder of the season.

Risk	Impact	Likelihood	Outcome	Mitigation
Vehicle or payload designs become too complex	High	Medium	Redesign, delayed project completion, increased spending	All systems are to be designed modular for ease of access before and after flight, and rigorous testing will reveal difficult techniques that can be fixed sooner rather than later.
Team members unable to attend and help meetings and build sessions	Medium	Medium	Loss of team morale, delayed project completion	All meetings and other sessions involving multiple team members will be announced in advance, and balanced workloads will be required by team leads.
Products delayed/lost in shipping or not available	Medium	Low	Delayed project completion, increased funding	All shipped hardware will be tracked, and chosen so that vendors have available amounts at time of purchase.
Exceed budget/low funding	High	High	Delayed project completion, possible dissolution of team if bankrupt	The team will appropriately fundraise through online crowdfunding, the school's Giving Day event, and through donations.
Loss of on-campus lab spaces	High	Low	SLI project failure, possible dissolution of team	The team will maintain a credible and professional relationship with the UCSC S-Lab organization.
Missed deadlines	Medium	Low	Loss of competition points, loss of team morale, delayed project completion	Calendars will track project deadlines and team events, and documentation will begin early and organized.

Breaking federal law or NASA SLI requirements	Medium	Low	Loss of competition points, governments fines and punishments	The Safety Officer will ensure the team understands and follows laws and requirements by holding informational meetings
Loss of vehicle or onboard systems	High	Medium	Delayed project completion, loss of competition points, loss of team morale, possible SLI project failure	Checklists will be used before flight to ensure that all precautionary measures have been taken, and weather conditions check fervorously prior to launching

Table 4.15 Project Risks and Impacts Analysis

4.4 Regulation Compliances

4.4.1 NAR Safety Code Procedures

The NAR High Powered Rocket Safety Code will be adhered to throughout the project in regards to rocket development and launches. Each requirement laid out in the code has been complied with by the team as seen in Table 4.16.

NAR Code	Team Compliance
1. **Certification**. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.	David Raimondi, the team mentor, or other certified members will be the only persons allowed to purchase and handle motors.
2. **Materials**. I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.	The rocket and its subsystems will only use the materials allowed, with the only addition to the list potentially being carbon fiber, but it is lightweight and composite.
3. **Motors**. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will	All motors will be purchased from commercially available vendors, with David Raimondi doing the purchase and handling for the majority of the time. Other personnel will maintain Safety Manual

not allow smoking, open flames, nor heat sources within 25 feet of these motors.	standards in regards to the motors should they be nearby.
4. **Ignition System**. I will launch my rockets with an electrical launch system and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.	Only on the launchpad at NAR/TRA certified events will the electronic ignition system be installed onto the vehicles. Onboard recovery altimeter systems will be inhibited from activation while the vehicle is on the launch pad. The Range Safety Officer will also communicate any concerns and requirements to safety issues at these events.
5. **Misfires**. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	The Range Safety Officer and the team's Safety Officer will be responsible for communicating any issues before, during, and after a misfire. In the case where one occurs, the defined procedure will be followed.
6. **Launch Safety**. I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.	All pre-launch procedures will be followed and carried out by the officials at the NAR/TRA events or by the team if necessary. Further requirements set for by the Range Safety Officer or team mentor will also be adhered to.

7. **Launcher**. I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.	Sufficient testing of the launch vehicle will occur before any launch event. This will ensure the supplied rails at the NAR/TRA launchpad are capable of handling the team's design.
8. **Size**. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.	The team will not build a vehicle that surpasses allowed weight, nor will it select motors that exceed the specified threshold.
9. **Flight Safety**. I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.	These guidelines, as well as those determined by the Range Safety Officer and team mentor, will be carried out at the launch events. FAA waivers and other advisory notices will also be checked for by the team mentor.
10. **Launch Site**. I will launch my rocket outdoors, in an open area where trees,	All launches will occur at events and locations approved by NAR/TRA, the team

power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).	mentor, as well as the team itself should travel concerns arise.
11. **Launcher Location**. My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.	The team will ensure the location being used at any launch site will fulfill this requirement, as well as any advisement from the Range Safety Officer.
12. **Recovery System**. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.	A recovery subsystem will be designed and tested by the Recovery subteam that meets these guidelines. In addition, a recovery checklist will be followed throughout the event to ensure the compliance in preparing the recovery methods is met.
13. **Recovery Safety**. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.	All team members and persons at the event will adhere to this rule. The Range Safety Officer can also declare unsafe conditions for retrieval as necessary, and their guidelines will also be followed. Professional third-parties may be contacted in order to recover the item(s).

Table 4.16 NAR Safety Code Compliance

4.4.2 Federal Laws

The Safety Officer and all team members who have signed the Safety Acknowledgement Form will be able to understand and abide by the relevant federal laws (which are fully adopted by the state of California) regarding high-powered rockets, specifically the following:

- Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; Amateur Rockets
- Code of Federal Regulation 27 Part 5: Commerce in Explosives; and Fire Prevention
- NFPA 1127 “Code for High Power Rocket Motors”

4.4.3 Team Safety Acknowledgement

Once team members finish required safety training by reading the Safety Manual, they will be prompted to sign the Safety Acknowledgement Form. This document is used to certify the personnel who have full understanding of the rules set forth by NASA, relevant government regulations, demonstrated sufficient training, and have secured certification for UC Santa Cruz lab safety and access credentials. Upon signing the form, personnel will submit it to the Safety Officer who will maintain a working list of names of those who have completed the process so that they may work on the rocket project without needing supervision from the Safety Officer for menial tasks. A copy of the Safety Acknowledgement Form can be found in Appendix B.

5 Payload Criteria

5.1 Payload Objective

5.1.1 Experiment Requirements

The payload experiment the team has chosen is the autonomous rover and soil collection experiment. The rover is required to be remotely activated upon landing to autonomously travel 10ft and then collect a 10mL soil sample. The rover must also be securely fastened during the flight and only be released once needed.

5.1.2 Mission Statement

The rover, Slim Sammy, will be securely fastened within the rocket during flight and will be remotely activated once landing has been confirmed. From there, Slim Sammy will autonomously travel 10ft and collect a 10mL soil sample.

5.1.3 Mission Success Criteria

A successful mission will entail being remotely activated, autonomously travel 10ft, and the collection of a 10mL soil sample. Anything preventing the rover from completing these tasks will result in a failed mission. A success is defined by collection of the 10mL soil sample, a smaller volume will indicate mission failure.

5.2 Payload System Level Trade Studies

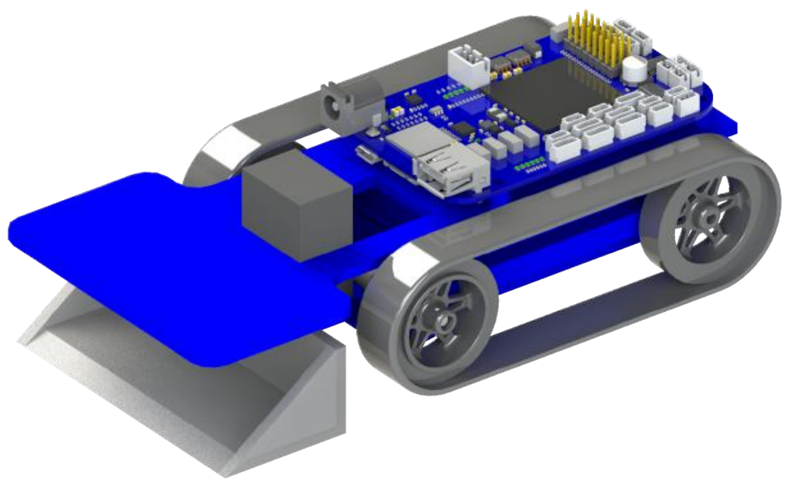


Figure 5.1: Exposed view of the Slim Sammy Rover

5.2.1 Rover Chassis Trade Study

Four key characteristics were considered for designing the overall plans for the rover chassis in the following table 5.1:

Criteria	**Description**
Mobility	The rover's ability to traverse a wide array of potential soil types
Integration	Ease of integration between the rover and the rocket, mainly in the requirement of landing adjustment
Cost	Cost effectiveness of the rover
Complexity	Difficulty in implementing design

Using these criteria, the options were narrowed to three possible designs (single axle, double axle, and legs) and a trade study was performed to determine which would suit our needs best.

5.2.1.1 Single Axle Design

The single axle design utilized one pair of rear drive wheels to power the forward motion of the rover as well as the soil collection process. The design is similar to that of bulldozers with a single rear drivetrain. The benefit of this is the easier design process and focus on rear drive chain power. Difficulties with this design include mobility concerns and possible power issues with only a single set of wheels.

5.2.1.2 Legged Rover

A legged rover design was proposed as an alternative to a wheeled design. The benefit of this design is its ability to traverse many different types of terrain. However, the problem with this design is the complexity in design of the movement mechanism itself as well as the integration with the soil collection method. The difficulties with this design make it a more intensive commitment and prohibitively difficult to implement.

5.2.1.3 Trade Study matrix

		Options					
		Single Axle		Double Axle		Legged	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Mobility	5	3	15	4	20	5	25
Integration	4	5	20	3	12	3	12
Cost	2	3	6	4	8	3	6
Complexity	3	3	9	5	15	1	3
Total Score		50		55		46	

5.2.1.4 Double Axle (Leading Choice)

The double axle design was the best design for its relative simplicity and high mobility. Since the idea of a two-axle vehicle is not a new task, existing manufacturing and design methods can be easily leveraged to create a rover. In addition, with two axles, the power transfer towards forward momentum is increased and makes the soil collection method easier. The points reflected in the selection criteria also make the double axle design the clear choice.

5.2.2 Motors

5.2.2.1 Greartisan 3V 50RPM

The Greartisan DC 3V 50RPM has the lowest weight of 9g, as well as the lowest price of $11.99. The Greartisan scored the highest in these two categories, however, it suffered from having the lowest speed and torque. The speed of this motor is 50RPM, which is why it got a score of 2 in this category. The main reason this motor wasn't chosen is because of its low torque. The Greartisan has torque of only 2.77 oz-in. Thus the Greartisan was given a score of 2 in this category which ultimately ruled out this motor.

5.2.2.2 Micro Gearmotor 6-12V 460RPM

It should be noted that we used the values for running this motor at 6V, since we know we will not be using a 12V battery. The Micro Gearmotor ranked highest in the speed category, due to its 460RPM rating. This led us to give it a 5 in this category. The Micro Gearmotor also received a 5 in the cost category because it costs $13.96, only $1.97 more than the Greartisan. However, the Micro Gearmotor weighs significantly more than the other two options. The Greartisan and Pololu motors weigh 9g and 9.5g respectively, while the Micro Gearmotor weighs 50g. It received a score of 3 in torque because its 7oz-in torque is better than the 2.77oz-in of the Greartisan, but not nearly as good as the 23.6oz-in of the Pololu motor.

5.2.2.3 Trade Study matrix

		Greartisan DC 3V 50RPM		Micro Gearmotor 6-12V 460RPM		Pololu Gearmotor 6V 310RPM	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Weight	2	5	10	2	4	5	10
Torque	5	2	10	3	15	5	25
Cost	4	5	20	5	20	4	16
Speed	1	3	3	5	5	4	4
Total Score		43		44		55	

5.2.2.4 Pololu Gearmotor 6V 310RPM (Leading Choice)

The Pololu Gearmotor 6V 310RPM motor fits our needs the best. It's inexpensive, costing only $16.95, and running at 310RPM, which is plenty for our needs. The Pololu Gearmotor received a score of 4 in both of these areas because it costs more than the other two options, but not by a large amount, and its speed is in between the other two. However, the Pololu Gearmotor weighs less than the Micro Gearmotor and about the same as the Greartisan, so it got a score of 5 for weight. What stood out the most in this motor was its torque of 23.6 oz-in, which is greater than both of the other options. This earned it a ranking of 5 in this category.

5.2.3 Servo Motor

5.2.3.1 Micro Servo

The Micro Server weighs only 9g and is the most inexpensive at $7.79. This earned the servo a rating of 5 in both of those categories. However, it has the worst torque of the three servo motors we looked at. This servo has a torque of 0.14 oz-in. We determined that since this was so low, we would assign this servo motor a score of 1 in this category. We believe this torque is not nearly enough to lift the required amount of soil, so we decided to not use the Micro Servo.

5.2.3.2 Keeywish

The Keeywish servo motor is an all-around good motor for our needs. Its weight and torque are both adequate. It has a weight of 25g and a torque of 27.8 oz-in, we decided to give the Keeywish a 4 in both of these categories. However, it suffers from a large cost of $19.99, so we gave it a 1 in this category. Due to it not having as high of a torque as the LewanSoul servo and a higher price point, we decided to not use this option.

5.2.3.3 Trade Study Matrix

The servo will lower and raise the lower scoop of the bulldozer-like portion of the rover. This means that the servo must have enough torque to lift the scoop and the required amount of soil. We calculated that a torque of 10 oz-in would suffice for the servo. This, however, is an overestimate, so anything close to 10 oz-in will work. With this being said, we decided that the more torque we have, the better, so we gave torque a weight of 5. The weight and cost are not nearly as important as the torque, so we assigned them weights of 3 and 1 respectively.

		Options					
		LewanSoul		Micro Servo		Keeywish	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Weight	3	2	6	5	15	4	12
Torque	5	5	25	1	5	4	20
Cost	1	3	3	5	5	1	1
Total Score		34		25		33	

5.2.2.4 LewanSoul (Leading choice)

We decided that the LewanSoul servo motor is the most well-suited servo for this use. It has a weight of 52g, which is the heaviest of the three options; this earned the LewanSoul a score of 2 in the weight category. It was also more expensive: the LewanSoul costs $14.99, which is almost twice as much as the Micro Servo. However, since both options are fairly inexpensive, we decided to give it a score of 3. While the cost and weight are not ideal, the LewanSoul compensates with its torque. The torque on the LewanSoul is 208 oz-in. This is far superior to the other two options, so we gave it a 5 in this category. We decided that the large torque makes up for the weight and cost, so we decided to use this servo.

5.2.4 Battery

The rover battery will power the BeagleBone microcontroller, two DC motors, and one servo motor. The BeagleBone microcontroller will serve as the rover's overall control system and will communicate with the two DC motors that control the movement of the rover and the servo motor that controls the soil collection system. The microcontroller is the most power-intensive component, needing a max current of 3200mA. The servo motor needs the second most power with a max current of 1000mA and the DC motors need the least power with a max current of 330mA each. Assuming that the rover runs for a maximum time of 10 minutes, a battery with at least 809.33mAh will be needed to run the rover. The 7.4V, 1 Ah Lithium-ion battery manufactured by Sparkfun Electronics fits these needs. This battery provides an excess of about 200mAh and a high enough voltage to power the rover.

In addition, the battery will power a set of sensors. Their power consumption is negligible, thus they will not be included here. Also, the servo motor used for these calculations may have size constraints that might necessitate opting instead for a smaller, less power-hungry motor. In this case, the power density shown here is an overestimation of what is needed.

Battery Budget Estimate (LI-ION BATTERY 1AH)					
System	Component	Max Current Draw (mA)	Qty	Run Time (hr)	Power Density (mAh)
Rover	Microcontroller (BeagleBone Blue) High Torque Motor Servo	3200 330 1000	1 2 1	0.166 0.166 0.166	533.33 110.00 166
				Total	809.33

Table 5.2: Battery budget estimation

5.2.4 BeagleBone Blue Microcontroller

Figure 5.2: Top view of the Slim Sammy, showing placement of the BeagleBone Blue microcontroller

We will be using the BeagleBone Blue microcontrollers to control both the rover and ADAS. Having the same microcontroller model for both ADAS and Payload will make it easier for team members to contribute to both systems, without the added difficulty of learning how to work with two different microcontrollers. In addition, it was decided that having a fully programmable Linux system alleviates the overhead of working with embedded systems. This benefit makes the coding and development process easier and justifies the larger size, weight, and cost characteristics. In addition, the larger processing power alleviates any potential issues with coding and optimizing for an embedded system. Further documentation and the trade study design matrix is investigated further in *Section 3.3.3.1: ADAS microcontroller.*

5.2.5 Motion Sensors Beaglebone Integrated IMU

The built in sensors on the BeagleBone Blue microcontroller will be utilized to control determining the current distance traveled as well as orientation. The integration of the onboard Inertial Measurement Unit (IMU) makes it simple and straightforward to calculate current position and traveled distance. The design characteristics were deemed sufficient to meet our design requirements in terms of both accuracy and range. Further documentation and trade report design matrix is detailed further in *Section 3.3.3.5: ADAS IMU.*

5.3 Preliminary Payload Design

5.3.2 Rover Deployment Method (RDM)

The rover payload can only leave the rocket once the vehicle has safely landed on the ground. In order to find the most effective method to separate the payload housing section from the lower and upper airframe, a large amount of force is required. Three designs were considered as leading choices for separating the vehicle body, each having its own benefits and drawbacks to implementation. Namely, the alternatives investigated were: black powder charge detonation, CO2 canisters, and a pneumatic piston device.

5.3.2.1 C02 Canisters

CO2 Canisters scored second behind Black Powder. In researching the method it was found to be easier to implement and more reliable than pneumatic action. The downsides of a CO2 canister deployment system are poor cleanliness and safety.

5.3.2.2 Pneumatic Action

Pneumatics are particularly clean and safe. While they excel in those two categories, they lack complexity score and reliability. A pneumatic deployment system would be difficult to implement and is less reliable than black powder.

5.3.2.3 Trade Study Matrix

Complexity measures how difficult the method will be to integrate into the rocket and the technical knowledge and skill required to develop the product. Cleanliness measures how the separation might pollute other components with debris. Safety indicates how hazardous the separation method will be to other systems or the vehicle and environment. Reliability is the number of successful separations the option is capable of performing at a wide variety of landing positions.

		Options					
		Black Powder		CO2 Canisters		Pneumatic Actuation	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Complexity	3	5	15	3	9	1	3
Cleanliness	2	2	4	2	4	5	10
Safety	4	3	12	2	8	4	16
Reliability	5	5	25	4	20	3	15
Total Score		56		41		44	

5.3.2.4 Black Powder

Table 5.3.2.3 shows that the black powder charge has the highest trade study score for separation method. It will be used if the RSO and other personnel at launches allow such a technique when the rocket lands. Sufficient precautions will be taken for the charge installation, and isolated testing to determine the feasibility and hazards that could emerge from a black powder system.

5.3.3 Rover Mobility System (RMS)

To fulfill the requirement for the rover to move 10ft, there must be a system to move the rover. Wheels, tire treads, a treads & wheels combination, and tank treads are all considered.

5.3.3.1 Wheels

Wheels have the benefit of smaller size in comparison to treads. If the rover was on a flat surface, wheels would be very mobile, but wheels may not be able to traverse rough terrain. Therefore, this option had to be eliminated.

5.3.3.2 Tire Treads

Tire treads (with one tread on each wheel) would allow the rover to traverse rough terrain. However, this design is more complicated to implement and will not be as durable as tank treads.

5.3.3.3 Treads & wheels combination

We considered a combination of wheels and treads, with treads on the front wheels (refer to diagram below). This design may provide the benefit of having additional space for soil collection if needed, but would be more difficult to control and less mobile on rough terrain.

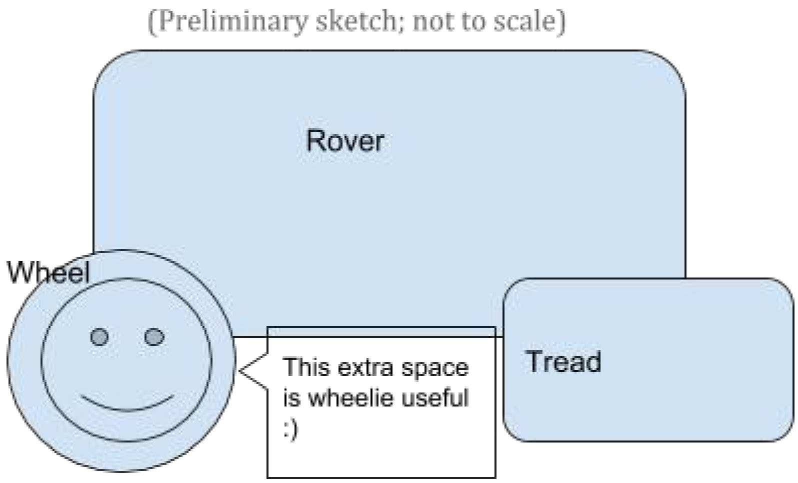


Figure 5.3: Benefits of the wheel/tread combination

Since what type of terrain Slim Sammy will be traveling on is uncertain, mobility in diverse terrain is the primary concern. Feasibility of design for implementation (integration), budget-friendliness (cost), durability, and size must also be considered.

5.3.3.4 Trade Study Matrix

		Options							
		Wheels		Tank Treads		Tire Treads		Treads & Wheels	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Mobility	5	3	15	5	25	5	25	4	20
Integration	5	4	20	5	25	4	20	3	15
Cost	3	5	15	4	12	2	6	3	9
Durability	5	2	10	5	25	3	15	2	10
Size	2	5	10	2	4	2	4	4	8
Total Score		70		91		70		62	

5.3.3.5 Tank Treads (Leading Choice)

Ultimately a tank tread design was decided upon, with two treads spanning the length of the rover. This satisfies the desired characteristics: ease of implementation, durability, budget-friendliness, and mobility in rough terrain.

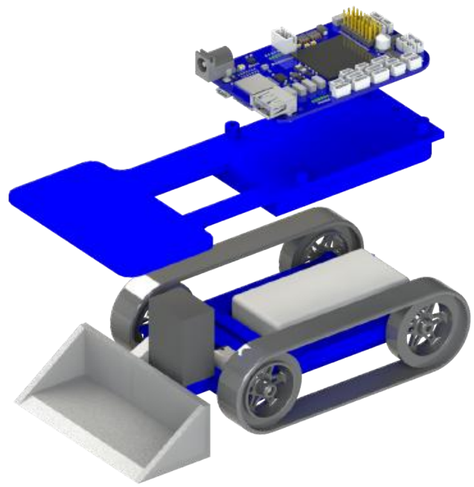


Figure 5.4: Rover mobility system decision: tank treads.

5.3.4 Obstacle Detection and Avoidance System (ODAS)

A mechanism to avoid obstacles is necessary, as the rover needs to travel 10ft, regardless of any objects in the rover's path. Three options were considered for object detection: LiDAR, vision detection, and ultrasonic rangefinder.

Criteria	Description
Integration	Difficulty of installing and adapting the sensors/camera onto the rover.
Complexity	A measure of how technical the object detection method is in terms of time and knowledge commitments to team.
Cost	The cost effectiveness of the sensors against the usefulness of the rover avoiding obstacles.
Reliability	Qualitative measure of correct object recognition and response to microcontroller.

Table 5.3: ODAS selection criteria

5.3.4.1 LiDAR

LiDAR is a light-based rangefinder that also detects the nearest object in its range. This sensor has a range of 131ft (40m). While it may be more reliable than the ultrasonic rangefinder, at an approximate cost of $300, it is significantly more expensive than both other options.

5.3.4.2 Vision Detection

A camera that will process vision input to detect objects the rover is approaching to avoid them would be an interesting challenge to tackle, however, the technical complexity (and consequently, potential unreliability) of this method caused it to be ruled out.

5.3.4.3 Trade Study Matrix

		Options					
		Ultrasonic		LiDAR		Vision Detection	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Integration	5	5	25	4	20	2	10
Complexity	4	5	20	4	20	1	4
Cost	3	5	15	3	9	4	12
Reliability	5	4	20	5	25	2	8
Total Score		80		74		34	

5.3.4.4 Ultrasonic Rangefinder (Leading Choice)

An ultrasonic rangefinder will feed the distance from the sensor to the nearest object in its range. The sensor can only detect objects in front of it in a range of 13.12ft (4m).

Among the options for ODAS, an Ultrasonic Rangefinder is the best. The Ultrasonic rangefinder is low cost, easy to integrate, and simple to program. These qualities account for its shortcoming in reliability when compared to LiDAR which is more expensive and challenging to integrate.

5.3.5 Soil Collection Method (SCM)

5.3.5.1 Auger Method

The first design that was considered was to give the rover an auger to dig soil with. However, given the size constraints for the rover, the difficulty in implementation and complexity (difficult to determine how much soil is collected or to transfer the soil collected to a compartment) of the auger led to its elimination.

5.3.5.2 Tube & Scoop Method

This method would utilize a scoop at the front of the rover that is melded into a container towards its back. The rover would position the scoop towards the ground and collect soil as it moves forward. Then the rover would lift the scoop up, and the soil would slide into the container.

5.3.5.3 Trade Study Matrix

Deciding on a soil collection method is dependent on a variety of things such as reliability, size, and complexity. It's important that whatever method is chosen will be successful in its mission to collect a 10mL soil sample. Should the rover fail to collect the required sample, the mission will be considered a failure. As such, reliability is a priority.

		Options					
		Bulldozer		Tube & Scoop		Auger	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Reliability	5	4	20	3	15	2	10
Size	4	3	12	2	8	2	8
Cost	3	3	9	3	9	2	6
Complexity	3	4	12	3	9	2	6
Weight (Mass)	4	3	12	4	16	3	12
Coolness Factor	2	2	4	2	4	4	8
Total Score		69		61		50	

5.3.5.4 Bulldozer Method (Leading Choice)

The method that the team decided upon was a bulldozer design. The bulldozer is effectively similar to the tube and scoop method, but its simplicity makes it much more reliable. A motor lowers the bottom scoop, the rover drives forward to collect the soil, and the "mouth" (now full of soil) returns to its closed position. Along with the simplicity of the design comes other benefits. Since the type of soil that the rocket will land on is unknown, the bulldozer's ability to penetrate and collect even very dense soil weighs heavily in its favor.

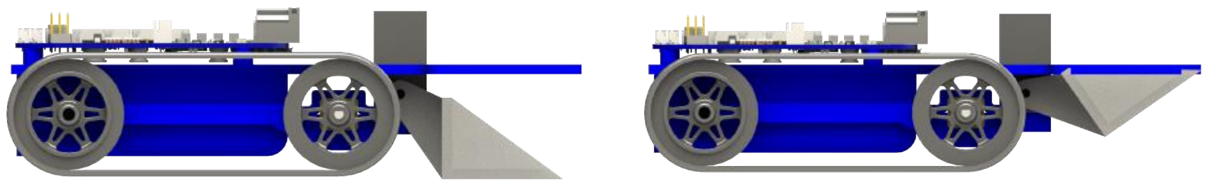


Figure 5.5: Bulldozer soil collection model

5.4 Payload Testing

Various tests will be completed in an effort to verify the design choices made and the overall effectiveness of the rover. These tests are outlined in Table 5.4.

Payload Testing

Payload Test	Test Details	Success Criteria	Failure Analysis
Soil Type: Hard Dirt	A test of the rover will be completed on hard dirt. This will include a full mobility and soil sample test.	The rover is able to travel a minimum of 10ft and is able to collect a 10mL soil sample.	A detailed analysis of the failure mode will be completed. A design change will then be researched and discussed in the form of a Trade Study.
Soil Type: Sand	A test of the rover will be completed on sand. This will include a full mobility and soil sample test.	The rover is able to travel a minimum of 10ft and is able to collect a 10mL soil sample.	A detailed analysis of the failure mode will be completed. A design change will then be researched and discussed in the form of a Trade Study.
Soil Type: Mud	A test of the rover will be completed	The rover is able to travel a minimum of	A detailed analysis of the failure mode

	on mud. This will include a full mobility and soil sample test.	10ft and is able to collect a 10mL soil sample.	will be completed. A design change will then be researched and discussed in the form of a Trade Study.
Soil Type: Grass	A test of the rover will be completed on grass. This will include a full mobility and soil sample test.	The rover is able to travel a minimum of 10ft and is able to collect a 10mL soil sample.	A detailed analysis of the failure mode will be completed. A design change will then be researched and discussed in the form of a Trade Study.
Battery Life	A test of the battery life will be completed. This will involve running the rover to verify the integrity of the batteries used.	The battery life lasts a minimum of 3 times as long as the longest soil type test.	A design change and/or part exchange will be researched and discussed in the form of a Trade Study.
Internal Fastening	A test of the internal fastening device used during flight. Includes physical drops and/or simulated loads.	The fastening device securely holds the rover and no damage is passed to the rover.	A detailed analysis of the failure mode will be completed. A design change will then be researched and discussed in the form of a Trade Study.
Ejection Method	A test of the rover's ejection method will be completed on the ground.	The ejection method successfully deploys the rover with no damage to either system.	A detailed analysis of the failure mode will be completed. A design change will then be researched and discussed in the form of a Trade Study.
Orientation Method	A test of the rover's orientation method to verify its	The orientation method successfully orients the rover.	A detailed analysis of the failure mode will be completed. A

	effectiveness and reliability.		design change will then be researched and discussed in the form of a Trade Study.

Table 5.4: Payload Testing Criteria

6 Project Plan

6.1 Requirements Verification

6.1.1 NASA SLI Requirements

The Nasa Student Launch provides five major sets of requirements that each team is expected to recognize and fulfill:

1. General Requirements
2. Vehicle Requirements
3. Recovery System Requirements
4. Payload Experiment Requirements
5. Safety Requirements

Table 6.1 to Table 6.5 describe how the team will comply with these stipulations, using the following four methods of verification:

- **Inspection** - Examination of the object or system using the senses and tools available to the team. This method is very unobtrusive and does not require much interaction or modification of the object or system being examined.
- **Demonstration** - Making the system or object perform its intended purpose under scrutiny to ensure that it functions as desired.
- **Analysis** - Verification that the system or object performs as intended through a set of calculations, models, and simulations.
- **Test** - Verification of the system or objects by means of controlled inputs, and comparison of output to the intended output of the object or system.

General Requirements

#	Requirement Description	Method of Verification	Description of Verification
1.1	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	Inspection	There will be constant inspections to ensure that all work is being done solely by students members, with the exception of operations that must be performed by team mentors (i.e. motor assembly, black powder handling,

	preparing and installing electric matches (to be done by the team's mentor).		preparing/installing electric matches).
1.2	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.	Inspection	The project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks/mitigations will be inspected and discussed weekly at team meetings.
1.3	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.	Inspection	All members of the team will be asked if they are Foreign Nationals and will be identified by the PDR.
1.4	The team must identify all team members attending launch week activities by the Critical Design Review (CDR). Team members will include:	Inspection	All members of the team will be asked if they are able to attend launch week, and if funding allows, they will be identified before the CDR.
1.4.1	Students actively engaged in the project throughout the entire year.	Inspection	Engaged student members that are committed to attending launch week will identify themselves by the CDR.
1.4.2	One mentor (See requirement 1.13)	Inspection	A mentor that is committed to attending launch week will be identified by the CDR. The mentor will ensure that all attending personnel meet the necessary requirements.
1.4.3	No more than two adult educators	Inspection	No more than two adult educators will attend launch week, and will identify themselves by the CDR.
1.5	The team will engage a minimum of	Inspection	STEM Engagement Activity

	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 Report must be submitted via email within two weeks of the completion of the event. A sample of the STEM Engagement Activity Report can be found on page 33 of the handbook.		Reports will be inspected to ensure that they are submitted within two weeks of event completion. Weekly meetings will include inspection of past events to ensure that a minimum of 200 participants are engaged between project acceptance and the FRR.
1.6	The team will establish a social media presence to inform the public about team activities.	Inspection	Any team social media will be inspected and updated regularly to inform and engage the public about team activities.
1.7	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.	Inspection	Team members will inspect all deliverables to ensure they are completed and emailed by their respective deadlines. In the event that a deliverable exceeds the maximum file size, a link to a download of the file will be sent.
1.8	All deliverables must be in PDF format.	Inspection	Deliverables will be inspected before submission to ensure that they are in PDF format.
1.9	In every report, teams will provide a table of contents including major sections and their respective sub-sections.	Inspection	Reports will be inspected to ensure that all major sections and respective sub-sections are included in the table of contents.
1.10	In every report, the team will include the page number at the bottom of the page.	Inspection	Report will be inspected for page numbers.

1.11	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.	Inspection	All necessary equipment will be procured by the team, and will be inspected to ensure that it functions as intended, including, but not limited to; a computer system, video camera, speaker telephone, and an Internet connection.
1.12	All teams will be required to use the launch pads provided by Student Launch's launch services pro- vider. 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.	Inspection	The team's launch vehicle will be inspected to ensure that it is compatible with the launch pads provided by Student Launch's launch service provider.
1.13	Each team must identify a "mentor." A mentor is defined as an adult who is included as a team 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	Inspection	A qualified mentor will be identified, and will be designated the individual owner of the rocket, as well as fulfill any other responsibilities. The mentor will accompany and supervise the team at launch week.

	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.		

Table 6.1 Student Launch General Requirements

Vehicle Requirements

#	Requirement Description	Method of Verification	Description of Verification
2.1	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.	Demonstration	The launch vehicle will reach a chosen apogee between 4,000 and 5,500 using a combination of motor selection and air-braking.
2.2	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.	Inspection	A "Planned Altitude" value will decided upon and presented in the PDR.
2.3	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	Inspection	The vehicle will be designed and inspected to accommodate one commercially available barometric altimeter that will be included in all launches.

	their official target altitude on launch day.		
2.4	Each altimeter will be armed by a dedicated 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.	Inspection	A dedicated arming switch will be built into the design of the vehicle and identified in the design documents.
2.5	Each altimeter will have a dedicated power supply.	Inspection	Dedicated batteries will be supplied and planned for in the design.
2.6	Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	Inspection	The rocket will utilize arming switches with locked positions, such as screw or key switches.
2.7	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.	Inspection	Launch vehicle will be built and tested for recoverability and durability.
2.8	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.	Inspection	The rocket will be designed to have a maximum of 4 independent sections, Thrust Section, Avionics/Payload, and Nosecone. Every section will have a tether point and a connection to the parachute(s).
2.8.1	Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length.	Inspection	Every shoulder will measured and verified of its length compared to the body diameter.
2.8.2	Nosecone shoulders which	Inspection	The nose cone shoulder will be

	are located at in-flight separation points will be at least 1⁄2 body diameter in length.		measured and verified that it is at least ½ of the body diameter.
2.9	The launch vehicle will be limited to a single stage.	Inspection	Launch vehicle will possess a single motor.
2.10	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.	Demonstration	A comprehensive flight checklist will be made and tested before launch to verify the preparation time.
2.11	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 components.	Analysis	All critical on-board components will have power supplies that can provide power for a minimum of two and a half hours without losing functionality.
2.12	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.	Demonstration	The motor mount and chosen motor will be made and fit in order to be capable of being launched by a standard 12-volt direct current firing system.
2.13	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).	Inspection	All necessary circuitry and support will be included within the vehicle and does not rely on external support.
2.14	The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by	Inspection	Launch vehicle will use a commercially obtained APCP motor that is approved and certified by the NAR, TRA, and/or CAR.

	the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).		
2.14.1	Final motor choices will be declared by the Critical Design Review (CDR) milestone.	Demonstration	From simulations, a final motor choice will be made by the CDR and presented clearly.
2.14.2	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.	Inspection	Any change to the motor after the CDR will be announced and approved by the RSO as soon as the change is made.
2.15	Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria:	Inspection	All pressure vehicles will be brought to the attention of the RSO and approved.
2.15.1	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.	Inspection	The pressure vehicles used will be verified from documentation to have the proper factor of safety.
2.15.2	Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.	Inspection	The pressure vessels used will all have pressure relief valves that are capable of withstanding the maximum pressure and flow rate according to documentation.

2.15.3	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.	Inspection	A full documentation of the tank will be provided on design documents.
2.16	The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class). The total impulse provided by a High School or Middle School launch vehicle will not exceed 2,560 Newton-seconds (K-class).	Inspection	The chosen motor will be verified by documentation to have a total impulse less than 5,120 Newton-seconds.
2.17	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.	Analysis	OpenRocket simulations will be used to verify the static stability margin of the vehicle exceeds 2.0 upon rail exit.
2.18	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	Analysis/ Demonstration	OpenRocket simulations will be used to verify the rail exit velocity. Test flights will also be used to verify the velocity.
2.19	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.	Demonstration	Team will successfully launch and include a flight report of the subscale model in the CDR.
2.19.1	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.	Demonstration	The subscale model will be separate from the full-scale launch vehicle, and will feature several similar components.
2.19.2	The subscale model will	Demonstration	Subscale model will include a

	carry an altimeter capable of recording the model's apogee altitude.		commercially available altimeter that is capable of recording apogee altitude.
2.19.3	The subscale rocket must be a newly constructed rocket, designed and built specifically for this year's project.	Inspection	The subscale model will be built entirely during the school year and solely for NASA 2019 SLI.
2.19.4	Proof of a successful flight shall be supplied in the CDR report. Altimeter data output may be used to meet this requirement.	Demonstration	All analysed flight data will be document and supplied by the CDR report.
2.20	All teams will complete demonstration flights as outlined below.	Demonstration	Test flights will be completed at the local range.
2.20.1	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 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.). The following criteria must be met during the full-scale demonstration flight:	Demonstration/ Inspection	The vehicle will be flown in its competition configuration during its test flight prior to the FRR. All test flight data will be analyzed and supplied to verify successful launch. Flight checklists will be used to ensure contant construction methods.

2.20.1.1	The vehicle and recovery system will have functioned as designed.	Inspection/ Demonstration	Flight data will verify the success of the recovery system.
2.20.1.2	The full-scale rocket must be a newly constructed rocket, designed and built specifically for this year's project.	Inspection	The full-scale model will be built entirely during the school year and solely for NASA 2019 SLI.
2.20.1.3	The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply:	Inspection	The team will state whether or not the payload was included in the full-scale demonstration flight.
2.20.1.3.1	If the payload is not flown, mass simulators will be used to simulate the payload mass.	Demonstration/ Inspection	A correct mass simulator will be used in place of the payload should it be necessary. The mass simulation will be made beforehand and will accurately model the payload.
2.20.1.3.2	The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.	Inspection	Proper attachment points will made to fit the mass simulation if needed.
2.20.1.4	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.	Inspection	Any external surfaces will be made to exist with or without the payload.
2.20.1.5	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	Inspection/ Demonstration	The chosen motor will be purchased and used during the full-scale demonstration flight.

	day motor or in other extenuating circumstances.		
2.20.1.6	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 flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.	Demonstration/ Inspection	The final chosen amount of ballast from simulations will be flown during the full-scale demonstration flight. The flight checklist will verify that the ballast is added.
2.20.1.7	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).	Inspection	No further modifications will be made after the full-scale demonstration flight and the flight checklist will make sure it is unchanged.
2.20.1.8	Proof of a successful flight shall be supplied in the FRR report. Altimeter data output is required to meet this requirement.	Demonstration	Flight data will be analyzed and supplied in the FRR.
2.20.1.9	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.	Demonstration/Inspection	Planned launch dates for the full-scale demonstration flight will be before the FRR submission deadline. Any backup dates will be verified and changes will be made if necessary.

2.20.2	Payload Demonstration Flight - All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown must be the same rocket to be flown on launch day. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent, the payload is fully retained during ascent and descent, and the payload is safely deployed on the ground. The following criteria must be met during the Payload Demonstration Flight:	Demonstration/ Inspection	The payload will be completed and flown with the full-scale vehicle during the demonstration flight. All aspects of the payload will be verified to have been successful from data and post-launch analysis.
2.20.2.1	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.	Demonstration	A post-flight analysis will verify the successful retention of the payload.
2.20.2.2	The payload flown must be the final, active version.	Inspection/ Demonstration	The payload will be finished by the full-scale demonstration flight.
2.20.2.3	If the above criteria is met during the original Vehicle Demonstration Flight, occurring prior to the FRR	Inspection	A FRR Addendum will not be included should all flights be completed before the FRR deadline.

	deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required.		
2.20.2.4	Payload Demonstration Flights must be completed by the FRR Addendum deadline. No extensions will be granted.	Inspection	The payload will be completed and flown before the FRR Addendum deadline.
2.21	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.	Inspection	Should the team require an FRR Addendum a request will be made and the re-flight will be completed before the deadline.
2.21.1	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.	Inspection	All re-flight flights and paperwork will be completed before the deadline in order to fly during launch week.
2.21.2	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.	Inspection	The payload will be completed and flow during the full-scale demonstration flight/re-flight in order to fly it during launch week.
2.21.3	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	Inspection	The team will petition the NASA RSO if the payload demonstration flight is unsuccessful in any way.

	Review Panel have any safety concerns.		
2.22	Any structural protuberance on the rocket will be located aft of the burnout center of gravity.	Inspection/ Analysis	The design of the rocket will feature all protuberances behind the burnout center of gravity.
2.23	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.	Inspection	During construction all contact information for the team will be included on any parts that separate during flight.
2.24.1	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.	Inspection/ Analysis	Should the vehicle feature forward canards, simulations will show a minimal aerodynamic effect.
2.24.2	The launch vehicle will not utilize forward firing motors.	Inspection	The flight checklist will include a verification that all motors are not forward facing.
2.24.3	The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	Demonstration/ Inspection	The documentation provided with the motor will verify the motor composition.
2.24.4	The launch vehicle will not utilize hybrid motors.	Demonstration/ Inspection	The flight checklist will verify that any motor used are solid fuel.
2.24.5	The launch vehicle will not utilize a cluster of motors.	Demonstration/ Inspection	The flight checklist will verify that clusters of motors is not used.

2.24.6	The launch vehicle will not utilize friction fitting for motors	Inspection	The vehicle will be designed so that the motor retention is done with bolts, not friction.
2.24.7	The launch vehicle will not exceed Mach 1 at any point during flight	Analysis/ Demonstration	OpenRocket simulations and post-flight analysis will verify the vehicle does not exceed Mach 1.
2.24.8	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).	Inspection/ Analysis	From calculated vehicle mass, the total ballast will not exceed 10% of this value.
2.24.9	Transmissions from onboard transmitters will not exceed 250 mW of power.	Inspection/ Demonstration	The onboard transmitters will be tested and proven to not exceed 250 mW of power.
2.24.10	Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	Analysis/Inspection	All construction materials will be documented and verified to be lightweight and reasonable.

Table 6.2 Student Launch Vehicle Requirements

Recovery Requirements

#	Requirement Description	Method of Verification	Description of Verification
3.1	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	Demonstration/ Inspection	The vehicle design will be made to deploy a drogue parachute at apogee and a main parachute at a lower specific altitude. This will be verified through inspection of the systems and

	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.		demonstration flights.
3.1.1	The main parachute shall be deployed no lower than 500 feet.	Demonstration/ Inspection	The sensor used for parachute deployment will be set for an altitude higher than 500 feet.
3.1.2	The apogee event may contain a delay of no more than 2 seconds.	Demonstration/ Inspection	A delay of no more than 2 seconds will be used.
3.2	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.	Demonstration	The safety officer will oversee and verify a successful ground ejection test before each flight for both parachutes.
3.3	At landing, each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.	Analysis	OpenRocket simulations and the mass properties of the vehicle will be used to calculate landing energy.
3.4	The recovery system electrical circuits will be completely independent of any payload electrical circuits.	Inspection	All circuits will be located in a separate and isolated section of the vehicle.
3.5	All recovery electronics will be powered by commercially available batteries.	Inspection	All batteries for the recovery electronics will be documented to be COTS batteries.
3.6	The recovery system will contain redundant, commercially available altimeters. The term “altimeters” includes both	Inspection	All recover flight computers will be be documented to be COTS flight computers.

	simple altimeters and more sophisticated flight computers.		
3.7	Motor ejection is not a permissible form of primary or secondary deployment.	Inspection/ Demonstration	All ejections will be done using black powder charges as opposed to motor ejection.
3.8	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Inspection	The vehicle design will feature shear pins for attaching any section of the vehicle that detaches, including the parachute compartments.
3.9	Recovery area will be limited to a 2,500 ft. radius from the launch pads.	Analysis/ Demonstration	OpenRocket simulations and numerical analysis will verify that the vehicle does not exceed a drift of 1250 ft.
3.10	Descent time will be limited to 90 seconds (apogee to touch down).	Analysis/ Demonstration	OpenRocket simulations and post-flight analysis will verify the vehicle takes no longer than 90 seconds from apogee to landing.
3.11	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.	Inspection	A planned GPS Tracking devices will be included in the construction of the vehicle. Verification that it is functional will be completed before the flight.
3.11.1	Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic tracking device.	Inspection	Addition GPS Trackers will be included on any section that lands untethered from the launch vehicle. Verification that is functional will be completed before the flight.
3.11.2	The electronic tracking device(s) will be fully functional during the official flight on launch day	Inspection/ Demonstration	The GPS Tracker(s) will be tested before the flight to verify it is in working condition.
3.12	The recovery system electronics will not be adversely affected by any	Analysis/ Demonstration	The isolation from other devices will remove any potential adverse effects from other

	other on-board electronic devices during flight (from launch until landing).		electronics on the vehicle to the recovery electronics.
3.12.1	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.	Inspection	The vehicle design will isolate the recovery electronics from any other electronics aboard the vehicle.
3.12.2	The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.	Inspection/ Demonstration	The vehicle design will include shielding from any other electronics to verify the functionality of the recovery electronics.
3.12.3	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	Inspection/ Demonstration	The vehicle design will include shielding from any other electronics to verify the functionality of the recovery electronics.
3.12.4	The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	Inspection/ Demonstration	The vehicle design will include shielding from any other electronics to verify the functionality of the recovery electronics.

Table 6.3 Student Launch Recovery Requirements

Payload Requirements

#	Requirement Description	Method of Verification	Description of Verification
4.2	College/University Division – Each team will choose one	Inspection	The rover option has been chosen for the payload.

	experiment option from the following list.		
4.2.1	An additional experiment (limit of 1) is allowed, and may be flown, but will not contribute to scoring.	Inspection	The team will not include any additional experiments in the launch vehicle.
4.2.2	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.	Inspection	The team will not include any additional experiments in the launch vehicle.
4.3			
4.3.1	Teams will design a custom rover that will deploy from the internal structure of the launch vehicle	Demonstration	The team has designed a custom rover as the payload for the launch vehicle. The rover deploys from the internal structure.
4.3.2	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.	Demonstration/ Test	The design retention system will be tested to verify its integrity and test any failsafe methods.
4.3.3	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.	Demonstration	The team will use a radio transmitter to remotely deploy the rover once the all-clear is given.
4.3.4	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.	Demonstration	The rover has been designed to autonomously move a minimum of 10 ft. from the launch vehicle, then collect a soil sample.

4.3.5	The soil sample will be a minimum of 10 milliliters (mL).	Demonstration	The rover has been designed to collect a minimum of 10 milliliters of soil before stopping soil collection.
4.3.6	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.	Demonstration	The rover will contain a container that will be sealed after the soil sample has been deposited.
4.3.7	Teams will ensure the rover's batteries are sufficiently protected from impact with the ground.	Demonstration	The rover's batteries will be housed internally, so as to eliminate any risk of impact with the ground.
4.3.8	The batteries powering the rover will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other rover parts	Demonstration	Batteries will be marked with a bright color separate from any other color found on the rover, and will have labels marking it a fire hazard.

Table 6.4 Student Launch Payload Requirements

Safety Requirements

#	Requirement Description	Method of Verification	Description of Verification
5.1	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.	Demonstration	Safety checklist will be comprehensive and include all crucial safety checks. Final checklist will be included in the FRR, and will be used in the LRR and any launch day operations.
5.2	Each team must identify a student safety officer who will be responsible for all items in section 5.3.	Demonstration	Richard Alves will act as the team's student Safety Officer and has accepted responsibility for all items in section 5.3.
5.3.1	Monitor team activities with an emphasis on safety.	Demonstration	The Safety Officer will attend all major team events and building

			times and ensure applicable team rules and competition requirements are being met at all times throughout the project.
5.3.2	Implement procedures developed by the team for construction, assembly, launch, and recovery activities.	Demonstration	A safety manual will guide personnel to follow a safe work habit, and the Safety Officer is required to train inexperienced members and observe all major vehicle development.
5.3.3	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data,	Demonstration	A safety manual will be maintained by the Safety Office such that it contains all pertinent information on the team's protective measures, and a spreadsheet will track compounds stored in the lab spaces and beyond.
5.3.4	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	Demonstration	The Safety Officer will be responsible for ensuring the documentation written throughout the year's competition reflects the latest designs and the hazards they present, and how to mitigate such risks.
5.4	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	Demonstration	The team will has created a set of compliances for the NAR High-Powered Rocketry code. In addition, the team mentor David Raimondi will handle logistical and communications between the team and

	NAR or TRA launch.		
5.5	Teams will abide by all rules set forth by the FAA.	Inspection	All team members will be informed of all rules set forth by the FAA, and regular inspections will be made to ensure that all rules are abided by.

Table 6.5 Student Launch Safety Requirements

6.1.2 Team Derived Requirements

The team has created its own system requirements to be met throughout project completion, which include the following:

1. General Requirements
2. Vehicle Requirements
3. Recovery Requirements
4. Payload Requirement
5. ADAS Requirements
6. Safety Requirements

Table 6.6 to Table 6.11 describe how the team will verify these requirements have been met, using the previously described four methods of verification.

Team Derived General Requirements

#	Requirement Description	Method of Verification	Description of Verification
1.1	General meetings will be held at 6:30 on Friday nights.	Inspection/ Demonstration	Rooms and hardware will be reserved every Friday and announcements will be made for the meeting.
1.2	Slack will be used for all intra-team communication.	Inspection/ Demonstration	All members will be added onto the Team Slack and is assisted with joining channels or anything else needed.
1.3	All code will be uploaded to a team GitHub.	Inspection/ Demonstration	The members interested in contributing code will be given access to the team GitHub.
1.4	Any documents relative to	Inspection/	All members will be added to the

	the team will posted for all on the Team Google Drive.	Demonstration	team Google Drive.

Table 6.6 Team Derived General Requirements

Team Derived Vehicle Requirements

#	Requirement Description	Method of Verification	Description of Verification
1.1	Vehicle will feature an adaptive air-braking system (ADAS).	Inspection	ADAS will be inspected and tested for functionality.
1.1.1.1	The ADAS will regulate drag with the help of two retractable fins.	Inspection	ADAS fins will be inspected to fit inside the launch vehicle frame and to have a minimum and maximum protrusion that allows for adequate drag control during flight.
1.1.1.2	The ADAS fins will be able to withstand the maximum forces during flight.	Analysis	After several completed landings perform visual and structural inspection of ADAS fins
1.1.1.3	The ADAS system will deploy the fins to the correct range.	Demonstration	Optical sensor feedback look reading position of fin deployment.
1.1.2.1	The ADAS system will stop the rocket to an apogee within 50 feet of the target.	Demonstration	Cross verification of onboard altimeter sensors to verify we reached an actual apogee within 50 of the target.
1.1.2.2	The ADAS system will have an accurate flight curve profile.	Inspection	Calculate flight envelope for none and maximum ADAS deployment and compare to physical launch.
1.1.2.3	The ADAS system will follow the flight curve within an error margin of 15%.	Demonstration	Record sensor metric data and calculate deviation.
1.1.3	The ADAS system will adjust itself at a frequency	Inspection	Set time measurement between beginning of algorithm calculation

	of 20Hz.		and motor movement signal.

Table 6.7 Team Derived Vehicle Requirements

Team Derived Recovery Requirements

#	Requirement Description	Method of Verification	Description of Verification
3.1	Packed parachute size of less than 5.5 in.	Inspection	Inspect the packaging of the purchased parachutes
3.1.2	Landing energy less than 70 lbs.	Analysis, Test	Analyze using mathematical calculations and sensor information recorded during launch tests
3.1.3	Motor that gets the apogee 10% above a mile	Inspection, analysis, test	View the details of the motor being purchased, and test to verify
3.1.4	Data recording capabilities are less than 20 Hz	Inspection	Verify with the product details
3.1.5	Data storage is more than 2GB minutes	Inspection	Verify with the product details

Table 6.8 Team Derived Recovery Requirements

Team Derived Payload Requirements

#	Requirement Description	Method of Verification	Description of Verification
4.1	Rover will be deployed with the help of a motor-driven internal section, to ensure the rover exits the vehicle right-side up.	Demonstration	Section containing rover will house a motor-driven rotating internal section, that will orient the rover right-side up during deployment.
4.1.1	Rotating internal section will be in a locked position during flight.	Test	Motor responsible for rotation of internal section will be locked during flight.
4.1.2	Black powder charge will	Test	Ground testing will be performed

	eject the payload and nose cone sections, allowing the rover to exit.		to ensure that the nose cone can be removed by the powder charge.
4.1.3	Rover will be durable enough to withstand the flight and ejection.	Test	Ground test the ejection, checking that no damage to the rover occured.
4.1.4	An accelerometer will measure the orientation, so the motor can be controlled accordingly to orient the rover correctly (right-side up).	Test	Test that the rover lands oriented upright.
4.1.5	Rover will fit inside the 5.5" inner diameter rocket, with room to spare for rotation.	Analysis, Inspection	Analysis: before building the rover, CAD analysis will be done to ensure the rover will fit inside the rocket Inspection: The rover will be measured and inserted inside the rocket to ensure it fits.
4.2	Rover will be able to reliably travel over 10 feet on rough terrains and elevations.	Test	Test driving the rover on a variety of terrains and elevations.
4.2.1	Motors controlling the rover's motion will have sufficient torque to propel the rover.	Test	Test driving the rover on a variety of terrains and elevations.
4.2.2	Treads will generate sufficient traction to propel the rover.	Test	Test driving the rover on a variety of terrains and elevations.
4.2.3	Rover will avoid impassable obstacles.	Test	Test deploying the rover in front of obstacles.
4.3	Rover will be able to reliably pick up and seal over 10 mL of dirt of different types and moisture levels.	Test	Test soil collection method on different soil types (hard and soft, wet and dry). Ensure bulldozer design can penetrate even hard clay.
4.3.4	Rover soil container will be	Demonstration	Ensure the container has a

	able to contain at least 10mL of soil.		volume large enough to contain over 10mL of soil.

Table 6.9 Team Derived Payload Requirements

Team Derived ADAS Requirements

#	Requirement Description	Method of Verification	Description of Verification
5.1	The ADAS system will stop the rocket to an apogee within 50 feet of the target.	Demonstration	Cross verification of onboard altimeter sensors to verify we reached an actual apogee within 50 of the target.
5.2	The ADAS system will deploy the fins to the correct range.	Demonstration	Optical sensor feedback look reading position of fin deployment.
5.3	The ADAS system will adjust itself at a frequency of 20Hz.	Inspection	Set time measurement between beginning of algorithm calculation and motor movement signal.
5.4	The ADAS system will have an accurate flight curve profile.	Calculation	Calculate flight envelope for none and maximum ADAS deployment and compare to physical launch.
5.5	The ADAS system will follow the flight curve within an error margin of 15%.	Analysis	Record sensor metric data and calculate deviation.

Table 6.10 Team Derived ADAS Requirements

Team Derived Safety Requirements

#	Requirement Description	Method of Verification	Description of Verification
6.1	All team members must take required safety training from UC Santa Cruz to gain permission to enter and use lab equipment, and must sign the Safety Acknowledgement Form before being allowed	Demonstration	The Safety Officer will maintain a list of students who have completed the trainings and signed all needed forms.

	entrance or privileges.		
6.2	Personnel will wear appropriate attire and PPE when in lab and work spaces.	Inspection	All members will be responsible for ensuring a safe work environment by wearing and reminding others to wear PPE. The Safety Officer will be inspecting other of their outfits and clothing on a usual basis.
6.3	Hazardous chemicals will be stored and handled with proper technique and rules as laid out in training.	Inspection	The Safety Officer and team members will ensure that materials are used appropriately, and the team mentor will handle pyrotechnic and explosive devices for the team at launch sites.
6.4	Material safety data sheets will be reviewed before use of said chemicals.	Demonstration	Personnel will show their trained ability to the Safety Officer prior to independent work. MSDS and electronic components can all be found online, including on the team website.
6.5	Launches will involve cross-checking and referencing between the Safety Officer and involved personnel.	Demonstration	The Safety Officer will coordinate with numerous team personnel at launch events and facilitate a safe area for bystanders.
6.5.1	All e-matches and igniters will be tested, with the mentor and other critical personnel, for continuity prior to installation, and the failed components will not be used.	Test	Necessary testing equipment will be brought by the team for system testing at all levels of the launches, including recovery devices.
6.5.2	Parachutes and other delicate installation materials will be handled by the proper sub-team personnel with oversight by the Safety Officer.	Analysis	The recovery sub-team will ensure the proper parachute folding will be performed, and other sub-teams will inspect for their own issues. The Safety Officer ultimately determines if some part of the vehicle is unfit for flight.
6.5.3	Multiple team personnel	Demonstration	A collaborative setup will occur at

	will ensure the systems and checklists are in agreement with proper procedures for launching.		launch sites such that sub-team leads discuss any concerns with the Safety Officer throughout the events to ensure complete safety.
6.6	Misconduct and violations of the safety manual will be dealt with by the Safety Officer.	Demonstration	It is expected of all personnel to report incidents involving unsafe actions, as well of the Safety Officer to patrol the workspaces as needed. Personnel caught in risky behavior will be reprimanded appropriately.
6.7	Injured personnel must notify emergency services or the Safety Officer as conveniently needed.	Demonstration	The Safety Officer will be listed as an emergency contact, and all personnel are expected to know nearby showers, and of course to call 911.

Table 6.11 Team Derived Safety Requirements

6.2 Budgeting

6.2.1 Funding

The team's funding comes largely from crowdfunding events. The two events that made up the bulk of the team's funding last year are the yearly University of California, Santa Cruz's Giving Day event and the team's GoFundMe campaign, which combined to over $5,000. The team plans to participate in both of these events this year, as well as to establish a financial outreach program that forms sponsorships with local, as well as non-local businesses to receive capital grants and material discounts.

6.2.2 Allocation of Funds

Subsystem	Item	Item Price per Unit	Quantity	Shipping Cost	Total Price	Vendor
Thrust	3.75in Aluminum Plate	$5.00	5	$0.00	$25.00	KC Sheet Metal
					$25.00	
ADAS	Socket Head Cap Screw	$0.25	10	$0.00	$2.50	Ace Hardware
	3.75in Wood Disk	$1.00	8	$0.00	$8.00	Ace Hardware
	Eyebolt	$5.00	4	$0.00	$20.00	Ace Hardware
	All-thread Material	$15.00	1	$0.00	$15.00	Ace Hardware
	Hex Nuts	$0.10	20	$0.00	$2.00	Ace Hardware
	Lock Nuts	$0.20	20	$0.00	$4.00	Ace Hardware
	ADAS Battery GOLDBAT 1300mAh	$17.99	1	$9.00	$26.99	Robotshop
	BeagleBone Blue Microcontroller	$82.00	1	$7.99	$89.99	Mouser Electronics
	NeveRest 40 Gearmotor 12V 160RPM	$39.95	1	$9.00	$48.95	Robotshop
	Cytron 13A DC Motor Driver	$10.49	1	$9.00	$19.49	Robotshop
	Carbon fiber body	$0.00 (donated)	2	$0.00	$0.00	(Donated by UCSC Slugbotics)
					$236.92	
Avionics	Main Parachute (58”)	$35.60	1	$4.50	$40.10	Apogee Rockets
	Drogue Parachute (15”)	$8.31	1	$4.50	$12.81	Apogee Rockets

	Perfectflite Stratologger	$49.46	1	$4.75	$54.21	Perfectflite
	9V Battery	$2.50	10	$0.00	$25.00	Ace Hardware
					$132.12	
Nosecone	3:1 Fiberglass	$40.00	1	$0.00	$40.00	Entropy Resins
	Beacon Battery	$15.00	1	$0.00	$15.00	Amazon
	Beacon	$80.00	1	$0.00	$80.00	Amazon
					$135.00	
Rover	Pololu Gearmotor 6V 310RPM	$16.95	2	$0.00	$33.90	Pololu Robotics
	LewanSoul Servo Motor	$14.99	1	$5.99	$20.98	Amazon
	BeagleBone Blue Microcontroller	$82.00	1	$7.99	$89.99	Mouser Electronics
	Li-ion Battery 7.4V 1Ah	$9.95	4	$9.99	$49.79	Digi-Key Electronics
	Wheel	$5.00	4	$0.00	$20.00	Amazon
	Tread	$15.00	2	$0.00	$30.00	Amazon
	Scoop	$5.00	2	$0.00	$10.00	KC Sheet Metal
					$254.66	
Misc	General Hardware	$150.00	1	0.00	$150.00	N/A
					$150.00	
Travel	General Travel	$100.00	4	N/A	$400.00	N/A
	Travel	$500.00	8	N/A	$4000.00	N/A
					$4400.00	

		Total: $5333.70	

6.2.3 Material Acquisition Plan

The materials will be ordered from the specified vendor. Prior to ordering materials, the team will attempt to establish a sponsorship with the vendor, both to possibly aid in the ordering process, and to lessen material costs. Certain vendors are included in the University of California, Santa Cruz's CruzBuy system, which grants benefits such as discounts and expedited shipping to users. The team is in the process of obtaining access to the system, which will aid in our material acquisition.

6.3 Timeline

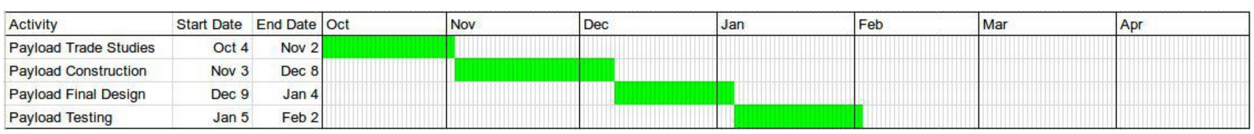
6.3.1 General Timeline

General Timeline

Task	Finish Date
Proposal Due	9/19/2018
Proposals Awarded	10/4/2018
Kickoff Teleconference	10/12/2018
Media Presence	10/26/2018
PDR Due	11/2/2018

PDR Teleconference	11/14/2018
CDR Q&A	11/27/2018
CDR Due	1/4/2019
CDR Teleconference	1/7/2019
FRR Q&A	1/25/2019
Vehicle Demo Flight	3/4/2019
FRR Due	3/4/2019
FRR Teleconference	3/8/2019
LRR Due	4/4/2019
Launch Day	4/6/2019
PLAR Due	4/26/2019

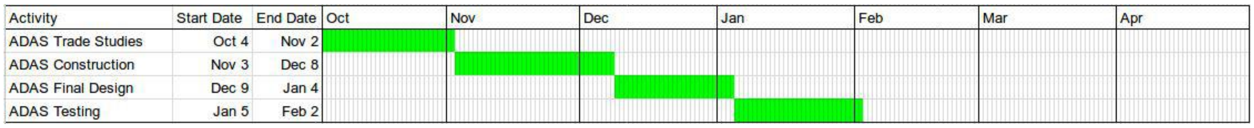
6.3.2 Payload Timeline



Payload Specific Timeline

Task	Start Date	Finish Date
Payload Trade Studies	9/19/2018	11/2/2018
Payload Construction	11/2/2018	12/8/2018
Payload Final Design	12/8/2018	1/4/2019
Payload Testing	1/4/2019	2/2/2019

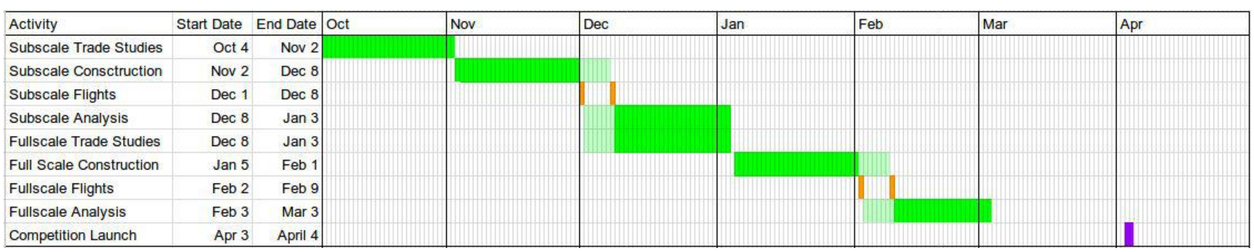
6.3.3 ADAS Timeline



ADAS Specific Timeline

Task	Start Date	Finish Date
ADAS Trade Studies	9/19/2018	11/2/2018
ADAS Construction	11/2/2018	12/8/2018
ADAS Final Design	12/8/2018	1/4/2019
ADAS Testing	1/4/2019	2/2/2019

6.3.4 Vehicle Timeline



Vehicle Specific Timeline

Task	Start Date	Finish Date
Subscale Trade Studies (Airframe, and Recovery)	9/19/2018	11/2/2018
Subscale Construction	11/2/2018	12/1/2018
Subscale Flight(s)	12/1/2018	12/8/2018
Subscale Analysis	12/8/2018	1/4/2019

Fullscale Trade Studies	12/8/2018	1/4/2019
Fullscale Construction	1/4/2019	2/2/2019
Fullscale Flight(s)	2/2/2019	2/9/2019
Fullscale Analysis	2/9/2019	3/4/2019
Competition Launch	4/3/2019	4/4/2019

7 Appendix

7.1 Appendix A: Example Launch Test Checklist

- ❏ Verify that the launch is taking place at a Tripoli or NAR event
- ❏ Verify that the planned apogee does not exceed the height ceiling for that event
- ❏ Check weather condition *Unacceptable weather conditions include but are not limited to: Rain, Snow, Winds > 15mph, >105 F temperature*
    - ❏ One week before launch
    - ❏ Day before
    - ❏ Morning of predicted launch
    - ❏ During preparation for launch
- ❏ Verify that a properly certified Tripoli or NAR member is present to assist with vehicle assembly
- ❏ **Fill out and return the launch card**
- ❏ Ensure all systems and components to be used on vehicle are tested and inspected for intended operation before installation.
- ❏ Test for continuity of recovery altimeters, e-matches, and charges.
- ❏ Perform a safe, isolated test of charges being able to separate rocket, and then install charges away from personnel as well.
- ❏ Connect altimeters and attach parachutes as needed to system as being integrated into rocket recovery sections.
- ❏ Make sure electronic systems are turned off and secured onto avionics sledding, payload housing, or other fastening when being prepared for placement into rocket.
- ❏ Install the lower avionics sled, then main chute, then recovery bay, followed by the drogue chute, payload housing comes after, then finally the nose cone and GPS locator.
- ❏ Ensure L2 certified mentor is present for motor installation process.
- ❏ Lubricate motor, then insert into motor tube, orient correctly by adjusting nozzle and coupling the retention ring so that motor mount can be inserted into motor bay.
- ❏ Perform a final assembly by ensuring rover payload is secured in housing, shear pins are connecting the chute cords to vehicle, and motor and nose cone are installed correctly.
- ❏ Setup the rocket onto the launcher by sliding onto horizontal launch rail and ensure igniter is properly fed into ignition system.
- ❏ Clear all personnel from launch area and ensure bystanders are sufficiently far away enough from launch pad to avoid injuries.

- ❏ Once vehicle is in launch position and igniter inserted, arm the onboard electronic systems, like recovery altimeters.
- ❏ Commence the LCO procedures, including arming of master switch, countdown sequence, and firing of ignition upon ending of countdown.
- ❏ Track launch vehicle using recovery GPS and visual inspection from launch until landing and manned recovery of the rocket.
- ❏ Wait for all-clear signal by RSO to deploy the roover using radio telecommunication signaling from launch area vantage point.
- ❏ Inspect rover and vehicle for damage or failures, followed by recovery of both payload and vehicle upon finishing the inspection.
- ❏ Document and record flight data once back at safe and desired location.

7.2 Appendix B: Safety Acknowledgment Form

Rocket Team at UCSC Safety Acknowledgement Form

I, ____, hereby agree to the terms and conditions specified in the following laws and guidelines with which the Rocket Team at UCSC shall abide by. They are as follows:

Federal Laws and Regulations:

1. Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; Amateur Rockets
2. Code of Federal Regulation 27 Part 5: Commerce in Explosives; and Fire Prevention
3. NFPA 1127 "Code for High Power Rocket Motors"

NASA Safety Guidelines:

1. Range safety inspections of each rocket before it is flown. Each team shall comply with the determination of the safety inspection or may be removed from the program.
2. The Range Safety Officer has the final say on all rocket safety issues. Therefore, the Range Safety Officer has the right to deny the launch of any rocket for safety reasons.
3. Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

In addition to the above, I also certify that I have completed the following courses located on the UC Learning Center website using my own UC Santa Cruz school student account in order to gain access to the on-campus Sustainability Lab program spaces:

1. Laboratory Safety for Research Personnel
2. Hazardous Waste Management

By signing this document, I acknowledge that I have read and understood the information listed above, have completed Rocket Team at UCSC's Safety Manual required deliverables, and agree to abide by the aforementioned laws, rules, regulations, guidelines, and any future iterations thereof. Failure to satisfy these conditions will result in punishment, or discharge from the team, by the Safety Officer at their discretion.

____

(Print Full Name)

____ ____________________

(Signature) (Date)