ROCKET TEAM

UNIVERSITY OF CALIFORNIA SANTA CRUZ

Rocket Team at UCSC

NASA Student Launch 2018-2019
Critical Design Review (CDR)
January 11th, 2019

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1 Summary

1.1 Team Summary

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		Certification Level:	3

1.2 Vehicle Summary

Table 1.1 outlines the major specifications of the updated main-scale vehicle design.

Length (inches)	Diameter (inches)		Mass (lbs)	Final Motor Selection	Recovery System (inches)		Predicted Altitude (feet)	Vehicle Material	CG (in, nose)	CP (in, nose
	Outer	*Inner*			*Drogue*	*Main*				
104	5.46	5.36	17.7	L1000	18	60	5280	Carbon Fiber	62.99	80.3 05

Table 1.1 Main-scale Rocket Parameters

Rail Size: 8ft 10-10

1.3 Payload Summary

Payload Title: *Slim Sammy*

For this year's experimental payload, the soil-collecting rover was chosen. The Actuated Landing Correction System (ALC) employs an electronic rotation system to ensure correct orientation of the payload upon landing. After the rover's orientation is corrected, the rover will be remotely deployed and drive a minimum of 10 ft from the landing site utilizing a drive system capable of traversing a majority of expected terrains and performing obstacle avoidance maneuvers. Upon reaching the minimum required distance from the airframe, the rover will then deploy its bulldozer-like soil collection system to collect and seal a 10 mL sample of soil.

2 Changes Made Since PDR

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
Airframe outer diameter from 5.52 inches to 5.46 inches	Refinement of the airframe production technique and testing shows that a 5 layers wrap of carbon fiber material provides sufficient strength. The airframe ID shall remain 5.36 inches in order to interface with COTS Blue Tube couplers
Vehicle length and weight	Changes made to the design of the various subsystems demanded that the overall length and mass of the rocket be changed.
Semi-permanent airframe-subsystem attachments have been changed from a ¼-20 & embedded nut in a 3D printed housing to a simple 8-32 bolt and tapped hole	During the subscale flight vehicle assembly, torque from fastening a ¼-20 bolt into one of the 3D printed embedded nut fixtures sheared the epoxy binding the 3D printed piece to the airframe, thus leaving the nut and bolt assembly free spinning. This presented a major issues, since there was no way to access the nut from outside the airframe. After various prototypes, and discussion with our mentor, the mentioned change was enacted.
Fin size and shape	As the predicted masses and dimensions of the rocket's components have refined, the mass has increased and CG has shifted. To maintain an acceptable stability margin, modifications to the fin geometry was necessary
AeroTech K560W to AeroTech L1000	To accommodate the vehicle's mass growth

2.2 Payload Changes

Change	Rationale
Rover securement	Verify rover is secured during flight to prevent a free falling object in the case of premature deployment
Payload bay securement	Verify payload bay is secured during flight to

	prevent a free falling object in the case of premature deployment
General rover design	Finished rover design
Added camera for Object Detection and Avoidance	A camera used for computer vision will aid the existing ultrasonic sensor to allow for more accurate obstacle detection.
Switched from servo to continuous servo motor for ALC	ALC requires 360˚ rotation, which will be accomplished with a SpringRC SM-S4303R Continuous Rotation Servo. The original standard servo was only capable of 180˚ rotation.

2.3 Adaptive Aerobraking System (ADAS)

Change	Rationale
Switched DC motor to Chihai CHR-GM25-370-ABHL 330rpm motor	Lighter and faster rotation speed closer to the 25Hz deployment rate

2.3 Project Plan Changes

Change	Rationale
No Changes to the Project Plan	Nothing was changed

2.4 PDR Action Items

Action Item	Response
“The team must design the payload section so that if it detaches in midair that it will be tethered to the rest of the airframe or have it's own recovery element to ensure that a premature separation of the payload section would not result in an unsafe/uncontrolled descent."	The payload section has since been designed to have cable tethers to the recovery section and a securement device for the rover in the case of a premature separation of the section. Further details are provided later.

3 Vehicle Criteria

3.1 Design and Verification

3.1.1 Mission Statement

The Rocket Team at the University of California, Santa Cruz's larger mission is to advance the STEM education of our members and community, while promoting space exploration in general.

Drawing on previous experience and the unique skills sets of our members, the Rocket Team at the University of California, Santa Cruz has designed a high powered rocket compliant with the NASA SLI requirements. With the full scale rocket, *Country Roads*, the Rocket Team at the University of California, Santa Cruz will demonstrate launch and recovery reliability, the delivery and operation of a soil sample collection rover, and the premiere of the team's internally developed ADaptive Aerobraking System (ADAS).

3.1.2 Mission Success Criteria

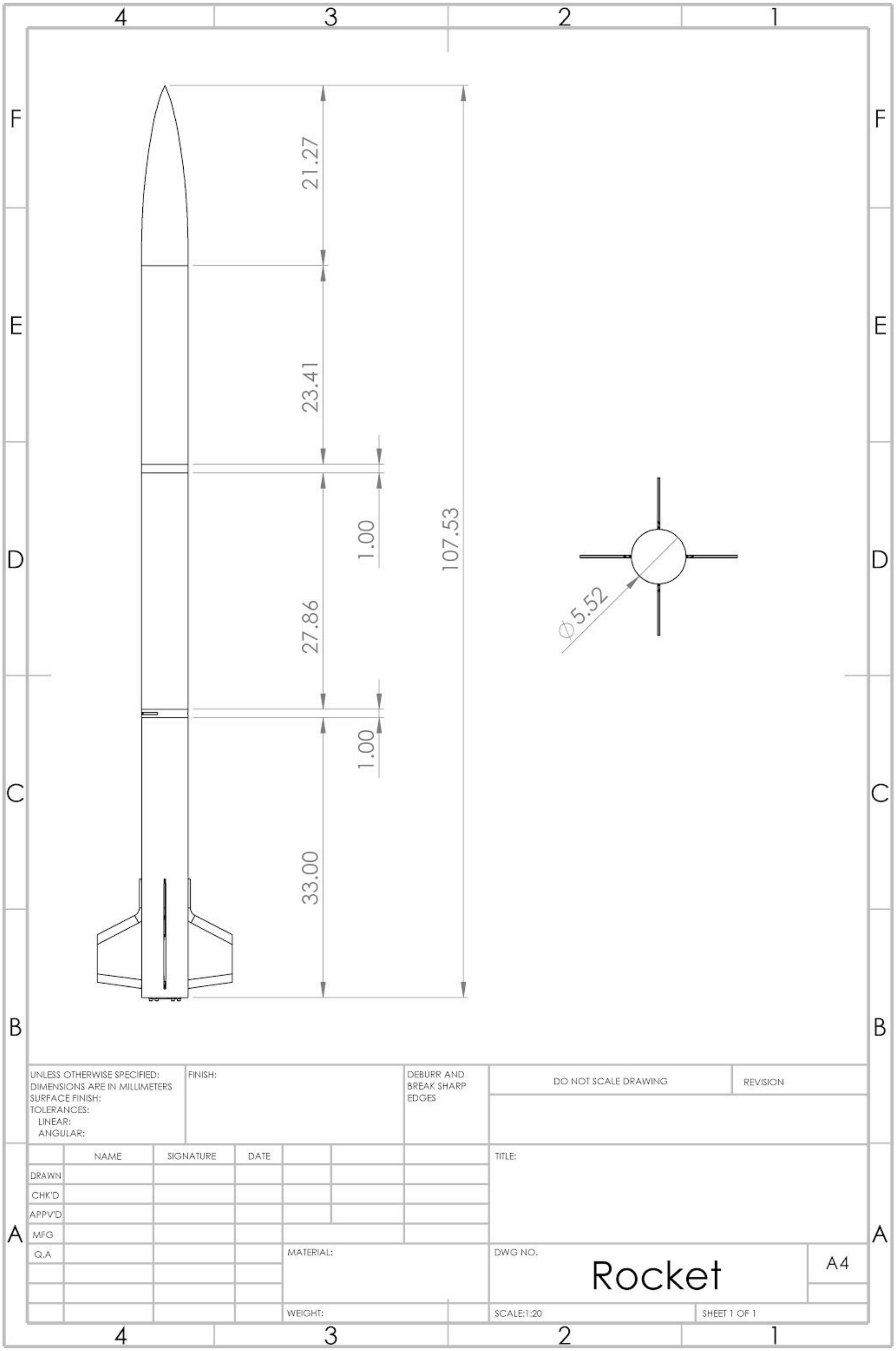
The success of the team's mission will be judged by the following metrics:

- Minimum deviation from the 1609 m (1.0 mile) target apogee
- Undamaged recovery
- Deployment of the payload rover and the collection of a sufficient soil sample
- Simplicity of vehicle assembly and payload integration

If the vehicle acceptably satisfies all of the goals, the mission shall be considered a success.

3.1.3 Design Review and Selections

Figure 3.1 Overall Vehicle


21.27
23.41
1.00
107.53
27.86
1.00
33.00
⌀5.52
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
MATERIAL:
WEIGHT:
TITLE:
DWG NO.
Rocket
A4
SCALE:1:20
SHEET 1 OF 1

3.1.3.1 Airframe

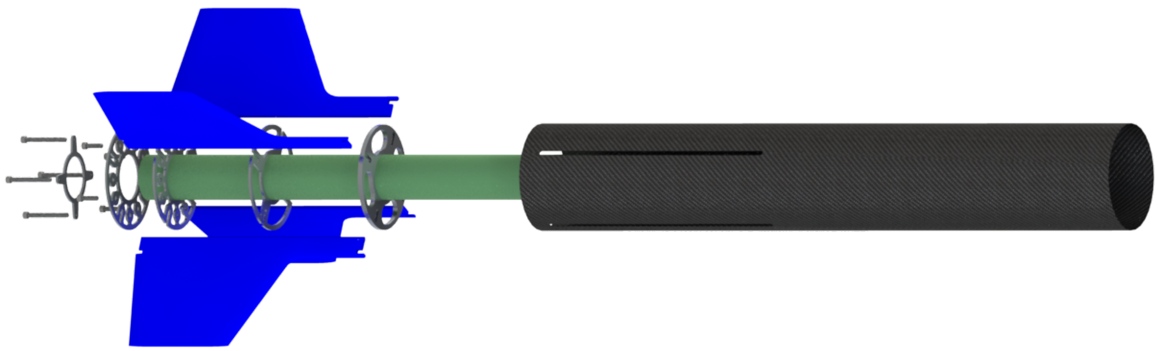


Figure 3.2 Thrust Subsection

Airframe Material

The rocket's airframe shall be an in-house manufactured piece of carbon fiber composite material. Based on the donation of dry woven carbon fiber fabric and a scrappy wet-layup technique developed by a fellow member of the amateur rocketry community, the team can manufacture a rigid, lightweight airframe at a fraction of the traditional cost. These strengths greatly outweigh the pros for the Blue Tube (which was primarily simplicity) and the lightweight carbon fiber material greatly exceeds the performance of the last remaining option considered, fiberglass.

The production of the sub-scale airframe has prove the team's capability to manufacture carbon fiber airframe. The full-scale rocket shall follow a similar process.

Removable Fin Mechanism

The removable fin feature proved extremely useful during the production, assembly, and launch of the subscale rocket. While the team was informed by NASA SLI representatives that a damaged fin would result in the failure of a launch, the removable fin feature still provides numerous benefits. Firstly if such fin is damage does occur during a flight, the fins can be easily removed and modified which is preferable to rebuilding the complete thrust section. Also transport of the rocket is simplified without the fins. And finally, fin shape can be recalculated with the measured CG of the as built rocket, better optimizing the fin geometry and improving the safety of the rocket's as built stability.

The subscale included this mechanism, and thus the team has proven their capability to manufacture the required parts.

Nose Cone

The team has selected to use a 4:1 5.5" fiberglass Ogive nose cone. This nose cone is more widely commercially available as opposed to the alternative parabola nose cone. While the parabola nose cone shows slightly improved performance, the availability of the Ogive nose cone was prefered.

Coupler Material

The rocket's couplers shall be made of Blue Tube, since the material is durable and commercially available. Because Blue Tube coupler material is integrated in the airframe manufacturing process, the team can be sure that any airframe produced with the established method will fit with a Blue Tube coupler.

Rocket Diameter

The team has defined the airframe to have a 5.36" ID. This is the minimum size required to accommodates the payload which will best limit overall vehicle mass while interfacing with commercially available parts.

3.1.4.3 Recovery

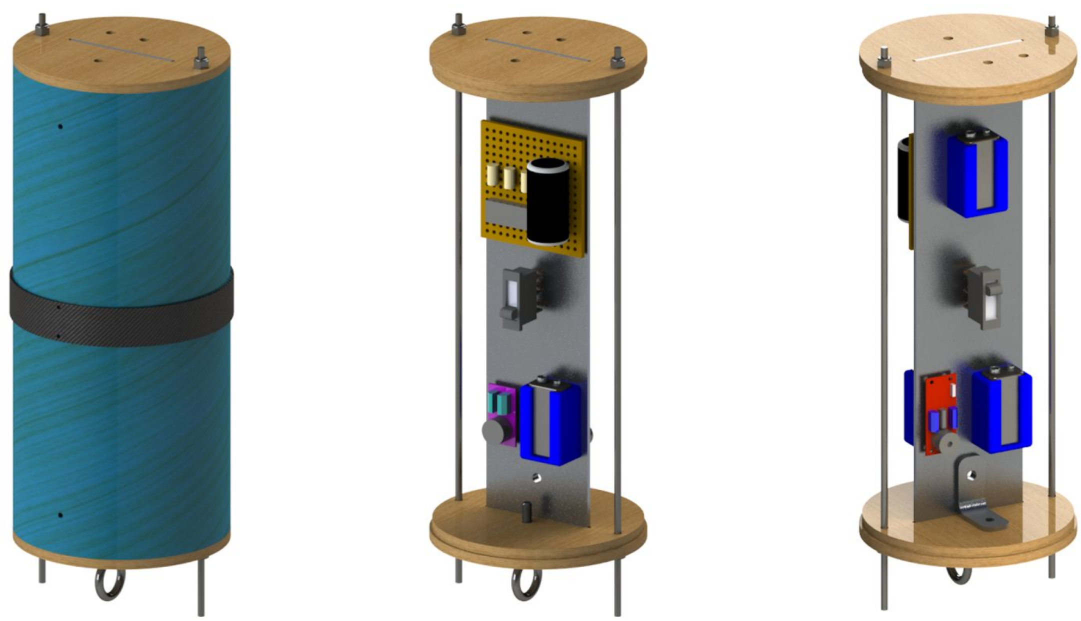


Figure 3.3.1 *CAD Rendering of the recovery section*

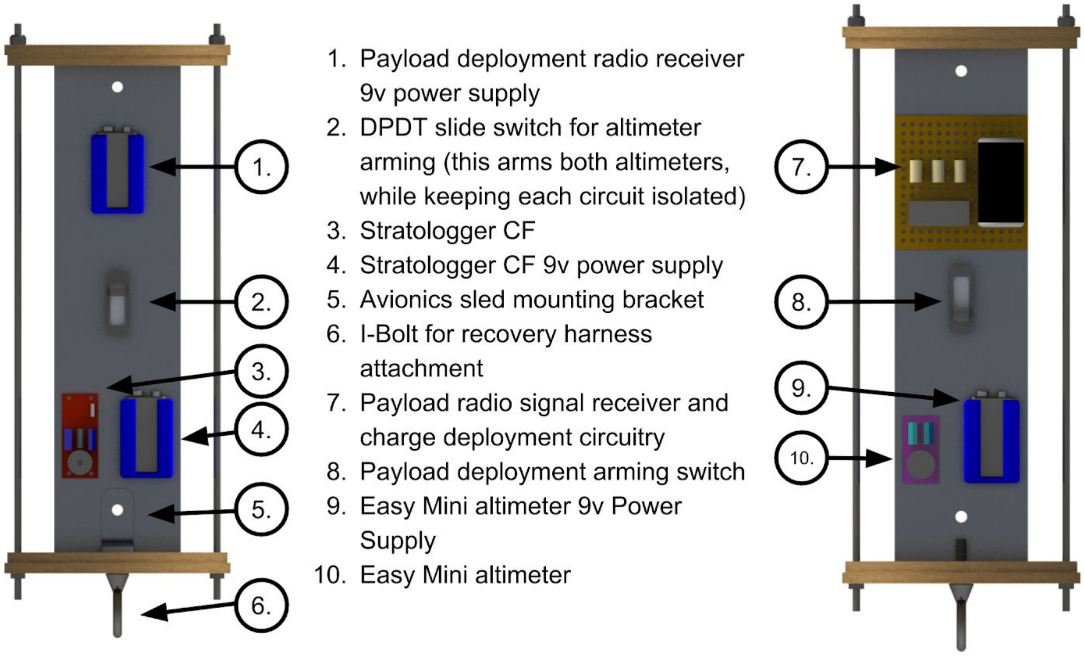


Figure 3.3.2 *Recovery inner components*

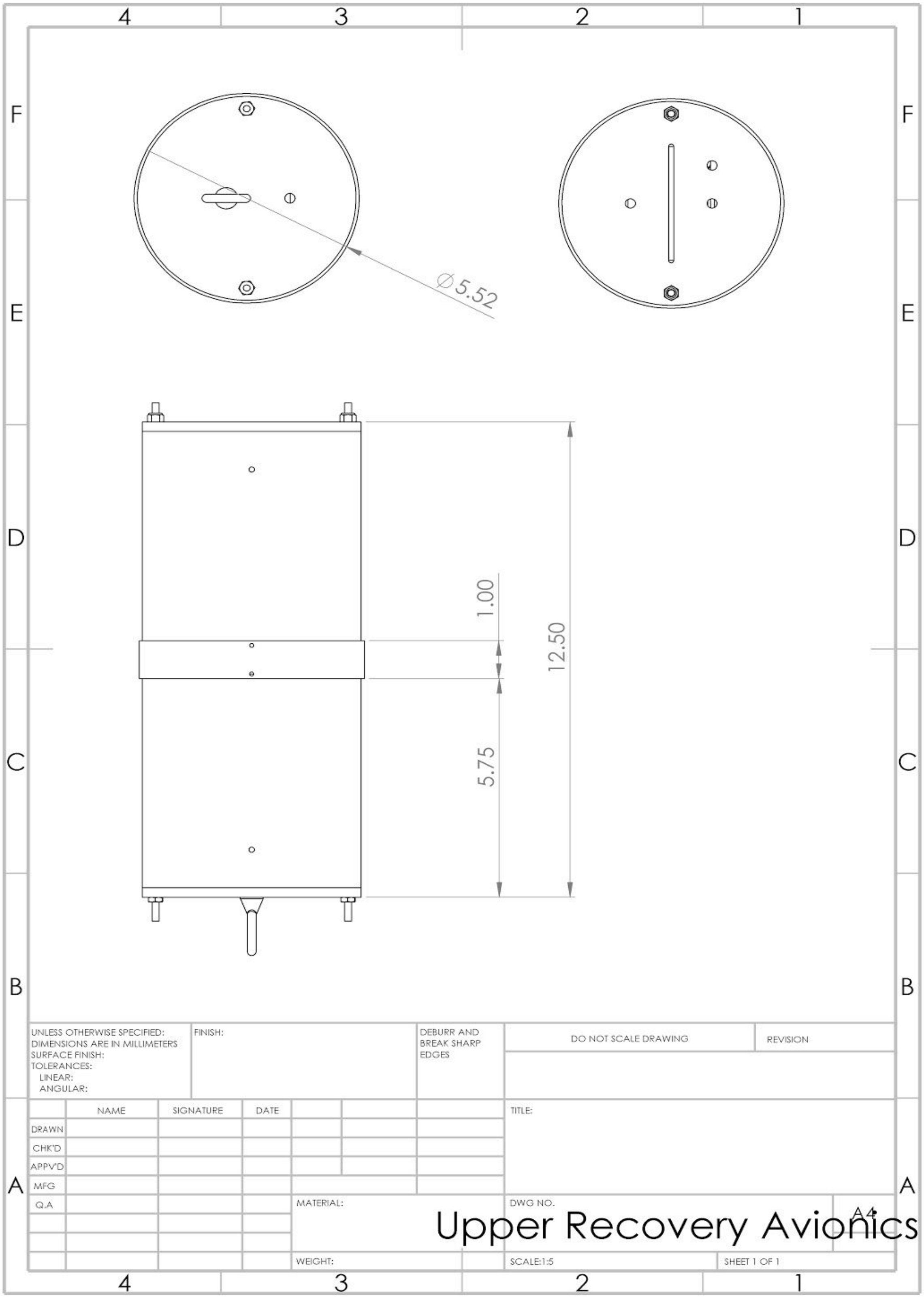


Figure 3.3.3 *Recovery dimensions*

3.1.4.4 Payload

3.1.5 Design Integrity

3.1.5.1 Fins

The fin shape adequate provide a static stability margin of 3.1. This is sufficient to comply with NASA SLI regulations.

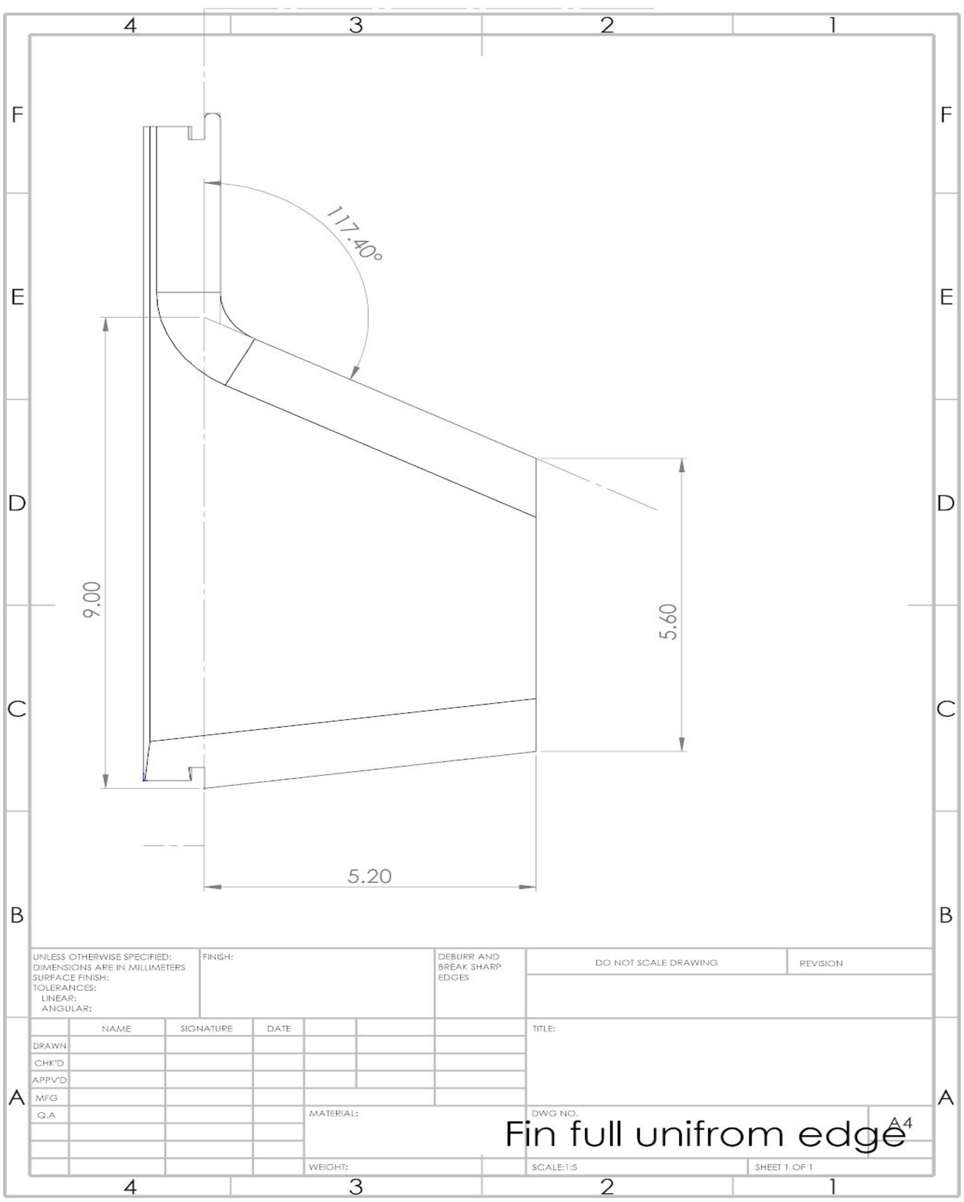


Figure 3.4 Fin dimensions

3.1.5.2 Material Choice for Fins

¼" fiberglass was selected as the fin material to provide the necessary rigidity to withstand flight, and hard impacts upon landing.

3.1.5.3 Motor Mount

The primary thrust ring shall serve as the primary structure branching the fiberglass motor tube to the carbon fiber airframe. This thrust ring shall be machined from an aluminum 6061 ⅛" plate. The following is an FMEA of the proposed geometry with a 1261 Newton thrust load. This load is above the maximum expected to be produced by a nominal motor burn.

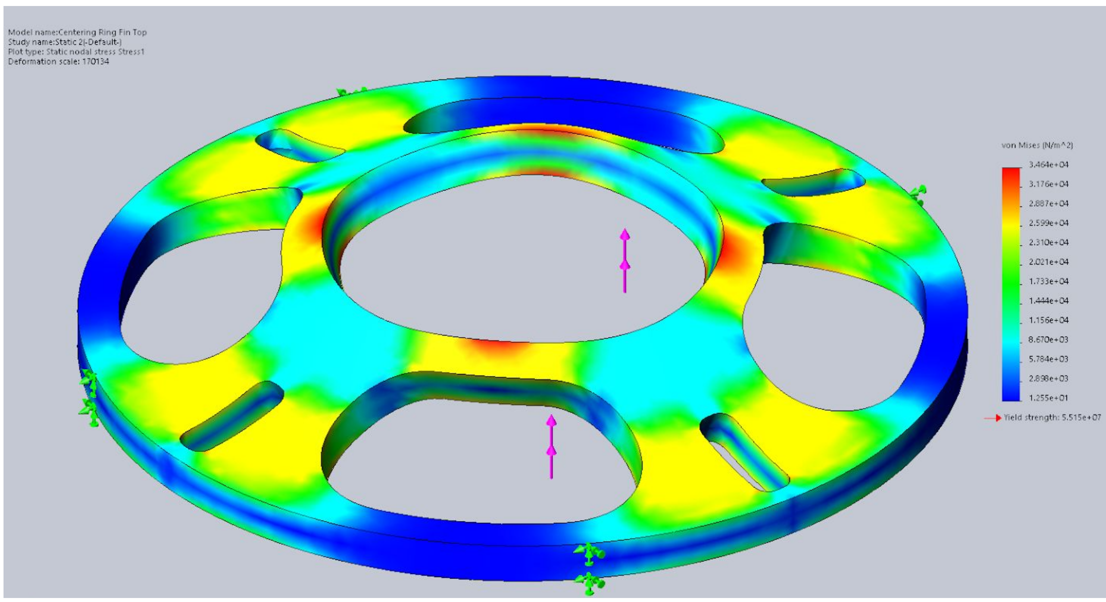


Figure *3.5.1* *Main thrust ring FMEA stress results. Note that the maximum stress seen in the simulation (3.464e+4 N/m^2) is well within the 5.51e+7 yield strength of the material*

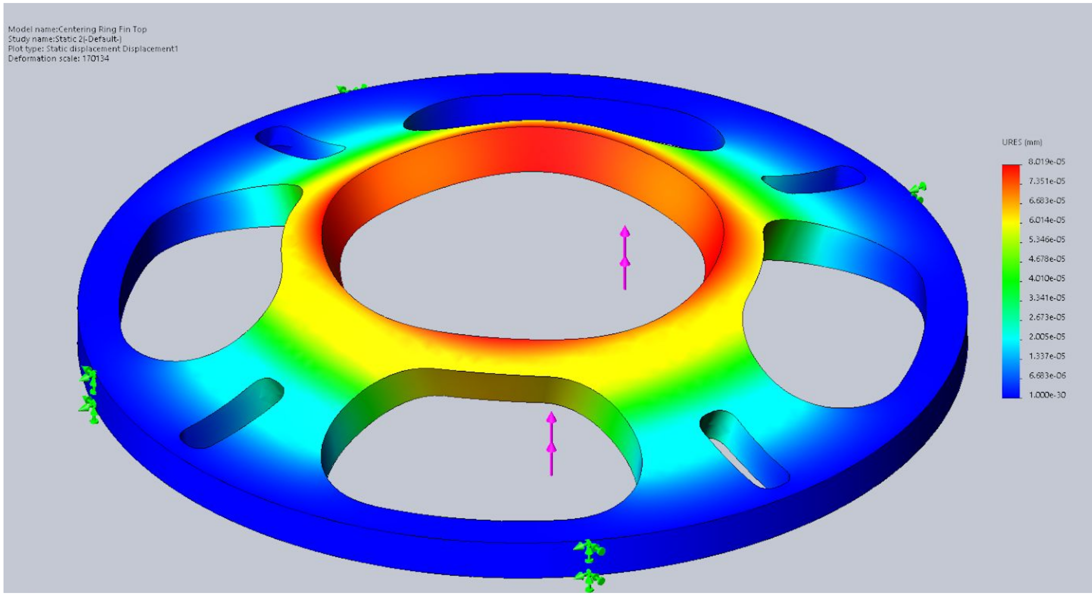


Figure 3.5.2 *Main thrust ring FMEA displacement results.*

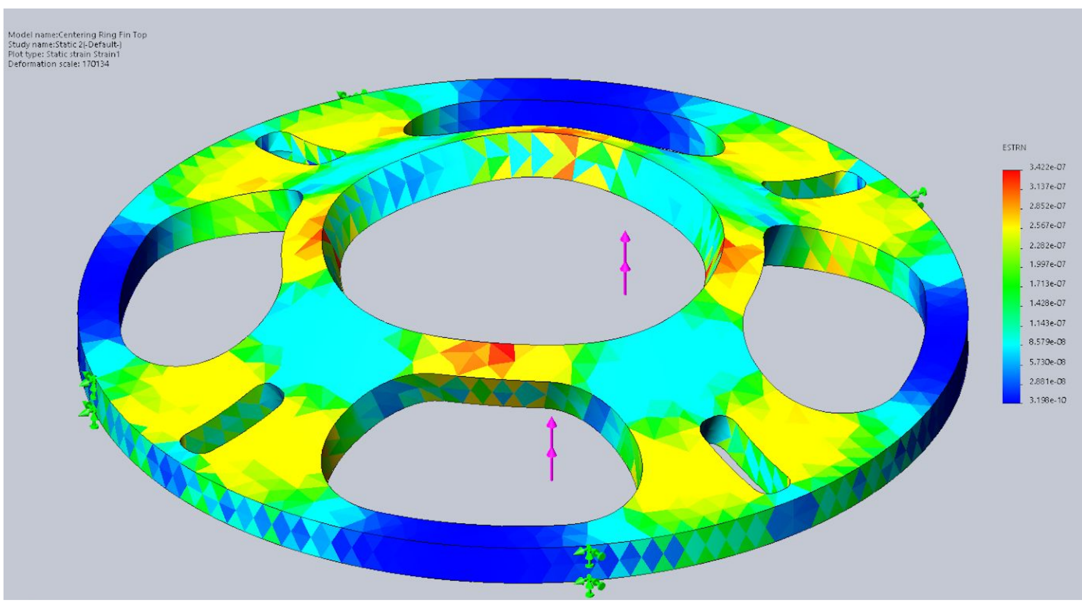


Figure 3.5.3 *Main thrust ring FMEA strain results*

Since the primary thrust ring has thus proven to be more than sufficient to withstand the thrust loading, and with two other such rings bound to the motor tube and airframe, the thrust rings are declared sufficiently strong and reliable.

3.1.5.4 Motor Retention

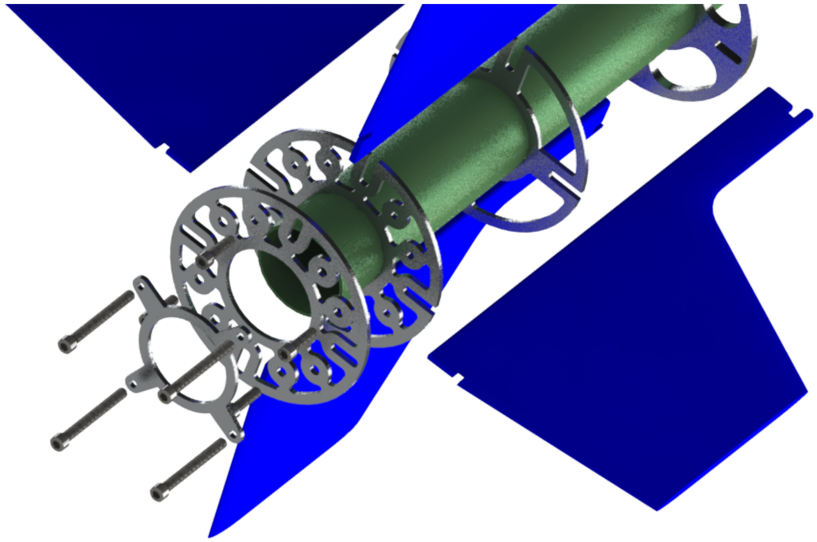


Figure 3.5.4 *Motor retainment*

The motor is retained via a ¼” 6061 aluminum retention ring. This ring is mounted to the lowest centering ring via 4 ¼-20 bolts threaded into said ring. The clamping tension applied by these bolts will be sufficient to prevent the motor from falling out backwards, while the fiberglass motor tube shall provide a proper stop for the aft enclosure of the motor, limiting forward motion.

3.1.6 Subsystem Masses

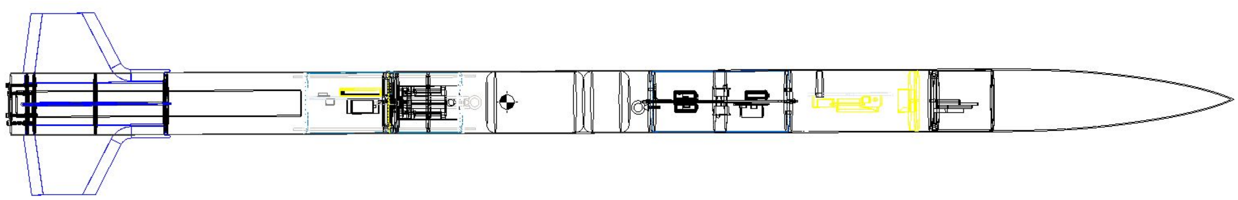


Figure 3.6 Subsystem overview

Dry Vehicle:	9.4 kg

Thrust Section:	3.0 kg
ADAS:	1.3 kg
Recovery Section:	2.37 kg
Payload:	1.9 kg
Nose Cone:	.78 kg

3.2 Adaptive Aerobraking System (ADAS)

ADAS is designed to attenuate the rocket's apogee to the target 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 longitudinal axis, increases the rocket's cross-sectional area, thus increasing drag and reducing the vertical acceleration of the rocket in accordance with the drag-force equation. SolidWorks simulations and (future) flight analysis provide interpolatable estimates of the coefficient of drag of the rocket for various fin deployments and rocket velocities.

3.2.1 General Characteristics

The ADAS unit is designed to be encapsulated by a piece of Blue Tube coupler (ID=5.217", OD=5.36"), contained by end caps that are held in place by allthreads, as pictured in Figure 3.1. The total mass of the unit, including the Blue Tube coupler is 1.317kg, and the length of the cylinder, measured from the outsides of the endcaps, is 14.08" (35.8cm).

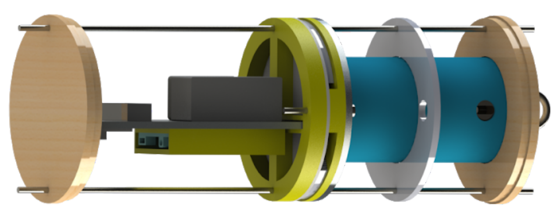


Figure 3.7: *ADAS without external Blue Tube housing*

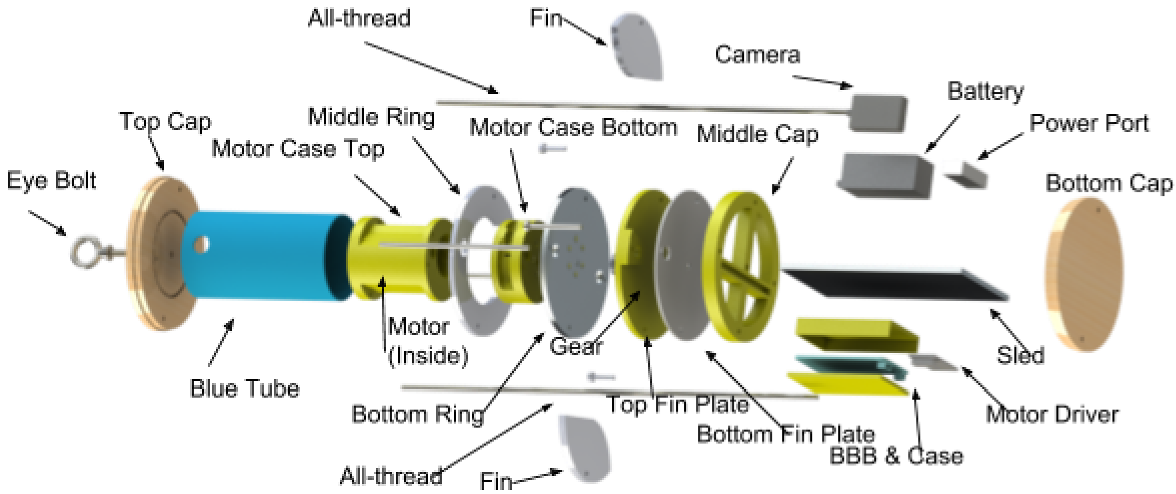


Figure 3.8: *Exploded view of ADAS with labeled components*

Component List and Specifications

Component	Sub Pieces	Material, Notes	Weight (g)	Dimensions
End Caps	Top Cap	Wood, 5 holes. Coupler cutout	~73	OD 5.36” ID 5.22” Thick .5” Coupler .1”
	Bottom Cap	Wood, 2 holes. Sled cutout	~73	OD 5.36” ID 5.22” Thick .5” Sled .25”
Electronics Bay	Sled	Aluminum plate	~72	Length 7” Width 4” Thick .2”
	Inner Cap	PLA, 3D Printed, 5 holes, sled cutout	30	OD 5.22” Thick .5”
	Battery	GOLDBAT 1300mAH Battery	169	Length 2.83” Width 1.38” Thick 1.26”
	Camera	Keychain camera	17	Length 2.2” Width 1.27”

				Thick .58”
	Motor Driver	Cytron 13A DC Motor Driver	22.5	Length 2.4” Width 1.3” Thick --
	Power Port	PCB, screw terminals to divert power	15	Length 1.95” Width .84” Thick .51”
	Beaglebone Blue (BBB)	PCB, microcontroller	36	Length 3.5” Width 2.15” Thick --
	BBB Case Top	PLA, 3D Printed. Plate with cutouts	8	Length 3.55” Width 2.34” Thick .62”
	BBB Case Bottom	PLA, 3D Printed, mounts and cutouts	19	Length 3.55” Width 2.34” Thick .06 ”
Fin Assembly	Fin	PLA, 3D Printed, teeth, 1 hole	~13	Thick .25” Length 4.22”
	Gear	PLA, 3D Printed, spur, D-Hole, metal insert cutout	1	Thick .25” OD .75”
	Top Plate	PLA, 3D Printed, 7 holes	38	Thick Min .23” Thick Max .5” OD 5.22”
	Bottom Plate	Clear Acrylic, 7 holes	40	OD 5.22” Thick .09”
Upper Section (Motor)	Motor Coupler	Blue Tube, 2 holes	55	Length 5.5” OD 3” ID 2.87”
	Motor Housing Top	PLA, 3D Printed, too many holes	60	Length 3.02” OD 2.87”
	Motor Housing Bottom	PLA, 3D Printed, too many holes	31	Length 1.14” OD 2.87”
	Middle Ring	Aluminum, 5 holes, epoxied to Motor Coupler	~40	OD 5.22” ID 3.05” Thick .2”

	Bottom Ring	Aluminum, 13 holes, Motor Coupler cutout, motor screw holes	~80	OD 5.22” Thick .2” Coupler .1”
	Motor	Chihai 330rpm motor	~100	Length 4” OD 1”
Hardware	Allthreads (4x nut)	Steel, passes through majority of parts, secures entire assembly	60	OD .18” Length 16”
	Eyebolt (1x nut, 3x washer)	Steel, Tie down for parachutes	28	Length 2.28” OD .25”
	Fin Assembly Bolt (2x bolt, 2x nut)	Steel. Secures fin assembly to itself and the two halfs	8	Length 2.15” OD .18”
	Motor Case Bolt (2x bolt, 2x nut)	Steel, secures two halves of motor case	7	Length .93” OD .18”
	Motor screws (6x screw)	Steel, secures motor to bottom plate and bottom motor housing	2	--
	Motor Allthreads (4x nut)	Steel, secures motor housing to top cap	19	Length 5.75” OD .18”
	Containment Tube	Blue Tube Coupler, holes for semi-permanent and shear attachments, cutout fin slots	~200	Length 13.58” OD 5.38” ID 5.217”
Total Mass			1316.5	

Table 3.1: *List of components of ADAS and their specifications. Estimations of weights that are not known exactly are denoted by ~.*

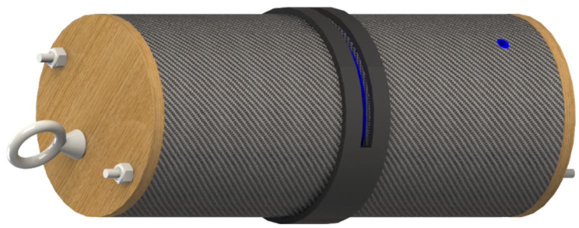


Figure 3.9: *ADAS in Blue Tube housing*

3.2.2 Design Theory

The design of ADAS was influenced from that of the previous year's rocket. As detailed above, ADAS consists of a tube that sits within the mid section of the rocket, as shown in Figure 3.3,, and employs a fully integrated microcomputer to control the ascension of the rocket. A flow chart of the overall design is presented below.

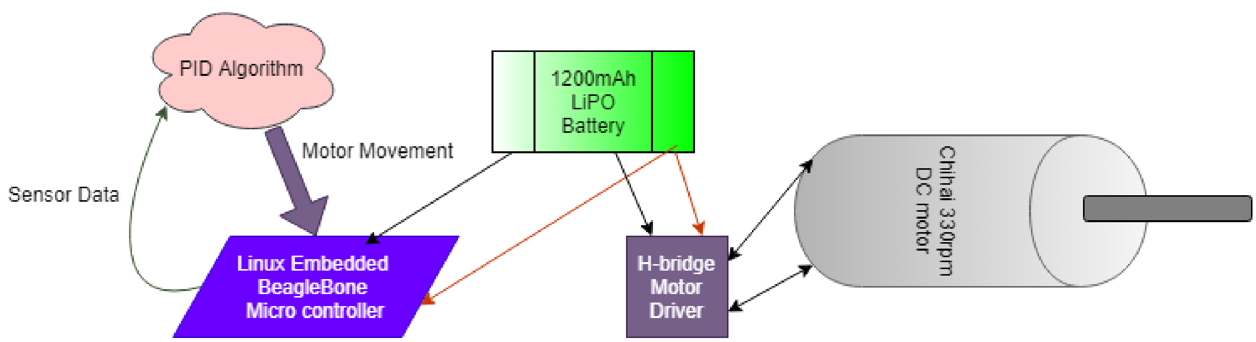


Figure 3.10: *ADAS flow chart*

The design and fabrication was divided into two parts: hardware and software. The hardware side was responsible for the physical component of ADAS capable of the necessary requirements derived in the PDR. The goal was to create a "black box" component that made filtered sensor data from the onboard embedded system available, and guaranteed deployment of two retractable fins at a rate of 25Hz, with one period defined as full deployment from full retraction.

The fin shape was selected because it maximizes drag while minimizing turbulence in fluid simulations. The fins were chosen to be dual axis as this provided better stability, and the fins were actuated together since they need to control the altitude of the rocket without compromising orientation.

3D printing the fins, gear, and housing units for the fins and motor enabled some freedom in their design. Additionally, the PLA material is relatively lightweight and sturdy with a 20% infill density, keeping the weight of the unit low and ensuring integrity of the parts. Between the fins and electronics bay was added an acrylic sheet cut on a CNC router that allows a small camera to view the fins. The resulting video acts as another verification of the unit's activity and will provide information in the event that ADAS does not function as predicted.

The algorithm portion consisted of a constantly updating stream of sensor data being fed as input, and the output was a current deployment percentage of the fins corresponding to a known drag force. The algorithm utilizes a closed PID feedback loop and mathematical approximation methods used to follow the desired flight curve. Values for the coefficient of drag are critical for effective approximations. The coefficient is obtained from a lookup table that was computed with SolidWorks flow simulations.

3.2.2.1 Electronic Hardware

BeagleBone

The BeagleBone Blue (BBB) board was chosen in the PDR and remains the computer of choice for ADAS. It has a number of ports specifically for interfacing with the motor and sensors. Having dedicated real-time CPU cores alongside a traditional dual core CPU will allow an operating system to be run in addition to the embedded software. This allows for easier utilization of the CPU's multiple threads while maintaining the accurate timing that running embedded software guarantees. Although the BeagleBone Blue was the most expensive option on our list, the time it will save our programers will make up for the extra cost.

Wiring

The internal wiring of the component was redone in order to accommodate the various components and to fit the numerous wires needed. A terminal block was used to connect the BeagleBone and motor driver to the battery power supply. The motor driver and a camera power line were connected to interface with the BeagleBone using our own uniquely created wires that plugged into the JST ports. The wires to connect the motor to the driver were routed through the fin body plate and into the main control section of the component.

Motor

The original Neverest 160 rpm DC motor that actuated the fins was replaced with the new Chihai 330 rpm DC motor. This change from the original design was due to the higher speeds in the actuation of the fins. It was calculated that to reach the desired 25Hz adjustment rate for the fins a motor with a minimum 375 rpm would be ideal, according to the following formula:

$$25 \textit{ deployments per second } * 90^o/360^o \textit{ rotation per deployment } * 60 \textit{ seconds } = 375 \textit{ rpm}$$

With this new characteristic in mind a new trade study was performed to find possible candidates.

New ADAS Motor Trade Report

		Options					
		Ali express motor		chihai motor		robot motor	
Selection Criteria	Weight (1-5)	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score	Score (1-5)	Weighted Score
Cost	3	5	15	4	12	1	3
Speed	5	2	10	4	20	5	25
Power Draw	3	4	12	3	9	2	6
Dimensions	2	5	10	3	6	2	4
Weight	1	4	4	5	5	4	4
Max torque	3	1	3	4	12	5	15
Precision	5	2	10	4	20	5	25
		64		84		82	

Table 3.2 ADAS new motor trade report

The winning candidate was the Chihai motor with a speed of 330 rpm and torque of 12 kg*cm (167 oz*in). The motor performed best overall in the chosen categories, with a particularly desirable weight of 128g. There is a trade of 66% reduction compared to the previous torque in exchange for higher speed. However, this was deemed acceptable because the high torque from the previous motor was excessive. While the deployment speed is rated below the target, the output voltage of the powering battery is higher than the assumed voltage; therefore the actual speed of the motor will be higher and closer to the target speed.

Software

The software that controls the physical hardware is written in C and utilizes the onboard robotcontrollibrary, a project started by James Strawson and developed specifically for the BeagleBone. There are two programs: one controlling the collection and filtering of data from our sensor, and the other handling the actuation of the motor in accordance with the encoder. The program that controlled the movement of the motor was updated since the PDR to reflect the change in motor selection. In addition, safety checks were added to ensure the program exits safely if components are not initialized correctly.

3.2.2.2 Mechanical Hardware

Fins

The actuation of the fins is the same design as proposed in the PDR. The fins are deployed by a DC-actuated spur gear. Full deployment of the fins corresponds to 90 degrees of rotation from retraction. The upper limit of deployment in the algorithm is set to 95% of quarter rotation to prevent the fins from disengaging from the gear. The downward force experienced by each fin at full deployment at 240m/s was calculated in a SolidWorks simulation to be 10.5N. With such a large drag force, the structural integrity of the fins were necessarily tested to ensure they would not break during flight. A 1.5kg weight was used to simulate the downward drag force and ensured that the fins and surrounding housing are able to handle the load effectively without stripping the gear or breaking the fins or surrounding housing. Additionally, under the 1.5kg load, the friction between the fins and the lower fin plate (acrylic) did not influence the performance of the deployment protocol that was used for testing.

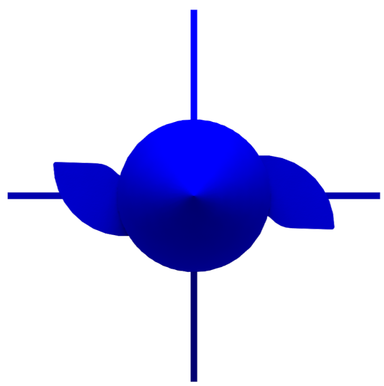


FIgure 3.10: *Deployed fins*

Drag Force

The force of aerodynamic drag acting on the fins for various deployments and various velocities was simulated using SolidWorks. From these values, drag coefficients are calculated using the relation

$$c_d = 2 \cdot F_d / (A \cdot \rho \cdot v^2)$$

Where the air density ρ is assumed to be constant at the standard value of 1.15 kg/m^3. Drag coefficient values are presented in the following table, and can be interpolated to obtain a continuous function in velocity and deployment for the coefficient. The force of drag is controlled through the deployment of the fins, which can vary between 0 and the maximum deployment within a precision of 3 degrees. The total surface area of both fins at maximum deployment is 1.64in^2 which corresponds to a 7% increase in the rocket's cross-sectional area. This number is considerably less than the PDR-predicted value of 25% but we find that the added area is capable of substantially attenuating the apogee. Given a maximum airspeed of 240m/s the drag force at maximum deployment is over 21N. For the simulated full-scale flight, the maximum distance that

ADAS can remove from apogee is projected to be 111m if deployment begins after main engine cut off (MECO). This means that motors that would take the rocket above 1720m should not be selected if the target apogee is to be reached exactly.

Drag Coefficients

	20	40	60	80	100	120	140	160	180	200	220	240
0 (0)	0.48971306	0.46050844	0.45662778	0.45726016	0.45771400	0.45709579	0.45666260	0.56427324	0.56809289	0.57172831	0.57454960	0.57878936
14.4 (20)	0.56975804	0.46027825	0.45651371	0.45671626	0.45697599	0.45642417	0.45541568	0.55835886	0.56201758	0.56496777	0.57795253	0.57121466
21.6 (30)	0.56687253	0.46828191	0.44697624	0.46450247	0.46448370	0.46398102	0.46253543	0.55649606	0.55996565	0.56299190	0.56535724	0.56839826
28.8 (40)	0.56385860	0.48306336	0.48046393	0.48131503	0.48159775	0.48224402	0.48047653	0.55570614	0.55893131	0.56196460	0.56421172	0.56710178
36 (50)	0.56417736	0.48393146	0.48254877	0.48211145	0.48311164	0.48272549	0.48110144	0.55415608	0.55753698	0.56045683	0.56238568	0.56562834
43.2 (60)	0.56900756	0.48467695	0.48165894	0.48223904	0.48273775	0.48302447	0.48063399	0.55875688	0.56199858	0.56473843	0.56642194	0.56915537
50.4 (70)	0.57021649	0.49231299	0.48926735	0.48939805	0.48920619	0.48858892	0.48692398	0.56219267	0.56559117	0.56836521	0.56993955	0.57230704
57.6 (80)	0.57425205	0.50929906	0.50635695	0.50655044	0.50637515	0.50607557	0.50645381	0.56622799	0.56941193	0.57219142	0.57380129	0.57590099
64.8 (90)	0.57927089	0.50547568	0.50307373	0.50335420	0.50327042	0.5022323	0.50472650	0.57138751	0.57443150	0.57685401	0.57868254	0.58064269
72 (100)	0.57888640	0.51924016	0.51659471	0.51705445	0.51717237	0.51657789	0.51514392	0.57199016	0.57509840	0.57800468	0.57968946	0.58159073

Table 3.2: *Drag Coefficients for varied velocities [m/s] (columns) and ADAS deployment [degrees (%)] (rows)*

3.2.2.3 Impact of Subscale on Design

Software

Difficulties from the subscale launch exposed issues with the software toolchain, specifically with the communication between software components and program execution on the BeagleBone. As the device is headless, there is no graphical interface with the component and no external input sources aside from SSH. Therefore, it was decided to compile and set the program to run on boot of the machine rather than relying on user-execution. This was accomplished by linking the program to a daemon-like file within the operating system that runs on computer boot. As the main program handles the calling and closing of the subprograms itself, it is sufficient to run the main program on boot and ensure the necessary subprograms are simply compiled and ready to be executed.

Wiring

The original CAD design of the components did not include enough space for the wiring, or consideration on how the physical components would be connected together to the power source. As a result the larger components and the bulk of the wire prevented the full assembly of the component. Therefore in the redesign a smaller mount block terminal will be used and the length and gauge of the wires will be reduced. As the maximum power draw from the motor and BeagleBone is at most 15 amps, a fuse was placed as a safeguard on the battery as well as on the BeagleBone itself to ensure it doesn't short the board on large current pulls from the motor.

Battery

A large concern with the battery and its work with the component was its capacity and ability to provide power the entire flight time. After testing the component it became clear the battery held more than enough power for the components and all the subsequent power draws. The component was turned on and idle for several hours, drawing light power usage from the battery for a sustained rate from the board. Post flight, the charge level of the battery was tested and there remained an excess 70% of the total battery charge.

End Caps

To simplify the design and manufacturing of the component it was decided that wooden end caps would be used in place of the plastic end caps. This change made it simpler to create the end caps and stronger in the overall design. In addition the wood is much simpler to modify and add holes or different features to the design.

3.2.3 Software

ADAS implements PID control over the variable deployment of two drag-inducing fins with the objective of attenuating the rocket's apogee to the desired height of 5,280ft or 1609m. The drag curve for varying fin deployment and air velocity is interpolated from SolidWorks simulation data (see Table 3.2).

At the time of flight, the ADAS computer is set to run the Python driver file that houses the algorithm on boot. The computer, mounted to the sled, is manually turned on before the unit is encapsulated in its Blue Tube shell. Once in the rocket the computer is set to run in simple idle mode, passively monitoring sensor data and consuming minimal power. The program is set to emit a small chirp every 10 seconds as a heartbeat to ensure that the board is on and running the program.

The Python program is seperate from the C programs that control the hardware, and runs in parallel with them. It uses pipes to interface with the C programs to read data from the IMU and to read motor encodings and write deployment percentages to the motor driver. A flow chart of the software control structure is presented below.

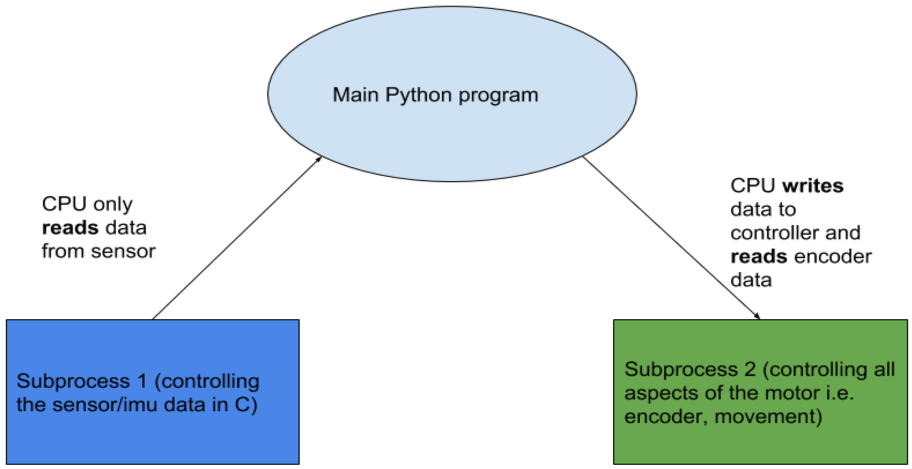


Figure 3.6: *Diagram of the software control structure*

Algorithm

Launch is detected when the measured vertical acceleration exceeds a threshold value. After MECO, PID control of the fin deployment begins. Waiting to start deployment until after MECO helps to ensure a stable flight. A pre-flight simulation is used to compute a deployment profile that should attenuate the rocket's flight to reach the target apogee, and a simulation that leverages the Euler method produces data to be used as reference mid-flight. As the deployment profile is executed, corrections are made based on in-flight predictions of the trajectory of the rocket.

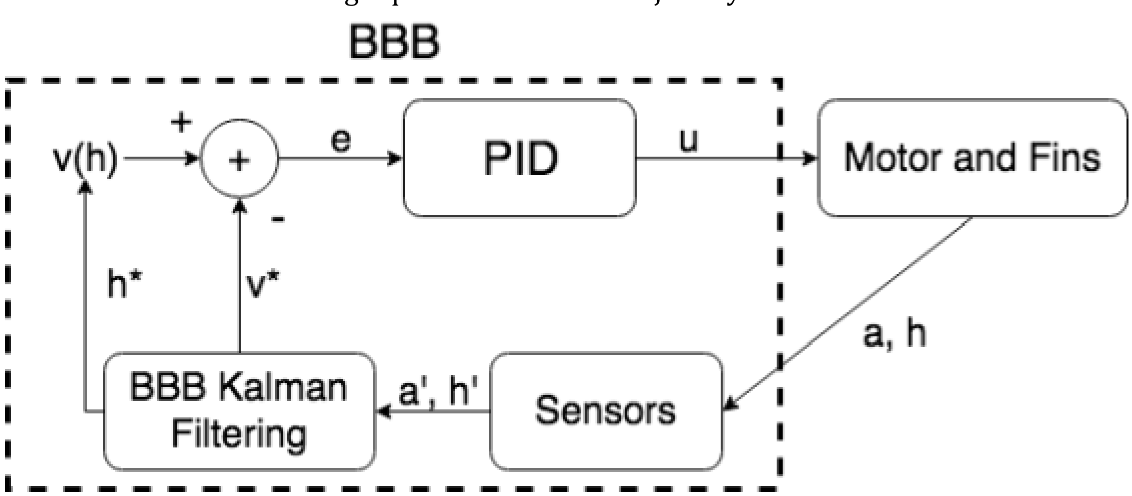


Figure 3.7: *Block diagram of the closed loop control system*

Pictured in Figure 3.7 is a block diagram of the control system feedback loop. The reference vertical velocity value $v(h)$ is provided by the Euler method-based simulation previously discussed. The error e at some height h is computed as the difference between the simulation-given value for velocity and the value measured and Kalman-filtered by the BeagleBone Blue. The control correction that is given to the motor is then calculated by the following,

$$u = k_P e + \int k_I e \, dt + k_D \frac{d}{dt} e,$$

Where the tuning constants k_P, k_I, and k_D are determined by trial and error in numerical simulations that introduce noise to pre-known flight data.

The controlled deployment continues until the measured vertical velocity changes sign, indicating apogee has been reached and descent has begun, and the fins retract. Sensor data, computed deployments, and other values of interest are time-stamped and logged in CSV format on the computer's SD card. Data collection ends along with the Python program and the associated C programs 90 seconds after launch and the computer turns itself off.

Simulation

A trajectory that reaches the target apogee given the rocket's characteristics and external conditions is generated by a Python code. The vertical acceleration is approximated from the predicted forces of gravity F_g, drag F_d, and thrust F_{th},

$$a_y(t) = (F_g(t) + [F_d]_y(t) + [F_{th}]_y(t)) / m(t)$$

Where, for azimuthal angle θ, the y-components of the forces are

$$F_g(t) = m(t) \cdot g, \qquad [F_d]_y(t) = F_d(t) \cdot cos\,\theta, \qquad \text{and } [F_{th}]_y(t) = F_{th}(t) \cdot cos\,\theta.$$

The rocket's mass $m(t)$ varies with time between launch and MECO as the propellant is burned and expelled. Since the thrust at any time is proportional to the mass being expelled, the mass flow over a time step Δt is approximated as

$$m(t) = \Delta t \cdot (F_{th}(t) \cdot m_{tot} / J).$$

The thrust F_{th}, the mass of the unburned propellant m_{tot}, and the impulse J, or net thrust, over the rocket's burn time are given or interpolated from data from John Coker's ThrustCurve database[1]. The vertical velocity and height are then obtained with Euler's method in one dimension,

$$v_y(t) = \Delta t \cdot a_y(t), \qquad h(t) = \Delta t \cdot v_y(t).$$

Comparisons of the resulting flight profiles compared with those of OpenRocket Simulations for the same conditions verify that the results of the Python simulation are reasonably accurate but improvements must be made for ADAS to perform as desired. The comparisons are discussed further in Section 3.3.3.1, *Predicted vs. Actual*. Including considerations of the height-dependence of air pressure and density, among other alterations to the algorithm, are hypothesized to improve the quality of the Python simulation considerably.

3.3 Subscale Flight Results

The subscale rocket, dubbed “Take Me Home” (TMH), was launched with an Aerotech J420 motor at the LUNAR Launch Snow Ranch on December 8th at 4:01pm PST. It weighed 4.75kg, was 85.5” long, and had an outer diameter of 3.15”. It had a base CG position of 39.173” from the tail.

The EasyMini and Stratologger altimeters onboard in the recovery bay obtained and logged data including the altitude, velocity, acceleration, and pressure during the flight and descent. GPS tracking was performed by an Eggfinder TX transmitter, also housed in the recovery bay. The data-logging algorithm on the ADAS computer, the BeagleBone Blue, failed to execute and did not record any flight data.

3.3.1 Scaling

The scaling ratio between the subscale rocket (OD=3.15”) and the full scale rocket (OD=5.5”) is 57%. The sizes and massed of electrical hardware components inside of the rocket are understandably not scalable, however, masses and dimensions were scaled where possible, such as for the simulated mass of the payload. The stability margin, which scales with diameter, also scaled accordingly between the subscale and full scale rockets. The general shapes of the rockets should additionally be similar, though the height of the full scale rocket will be 104", only 25.5% larger than that of the subscale one.

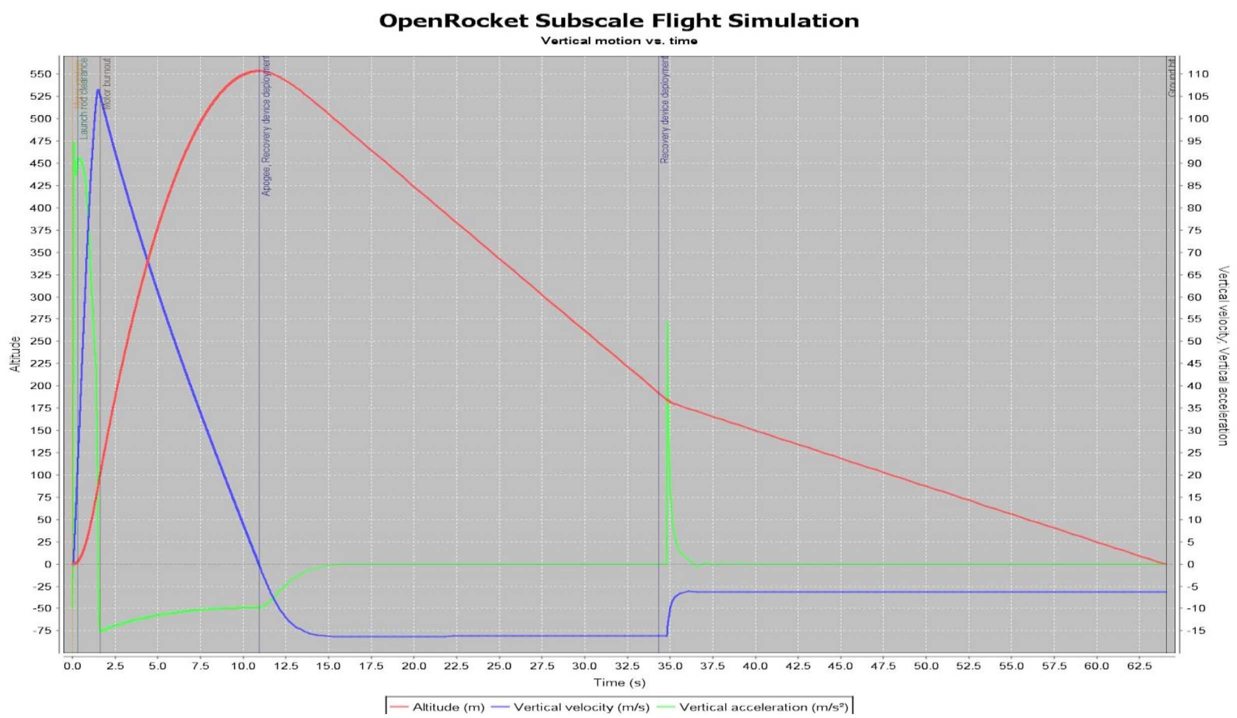


Figure 3.8: *Acceleration (green), velocity (blue), and height (red) from Open Rocket subscale flight simulation*

3.3.2 Launch Day Simulations

Simulations were done using the OpenRocket modelling software and a specialty-made Python script that employs the Euler method with physics equations to predict the flight profile of the vehicle. OpenRocket was used for its availability and as it is what most members have experience with.

Using OpenRocket, we predicted an apogee of 554m, a maximum velocity of 106m/s, and a maximum acceleration of 9.66G. This was simulated using 5mph wind and standard pressure, approximately the same conditions as those on launch day.

3.3.3 Flight Analysis

Flight analysis was done using the data gathered by the EasyMini and Stratologger altimeters. The EasyMini recorded the altitude, pressure, acceleration and time. The Stratologger recorded altitude, velocity and time. Many of the recorded values from these devices are inaccurate, leading to sporadic and unclear data which was problematic for verification of values and further analysis. Also, due to what is recorded for each of the devices, the necessary application of mathematical functions (derivative, integral, etc.) further resulted in inaccurate data.

The onboard GPS, the Eggfinder TX module, recorded the latitude and longitude of the vehicle for approximately 20 minutes before and 5 minutes after the flight. Figure 3.3.2 shows the longitudinal and latitudinal motion of the vehicle during the various time segments, pre-flight, flight, and post-flight. It was determined that the vehicle stayed under the 2500ft drift limit throughout its flight.

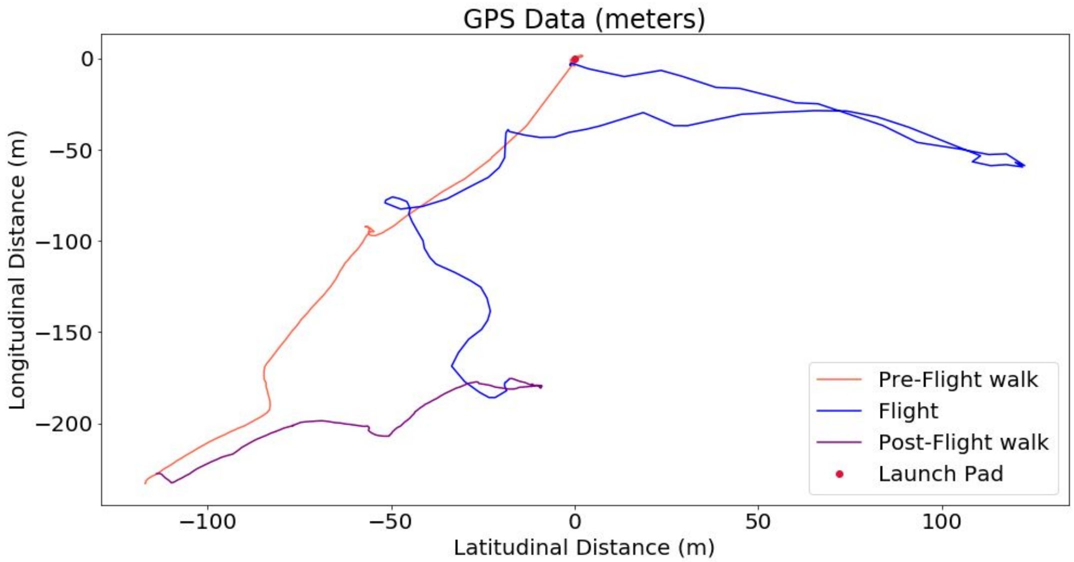


Figure 3.9: *GPS data of vehicle*

3.3.3.1 Predicted vs Actual

Altitude

The OpenRocket model predicted an apogee of 554m using launch day conditions. The Python code produced an apogee of 516m, whose large deviation (~7%) is believed to be attributable to the assumption of a constant air density. The Statologger and EasyMini recorded apogees of 547.12m and 553.94m, respectively. From Figure 3.3.3 we can see that the EasyMini and Stratologger are very similar throughout the flight. However, they are off by approximately 1s during flight and less through the later stages of flight. This is believed to be due to a lack of designated pressure holes for the altimeters. There exists one hole for the power switch but this is not aligned with either altimeter so it fails to provide adequate air flow through the recovery bay.

The OpenRocket model is only used until apogee as we were unable to accurately predict the vehicle's post-apogee motion using the software. Despite this, the OpenRocket simulation predicts the flight of the vehicle very well and closely predicted the apogee compared to the measured values with about a .72% deviation.

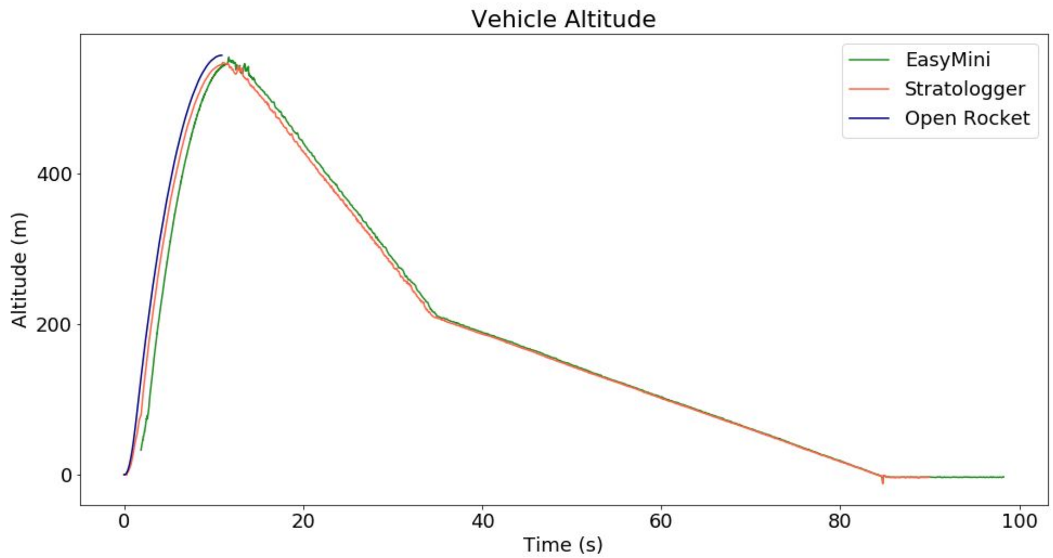


Figure 3.10: *Vehicle Altitude from various sources*

Velocity

The OpenRocket software and Stratologger both provided velocities but the EasyMini did not, requiring the use of differentiation of the recorded altitude to determine the velocity of the vehicle. Differentiation produced highly variable and noisy data which was smoothed by the application of a Gaussian filter. These two data sets (smoothed and unsmoothed), along with the Stratologger-recorded velocities are shown in Figure 3.3.4. Figure 3.3.5 shows only the smoothed velocity from the EasyMini with the Stratologger- and OpenRocket-given velocities. We find that all three methods very closely agree, including the OpenRocket model.

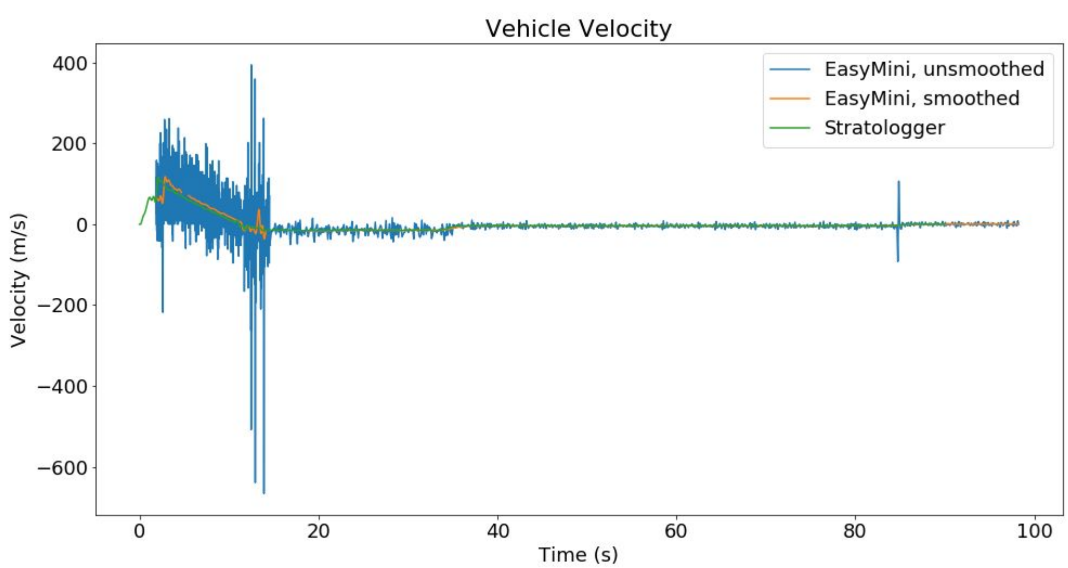


Figure 3.11: *Comparison of noisy EasyMini-derived velocity with the same, smoothed, and data from the Stratologger*

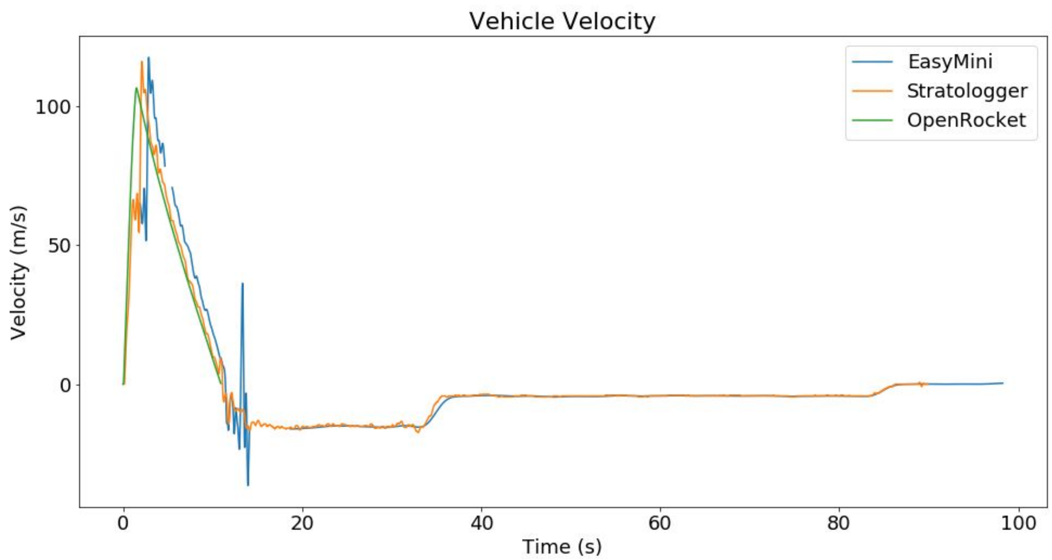


Figure 3.12: *Vehicle velocity from various sources*

Acceleration

The Stratologger did not record acceleration, but data was obtained through the process of differentiation of the recorded velocity. However, the resulting data was similar to the EasyMini-calculated velocity (in that it was noisy and inaccurate), and a Gaussian filter was again applied to smooth the data. As seen in Figure 3.3.6, both the Stratologger and EasyMini's acceleration data was found to be very inaccurate when compared to the OpenRocket and Python simulation results, which match almost perfectly. As stated above, this is believed to be due to a lack of pressure holes which minimized the amount of air flow to the altimeters, potentially affecting the accuracy of recorded data.

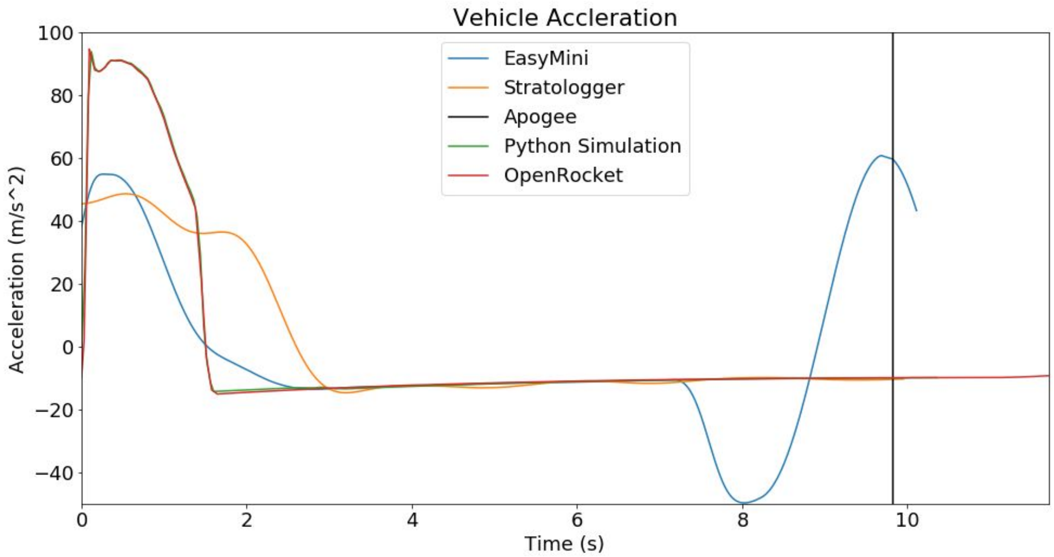


Figure 3.13: *Vehicle acceleration from various sources*

3.3.3.2 Drag Estimate of Full Scale Rocket

The drag coefficient can be calculated from the acceleration,

$$c_D = 2 \cdot m \cdot a / (A \cdot \rho \cdot v^2).$$

Because the flight data for acceleration — from the EasyMini and from the Stratologger's velocity — is faulty and unreliable, we are unable to estimate the drag coefficient of the subscale (and by relation, the fullscale) rocket. To compensate for this, flow simulations in SolidWorks were ran at various velocities in order to estimate the vehicle's drag coefficient. The data received from the flowsims is available in Table 3.2. The flow simulations were run for a number of velocities between 20 and 240m/s and all assumed constant fluid density of 1.15kg/m^3 and temperature of 10°C. We found that the OpenRocket coefficient of frictional drag closely follows the flow simulation values, which helps to verify the validity of the generated values.

3.3.4 Impact of Subscale Flight

The software malfunction that attributed to the BeagleBone Blue's failure to execute a data-logging program has been corrected, and investigations are currently underway to diagnose the cause or causes of the altimeters' unreasonable acceleration data. It is expected that including pressure holes in the airframe around the recovery section will reduce the noise and error in the altimeters' data measurement. The subscale rocket will likely be launched again to verify predictions including those of the drag coefficient before the full scale rocket is flown.

3.4 Recovery

3.4.1 Overview

3.4.1.1 Final Changed From PDR

From the PDR we have chosen to use a new main parachute. This parachute will be the Iris Ultra 60” Standard Parachute. Details in section 3.4.3.

3.4.1.2 Deployment Events

Event	Altitude (ft)	Description
0	0	Recovery Avionics are switched on at launchpad
1	~5,280	The main and drogue parachutes are released from the recovery bay by the Stratologger ejection charge fire at apogee. (Main parachute is not deployed)
2	~5,200	The Easy Mini fires its redundant ejection charge 2 seconds after apogee. If Event 1 failed, parachutes will be released.
3	500	The Jolly Logic Chute releases release the main parachute and allow it to deploy.
4	0	The rocket lands safely.

Table 4 Deployment sequence

3.4.2 Recovery Bay Design

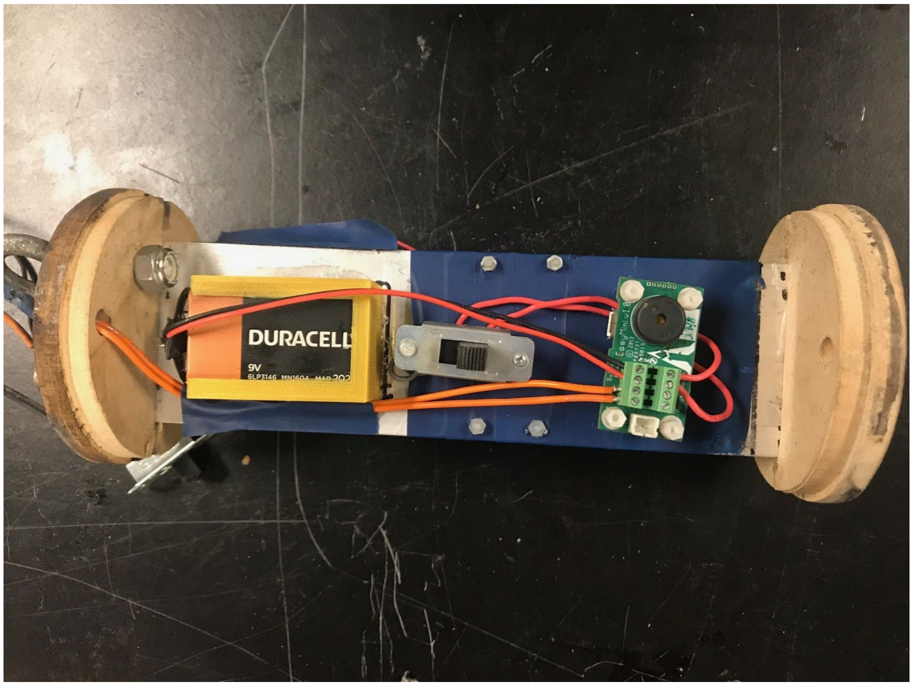


Figure 3.14.1: *Front of recovery bay*

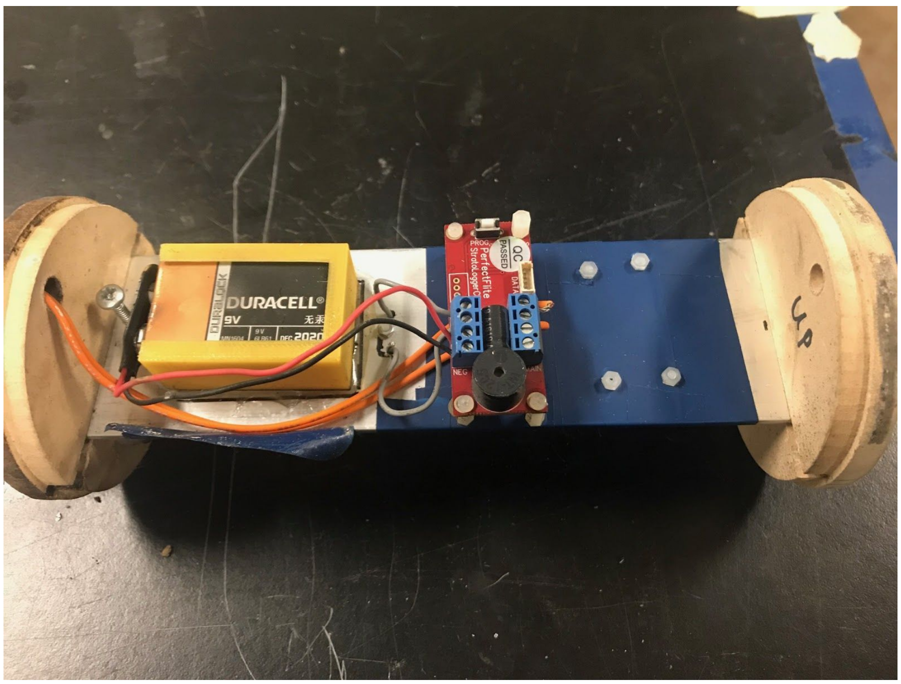


Figure 3.14.2: *Back of recovery bay*

The orientation of the switch is vertical because it's DPDT and acceleration would work in its favor. The ON position is closer to the ground.

3.4.2.1 Electrical Schematics

Pictured on the left side shows how the recovery bay design utilizes an Easy Mini Altimeter, a Duracell 9V battery, a 3D printed battery case, and a DPDT slide switch.

The recovery bay design pictured on the right side utilizes a StratoLogger CF altimeter, a Duracell 9V battery, and a 3D printed battery case.

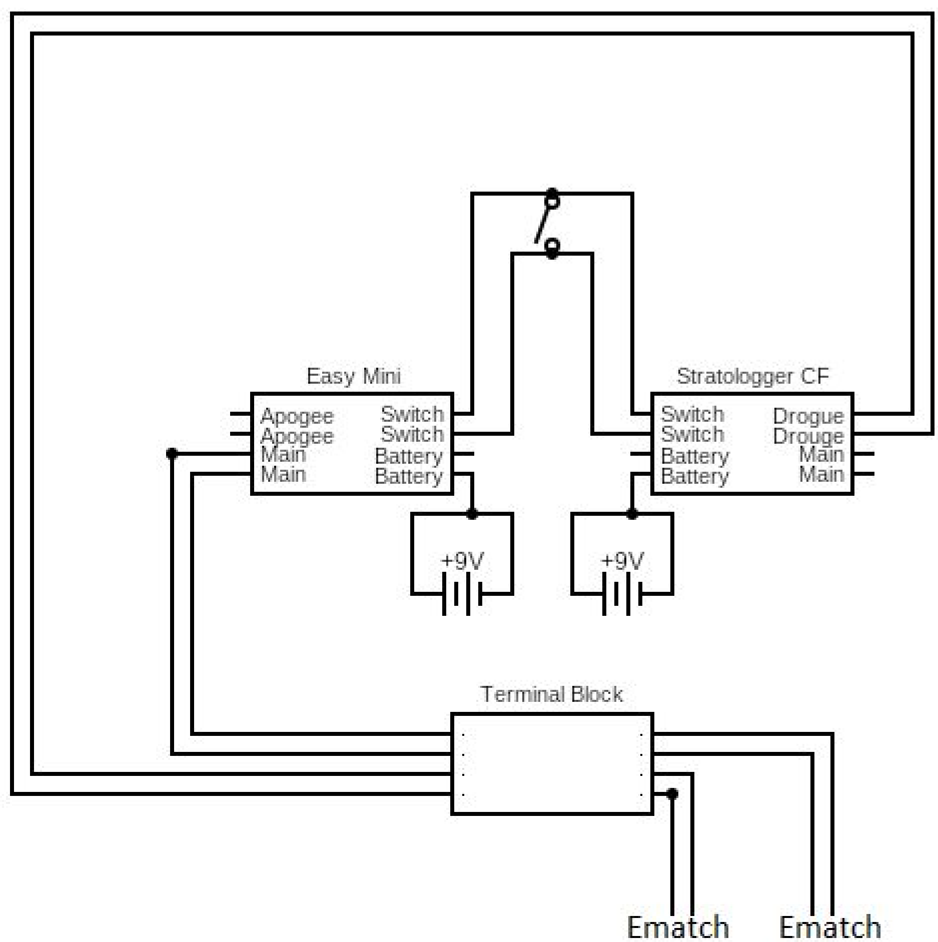


Figure 3.15: *Electrical Schematics*

3.4.3 Hardware Description

3.4.3.1 Parachutes

Main Parachute:

Figure 3.16: *Iris Ultra 60" Standard Parachute*

We chose to use a 60" parachute toroidal in design as our main parachute. We settled on the Iris Ultra 60" Standard nylon parachute manufactured by Fruity Chutes. We decided to go with Fruity Chutes as we have used their products before on previous rockets, and have had great success.

The diameter and shape of the parachute were chosen with the Kinetic Energy Requirements in mind. A toroidal parachute was essential due to its high Coefficient of Drag, which allows us to choose a smaller and more lightweight parachute. We found the optimal diameter for our parachute using the drag force equation.

$$F_D = \frac{1}{2}(\rho\, C_D\, A\, V^2)$$

$$D = \sqrt{\frac{8F_d}{\rho\pi C_d V^2}}$$

ρ = the density of air (1.22 $\frac{kg}{m^3}$)

A = area of parachute = πr^2

F_D = drag force = F_G = (6.52kg) * (9.81 m/s^2) = 63.96N

C_D = Drag Coefficient = 2.2 (Toroidal parachute)

V = Maximum Landing Velocity = $\sqrt{\frac{2(100J)}{6.52kg}}$ = 5.5 m/s (using Kinetic Energy equation)

D = diameter of parachute

After plugging in values we are left with D = 1.41m = 55.51 inches. The final parachute diameter is rounded up to 60 inches to allow a buffer to prevent going over the kinetic energy requirements. The parachute will be released by Jolly Logic chute releases at an altitude of 500 feet. The main and drogue parachute will be connected by a shock cord that is 20ft. The shock cord is the Kevlar Cord 1500#.

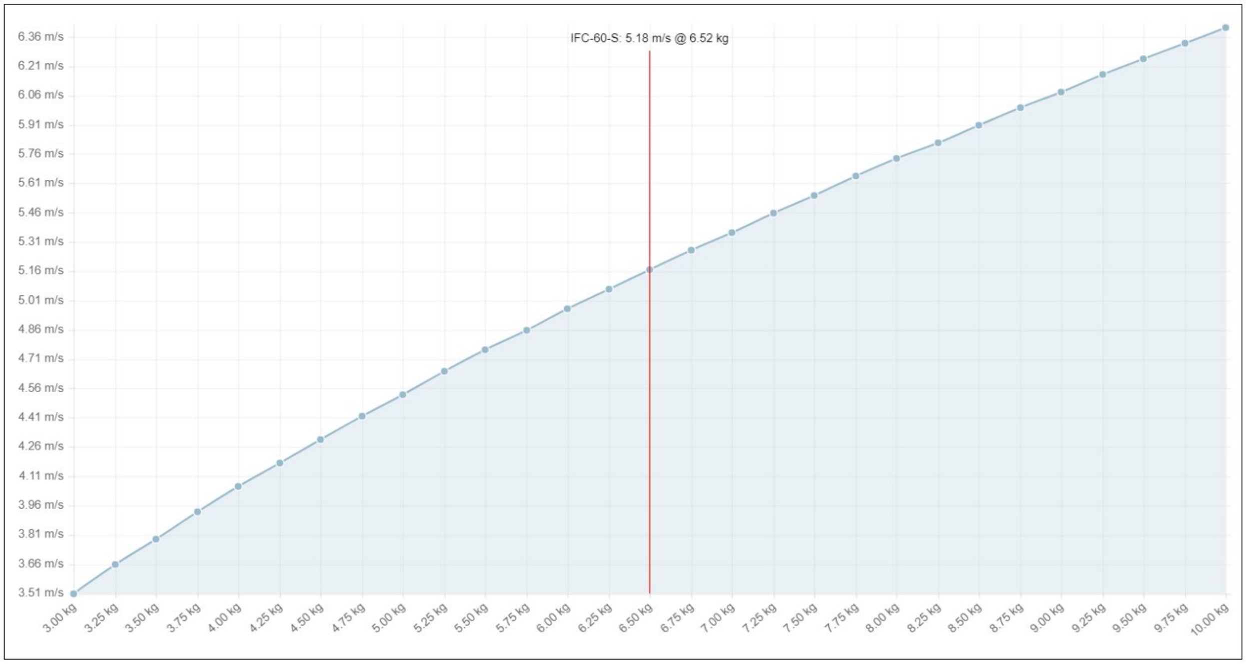


Figure 3.17: *Projected Model using Fruity Chutes Parachute Descent Rate Calculator*

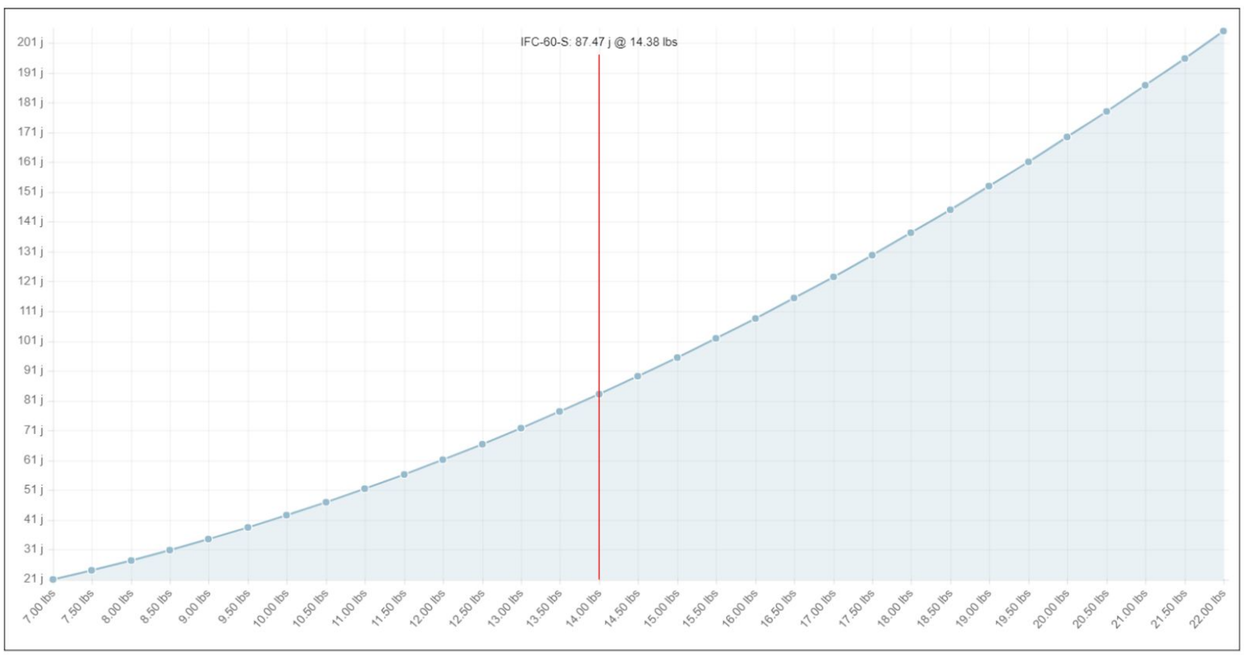


Figure 3.18: *Projected Model using Fruity Chutes Parachute Descent Rate Calculator*

Drogue Parachute

We will be using a 18 in Fruity Chute Drogue that will be released at apogee to meet the descent time requirement.

Nomex Chute Protector

The Nomex Thermal protection blanket is folded over the parachute to protect it from the black powder charge.

3.4.3.2 Batteries

Turnigy 800mAh 2S 20C Lipo Pack battery

Figure 3.19: *Turnigy 800mAh 2S 20C Lipo Pack battery*

The Turnigy 800mAH battery is used to power the Eggfinder TX GPS transmitter housed in the rocket nose cone. The Eggfinder TX draws 70mA - 100mA. So the transmitter will be able to realistically transmit for 5+ hours.

Duracell 9V Battery x2

Figure 3.20 : *Duracell 9V Battery*

Both altimeters (StratologgerCF & EZmini) are powered by 9V Duracell batteries. This will be enough to provide more than 3 amps of current to the ematches.

3.4.3.3. Switches

DPDT Slide Switch

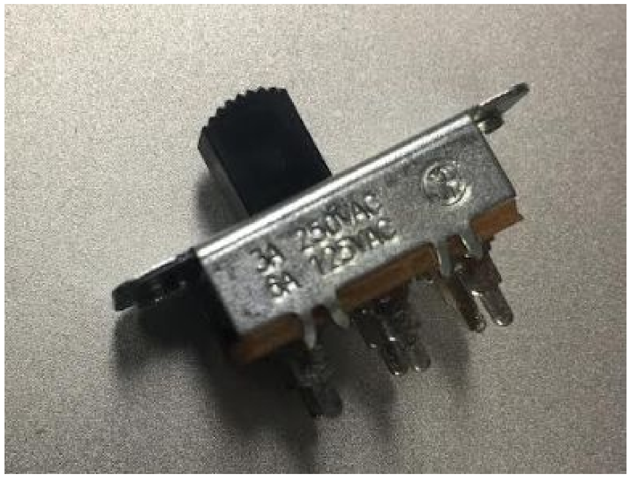


Figure 3.21 : *DPDT Slide Switch*

This is the main and only switch that controls the recovery avionics. It is configured so the ON side is closest to the ground. This prevents the switch from accidently switching to the OFF position during launch due to the acceleration forces. Both altimiters are connected to this sole switch.

The switch is turned on and off from outside the rocked by utilizing two 3mm holes drilled through the coupler that allows for a small flathead screwdriver to be used to move the slide back and forth. The ability to disarm the ejection charges before flight is crucial to maintaining proper safety.

3.4.3.4 Mounts and Attachments

Eyebolt (1 in diameter)

Figure 3.22: *Eyebolt*

An eyebolt is fastened into one of the bulkheads. Connected to the eyebolt is the shock cord that contains the main parachute and drogue parachute.

Four Circuit Terminal Block

Figure 3.23: *Four Circuit Terminal Block*

The terminal block is attached to the top of the bulkhead facing the recovery bay. It will allow for easier detonation of the ematches. The wires coming directly from the altimeter will not be disturbed, preventing any accidental disconnections of the charge wires. Detonation wires from the altimeters will be connected to the terminal block with the ematch wires connected to the other side. This allows for a simpler set up, without disturbing the rest of the avionics.

3.4.4 Avionics and Redundancy

3.4.4.1 Altimiters

PerfectFlite Stratologger CF

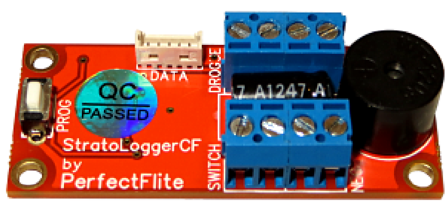


Figure 3.24: *PerfectFlite Stratologger CF*

The Stratologger CF is the primary altimeter in charge of firing the first ejection charge at directly at apogee. It is powered by a 9v battery. It has redundant charge capabilities, but we have chosen to use an alternate altimeter for greater redundancy. Vent holes were made to allow for the altimeters to accurately gauge altitude, but they will need to be changed.

Easy Mini Altimeter

Figure 3.25: *Easy Mini Altimeter*

The EasyMini is the secondary altimeter in charge of firing the second ejection charge. There is a 2 second delay to not overload the rocket with pressure. The EasyMini is put in place for redundancy purposes. It is set on redundancy mode through its settings.

Jolly Logic Chute Release x2

Figure 3.26: *Jolly Logic Chute Release*

In order to release the main parachute at the correct altitude of 500ft, there are 2 jolly logic chute releases connected in series that wrap around the folded parachute. Since our rocket does not have a dual-release design, both the main and drogue parachute are released at apogee. The main parachute is kept from opening by the chute releases until the main deployment altitude. Only one of the chute releases must work due to the redundancy of the series connections.

The StratoLoggerCF is the main use of the altimeter sequence. The EasyMini is used for redundancy purposes. Each altimeter has separate power supply, and is located on opposite sides from each other.

The first phase of recovery is accomplished by detonating a black powder charge to separate the nose cone from the rocket and eject the drogue chute. This is triggered primarily by the Stratologger CF altimeter with the EasyMini altimeter serving a backup. The EasyMini altimeter is powered by a separate source and is connect to its own black powder charge of greater strength than the primary charge connected to the Stratologger. This ensures that if the Stratologger does not trigger ejection, or the Stratologger triggered charge is not sufficient to separate the rocket, the EasyMini will have the highest chance of completing the ejection process. The EasyMini backup trigger will also be delayed from apogee to ensure that both charges do not go off simultaneously.

The black powder ignition also frees the main chute from the airframe, but while it is still wrapped with the Jolly Logic Chute Release devices. Two of these devices are included in series to provide redundancy for the main chute deployment.

3.4.4.2 Tracking Equipment

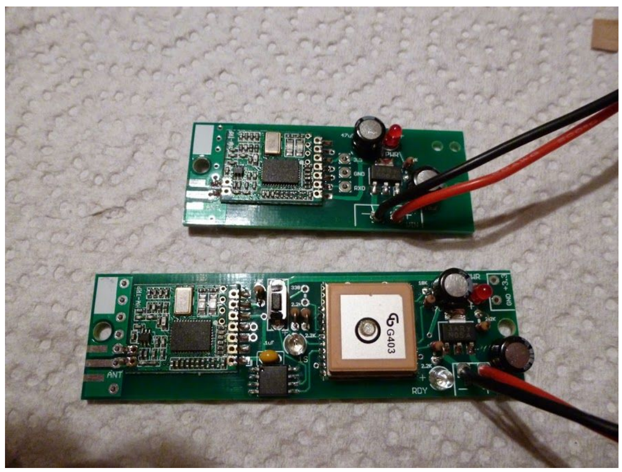


Figure 3.27: *Eggfinder RX (top) Eggfinder TX (Bottom)*

The Eggfinder TX was chosen in order to record the real-time position of the rocket as it lands. This unit is relatively cheap, and we have had good experiences using it in past rockets. It will be used with the Eggfinder RX receiver.

Range: 10,000 feet
Resolution: 2.5 meters

3.4.5 Tracker(s) Frequency

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.

GPS Unit	Operating Frequency	Receiver
EggfinderTX	921 MHz	EggfinderRX

Table 4: *Operating Frequency of Trackers*

3.4.6 Risk Analysis

Potential Problem	Description	Risk Score (1-5)	Solution
Avionics switch fails	All recovery systems will fail.	5	Securely mount switch to sled and check wire joints before and after every launch.
Altimeter battery fails	Due to redundant altimeters, one charge will detonate while other will not. Charge will need to be disarmed on ground.	4	Check batteries before every flight. Secure connections before flight.
Main Chute gets tangled with Jolly logics during descent	This would prevent the main chute deploying properly. Recovery would fail	4	Properly fold, and pack parachute before launch.

Table 5: *Risk Analysis of Potential Problems*

3.5 Mission Performance Predictions

3.5.1 Flight Simulations

Using OpenRocket simulations, the vehicle is expected to have an apogee of 5727ft, maximum velocity of 748ft/s, and maximum acceleration of 391ft/s^2. The vehicle's CG and CP are located 62.992in and 80.305in respectfully, from the nose. This produces a static stability margin of 3.14 with the motor, and 4.54 without. [Figure --] is the OpenRocket model of the vehicle with its various parts and part layout. [Figure --] shows the flight profile of the vehicle simulated in OpenRocket. [Figure --] is the thrust profile of the AeroTech L1000 motor, the chosen motor for the fullscale rocket.

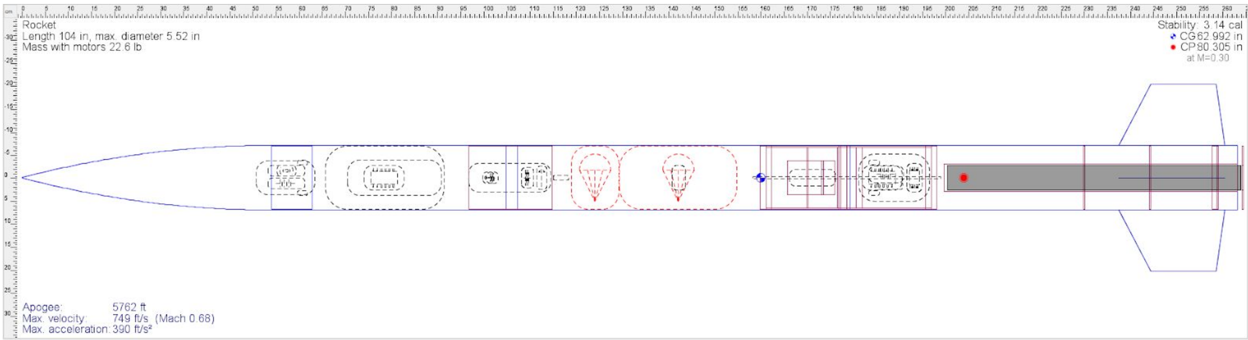


Figure 3.28 OpenRocket Model of the Fullscale Rocket

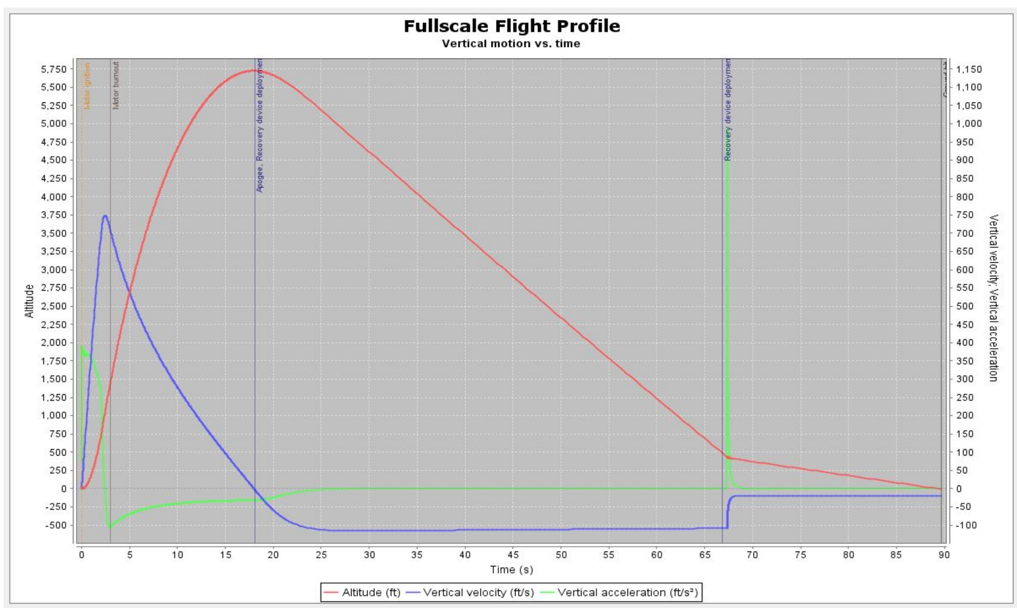


Figure 3.29 Full scale Flight Profile from OpenRocket

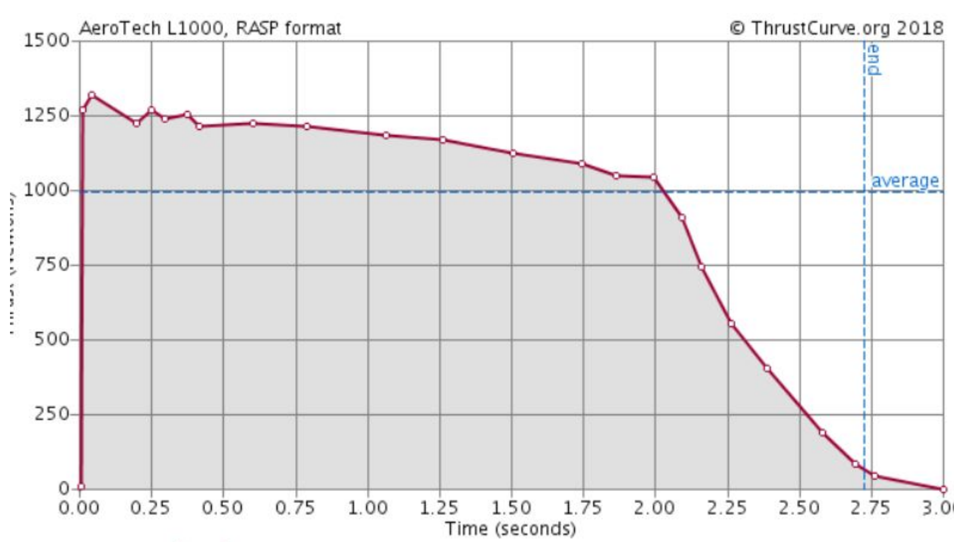


Figure 3.30 Thrust Profile

of the AeroTech L1000 Motor

3.5.2 Requirement Verification

3.5.2.1 Decent Time

Based on simulations run in OpenRocket, the time for the flight is estimated at about 89 seconds, and the time to apogee is estimated at about 18 seconds, so we're assuming the time from apogee to touchdown is approximately 71 seconds.

3.5.2.2 Drift

When calculating by hand, the drift radius is given by multiplying the horizontal wind velocity with the total time from apogee to touchdown:Drift radius = $v_{wind}t_{flight}$

For this estimation, we're assuming that the apogee is directly above the launch site, that the drogue parachute will deploy at apogee, that the launch vehicle velocity is entirely vertical, and that the wind velocity is entirely horizontal.

Wind Velocity (in mph)	Drift Radius (ft)
0	0
5	159
10	380
15	566
20	767

Table 3.6: *Drift values calculated by hand*

Table 3.Z details the drift values from using the OpenRocket simulation and the values for the variables assumed above.

Wind Velocity (in mph)	Drift Radius (ft)
0	0
5	129
10	295

15	485
20	683

Table 3.7: *Drift values calculated by OpenRocket*

Table 3.A details a comparison of the drift values from both methods of calculation, including percent difference.

3.5.2.3 Differences

Wind Velocity (in mph)	Drift Radius by Hand (ft)	Drift Radius by OpenRocket (ft)	Percent Difference
0	0	0	-
5	159	129	23%
10	380	295	29%
15	566	485	17%
20	767	683	12%

Table 3.8: *Drift values calculated by OpenRocket versus drift values calculated by hand*

Even though the values for drift radius varied slightly between hand calculations and OpenRocket's simulations, both are under the 2500-foot drift radius limit, even for high wind speeds. Based on these values, we believe that our rocket will stay under the drift maximum.

Based on the OpenRocket predictions, the landing velocity will be approximately 5.85 m/s (19.2 ft/s). Based on that and the mass of the largest independent section, 5.154 kg (11.36 lbs), the maximum landing energy of the rocket should be 88.2 J (65.05 ft-lbs). This is within the requirement of 75 ft-lbs, therefore our recovery design is acceptable.

4 Safety

4.1 Safety Officer Responsibilities

4.1.1 Team Safety Officer and Identified Duties

Richard Alves is the Rocket Team at UCSC's Safety Officer for the 2018-19 SLI project season. He has experience in electronic labs from his time as an Electrical Engineering student and understands the health and safety requirements of campus lab and work spaces thoroughly. For this year, he is responsible for the following aspects of the team:

- Write and enforce a team Safety Manual
- Create or distribute safety documentation, stating all members will abide by standard protocol as dictated by the office of Environmental Health & Safety, the FAA, and NASA, as well as any other relevant laws, and require that these documents be completed and signed by team personnel before they are permitted to physically work for the team
- Lead a tour through campus lab spaces to personnel before they may begin working in those areas with any tools or materials
- Attend and monitor the following activities when capable (and if unavailable then ensure trained and certified personnel can act as a replacement):
    - Launch events
    - Vehicle and sub-system design and construction
    - Outreach and educational engagement events
    - System and vehicle testing
    - Painting and other decorative activities for the rocket
- Provide the MSDS documentation and ensure it remains public and available freely for all personnel via the team website and Google Drive
- Cooperate with range safety officers or other NAR/TRA personnel during launch events should the need arise
- Comply with the safety requirements in Section 5 of the NASA SLI handbook and the team's own derived safety requirements (see Section 6.2.1 for details)

In addition, Richard and the other Co-captain, Duncan, will represent the team and its operations to the Sustainability Lab, the UCSC organization which provides the team with lab space and equipment, so as to maintain the team's work station status and priorities for the entirety of SLI.

4.1.2 Safety Manual

The team Safety Manual has been revised since its inception in September of 2018 and also posted onto the team's website. Contents of the document include information on the major rules and regulations surrounding amateur high-powered rockets, NAR compliance, MSDS and electronic datasheets, risk and hazard analysis, lab and workspace etiquette, and other resources needed for all members to participate with the team in a safe and legal manner. A finalized revision of the document will be tentatively available by the FRR.

4.2 Operation and Launch Procedures

Sections 4.2.1 through 4.2.7 and their constituent checklists represent the team's current iteration of the procedures and delineated tasks used to safely prepare, launch, and recover the flight vehicle and subsystems. Current estimates place the time requirement for completion of all procedures to be between 120 - 150 minutes. All operations involved are to be done mostly on flat surfaces and entirely outdoors, assuming no adverse weather occurs that could jeopardize electronics or specific chemicals. Throughout the lists are a variety of symbols highlighting relevant information and PPE where required. Table 4.1 documents the images for a mask, safety glasses/goggles, nitrile gloves, and grounding and when they are needed for personnel performing setup for the launch:

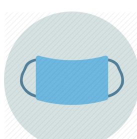
			
Personnel must wear protective mask	Personnel must wear safety glasses/goggles	Personnel must wear nitrile gloves	Personnel must be electrically grounded

Table 4.1: Symbols identifying PPE required to be worn when they appear in the launch setup.

When an important or critical piece of information needs to be mentioned while following the procedures outlined, the following notation will be used to reliably highlight the content:

NOTE: used to label relevant non-critical information

CAUTION: identifies when PPE should be worn and when special care is needed

WARNING: identifies major steps or hazards that could be dangerous to human health and mission success

4.2.1 Equipment and Personnel Checklists

Personnel	**Personal Protective Equipment**
❏ Co-Captain: Duncan ❏ Safety Officer/Co-Captain: Richard ❏ Project Lead: Kent ❏ Outreach Lead: Vera ❏ Range Safety Officer ❏ NAR Certified Mentor ❏ California Basic Class C licensed (or other applicable license) automobile drivers (x3) ❏ Recovery subteam member (x2) ❏ ADAS subteam member (x4) ❏ Payload subteam member (x4) ❏ Vehicle subteam member (x4)	❏ Safety glasses (x5) ❏ Disposable nitrile gloves (x10) ❏ Breathing/medical masks (x2)
Tools	**General Supplies**
❏ Hammer ❏ Phillips screwdrivers (x3) ❏ Power drill ❏ Drill bits ❏ Dremel kit	❏ Laptop (x3) ❏ Laptop chargers (x3) ❏ Quick-dry epoxy (x2) ❏ Electrical tape ❏ Zip ties (x30)

❏ Soldering kit ❏ Multimeter ❏ Pliers (x3) ❏ Wire strippers/cutters (x2) ❏ Calipers (x2) ❏ Scissors ❏ DC-AC inverter ❏ Hot glue gun ❏ Allen wrench set	❏ Foldable table ❏ Automobiles (x3) ❏ Water (x5) ❏ Super glue ❏ Velcro ❏ Electronic gripping hardware ❏ Weight scale ❏ Pencils (x3) ❏ 9-V batteries (x8) ❏ AA batteries (x8) ❏ Assorted rechargeable batteries (x3) ❏ Wires ❏ Sand paper
Vehicle Components	**Recovery Components**
❏ Thrust section (assembled) ❏ Payload section (assembled) ❏ Recovery section (assembled) ❏ Nosecone	❏ Two 9v batteries ❏ Turnigy 800mAh battery ❏ Assembled avionics sled ❏ Two Ematches ❏ Eggfinder RX GPS receiver ❏ 2mm flat long head screwdriver ❏ 18 in Drogue Parachute ❏ 60 in Main Parachute ❏ Nylon Shock Cord ❏ Nomex chute protector ❏ 2x Jolly Logic Chute Releases ❏ Wooden jig
ADAS Components	**Payload Components**
❏ **ADAS Coupler and Bracelet** ❏ **Top Cap** ❏ **Bottom Cap** ❏ **Eye Bolt** ❏ **Washers (3)** ❏ **Hex Bolt LARGE** ❏ 14.8 V Battery ❏ Beaglebone ❏ NeveRest Motor ❏ Motor Driver ❏ **Fins (x2)**	❏ SM S4303R Servo ❏ Pololu 20 KG * CM servo ❏ DC motors * 2 ❏ King Max 1000 mAh Lipo battery x 2 ❏ Beaglebone Blue ❏ Wheels x 4 ❏ Wires x 6 ❏ 3D Printed Custom Chassis ❏ USB Camera ❏ Bluetooth speaker

- ❏ **Gear**
- ❏ Wire to power beaglebone
- ❏ Wire Connectors for motor and motor driver
- ❏ **Sled**
- ❏ **Middle Cap**
- ❏ **Top Fin Plate**
- ❏ **Bottom Fin Plate (Acrylic)**
- ❏ **Allthreads (x2)**
- ❏ **Camera**
- ❏ **Camera charging cord**

4.2.2 Recovery Preparation

Parachutes
❏ Lay down the shock cord, drogue parachute, main parachute, and nomex protector separately. ❏ Clamp wooden jig on table. Sort parachute strings by left main, center pull, and right main. ❏ While strings are separated on the wooden jig, begin to find the center loop of the parachute. This will be the top. Anchor the strings that are hanging from the jig onto something so it is taught. ❏ Fold back canopy gores. Flake a gore starting from an indicator on the chute that it's the bottom left side. ❏ Pull out the first seam tight so it goes to the center. Pull out the fabric away from the center and flatten. The fabric inside the flattened gore is also tight and wrinkle free. ❏ Keep folding fabric away from the center and flattening it. ❏ Repeat step 6 on the right side, having put weights on the left side to make sure it doesn't move. Fold the left side on top of the right side to make one long rectangular shape ❏ Remove the wooden jig, and then make an accordian, or Z fold with the remaining chute. ❏ Wrap strings around the chute ❏ Once the main parachute is folded, attach the Jolly Logic Chute releases by connecting them in series using the rubber band. Set the Jolly Logic Chute releases to 500ft.
Nose Cone / GPS

- ❏ Insert Eggfinder TX into its housing and connect it to the Turning 800mAh battery.
- ❏ Make sure it is inserted correctly, preventing the battery from getting disconnected or hitting the transmitter during liftoff.
- ❏ Secure housing into nose cone, and place nosecone back over the rest of the body

Avionics Bay

- ❏ Remove sled from avionics bay housing.
- ❏ Unscrew battery retaining bolt from the bottom of the sled.
- ❏ Replace and insert new batteries into the battery case on each side of the sled.
- ❏ Press respective battery clip onto the connectors and each battery and make sure clip is snug and tight.
- ❏ Re-screw retaining bolt onto the bottom of the sled.
- ❏ MAKE SURE NO CHARGES SET, flip the switch on and 2 distinct frequencies of beeps should be heard. (3 short beeps, long beep, 3 short beeps)
- ❏ Turn off switch. Check all joints and connections for strong connections, and sturdy mounting.
- ❏ Insert sled into avionics housing, and align bulkheads for a good seal (use markings on bulkheads to correctly orient the sled). The Terminal Block should be facing the ground.
- ❏ Attach nylon shock cord to eyebolt. Double check to make sure it is secure.
- ❏ Have a certified team member connect the Ematches to the terminal block.
- ❏ Insert Avionics bay into rocket. Followed by the nomex blanket, covering the main chute, followed by the drogue chute.
- ❏ Make sure the parachutes are not tangled in any way, and aren't fit too tight in the recovery bay.
- ❏ Carefully close rocket, making sure couplers are fit snug with the rest of the rocket body
- ❏ Place shear pins to hold recovery bay together
- ❏ Re-check parachute prep and set up. Refit parachutes back into recovery bay.

4.2.3 Payload Preparation

- ❏ Insert radio receiver module into the top of recovery bay, with black powder charges
- ❏ Insert kill switch tether to back of door and attach to rover
- ❏ Assemble Rover
    - ❏ Plug in battery, 2 servo motors, and 2 drive motors to BeagleBone
    - ❏ Plug in rangefinder and camera to the BeagleBone
- ❏ Fasten Rover to ALC
    - ❏ Place rover onto ALC sled

    - [ ] Connect servo attachment to ALC sled backing
- [ ] Insert ALC, Sled, and Rover into coupler
- [ ] Ensure all pieces are securely fastened

4.2.4 ADAS Preparation

- [ ] Ground oneself before handling any ADAS equipment
- [ ] Flip power switches to “off” +
- [ ] Ensure micro SD cards are in beaglebone and camera
- [ ] Power on BeagleBone by pressing POW button and waiting for the below heart blink LED to settle and program initialization chirps to begin
- [ ] Ensure codes including deployment profile (Deployment.py) are the latest from ADAS github and has the desired conditions (n, n_step, min_deploy, max_deploy).
- [ ] Run rc_test_mpu to calibrate IMU if not calibrated
- [ ] Test deployment profile to ensure it deploys and retracts in more or less steps
- [ ] Power down BeagleBone and unplug for assembly
- [ ] Assemble ADAS
    - [ ] Insert motor into bottom motor cap +
    - [ ] Screw motor in +
    - [ ] Insert top motor cap and secure two halves
    - [ ] Assemble fin plate assembly
        - [ ] Acrylic sheet to top plate with fins and gears
        - [ ] Bolt middle cap to plate assembly
    - [ ] Attach fin plate assembly to motor housing
    - [ ] Run wires down to sled
    - [ ] Plug motor encoder wires into encoder port 3
    - [ ] Plug motor driver wires into GP0 port
    - [ ] Plug camera charge cable into pwr port
    - [ ] Screw in motor power cable to motor driver
    - [ ] Power componentes
        - [ ] Screw to motor driver
        - [ ] Place inline fuse to positive line of BeagleBone and power the board
        - [ ] Plug in battery
    - [ ] Power on BeagleBone
    - [ ] Insert allthreads
    - [ ] Attach top cap to assembly and bolt on
    - [ ] Turn everything on (Plug battery in + Camera)
    - [ ] Verify everything is on and working
    - [ ] Insert assembly into coupler from top to bottom

- ❏ Attach bottom cap to sled and bolt allthreads
- ❏ Attach ADAS to airframe

4.2.5 Vehicle Preparation

- ❏ Perform overall inspection of all outer parts
- ❏ Attach nose cone to recovery section using shear screws
- ❏ Attach recovery to ADAS section using shear screws
- ❏ Attach fins on motor section mounts
- ❏ Conjoin thrust section to upper rocket body using shear screws
- ❏ Perform final visual inspection of outside of rocket system to ensure all components connected correctly
- ❏ Install motor on motor mounts
- ❏ Secure firmly using end bolts
- ❏ Walk to launch rail
- ❏ Slide the rocket onto rail, using the rail buttons as guides
- ❏ Allow mentor to insert ignitor
- ❏ Retreat to safe distance
- ❏ Launch

4.2.6 Launch Preparation

Sub-System Integration into Vehicle
❏ Visually inspect all pieces for damage ❏ Connect rover to sled using lock and key system ❏ Plug rover into ACL system ❏ Slide ACL system and rover into Blue Tube coupler ❏ Attach nose cone using semi-permanent bolts ❏ Slide spacer bracelet onto frame ❏ Attach safety tethers to anchor points on both recovery and payload and make sure they are secure ❏ Attach door to pull string using knot ❏ Attach kill switch to rover ❏ Tie kill switch and pull line to recovery ❏ Close door to payload bay ❏ Fold all excess cordage and wire into recovery section ❏ Place nose cone assembly onto recovery section

❏ Gently attach shear pins to conjoin payload
Launchpad Setup
❏ Put rocket on launch pad. Align with rail system ❏ Switch Avionics Bay on using small screwdriver to turn on the switch. ❏ Wait for confirmation beeps. Listen for errors ❏ Launch Rocket ❏ Keep eyes on it at all times and point in its direction once visual is obtained. ❏ Wait and watch for dangers until it reaches the ground.

4.2.7 Post-Flight Inspection

Remove all undetonated black powder charges from the vehicle and ensure they are safely stored away before following these steps
❏ Unscrew ADAS from airframe ❏ Assess condition of ADAS ❏ Disassemble ❏ Turn off Camera ❏ Remove sd cards and store safely ❏ Cut Power to System ❏ Store electronics

4.3 Hazard Analysis

4.3.1 Risk Assessment

Effective identification and mitigation of the hazards involved with the activity of personnel, the rocket (including its systems and components), and the effects occurring between the vehicle and environment necessitated a revised risk analysis. The severity levels assigned to risks are listed in Table 4.2 and the frequency for which risks occur are given in Table 4.3. A subsequent risk assessment matrix was created (Table 4.4) by qualitatively combining the severity level and occurrence rate to develop four distinct risk assessment codes (RAC) and the corresponding authority approval needed for each risk level (Table 4.5). The hazard analyses have been updated with the new matrix and risks such that Sections 4.3.2 - 4.3.4 now prescribe risk assessment codes using a "before mitigation level" (BML) and "after mitigation level" (AML) to demonstrate the team's safety plans and their results on the identified hazards for the SLI project.

Description	Value	Criteria			
		Personnel Health & Safety	Environmental	Mission Status	Material Loss
Catastrophic	1	Death; Severe and/or chronic injury	Significant irreversible damage; Violation of at least one law or regulation	Complete loss of systems or vehicle; Total mission failure	At least $500 or more in monetary loss; Loss of facilities and hardware
Critical	2	Serious injury	Significant reversible damage; Violation of at least one law or regulation	Major damage to vehicle or systems; Majority of mission failed	Between $200 to $500 monetary losses; Major damage to facilities and hardware
Marginal	3	Minor injuries; Mostly treatable by first-aid care	Moderate and reversible damage with proper restoration technique; Does not violate any laws or regulations	Minor damage to vehicle or systems; Minor mission failure, but non-critical system severely impacted.	Between $50 to $200 monetary losses; Minor damage to facilities and hardware
Negligible	4	Insignificant injuries; Completely treatable by first aid care	Minor reversible damage; Does not violate any laws or regulations	Insignificant damage to vehicle or systems; Partial non-critical mission failure	Less than $50 in monetary losses; Minimal damage to facilities and hardware

Table 4.2: Hazard Severity Levels and Definitions

Description	Code	Criteria

		Qualitative	Quantitative
Frequent	A	High likelihood of occurring in immediate future or expected to consistently recur	Probability > 75%
Common	B	Significant likelihood to occur soon or eventually expected to recur over shorter amount of time	30% < Probability < 75%
Occasional	C	Noticeable chance to occur within the future or expected to recur within nominal of time	10% < Probability < 30%
Unlikely	D	Insignificant yet small possibility for the event to occur or recur within a longer span of time	1% < Probability < 10%
Improbable	E	Negligible likelihood the event will ever occur and not expected to recur in time	Probability < 1%

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
High Risk	Unacceptable. Documented approval from Safety Officer, team captains, Project Lead, sub-team leads, RSO, and team mentor. Notify NASA SL officials. Immediate mitigation required.

Moderate Risk	Undesirable. Documented approval from Safety Officer, Project Lead, and sub-team leads. Notify team captains, RSO, and team mentor if necessary. Mitigation required.
Low Risk	Acceptable. Documented approval from involved sub-team lead and Safety Officer. Notify the Project Lead. Mitigation required for necessary situations.
Minimal Risk	Acceptable. Review by Safety Officer recommended, but no documented approval needed. Some mitigation may be required.

Table 4.5: Risk Level Color Codes

4.3.2 Personnel Hazard Analysis

Hazard	Cause	Effect	BML	Mitigation	Verification	AML
Soldering burns	Inattention to task, improper use of equipment	Mild to severe burns	2A	Personnel must verify their soldering capabilities to the Safety Office before being allowed to independently work with the soldering iron	Safety Manual (4.1.2)	3C
Inhalation of carbon fiber or fiberglass particles	Lack of proper attire and PPE	Lung and breathing pain; asthma attack	1C	PPE will be available in the lab space and personnel must ensure that the fibers will not interfere with other lab patrons	Safety Manual (4.1.2)	2D
Flying workshop debris	Improper use of equipment or lack of attention	Loss of limb, eyesight, cuts, bruises	1C	Only trained individuals will be allowed to operate heavy machinery. PPE will be properly worn at all times.	Safety Manual (4.1.2)	1E
Improper use of power tools	Improper use of equipment or lack of attention	Loss of limb, eyesight, cuts, bruises, burns	2B	Only trained individuals will be allowed to operate power tools. PPE will be properly worn at all times.	Safety Manual (4.1.2)	3D
Electrical shock	Stray electronic charges, exposed	Mild to severe burns, muscle	1C	Personnel will be required to ground	Safety Manual (4.1.2)	4D

	wires	spasms, electrocution		themselves and use safe/working outlets when operating with electronics. Hazardous electronic situations must be reported to the Safety Officer.		
Extended exposure to RF signals	Electronic device emits RF signals in close proximity to personnel	Studies show that RF waves can cause cancers , sterility, etc. over long periods of time	2C	Use of RF electronics will be limited to specific time limits and distances to avoid personnel from over exposure.	Safety Manual (4.1.2)	4D
Rechargeable battery explosion	Improper storage, circuit configuration, charging, or punctured	Moderate to severe burns	2A	All batteries must be checked visually for damage and all personnel must demonstrate skills with charging and discharging devices to the Safety Officer.	Safety Manual (4.1.2)	3C
Inhalation or contact with noxious lab chemicals	Lack of necessary attire and PPE, improper handling	Skin, eye, and breathing irritation or damage	2B	PPE will be readily available for use in lab and all personnel will have access to MSDS online and be properly trained to handle chemicals.	Safety Manual (4.1.2)	3D
Extended exposure to high decibel noises	Improper PPE, misuse of equipment	Chronic ear and hearing damage	1D	Ear protection will be provided for louder machinery at all times.	Safety Manual (4.1.2)	3D

				Signs will be posted notifying personnel of rooms or spaces with loud sounds and machines.		
Moving parts of rover or machinery harm personnel	Improper training or incorrect control algorithms	Bruises, cuts, loss of limb	1B	Rover and other equipment will be handled with proper training and tested for correct operation frequently.	Safety Manual (4.1.2)	2D
Premature detonation of separation charges	Improper assembly or storage causing excess heat or electricity	Severe burns, loss of limb, trauma	1C	Black powder charges will only be acquired at launch events from certified mentors or other qualified personnel and vendors, and only handled by trained members. No black powder charges will be stored in campus labs.	Safety Manual (4.1.2)	1E
Motor detonation	Premature ignition installation, withdraw distance not enforced, or motor in poor condition	Severe burns, loss of limb, trauma, death	1C	Ignition will only be installed on launchpad, the motors will be purchased from reputable dealers, and the viewing distance will be enforced by range personnel.	Safety Manual (4.1.2)	1E
Rocket flies under unsafe conditions	Unstable flight trajectory, recovery system	Moderate to severe injuries to personnel; death	2B	A thorough checklist will be used to determine if electronics are working	Safety Manual (4.1.2), NAR Compliance, 4.2	2C

	failure	from high velocity impact		properly and the launchpad setup correctly.		
Misuse of lab equipment and privileges	Untrained or non-team personnel	Loss of equipment, cuts, burns, bruises, shock, etc.	2B	Only certified team members can access the team materials and there will be accountability held for all persons who occupy the lab spaces simultaneously.	Safety Manual (4.1.2)	2D

Table 4.6: Personnel Hazard Assessment

4.3.3 Failure Modes and Effects Analysis

Hazard	Cause	Effect	BML	Mitigation	Verification	AML
Computer (BBB) is turned off while contained in rocket	Wire or other component is pressed against power button	Cannot be turned back on without opening rocket, ADAS will fail	3C	Allot adequate space in the electronics bay to avoid crammed components	BBB is programmed to chirp at regular intervals to verify that it is powered on	3D
Battery death (14V)	Improper charging	Either partial (if death occurs during flight) or complete (if prior) failure to deploy fins and attenuate the rocket's apogee to the target height	3D	The battery will be charged within 12hrs of flight and tested before integration	Measure the battery voltage immediately before assembly pre-flight	3E

Stripped or broken gear	Resistance to fin deployment exceeds hardware limits	Gear is unable to actuate fins. Will not deploy if stripped before flight or in attempt to deploy, will not retract if stripped while deployed which may damage ADAS or the airframe on landing	3C	Avoid tests and handling that could result in stripped gear, change gear to thrust-bearing washer if hazard is encountered	Interior camera would provide information about failure, check integrity of gear and fin teeth before assembly	3D
Fins extend over upper threshold	Algorithm error or motor over-rotation	Fins are no longer actuated by gear and will not retract. Potential damage to ADAS or airframe on landing	3C	Set the upper threshold below the maximum deployment by a comfortable margin, potentially add hardware to limit deployment	Test sufficiently pre-flight. Use interior camera to assess performance	3D
BBB power supply failure	System runs too hot or experiences voltage spike	The BBB loses power and will not actuate the fins or log data	3D	Protect the BBB with a 3D printed case, test cases that may contribute to failure to mitigate risk	Assess BBB function before assembly	3C
Overcharged battery	Charged battery with too-high voltage	Battery is compromised, could combust, may not provide sufficient power	1D	Use charge controller	Assess battery before integration (should be able to visually detect)	1E
Poor/no cable connection	Incorrectly connected or	Could short a component on the	2B	Ensure that connection site is clean and secure	Double check each connection	2D

	strained during assembly	board causing failure				
Failure to detect launch	Failure of algorithm to detect crossing of acceleration threshold due to pre-flight activity or sensor error	Algorithm does not proceed to deployment and data logging protocol (no deployment or data logged)	3D	Use flight simulations to get good estimate of appropriate threshold that will not be crossed prior to launch	Further ground testing should sufficiently resolve the potential of the hazard	3E

Table 4.7: ADAS FMEA

Hazard	Cause	Effect	BML	Mitigation	Verification	AML
Pinched, cut, or disconnected wire.	Wires can be twisted during vehicle flight and recovery	Damaged wire can short an electrical system, leading to a failure of receiving a signal and consequently the payload mission.	3C	The receiver wires will pass through a slip ring flange that will be mounted.	The payload launch checklist will require wire-twisting prevention measures take place.	3D
Payload does not self-orient correctly.	Unexpected ALC component contact with airframe prohibits rotation of ALC.	The rover would be unable to exit the airframe, resulting in failure.	3D	The rover has been designed so all components are housed within the ALC.	The free rotation and integrity of rover housing will be tested.	3E
Black powder residue on sensitive rover	A black powder charge will detonate not far	The camera may not function properly when	3B	The black powder charge can be covered by a piece of fire retardant cloth to	Black powder charges must be used while covered by fire retardant cloth.	3D

parts.	from the rover, blasting residue on exposed surfaces.	afflicted by residue.		retain residue.		
Component falls out of payload bay during recovery.	A component can break or loosen due to the forces from the parachute, black powder, or vibrations.	A lost component is a risk to all. The payload may not perform as hoped, resulting in potential failure. Could be a projectile	1D	All components will be properly attached to the rover. Shear pins and tether provide extra security.	All systems of the rover will be verified as secure to confirm the rover's security during flight.	1E
Premature deployment (on ground)	Separate signal sets off the black powder charge pre-landing safely. Extreme care will be taken when wiring black powder activation and radio and handling radio.	The black powder separation may harm anyone if they are near or especially holding the rocket. The rover may suffer damage upon landing, resulting in a failed payload mission.	1D	A unique deployment signal will be sent by a team member.	Unique deployment signals will be confirmed before launch.	1E
Premature deployment (mid-flight)	Separate signal sets off the black powder charge pre-landing safely. Extreme care will be taken when	Payload section is tethered to airframe, and rover is tethered to payload section, so it is unlikely any parts will separate	1D	A unique deployment signal will be sent by a team member.	Unique deployment signals will be confirmed before launch.	1E

	wiring black powder activation and radio and handling radio.	from the airframe. Thus, risk of danger is small.				
Obstructed Rover Path.	Field terrain or launch vehicle prevent the rover from driving in a straight line.	The rover will not be able to drive ten feet away, resulting in failure.	3D	The rover will be designed to travel across various terrain and to take the path of least resistance.	Thorough testing of the rover's drive design.	3E
Batteries not fully charged.	Batteries installed before fully charging or are damaged sometime between assembly and flight.	Insufficient power, resulting in rover failure.	3D	Full charge of batteries is to be confirmed before installation.	Launch procedures will require batteries to be checked before integration.	3E
Electrostatic discharge to sensor or control electronics.	Electrostatic build up on team member.	Potential shorts and component failure.	3C	Grounding mats and wrist straps must be used when testing electronics.	Test procedures require grounding mats and wrist straps.	3E

Table 4.8: Payload FMEA

Hazard	Cause	Effect	BML	Mitigation	Verification	AML
Main chute gets tangled	Improper folding of parachute inside airframe	Failure deployment of main chute, rocket	1D	Team members use a wooden jig to assist them in getting the strings	Strings must be separated from left main, center pull and right main.	1E

		plummets at high velocity		untangled.		
Avionics Switch Failure	Connection loss between switch contacts and altimeter wires.	Failure of recovery bay to open. No parachutes are deployed.	1E	Check sauder between the altimeter switch wires and the switch contacts to ensure no disconnections.	Test switch before flight, tug wires to ensure good connection.	2E
Both black powder charges fail to detonate	Wire, communication, or spark failure	No parachutes are deployed and rocket descends at dangerous speed	1D	Ensure that the recovery section is packed correctly and assess the quality of the wires	Perform ground tests to reduce likelihood & check joints and connections before every flight	1E
Charges detonate, but parachutes fail to leave recovery bay.	Parachutes are packed too tightly.	No parachutes are deployed and rocket lands at high velocity.	1D	Ensure that parachutes are folded properly.	Perform ground tests to reduce likelihood of failure.	1E
Parachute or other sensitive part has black powder residue on it causing a fire hazard.	Black power charge residue lands on parachute or other sensitive parts because of improper positioning of Nomex protection cloth.	External objects may catch on fire. System failure. Parachute damage.	2C	Properly position Numex protection cloth between the recovery avionics bay and parachute.	See that the cloth is covering the whole surface of the parachute	3D
GPS Transmitter does not work	Battery disconnect during launch	Inability to find rocket easily if visual is lost	3C	Secure Transmitter and battery connections using tape.	Verify GPS transmissions using the receiver before flight.	3D

Black powder charges ignite at same time	Altimeter malfunction, or user error in settings.	Catastrophic effect on structural integrity	1D	Double check altimeter settings before flight.	Enuse altimeters have sufficient air holes for proper altitude measurements	1E

Table 4.9: Recovery FMEA

Hazard	Cause	Effect	BML	Mitigation	Verification	AML
Rocket drop (INERT)	Mishandling of rocket during transportation	If charges do not detonate, damage to fins and electrical components.	1C	Careful handling while transporting rocket.	Use of rocket supports during vehicle assembly. Multiple people to transport rocket.	1E
Premature black powder discharges	Open flame sets off charge, not properly handled.	Serious safety threat to everything nearby.	1D	All electronics will be turned off until the latest time to enable them.	Vehicle launch procedures prevent black powder charges and charge preparation.	1E
Seized nut or bolt due to galling or cross threading	Repetitive uninstalling and reinstalling of parts.	Component becomes unusable, ruining expensive, custom parts.	2D	Don't force sections to fit.	Vehicle launch procedures and threads will be evaluated following launch.	2E
Fin flutter	Inadequate material strength.	Fins detach from vehicle causing vehicle to fly in unpredictable ways, could endanger surrounding people.	1C	Fin flutter simulations will be conducted made of carbon fiber.	Carbon fiber fins will not be affected by fin flutter. Vehicle launch procedures require inspection of fins before launch.	1E

Lost GPS Signal	Damage or power loss to GPS unit	Could lose track of the rocket, temporarily or even permanently	2D	GPS device is charged prior to launch and it is housed securely	Verify with real-time connection to GPS	2E

Table 4.10: Vehicle FMEA

4.3.4 Environmental Hazard Analysis

Hazard	Cause	Effect	BML	Mitigation	Verification	AML
Launch pad not properly secured for takeoff	Soft soil due to damp weather conditions or unprepared personnel	Unpredictable flight pattern	2B	Launch pad will be visually inspected and leveled correctly before installing launch vehicle	Safety Officer will sign off the checklist item to signify the launch pad has been setup correctly (4.2.6)	2E
Electronics damaged by environmental conditions	Wet or humid atmosphere, high and low temperatures	Failure of electronics in on-board systems to function properly resulting in mission failure	1B	All electronics are to be visually inspected for damage before installation and are to be shielded from poor conditions	Personnel will be trained to keep electronics away from dangerous conditions (Safety manual)	2C
Obstacle blocks the rover from successfully completing mission	Natural or artificial terrain/objects cause significant topological blockade	Partial or total rover mission failure	1A	The rover payload will contain an ultrasonic sensor to detect larger, impassable objects.	Testing of the rover system will determine the threshold of object detection and what types of objects are climbable (Section 6.1)	1D
Outdoor	Rain, fog, snow,	Airframe	1C	All vehicle assembly will	The full-scale vehicle	1E

assembly of vehicle in unsafe conditions	high-winds, hot and cold temperatures	components expand and contract due to thermal expansion, electronics fail to work due to inclement water		take place in moderate temperatures, electronics will be guarded from excessive wetness, and every component will be tested to ensure working functionality while within test flight limits	contains a sled that allows for all component to enter based on a	
Overheating of rocket pyrotechnics	High temperatures in direct sunlight create overheating elements inside rocket	Excessive temperatures damage electronics, unleash mechanical connections, and can detonate the motor	1D	Team will take care to keep the rocket out of direct sunlight for long periods of time and will insulate the parts that are most at risk	Accounting for the heat conduction and capacity of the carbon fiber frame gives a safe upper bound on the time that the rocket can be exposed to direct sunlight	1E
Damage to parachutes and vehicle	Excessive winds and nearby obstacles.	Recovery equipment damaged by rover and no ground for the rover to deploy on.	3B	Team will not launch with winds exceeding 15 mph and ensure that each launch field adheres to proper launching distances.	Wind speed data logger can be brought and local weather stations' forecasts can be checked.	3D
Ventilation holes and other openings sealed in with ice	Extreme weather conditions can deform precision cut features that can lead to hull damages/ subsystem failures.	Ice and extreme heat can deform opens that are essential to launch or deployment.	1D	Team will see that all material be kept in a safe environment, free of environmental harm.	Tarps, blankets, and the it's are good protectors of the outside.	2E

Hazard	Cause	Effect	BML	Mitigation	Verification	AML
Recovery system failure	Separation charges fail to detonate, not enough force from charges, Jolly Logic failure, improper pressure readings, or parachutes entangled or packed too tightly	High impact velocity causes severe injuries or death, debris infiltrates wildlife habitats	1C	Thorough checklists will be made to ensure the rockets are setup properly on the launchpad and personnel can be alerted in case the trajectory becomes dangerous.	The Safety Officer and other personnel must check and verify the recovery system before being launched via the launch preparation scheme in Section 4.2.2.	1E
Motor CATO	Improper packing of motor or ignition system	Debris is set on fire and could cause brush fires due to dry conditions	1C	Extreme carefulness will be applied when packing of motor or ignition system	Multiple airframe sub-team members verify proper packing and external verifications for correct motor packing are validated	1D
Pyrotechnic charges detonate inadvertently	Premature connection of wires with altimeters in recovery section	Dangerous to surroundings if on ground, compromises flight and flight safety if in air	1D	Use quality components and wires and take care to make secure connections	Several team members check that the recovery section is properly assembled and the electronics are tested sufficiently	1E
Rechargeable battery leaks or	Extreme high or low	Toxic substance may pose risk to	2D	Batteries will be stored at a moderate temperature	Batteries tested before flight	2E

explodes	temperatures, inattention to charging battery	personnel, environment, or vehicle		and care will be taken to monitor electronics temperature.		
Improper disposal of e-waste	Lack of attention by personnel, rocket debris	Potential harm to premises, persons, or environment	2B	Safety training for the proper disposal of e-waste for all team members	Team members hold each other accountable for proper safety practice and lab checks are conducted regularly	2D
Chemical spill	Lack of attention by personnel	Toxic substances leak into ground and waterways, potentially harming wildlife	2C	Completion of safety lab trainings and extreme care when handling chemical substances. Contact appropriate resources to resolve in event	Routine safety checks and extra caution are put in place when chemical substances are in use	2D
Unsafe rocket landing	Recovery system failure, high-speed winds	Rocket descends with no or partial control at high velocity	1D	Ensure proper packing of parachutes and black powder charge and quality connections between components	This will be verified by multiple members of the recovery team	1E
Rocket debris	Components improperly secured or lost during flight	Various plastics or other pollutants enter local ecosystem, threatening wildlife	2A	Attempt to secure all parts to the rocket in multiple ways if possible and design rocket so that larger pieces are self-contained in the event of failure	Extra care during assembly and ground testing for loose parts	2C

Table 4.11: Environmental Hazard Analysis

5 Payload Criteria

5.1 Overview

5.1.1 Rover Description

For this year's experimental payload, the soil-collecting rover was chosen. The Actuated Landing Correction System (ALC) employs an electronic rotation system to ensure correct orientation of the payload upon landing. After the rover's orientation is corrected, the rover will be remotely deployed and drive a minimum of 10 ft from the landing site utilizing a drive system capable of traversing a majority of expected terrains and performing obstacle avoidance maneuvers. Upon reaching the minimum required distance from the airframe, the rover will then deploy its bulldozer-like soil collection system to collect and seal a 10 mL sample of soil.

5.1.2 Dimensional Overview

Depth	4.33 in.
Width	2.36 in.
Length	2.6 in.
Weight	15 oz.
Material	PLA

Table 5.1 Payload dimensions

5.2 Payload Subsystems

5.2.1 Overview of Subsystems

The Payload is comprised of six systems: Radio, Actuated Landing Control, Drive, Object Detection and Avoidance, Soil Collection, and Integration. Below is a brief description of the systems, each of whose design will be detailed in depth later in this section.

System	Description
Radio	Radio transmitter/receiver is responsible for triggering rocket separation.
Actuated Landing Control (ALC)	ALC is responsible for oriented the rover correctly, allowing it to successfully exit the vehicle and drive.
Drive	The Drive system is responsible for rover mobility, and driving the rover 10 feet away from the vehicle.
ODAS (Object Detection and Avoidance)	ODAS is responsible for ensuring the rover will drive 10 feet, regardless of any bumps or objects in its path.
Soil Collection	The Soil Collection system is responsible for collecting and sealing a 10mL soil sample.
Integration	Integration is responsible for securely holding the rover in the vehicle during flight, and separating it after the radio is triggered.
Entertainment	The payload will be equipped with a Bluetooth speaker that plays a curated selection of music handpicked and produced by UCSC Rocketry members.

Table 5.2 Subsystem overview

5.2.2 Subsystem Interactions

All six main subsystems interact with each other to ensure the rover has a successful mission and meets the NASA-specified payload requirements.

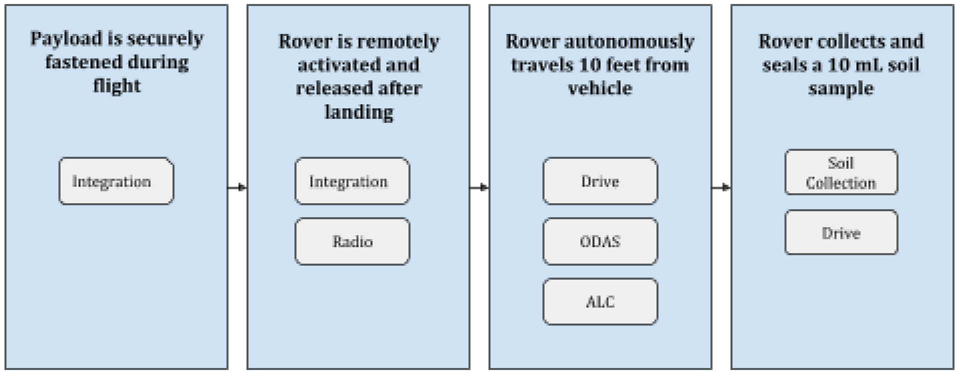


Figure 5.1: *Payload subsystems diagram*

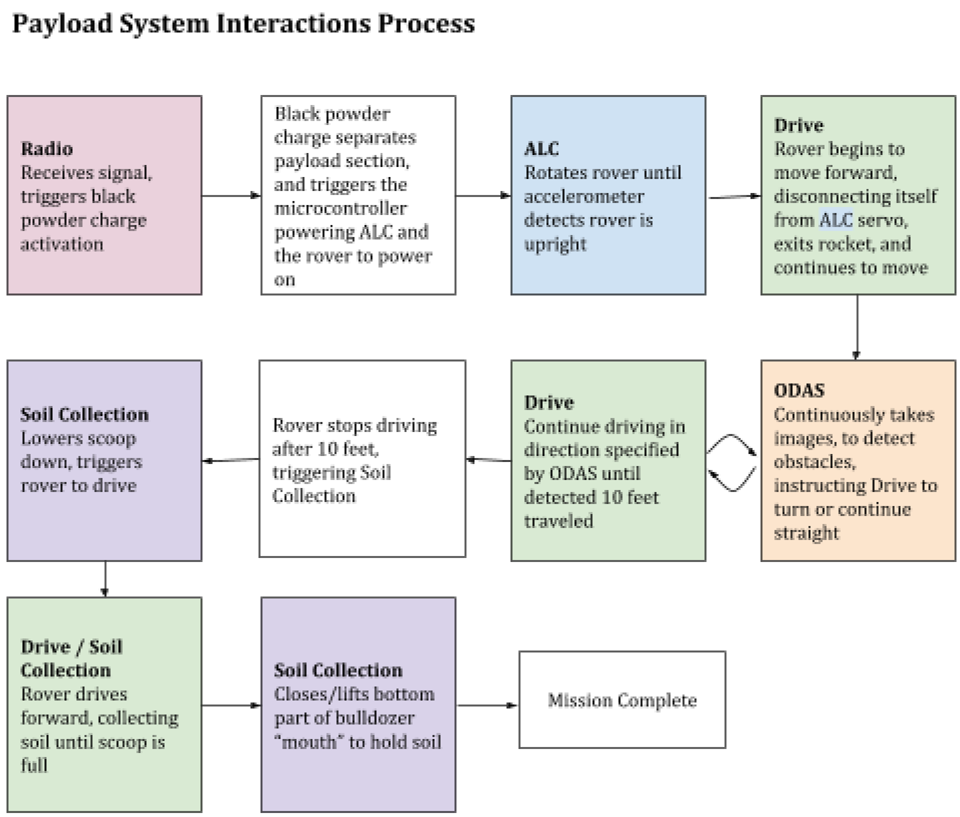


Figure 5.2 Payload overall flow chart

Description of processes

Mission Step	Description of Success
1	The rover will remain completely powered off during flight and landing. The integration system will keep the rover secure in place the entire flight. (In the unexpected event that the black powder charges activate during flight, the rover and payload section will be safely fastened to the rocket.)

2	After landing and the RSO gives permission, the tem will transmit a radio signal to the receiver in the recovery section.
3	The radio signal will be received, triggering the black powder charges to activate and separate the vehicle between the payload and recovery sections.
4	Black powder charges will pull on the reverse kill switch (see 5.4.2.2) and remove the payload section door, powering on the rover, and giving it clearance to leave the vehicle.
5	Actuated Landing Correction (ALC) rotates the rover and its platform into a upright position for exit.
6	ALC calls Drive system to begin, Drive system exits rover, unplugging itself from ALC.
7	Drive system communicates with ODAS to determine where, when, and whether to turn in real-time based on obstacle detection data. Rover travels over 10 feet away from vehicle, avoiding any obstacles.
8	Drive calls Soil Collection. Soil collection lowers bottom 'lip' using a servo, drives forward to collect over 10mL of soil, and raise bottom 'lip' to cap to seal soil sample.

Table 5.3 Overview

5.2.3 Radio

5.2.3.1 Objective

For the rocket's releasing of the rover, the radio's responsibility rests in routing and receiving a signal to set off the separation of the rocket with a black powder charge with a radio frequency of 900MHz.

5.2.3.2 Components

To transmit and receive the signal, we are using two XBee-PRO 900HP radio modules which will be connected to XBee Communication boards. The signal will be sent from a computer with the XCTU software.

Digi Xbee-Pro 900HP

- 902 to 928 MHz
- Up to 15 Digital I/O, 4 10-bit ADC inputs, 2 PWM outputs
- Data Rate: 200kbps
- Power - Output: 24dBm
- Sensitivity: 110dBm
- Serial Interfaces: SPI, UART
- Memory Size: 32kB Flash, 2kB RAM
- Antenna Type: Integrated, Wire
- Voltage - Supply: 2.4 V ~ 3.6 V
- Current - Receiving: 44mA
- Current - Transmitting: 229mA

5.2.4 Actuated Landing Correction (ALC)

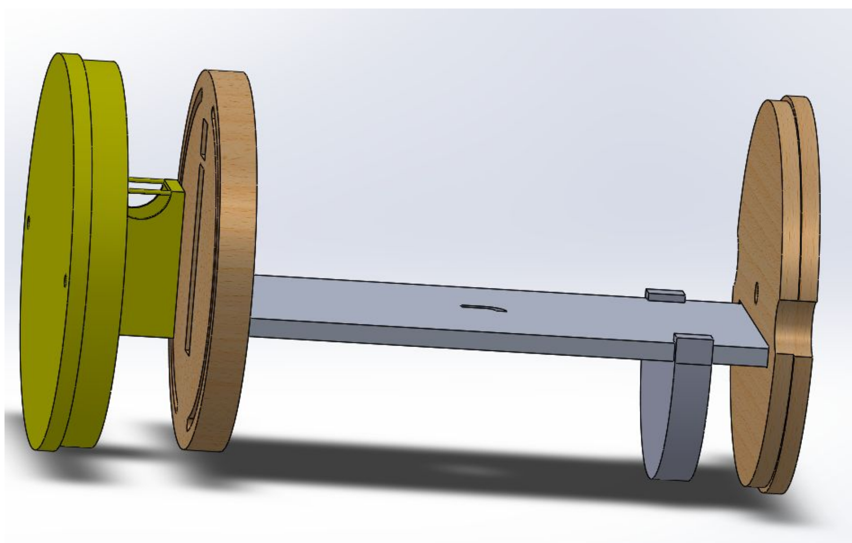


Figure 5.2: *The rover ALC sled with servo container (left) and 'keyhole' securement (center)*

5.2.4.1 Objective

The Actuated Landing Correction System (ALC) is responsible for ensuring the rover is upright before it exits the rocket, so that it can successfully exit, no matter what orientation the rocket lands. For this system, we initially considered having a double-sided rover (that can drive both upright or upside down), a gyroscope-balancing system, and an electronic rotation system. Ultimately, we decided on the electronic rotation system in the interests of limited space (see: 5.2" coupler inner diameter), and ease of implementation. The ALC detects rotation of the rocket, and rotates the rover's platform, accordingly, until the rover sits upright.

5.2.4.2 Components

In order to detect rotation, the built-in 3-axis accelerometer on the Beaglebone Blue is used. A 540 RPM, 5.1 kg-cm SpringRC SM-S4303R Continuous Rotation Servo is used to rotate the rover's platform.

5.2.4.3 Software

Upon rocket landing and radio receival, the Beaglebone runs the ALC program detailed below.

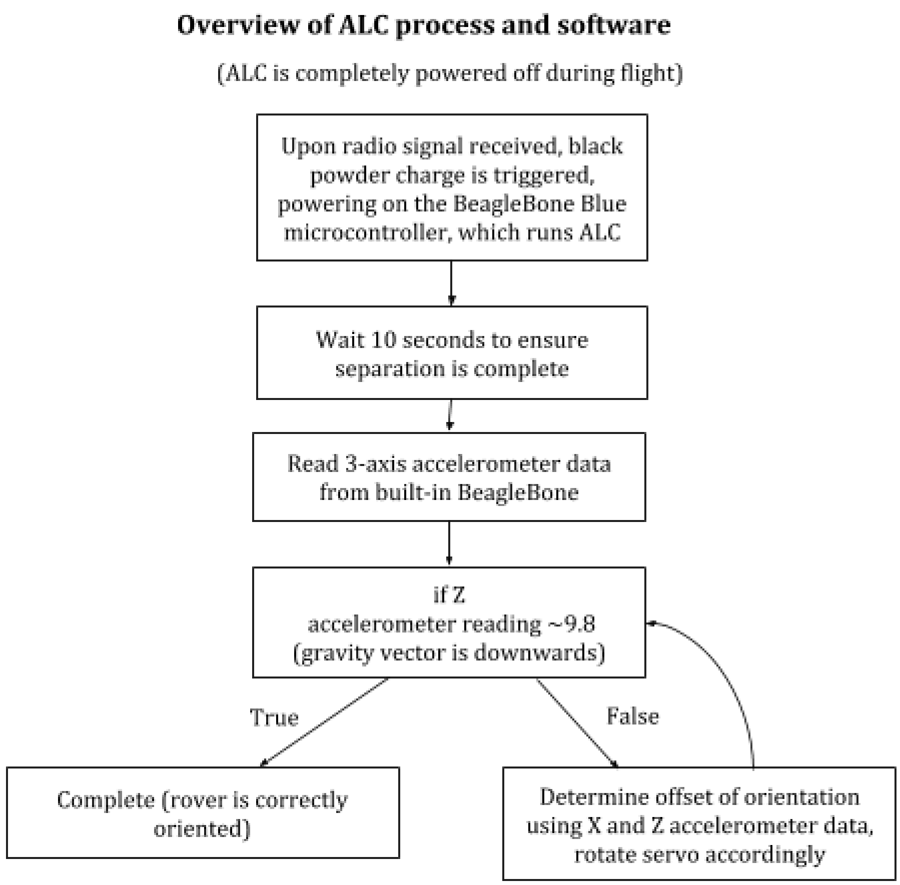


Figure 5.3: *ALC block diagram*

Complete, open-source code for the ALC can be viewed at https://github.com/UCSC-Rocket-Club/Payload.

5.2.5 Drive

5.2.5.1 Objective

The Drive System allows the rover to traverse all possible terrains as the rover travels away from the rocket. Because the terrain at the rocket's landing site is unpredictable, the rover must be able to account for various types of terrain to be able to reach a minimum of 10 ft from the rocket. As such, design decisions for each component of the Drive system emphasized high mobility while adhering to dimensional constraints of the payload housing.

5.2.5.2 Rover Mobility

Figure 5.4: *The Pololu 30T Track Set*

To maximize traction, the Drive system will implement tank treads of high contact area spanning the length of the rover. The Pololu 30T Track Set was chosen over other tank treads because it is cost-efficient at $14.95 and its width at 0.54 in. allows for more economical usage of rover housing space. The four wheels are made out of plastic and 1.33 in. in diameter. The Pololu tracks are sufficiently durable to withstand launch, landing, and deployment unharmed.

5.2.5.3 Axle and Bolt

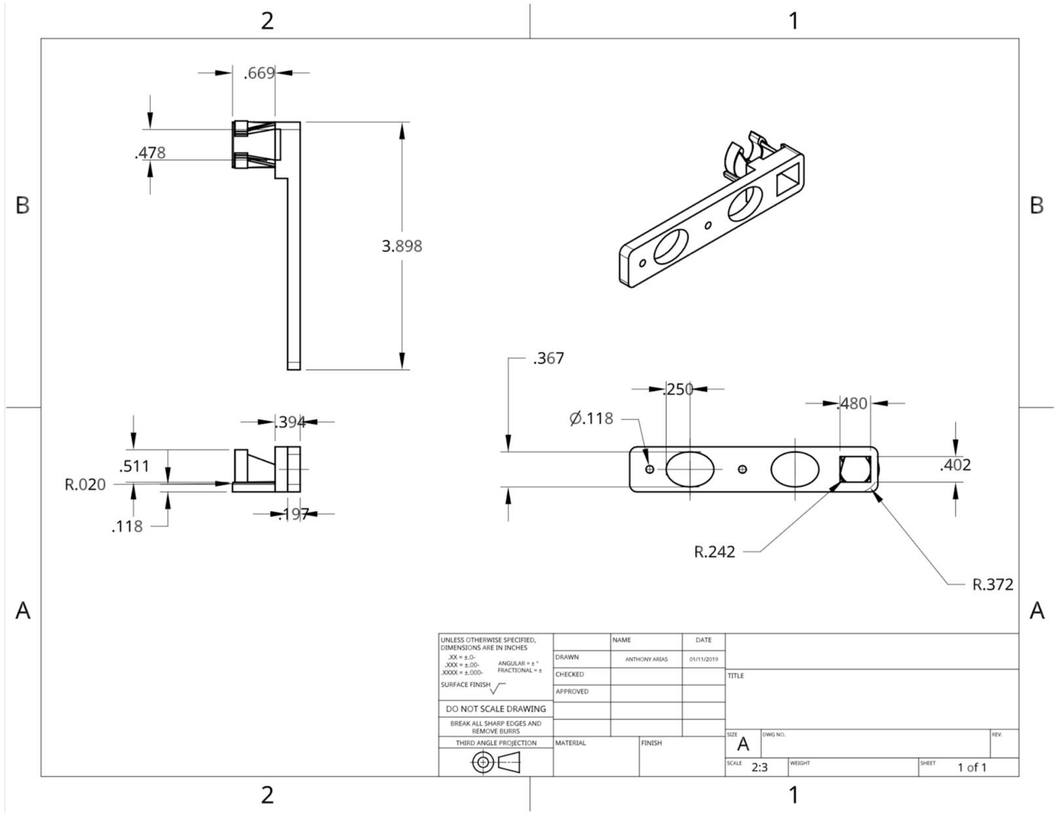


Figure 5.5: *drive system diagram*

The wheels of the Drive system will connect to the chassis via custom-made PLA axles and bolts. The axle and bolt are 23 mm in length. It holds the two DC motors near the front wheels.

5.2.5.4 Main Drive Motors

Figure 5.6: *The Pololu Gearmotor 6V*

Because the primary concern of the drive system is to maintain forward motion, main drive motors with high torque and low RPM are desired. Two Pololu 50:1 Micro Metal Gearmotor 6V

310RPM DC motors will be implemented in the rover's Drive system, driving the front wheels of the rover. Although this motor is slightly more expensive than alternatives under consideration, the motors' combined torque of 1.72 kg-cm was much higher than the other options. At 310 RPM, this motor's speed is sufficient for maintaining forward motion in various terrains.

In order to maintain forward motion, the engine must be able to provide a torque high enough to allow the rover to accelerate on inclines commonly found at the landing site. Ignoring friction, wind, and other external forces, the minimum torque τ_m required to overcome the weight of the rover on an incline of angle θ is given by the equation

$$\tau_m = \frac{WR\sin\theta}{2N\mu_m\mu_t}$$

where W is the weight of the rover, R is the radius of the rover's sprockets, N is the transmission gear ratio of the motor, μ_m is the motor efficiency, and μ_t is the gearbox efficiency. The rover is estimated to weigh 15 oz, and the motor efficiency of a Pololu motor is estimated to be at least 0.8. The gearbox efficiency is neglected, and the motor is assumed to be direct drive (N = 1). If the rover is expected to traverse maximal inclines of 40^0, the minimum torque required is

$$\tau_m = \frac{(15\ ozf.)(0.665\ in.)sin(40^0)}{2(0.8)} = 4.01\ ozf \cdot in.$$

Therefore, the mechanical torque of the Pololu motors, at 11.95 ozf. in. each, can sufficiently traverse inclines beyond the expected maximal incline of 40^0.

5.2.6 Object Detection and Avoidance System (ODAS)

5.2.6.1 Objective

Object Detection and Avoidance System (ODAS) ensures that the rover will travel 10 feet, regardless of any bumps or obstacles in its way. Since the rover is relatively light and small (therefore, less resistant to collisions and irregular terrain) and will be driving on unknown terrain, it is especially imperative that it avoids potential obstacles or irregularities. Ultrasonic and camera sensors will identify problematic objects or areas in rover's path, allowing the rover to turn and avoid these.

5.2.6.2 Sensor decisions and Changes From PDR

In PDR, we considered using an Ultrasonic sensor, Lidar, and camera for vision detection. It was determined that an Ultrasonic Rangefinder alone was the best option as it is low cost, easy to integrate, and simple to program.

However, after revisiting, it was decided it would be more accurate to use a camera for vision detection, in addition to the Ultrasonic Rangefinder. This is supported by a 2016 study, "When Ultrasonic Sensors and Computer Vision Join Forces for Efficient Obstacle Detection and

Recognition". This research proposed that computer vision combined with ultrasonic sensors is the most practical and accurate solution for object avoidance on devices that are small, low-cost, and powered by microcontrollers (Postolache 2016).

5.2.6.3 HC-SR04 Ultrasonic Ranging Sensor

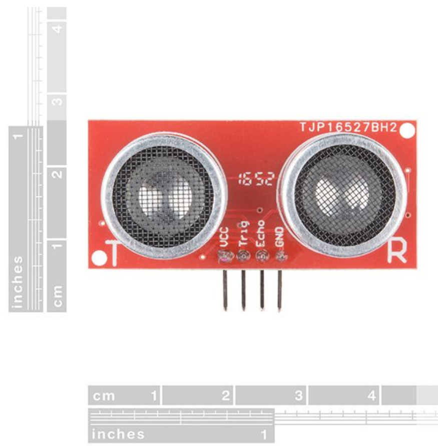


Figure 5.7: *The HC-SR04 Ultrasonic Sensor*

In order to detect objects, ODAS will be equipped with a HC-SR04 Ultrasonic Ranging Sensor. It provides 2cm-400cm non-contact measurement function with ranging accuracy of 3mm. It was chosen over other ultrasonic sensors because it is very economical at $3.95. Preliminary testing of this sensor has demonstrated that the sensor functional and will provide the accuracy needed to detect obstacles. Additionally, it is a popular and reputable sensor that has been used for other Beaglebone Blue and microcontroller projects on the Internet.

5.2.6.4 CMOS Camera

Figure 5.8: *CMOS Camera*

For computer vision, ODAS will use a 5MP mini CMOS camera, connected to the BeagleBone's USB port. It has dimensions of 1.5" width, 1.25" height, 0.5" diameter. This camera will be used to identify obstacles using computer vision, especially ones that the ultrasonic sensor may not capture.

5.2.6.5 Software

The BeagleBone Blue will read data from the Ultrasonic Ranging Sensor and the camera, and determine whether to turn based on whether there are any detected objects in near vicinity of the rover. The flowchart below details the general design of the ODAS software.

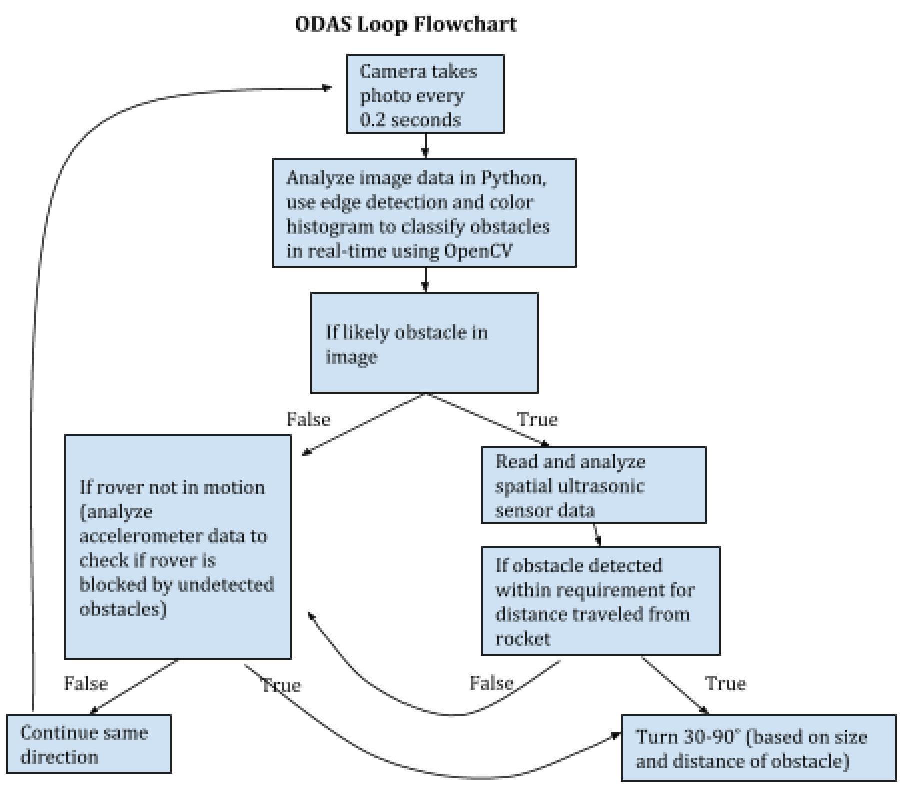


Figure 5.9: *ODAS*

Machine vision/image data will initially be used to identify obstacles. Ultrasonic sensor data will mainly serve to get spatial data on identified objects. The rover will turn to avoid any obstacles detected. In the event that the rover is blocked by an obstacle that was not detected, the rover will turn away from the obstacle.

OpenCV, an open-source machine vision library, will be used in Python for computer vision. Pandas, numPy, and imutils will also be used for managing image data. Edge detection and color histogram representation will be used to identify problematic terrain and obstacles through computer vision.

5.2.7 Soil Collection

5.2.7.1 Objective

After traveling 10 feet away from its landing position, the rover will need to collect, carry, and contain 10 milliliters of soil. Because the terrain at the rover's landing site is unpredictable, the rover's means for collecting soil will need to account for various conditions such as the level of moisture in the soil to be collected. The deliberations for the decisions of the design of the soil collection method included considerations such as the reliability of soil collection, the additional size it would add to the rover that needs to be contained within an airframe, the cost, and ease of implementation.

5.2.7.2 Soil Collection Method

The method of soil collection the rover uses is that of a bulldozer design. The rover's simply designed bulldozer scoop can reliably collect well over 10 milliliters of dirt. A motor lowers down the bottom scoop, the rover drives forward to collect the soil, and the "mouth" (now filled with soil) returns to its closed position. The design is both simple and reliable as the bulldozer boasts the benefit of being able to break through potentially dense soil at the rover's landing site.

Originally, the options of using an auger to dig soil with and using a scoop with its own separate tube-container were considered but ultimately outclassed. The auger was deemed much too unreliable to be trusted with the task of collected 10 mL of soil, and the tube and scoop idea is very similar to the decided upon bulldozer method, except that it is more complex and consequently less reliable.

5.2.7.3 LewanSoul Servo Motor

Figure 5.10: *Scoop servo motor*

The rover's soil collection system uses two LewanSoul Servo Motors to operate the opening and closing of the bulldozer scoop. With its high-precision potentiometer, 20kg large torque, and angle range from 0 to 180 degrees, it is the perfect candidate for operating our bulldozer scoop, allowing it to angle downwards, easily collect soil, angle upwards, and consequently seal the soil within the scoop.

5.2.8 Entertainment System

The rover will equipped with a compact Bluetooth speaker (1.6 x 1.6 x 1.7 in), powered by the Beaglebone Blue, that plays a curated selection of music handpicked and produced by UCSC Rocketry members. Tracks will include a EDM remix of John Denver's "Country Roads", our subscale rocket's namesake. This system was inspired by the Curiosity rover singing "Happy Birthday" to itself.

5.3 Body

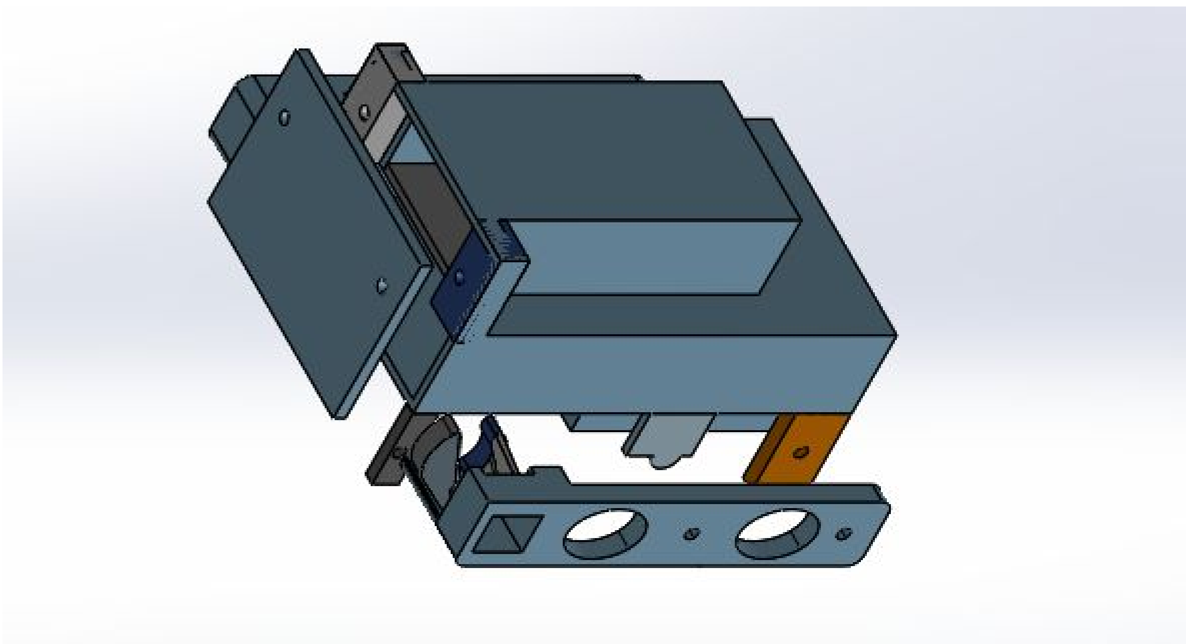


Figure 5.11: *Rover body*

The Rover chassis is custom-designed and 3D printed out of PLA. For the material, PLA was chosen as it is more accurate and easier to print with. The rover body was designed to be compact, as to fit inside the 5.217" coupler inner diameter.

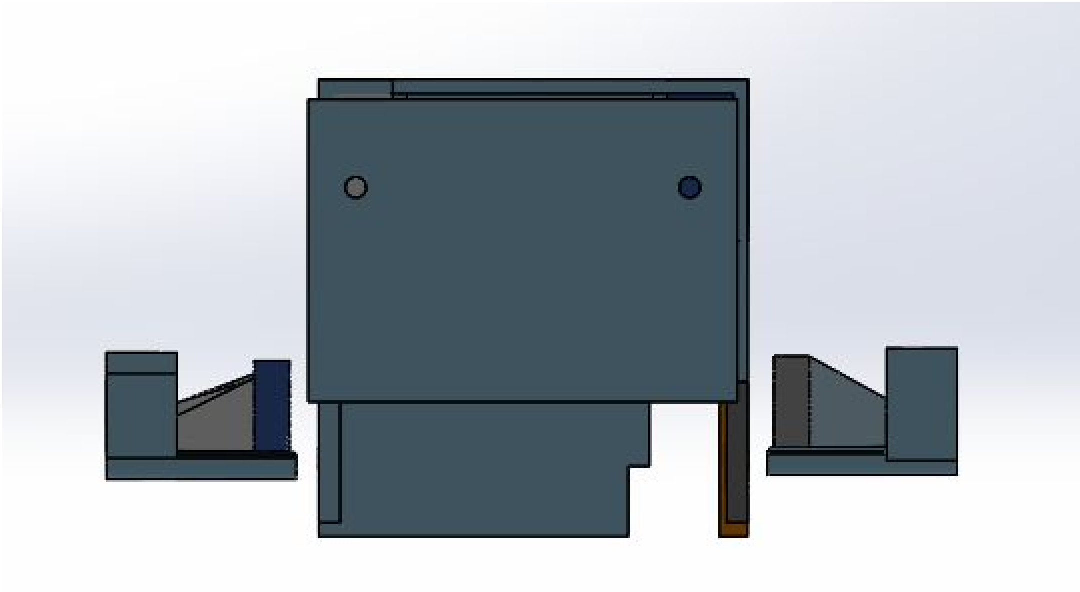


Figure 5.12: *Rover body: front*

3D printing the design also allows for much more creative freedom unlike, CNC machining

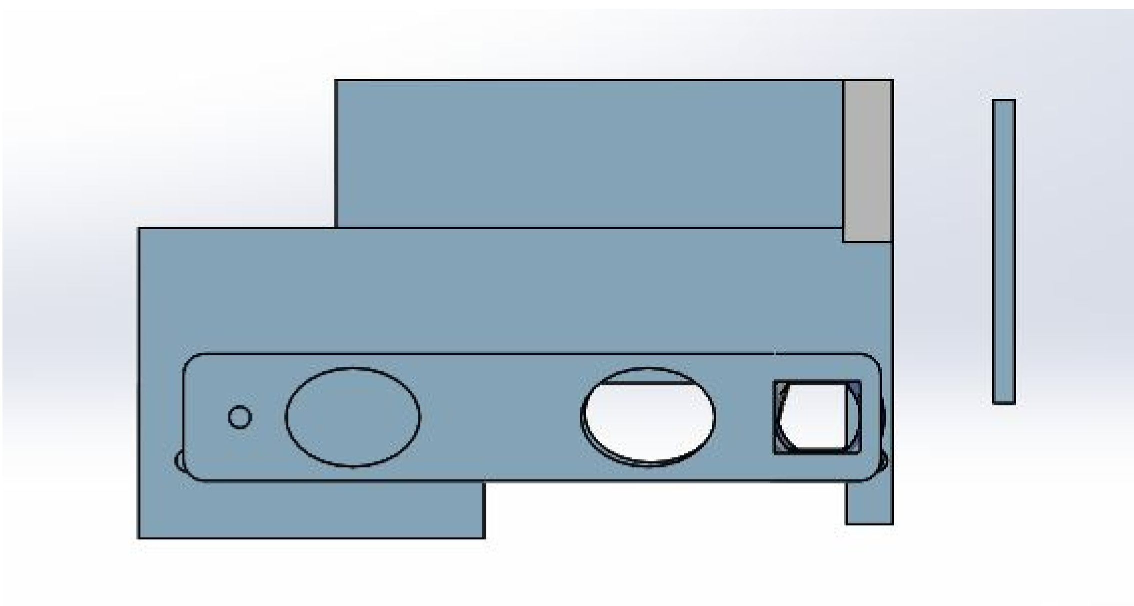


Figure 5.13: *Rover body: side*

PLA is sturdy enough to withstand the journey with the rocket, yet flexible enough to bend and to the motors sent in place.

5.4 Integration with Launch Vehicle

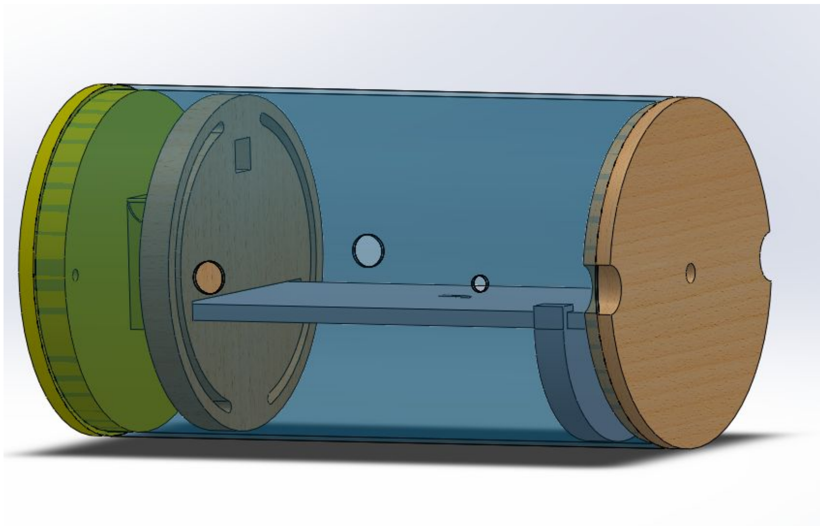


Figure 5.13: *The Payload coupler including the ALC sled*

5.4.1 In-Flight Securement

The securement of the payload rover within the rocket will be 2 fold. There will be an attachment with deployable shear pins which are designed to break off during deployment. And there is a safety tether secondary failsafe between the payload housing and the airframe in the event the shear pins rupture prematurely. Within the housing the motor is secured to the sled using a lock and key system to prevent movement of the rover until proper signal is sent by the launch team.

5.4.1.1 Securement to Nose Cone

The payload housing assembly is attached to the nose cone assembly using semi-permanent bolt to ensure the pieces do not separate in flight. The nose cone and housing are considered a single, conjoined piece. This was done so for stability reasons both in terms of rover housing and overall vehicle stability: placing the rover weight higher in the rocket increased the static stability. The component consists of the carbon fiber airframe encapsulating the Blue Tube rover housing. This design lends itself to easy disassembly as accessing the rover housing is equivalent to detaching the airframe piece as it was designed to do.

5.4.1.2 Shear Pins

Since the payload section must deploy upon landing, the nose cone component is connected to the remainder of the rocket body using shear pins. The design of the shear pins is meant to break upon large force i.e. from the black powder charge, and remain intact during the flight itself. As the airframe is supported against itself using the carbon fiber bracelet, the shear pins experience no lateral force from the nose cone down. This means that during normal flight the air pressure is transferred around the pins and to the airframe itself. Only an expanding force originating from within the rocket body itself can put force on the pins enough to break them. This force is projected to come either from the black powder charge, or unforeseen inertial forces at apogee.

5.4.1.3 Safety Tether

In the event of a failure in the safety pins a secondary attachment was deemed necessary to prevent the payload body from rocketing to the ground disconnected from the body. The solution to this was the use of 2 nylon safety tethers. The tethers are anchored to both the airframe and payload housing using bolts and structurally dependent on the airframe material itself. The anchors are placed several inches within the recesses of both sections directly opposite each other to distribute force as evenly as possible. The cords themselves are made of ¼'' thick nylon braiding, each rated to withstand 6.5kN of force. The cords are several feet long and stored in the recovery section of the vehicle. The anchor points are drilled through the carbon fiber airframe and secured in place with locking nuts and washers. The surrounding carbon fiber has a modulus of 228 Gpa as well.

5.4.1.4 Internal Section Securement

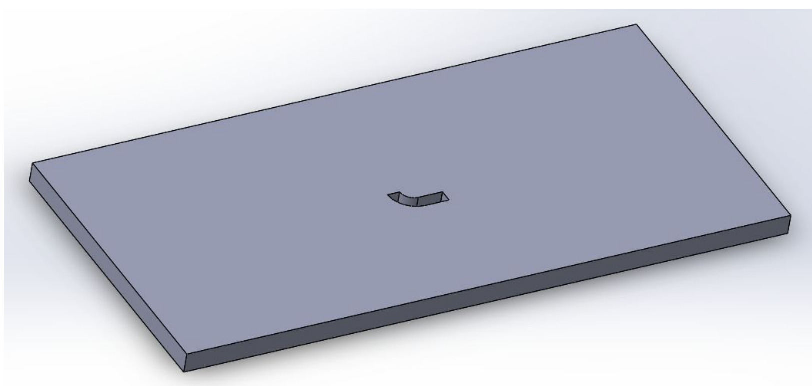


Figure 5.14: *A keyhole in the sled for internal section securement*

To prevent the rover from exiting the payload section in the event that the black powder charges activate mid-flight, the rover must stay secured to its section. It will have a "lock and key" design, powered by a servo motor. During flight, when the rover/servo is powered off, the key will be situated in a way so the rover will be blocked from exiting the section. After black powder charges trigger separation and power on the microcontroller, and upon confirmed landing by the accelerometer, a servo will rotate the "key", allowing the rover to exit. This design is subject to change based on test results, however the concept of a motor actuated "lock and key" securement device is final.

5.4.2 Separation on Ground

5.4.2.1 Rover Deployment Method

Once the rocket lands, the RSO gives permission, and the radio signal is received, the rocket must separate to allow rover deployment. Black powder charges will be used to separate the rocket and deploy the rover. This method was chosen for its ease of implementation nand reliability. CO2 Canisters and pneumatic action were considered during PDR, but were decided to be do complex to implement and less reliable than black powder.

The black powder charges will be located in the top of the recovery section, separated from the payload section by a door. The radio receiver, located below the charges in the recovery section, will activate the black powder charges, separating the payload section from recovery, and allowing the rover to exit the vehicle.

5.4.2.2 Rover Activation / Reverse Kill Switch

During flight, the BeagleBone Blue powering the rover will be completely turned off. Once the black powder charges activate, the BeagleBone will be powered on by a reverse kill pull switch. A motorcycle safety tether-style normally open reverse switch will be placed between the BeagleBone Blue and its battery. The BeagleBone Blue will be powered off until a cord pulls on this switch, completing the circuit.

A cord, attached to the Recovery frame and the Beaglebone, will go through the door between Payload and Recovery, pulling the door blocking the rover out, and pulling the switch to complete the circuit and power the Beaglebone Blue on.

Upon boot, the BeagleBone will wait for ten seconds (to allow effects of black powder charges to complete) and confirm that the rover is not in motion (i.e. free fall if the black powder charges activated mid-flight) using the built-in accelerometer before proceeding to ALC and exiting the vehicle.

5.5 Payload Electronics

5.5.1 Components Overview

The rover challenges include the use of many different spans of technology. Due to the complication in object detection and avoidance, landing orientation correction, and motor control. A BeagleBone

Blue integrated computer was chosen for its computing strength and ease of use. The drivetrain utilizes 2 independent high speed geared dc motors driving a tank tread to provide actuation. To accomplish landing correction of the rover housing and soil collection 3 servos were used for their high torque and precision. The task of object detection was accomplished by using a USB 50 megapixel camera and ultrasonic range detector in conjunction. The camera will be implemented with openCV, an open source AI image detection software, and the detected image data will be augmented with the ultrasonic data to provide accurate and reliable readings on the position of potential obstacles.

 **BeagleBone Blue**	• AM335x 1GHz ARM® Cortex-A8 processor • Size: 175mm x 112mm x 40mm • Motor control: 8 6V servo out, 4 bidirectional DC motor out • Sensors: 9 axis IMU (accels, gyros, magnetometer), barometer, thermometer • 4GB 8-bit eMMC flash storage • Cost: $78	 **Digi Xbee-Pro 900HP**	• 902 to 928 MHz • Up to 15 Digital I/O, 4 10-bit ADC inputs, 2 PWM outputs • Data Rate 200kbps • Power - Output: 24dBm • Sensitivity: 110dBm • Serial Interfaces: SPI, UART • Memory Size: 32kB Flash, 2kB RAM • Antenna Type: Integrated, Wire • Voltage - Supply: 2.4 V ~ 3.6 V • Current - Receiving: 44mA • Current - Transmitting: 229mA • Cost: $41.75
 **LewanSoul Servo Motor**	• Weight: 65g • Dimensions: 40 * 20 * 40.5mm • Speed: 0.16sec/60°@7.4V • Servo accuracy: 0.24° • Torque: 20 kg/cm • Working Voltage: 6-7.4V • Minimum working current: 100mA • Control method: PWM • Pulse Width: 500 ~ 2500 • Duty Ratio:	 **Li-ion Battery 7.4V 1Ah**	• Size: 70.0mm x 35.0mm x 18.0mm • 7.4V 2-cell pack • Cost: $9.95

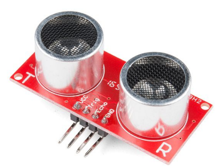
	0.5ms~2.5ms ● Pulse Period: 20ms ● Cost: $14.99		
 **Pololu Gearmotor 6V 310RPM**	● Size: 10 × 12 × 26 mm ● Gear Ratio: 51.45:1 ● Shaft Diameter: 3 mm ● Cost: $16.95	 **Smallest Mini 50.0 Mega Pixel USB HD Video Camera**	● Weight: 0.8 oz ● USB2.0/1.1 Compatible ● Auto exposing control
 **540 RPM, 5.1 kg-cm SpringRC SM-S4303R Continuous Rotation Servo**	● Size: 41.3 * 20.7 * 40.2 mm ● Weight: 41g ● Speed: 54 rpm @6V, 43 rpm @4.8V ● Stall torque: 71 oz·in @6V, 48 oz·in @4.8V ● Lead length: 11 in ● Cost: $12.95	 **Ultrasonic Sensor - HC - SR04**	● Working Voltage: DC 5 V ● Working Current: 15mA ● Working Frequency: 40Hz ● Max Range: 4m ● Min Range: 2cm ● Measuring Angle: 15 degree ● Trigger Input Signal: 10uS TTL pulse ● Size: 45 * 20 * 15mm

Table 5.3 Electronics overview

5.5.2 Beaglebone Blue Microcontroller

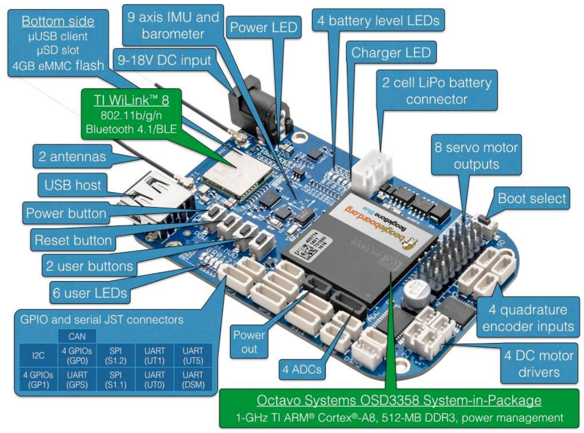


Figure 5.15: *A Beaglebone Blue microcontroller, to control both the rover and ALC*

A BeagleBone Blue microcontroller will be used to control both the rover and Actuated Landing Correction system. It is a Linux system with a 1GHz processor and 512MB RAM. Its on-board 3-axis accelerometer is used to detect when the rover is correctly oriented. In addition, it was decided that having a fully programmable Linux system alleviates the overhead of working with embedded systems. This system also allows us to work in both C and Python code. 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. 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.

5.5.3 Lithium Ion Battery

Figure 5.16: *The KingMax Lithium Ion Battery - 1000mAh 7.4v*

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 scoop 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 5.3**: Battery budget estimation*

5.5.4 Schematics

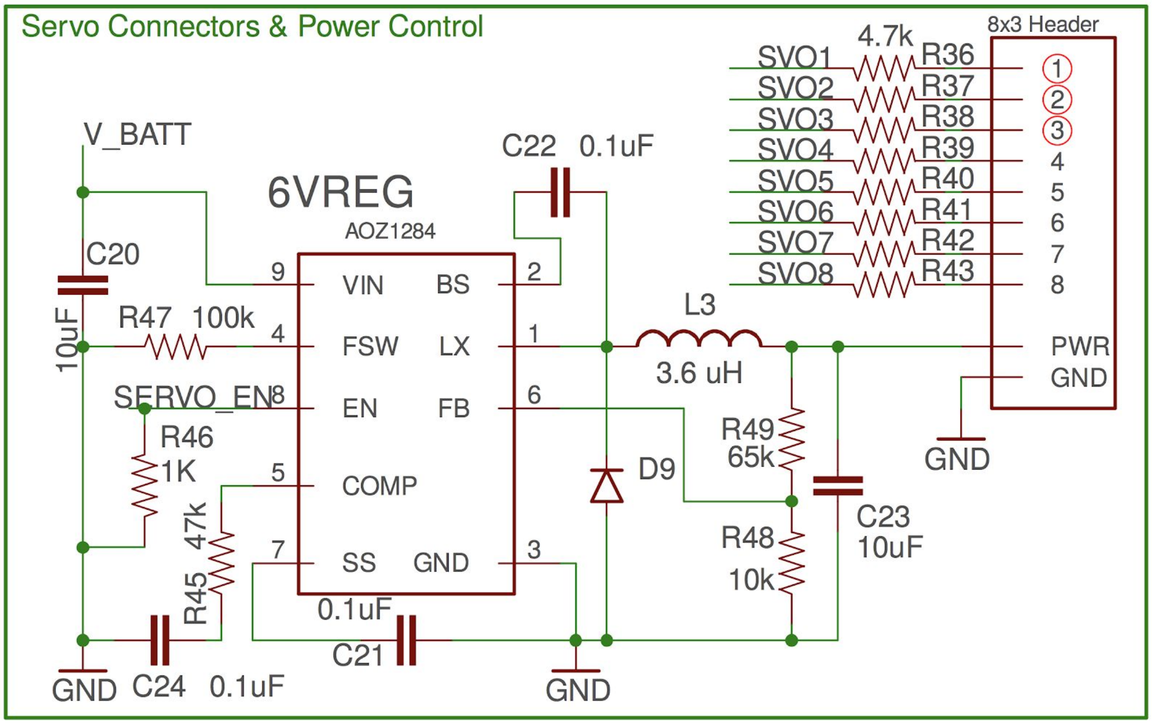


Figure 5.17: *Servo connectors & power control schematics*

Three servos will be used for our rover: one for Actuated Landing Control (ALC), one to power the soil collection scoop raise, and one for the key retention method. The BeagleBone Blue features an integrated AOZ1284 buck converter (schematic above) to control independently 8 servos. We will be using the three labeled pins on the 8x3 Header for our servo connectors, with shared power and ground. The actuation of the servos is done using the integrated pins already connected to the CPU output, and controlled using the built in robotcontrollibrary made by James Strawson.

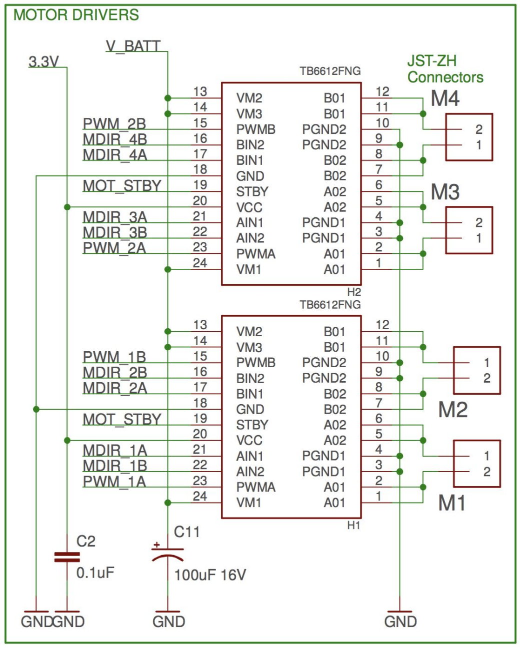


Figure 5.18: *BeagleBone motor drivers schematics*

Two of the BeagleBone's four motor drivers will be used, each one connecting to a front wheel. The motor drivers are standard TB6612FNG H-bridge IC's rated for 1.2A and supported PWM. The chip also features a short circuit breaking feature connecting the leads of the motors together and generating a breaking type force on the motor that can be used to either rapidly stop motion or lock the wheels in place. A schematic of the implemented circuit on the BeagleBone is presented above.

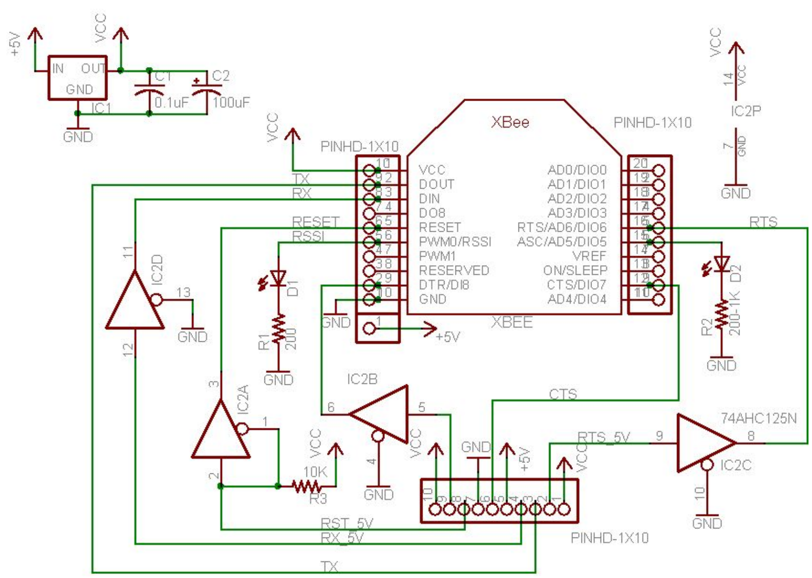


Figure 5.19: *Digi Xbee-Pro 900HP schematics*

The transceiver we will be using is the Digi Xbee-Pro 900HP. It will transmit and receive a radio frequency of 900 MHz for up to 2 miles with direct line of sight. The receiver features an integrated microcontroller that is able to handle all processes of decoding and processing the signal. The board itself runs off a 2.1-3.3V power supply drawing 2.5uA while idle and 35mA at max. We will be powering the receiver with a button battery outputting 3.3V. The board is fully equiped with several GPIO pins as well as a pwm pin. However since the maximum output current is 2mA, the received signal will be used to trigger a BJT transistor connected to the battery to trigger the black powder charge.

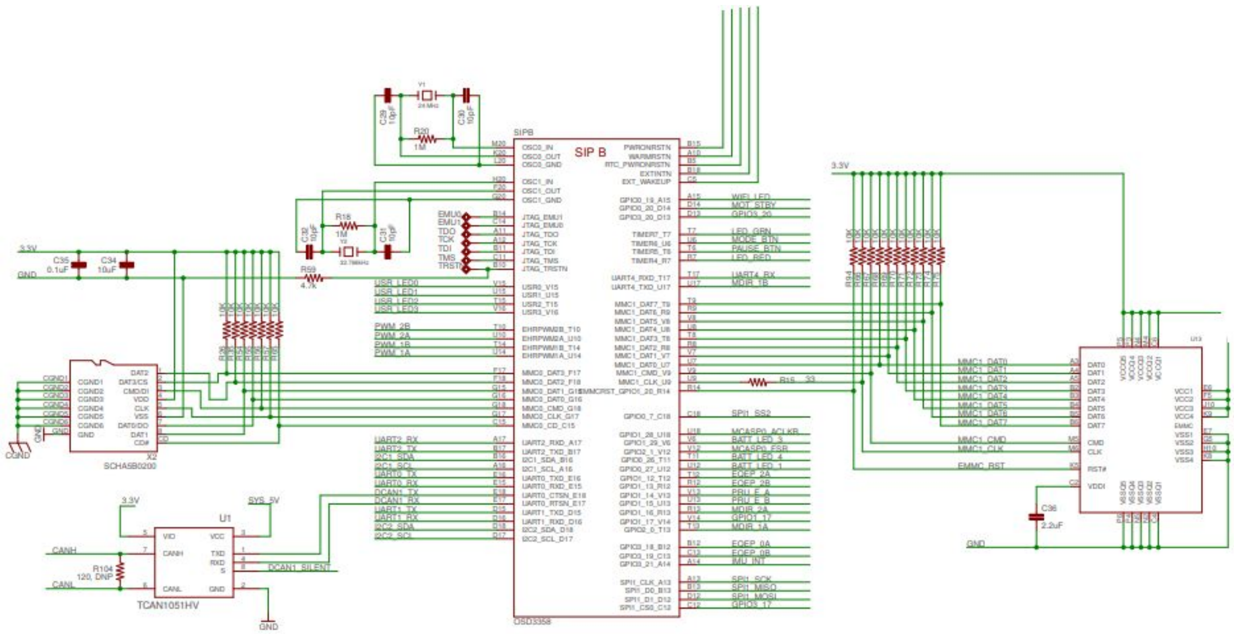


Figure 5.20: *BeagleBone Blue schematics*

The camera and ultrasonic sensors will both be connected to the BeagleBone through the use of the UART Tx/Rx ports. The camera will be connected through the USB interface for UT0 which provides both standard power and communication. The ultrasonic sensor will be connected through the UT1 port with a standard JST 4 pin connector. The board features an integrated connection and communications manager to handle the UART protocol in the form of the OSD3358 SIP communications ICl. Since the board runs a full version of linux, communicating with the components is as simple as connecting as it is on a standard computer i.e discovering them and installing the drivers. A schematic of the communication chip integrated with the CPU and various ports is depicted above.

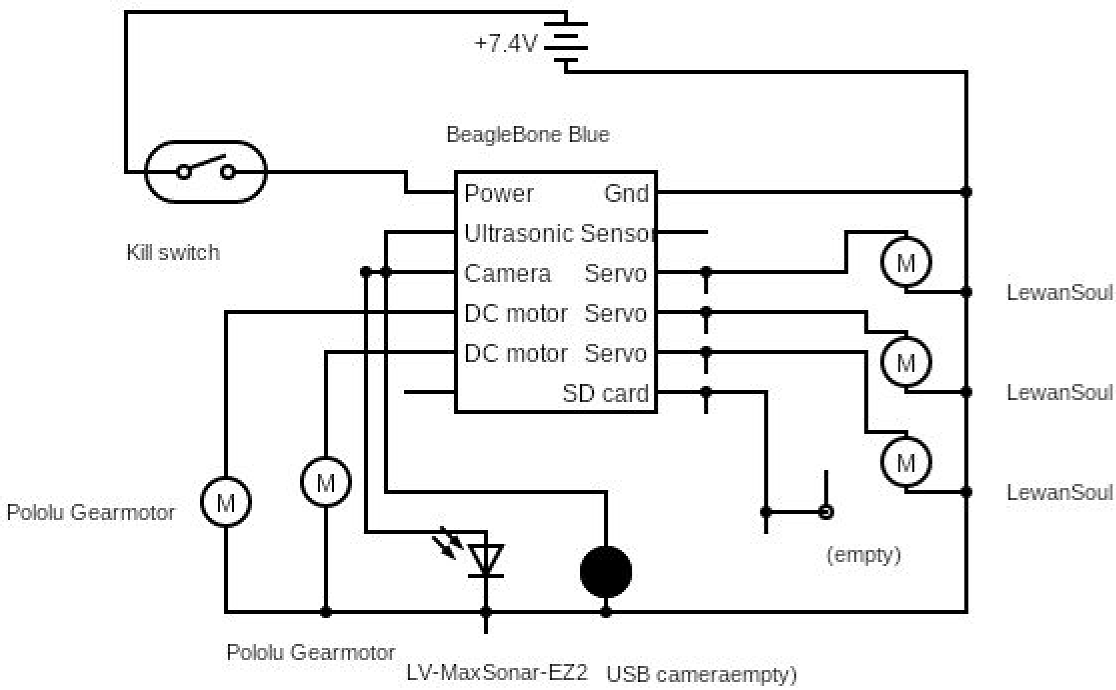


Figure 5.21: *Summary of Payload Electronics*

The rover will be governed by the use of the BeagleBone Blue, which will function as the nerve center of the entire system and manage input from the sensors as well as output to the various peripherals. An overview schematic of the component connection is shown above. For simplicity, only the relevant connected pins are displayed, and the UT connections to the camera and ultrasonic sensor are simplified to a single connection. As can be seen, all components draw power directly from the board and closes the circuit with connection to the onboard Li-ion battery. The board itself is connected to the battery through the kill switch, and a connection to power is only made on the close of the switch i.e. on powder detonation and deployment. Until the kill switch is triggered, all connection to the battery is shut off and the entire control circuitry remains an open circuit, preventing the flow of current.

6 Project Plan

6.1 Testing

6.1.1 Integrity of Vehicle

Through the subscale flight, many of the design aspects of the fullscale were flight proven, including the semi-permanent bolt attachments, the carbon fiber airframe, the recovery bay and ADAS section. Because the subscale flight when flawless, the integrity of the fullscale is believed to be adequate.

6.1.2 Payload

The payload is the only component of the project that was not built or tested in any fashion before and including the subscale launch. Because of this, rigorous tests have been designed to ensure the payload is functional for its test flight.

6.1.2.1 Payload housing

The rover payload is housed within the rocket using a Blue Tube coupler device. The housing is responsible for the securement of the entire component both externally to the rocket and internally for rover stability. In addition, the housing is responsible for correction of orientation upon landing of the rover, and the successful powering on of all onboard electronics only after the appropriate signal is received from the ground station. The largest danger to flight safety in terms of payload is its possibility to become accidentally detached from the airframe mid flight and begin ballistic approach to ground, therefore the housing and securement is thoroughly tested to avoid this scenario.

Payload Housing

#	Requirements Fulfilled	Description of test	Criteria for success
1	Team: 6.1.1. NASA: 4.3.2.	Pull apart payload bay from nose cone with force of maximum downward drag air pressure (160N) to ensure no failure during flight	Nose cone and housing will remain attached.
2	Team: 6.1.2. NASA:	Pull on retention straps with 240kg of force (maximum air pressure assuming 1 second	Payload housing and rocket body will remain attached with safety straps.

	4.3.2.	deceleration from max speed of 240m/s)	
3	Team: 6.2.1., 6.3.2. NASA: 4.3.2.	Vigorously shake rover assembly with rover inside	Rover will remain locked to payload sled
4	Team: 6.2.2. NASA: 4.3.2.	Drop payload housing from height of 6m (impact velocity of 10.8m/s)	Rover assembly (internal and external) will remain intact and locked in place
5	Team: 6.3.1.	Rotate payload bay to 90°, 60°, 30°, and 10° from upright and activate ALC unit each time	The rover will be oriented in correct vertical position after each starting position
6	Team: 6.3.3.	Set up payload section with pull switch and test current output from battery. Activate deployment procedure and test current again	Battery reading before deployment: current equal to 0A. Reading after deployment: current is >0A
7	Team: 6.4.1. NASA: 4.3.1, 4.3.3	Activate black powder charge using electronic switch	Black powder charges detonate and separate rocket
8	Team: 6.4.2., 6.4.4.	Pull on door of housing assembly with 20N of force (force from 1g of black powder)	Door will come off Kill switch will be activated
9	Team: 6.4.3.	Pull on payload assembly from rocket body with force of 20N	Shear pins will shear

Table 6.1 Payload housing test plans

6.1.2.2 Physical rover

The Rover body is printed from P.L.A. plastic. Two motors drive treads on either side of the rover for forward movement. The system is powered by a Li-ion battery. Onboard sensors include ultrasonic range sensor and a camera. A servo motor is mounted on front of the rover that actuates a scoop for collecting soil.

Physical Rover

#	Requirements Fulfilled	Description of test	Criteria for success
1	Team:	Shake rover while fully	Treads remain on rover and in

	6.5.1., 6.5.3. NASA: 4.3.2.	assembled with fitted treads then place rover down on ground surface and attempt to drive	working condition Rover moves across ground
2	Team: 6.5.3.1. NASA: 4.3.4.	Deploy rover on following materials: ● Compact soil ● Loose sand ● Mud with at least 25% water content ● Grass with length >5cm ● Gravel with average granularity of 5mm ● Rocky terrain with rocks at least 2cm	The rover is capable of traveling at least ten feet in all terrains
3	Team: 6.5.3.2. NASA: 4.3.4.	Repeat all tests from test 2 across following inclines (degrees): ● 0 ● 10 ● 20 ● 30 ● 40	The rover is able to successfully navigate all inclinations without tipping over or stalling
4	Team: 6.6.1.	Secure rover to housing, then execute detachment sequence and attempt drive motion	Rover will detach from housing and drive away
5	Team: 6.6.2 NASA: 4.3.7	Drop rover from height of 6m (impact velocity of 10.8m/s)	Rover will be in functional use Visually inspect batteries for impact damage
6	Team: 6.7.1., 6.7.3.	Charge battery to full capacity and run all tests outlined in tests 1 and 2. Check battery charge through voltage at end	Battery voltage will read at least 7.2V corresponding to >20% charge level
7	Team: 6.7.2. NASA: 4.3.8.	Record battery temperature and visual characteristics before use in launch	Temperature will be below 30 degrees celsius and no observable swelling Battery will be brightly colored and clearly marked as fire hazard while clearly distinguishable from other parts
8	Team: 6.8.1.	Visual inspection then tactile inspection of rover to ensure no	Cables secure and no wiring is exposed

		exposed wiring and cables secure	
9	Team: 6.8.2., 6.8.3, 6.8.4.	Run series of test scripts to: • Clear logs • Test motors are functions • Start main system service • Ensure sensors are gathering data and then visual inspection	Scripts run successfully and visual inspection passes
10	Team: 6.8.1., 6.8.2. NASA: 4.3.3.	Activate radio transmitter from a distance of at least a mile in the following environments: • Open field • Redwood forests • Building obstructions Each in the following conditions • Clear • Rain/fog	Receiver successfully received signal
11	Team: 6.11.2., 6.11.3.	Begin script to extrapolate ultrasonic sensor data into distance and pipe output to terminal screen. Show obstacle at 1m away from sensor across field of vision	Terminal will display 1m distance across entire field of view
12	Team: 6.11.4.	Create simulated indoor lego obstacle environment and activate rover	Rover will make it at least 15 feet aways from start point
13	Team: 6.9.1	Deploy scoop on variety of soils to ensure it functions correctly: • Compact soil • Loose sand • Mud with at least 25% water content • Grass with length >5cm • Gravel with average granularity of 5mm • Rocky terrain with rocks at least 2cm	Scoop is able to collect at least ten milliliters of soil
14	Team: 6.9.2 NASA: 4.3.6.	Scoop is filled with soil and then shook over white paper to ensure no soil is able to spill and no contaminants can get in	No soil is visible on the paper

Table 6.2 Physical rover test plans

6.2 Requirements Verification

6.2.1 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 6.2] 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	Completion	Details
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	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	In Progress	The team continues to be 100% student run and plans on continuing to be so.

	motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor).		team mentors (i.e. motor assembly, black powder handling, 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.	In Progress	A constantly updating timeline and project plan is used by all subteams.
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.	Complete	All FN have been identified.
1.4	The team must identify all team members attending launch week activities by the Critical Design Review (CDR).	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.	Incomplete	A preliminary list has been made but further clarification will be made before January 30th
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.	In Progress	Students are continually engaged in the team throughout the year
1.4.2	One mentor (See requirement 1.13)	Inspection	A mentor that is committed to attending launch week		David Raimondi has been

			will be identified by the CDR. The mentor will ensure that all attending personnel meet the necessary requirements.	Complete	identified as the team's mentor
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.	Complete	The team has only one adult mentor (Ian Garrick-Bethell
1.5	The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the STEM Engagement Activity Report, by FRR. To satisfy this requirement, all events must occur between project acceptance and the FRR due date and the STEM Engagement Activity 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.	Inspection	STEM Engagement Activity 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.	In Progress	STEM Engagement activities have been completed and their relevant info has been sent to NASA. More events are planned.
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.	Complete	All social media aspects have been established and have been used
1.7	Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each	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	In Progress	Derivables are continually emailed to NASA by the deadline and will continue to stay

	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.		maximum file size, a link to a download of the file will be sent.		true
1.8	All deliverables must be in PDF format.	Inspection	Deliverables will be inspected before submission to ensure that they are in PDF format.	In Progress	All derivables have been and will continue to be PDF formatted
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.	In Progress	A table of contents is included in every report
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.	In Progress	Previous documents have page numbers and so will future documents
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.	In Progress	Use of library facilities have proved to be sufficient for the teleconferences and will continue to be used
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	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.	Incomplete	The vehicle will be built to use the provided 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.				
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 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.	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.	Complete	David Raimondi has been identified as the team's mentor

Table 6.3 Student Launch General Requirements

Vehicle Requirements

#	Requirement Description	Method of Verification	Description of Verification	Complete	Details
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.	Incomplete	Full-scale flights will demonstrate the vehicle stays within the given altitude constraints
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.	Complete	A planned altitude of 5280ft was given on 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 their official target altitude on launch day.	Inspection	The vehicle will be designed and inspected to accommodate one commercially available barometric altimeter that will be included in all launches.	Incomplete	At the launch site, the validity of the altimeters will be confirmed
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.	Incomplete	Fullscale flights will demonstrate that the recovery altimeters are activated by a dedicated arming switch
2.5	Each altimeter will have a	Inspection	Dedicated batteries will be		Inspection of the

	dedicated power supply.		supplied and planned for in the design.	Incomplete	fullscale will reveal dedicated power supplies
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.	Incomplete	Inspection of the recovery bay will reveal locked arming switched
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.	In Progress	The vehicle is designed to be reusable however, tests are required to verify this claim
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).	Complete	The vehicle is designed and will be constructed to have a maximum of 4 independent sections
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.	Complete	Every should is designed and will be constructed to be at least 1 body diameter
2.8.2	Nosecone shoulders which are located at in-flight separation points will be at least 1⁄2 body diameter in length.	Inspection	The nose cone shoulder will be measured and verified that it is at least ½ of the body diameter.	Complete	The nose should is designed and will be constructed to be at least ½ the body diameter
2.9	The launch vehicle will be limited to a single stage.	Inspection	Launch vehicle will possess a single motor.	Complete	Vehicle is designed to only hold 1 motor
2.10	The launch vehicle will be capable of being prepared	Demonstration	A comprehensive flight checklist will be made and		At the launch site, the team will

	for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.		tested before launch to verify the preparation time.	Incomplete	demonstrate that the vehicle can be assembled within 2 hours of the scheduled times
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.	Incomplete	Full Scale flight tests will show all critical components will have enough power for 2 hours
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.	Demonstrati on	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.	Complete	Vehicle is designed to take COTS motors, which fit 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.	Complete	Vehicle is designed to on rely on any external circuitry
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 the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	Inspection	Launch vehicle will use a commercially obtained APCP motor that is approved and certified by the NAR, TRA, and/or CAR.	Complete	Vehicle will use a COTS motor manufactured by AeroTech
2.14. 1	Final motor choices will be declared by the Critical	Demonstrati on	From simulations, a final motor choice will be made	Complete	Final motor choice is the

	Design Review (CDR) milestone.		by the CDR and presented clearly.		L1000
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.	Incomplete	No change has been 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.	Complete	No pressure vehicles on board vehicle
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.	Complete	No pressure vehicles on board vehicle
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.	Complete	No pressure vehicles on board vehicle
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.	Complete	No pressure vehicles on board vehicle

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.	Complete	The L1000 has a total impulse less than 5120 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.	Complete	OpenRocket simulations have shown the vehicle exceeds 2.0 calipers at 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.	Incomplete	Fullscale flights will verify a rail exit velocity of 52 fps
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.	Complete	Subscale flight results are included 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.	Complete	Subscale is separate vehicle
2.19.2	The subscale model will carry an altimeter capable of recording the model's apogee altitude.	Demonstration	Subscale model will include a commercially available altimeter that is capable of recording apogee altitude.	Complete	Subscale contained EasyMini and Stratologger
2.19.3	The subscale rocket must be a newly constructed rocket, designed and built specifically for this year's	Inspection	The subscale model will be built entirely during the school year and solely for NASA 2019 SLI.	Complete	Subscale was built Fall 2018

	project.				
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.	Complete	Subscale Flight Results are included in the CDR
2.20	All teams will complete demonstration flights as outlined below.	Demonstration	Test flights will be completed at the local range.	In Progress	Flights are completed at the LUNAR launch site
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.	Incomplete	The final full scale flight will be with its full-competition ready configuration
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.	Incomplete	Flight has yet to be completed
2.20.1.2	The full-scale rocket must be a newly constructed	Inspection	The full-scale model will be built entirely during the		Fullscale has yet to be completed

	rocket, designed and built specifically for this year's project.		school year and solely for NASA 2019 SLI.	Incomplete	
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.	Incomplete	Full-scale demonstration flight has not yet been completed
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.	Incomplete	Full-scale demonstration flight has not yet been completed but a payload simulation will be used if necessary
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.	Incomplete	Payload simulation will be properly installed
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.	Incomplete	Payload will be built to exist without any external hardware
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 day motor or in other extenuating circumstances.	Inspection/ Demonstration	The chosen motor will be purchased and used during the full-scale demonstration flight.	Incomplete	The L1000 is available at local stores and is not rare
2.20.	The vehicle must be flown	Demonstrati	The final chosen amount of		Full-scale

1.6	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.	on/ Inspection	ballast from simulations will be flown during the full-scale demonstration flight. The flight checklist will verify that the ballast is added.	Incomplete	demonstration flight has not yet been completed
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.	Incomplete	No modifications will be made post demonstration flight
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.	Demonstrati on	Flight data will be analyzed and supplied in the FRR.	Incomplete	Full-scale demonstration flight has not yet been completed
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.	Demonstrati on/Inspectio n	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.	Incomplete	Full-scale demonstration flight has not yet been completed
2.20. 2	Payload Demonstration Flight - All teams will successfully launch and recover their full-scale	Demonstrati on/ Inspection	The payload will be completed and flown with the full-scale vehicle during the demonstration flight.	Incomplete	Full-scale demonstration flight has not yet been completed

	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:		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.		Full-scale demonstration flight has not yet been completed
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.	Incomplete	Payload will be built based on timeline
2.20.2.3	If the above criteria is met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR	Inspection	A FRR Addendum will not be included should all flights be completed before the FRR deadline.	Incomplete	Should an FRR Addendum be needed, one will be completed

	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.	Incomplete	FRR Addendum will be completed before the deadline should on be needed
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.	Incomplete	Contact with NASA about a FRR Addendum will be made ASAP and 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.	Incomplete	All deadlines will be met 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.	Incomplete	Full-scale demonstration flight has not yet been completed
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 Review Panel have any safety concerns.	Inspection	The team will petition the NASA RSO if the payload demonstration flight is unsuccessful in any way.	Incomplete	Contact with the NASA RSO will be made when needed.
2.22	Any structural protuberance on the rocket will be located	Inspection/ Analysis	The design of the rocket will feature all	Complete	The rocket is designed to have

	aft of the burnout center of gravity.		protuberances behind the burnout center of gravity.		protuberances located 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.	Incomplete	All contact information is yet to be recorded
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.	Complete	Simulations ensure that extraneous canards will not be put in place.
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.	Complete	No forward firing motors will be employed as per the design.
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.	Complete	Correct motor verification is in effect.
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.	Complete	The rocket will use a solid fuel motor.
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.	Complete	Verification that there is no clusters of motors is in effect.

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.	Complete	Rocket motor is attached to the air frame
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.	Complete	It is predetermined that the flight will not happen after March 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.	Complete	Calculations ensure that vehicle ballast will be under the 10% mark.
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.	Complete	Transmitters in design all use less than 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.	Complete	Extraneous metals will not be used due to prior planning and documentation.

Table 6.4 Student Launch Vehicle Requirements

Recovery Requirements

#	Requirement Description	Method of Verification	Description of Verification	Complete	Details
3.1	The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is	Demonstration/ Inspection	The vehicle design will be made to deploy a drogue parachute at apogee and a main parachute at a lower		The full scale rocket will be launched at a later time to

	deployed at apogee and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the RSO.		specific altitude. This will be verified through inspection of the systems and demonstration flights.	Incomplete	verify these requirements
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.	Complete	The sensor will be set ensuring that the main parachute is deployed no lower 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.	Complete	The delay was chosen to not have a delay of more than 2 seconds
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.	Incomplete	A ground ejection test has not been overseed and verified yet, as we have not tested the full-scale rocket
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.	Complete	Landing energy will be calculated through OpenRocket
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.	Complete	Recovery electrical components have separate wiring from all other systems

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.	Complete	The batteries are commercially available
3.6	The recovery system will contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	Inspection	All recover flight computers will be be documented to be COTS flight computers.	Complete	The recovery avionics sled has two altimeters for redundancy
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.	Complete	Black powder is being used
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.	Complete	The vehicle features shear pins
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.	Complete	Predetermined radius from OpenRocket simulations are in place
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.	Complete	Our OpenRocket simulations meet this requirement
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.	In progress	The construction of the full scale rocket will act as the completion of GPS tracking device
3.11.1	Any rocket section or payload component, which	Inspection	Addition GPS Trackers will be included on any section	Incomplete	Will be verified before the flight

	lands untethered to the launch vehicle, will contain an active electronic tracking device.		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.	Incomplete	Will be tested before the flight
3.12	The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	Analysis/ Demonstration	The isolation from other devices will remove any potential adverse effects from other electronics on the vehicle to the recovery electronics.	In Progress	Design configuration tested in subscale successfully, but not the full scale
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.	Complete	Each side of the avionics sled has an altimeter ensuring separation
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.	In Progress	Design configuration tested in subscale successfully, but not the full scale
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.	Complete	Protection is guaranteed in regards to external stimuli
3.12.4	The recovery system electronics will be shielded	Inspection/ Demonstrati	The vehicle design will include shielding from any	In Progress	Design configuration

	from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	on	other electronics to verify the functionality of the recovery electronics.		tested in subscale successfully, but not the full scale

Table 6.5 Student Launch Recovery Requirements

Payload Requirements

#	Requirement Description	Method of Verification	Description of Verification	Complete	Details
4.2	College/University Division – Each team will choose one experiment option from the following list.	Inspection	The rover option has been chosen for the payload.	Complete	The rover option garnered the most interest among team members
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.	Complete	No additional experiments will be flown
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.	Complete	No additional experiments will be flown
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.	In Progress	Rover design has been planned out and parts purchased, building/testing in progress
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	Demonstration/ Test	The design retention system will be tested to verify its integrity and test any failsafe methods.	In Progress	Design will be tested extensively in lab setting before full scale launch

	experienced.				
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.	Demonstrati on	The team will use a radio transmitter to remotely deploy the rover once the all-clear is given.	Incomplete	Remote deployment will be tested to protect against misfire
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.	Demonstrati on	The rover has been designed to autonomously move a minimum of 10 ft. from the launch vehicle, then collect a soil sample.	Incomplete	Rover treads will be tested to ensure design meets requirements
4.3.5	The soil sample will be a minimum of 10 milliliters (mL).	Demonstrati on	The rover has been designed to collect a minimum of 10 milliliters of soil before stopping soil collection.	Incomplete	Rover scoop will be tested to ensure design meets requirements
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.	Demonstrati on	The rover will contain a container that will be sealed after the soil sample has been deposited.	Incomplete	Rover scoop will be tested to ensure design meets requirements
4.3.7	Teams will ensure the rover's batteries are sufficiently protected from impact with the ground.	Demonstrati on	The rover's batteries will be housed internally, so as to eliminate any risk of impact with the ground.	Incomplete	Rover housing will be tested to ensure battery protection
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	Demonstrati on	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.	Incomplete	Rover battery will be wrapped in a single layer of neon duct tape with warning labels written on

Table 6.6 Student Launch Payload Requirements

Safety Requirements

#	Requirement Description	Method of Verification	Description of Verification	Complete	Details
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.	In Progress	Safety checklist is made and will be put in use in a later date.
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.	Complete	The Safety Officer is a current member of UCSC Rocket Team and assumed responsibilities.
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.	In Progress	The Safety Officer is present throughout the year during events and meetings and will continue to monitor upcoming events.
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.	In Progress	Continuation of procedure will occur all the way to the flight.
5.3.3	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory	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	In Progress	Maintenance of safety manual will guide safety procedures moving forward.

	data,		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.	In Progress	The Safety Officer will keep updating the documentation to reflect any new designs and hazards.
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 NAR or TRA launch.	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	In Progress	NAR High-Powered Rocketry code will ensure that safety precautions are being met, and will continue to be met throughout the course of the flight.
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.	In Progress	

Table 6.7 Student Launch Safety Requirements

6.2.2 Team Derived Requirements

6.2.2.1 Payload housing

The requirements outlined in this section are tested for compliance in the previous section (6.1.3 Payload housing testing)

Payload Housing Team Requirements

#	Requirement Description	Method of Verification	Complete
6.1	Housing is securely fastened to airframe assembly throughout flight		
6.1.1	Semi permanent fasteners securely attached to nose cone	Demonstration/Test	Incomplete
6.1.2	Shear pins and safety ropes securely attached to rest of air frame	Demonstration/Test	Incomplete
6.2	Strength testing of physical rover to housing assembly		
6.2.4	Rover lock and key attachment to sled	Demonstration/Test	Incomplete
6.2.5	Rapid acceleration securement during flight	Demonstration/Test	Incomplete
6.3	ALC component		
6.3.1	Successfully accomplishes landing correction	Test	Incomplete
6.3.2	Sled locks in place during flight and will not move	Test	Incomplete
6.3.3	System is powered off until signal is received for activation	Demonstration	Incomplete
6.4	Deployment		
6.4.1	Black powder charge detaches housing successfully	Demonstration/Test	Incomplete
6.4.2	Door disengages from coupler	Demonstration/Test	Incomplete
6.4.3	Shear pins detach coupler from rest of rocket body	Demonstration/Test	Incomplete

6.4.4	Kill switch activates onboard electronics	Test	Incomplete

Table 6.8 Payload housing team derived requirements

6.2.2.2 Payload physical rover

The requirements outlined in this section are tested for compliance in the previous section (6.1.4 Payload testing)

Physical Rover Team Requirements

#	Requirement Description	Method of Verification	Complete
6.5	Tread testing		
6.5.1	Treads are securely fastened and won't malfunction in flight	Demonstration/Test	Incomplete
6.5.2	Motors actuate treads correctly and move rover body	Demonstration/Test	Incomplete
6.5.3	Rover can navigate various inclines with various terrains	Demonstration/Test	Incomplete
6.5.3.1	Angles varying from 0, 10, 20, 30, 40, 50 degree inclines	Demonstration/Test	Incomplete
6.5.3.1	Terrains ranging from grassy, compact, muddy, gravel, large rocks, and sandy	Demonstration/Test	Incomplete
6.6	Chassis testing		
6.6.1	Rover can detach lock and key securement system and deploy	Demonstration/Test	Incomplete
6.6.2	Rover body will be able to handle stresses of flight and use	Demonstration/Test	Incomplete
6.7	Battery test		
6.7.1	Battery will not overheat during mission	Inspection	Incomplete

6.7.2	Visual inspection for swelling to ensure battery hasn't been overcharged	Inspection	Incomplete
6.7.3	Battery has capacity needed to carry out mission	Demonstration/Test	Incomplete
6.8	Electronics test		
6.8.1	Electronics are secured and no wires are exposed	Inspection	Incomplete
6.8.2	Servo motors actuate correctly	Demonstration/Test	Incomplete
6.8.3	Sensors all function and read distance data correctly	Demonstration/Test	Incomplete
6.8.4	Linux subsystem		
6.8.4.1	Logs are cleared	Inspection	Incomplete
6.8.4.2	Services are started	Inspection	Incomplete
6.8.4.3	Sensors are reading accurate data	Demonstration/Test	Incomplete
6.9	Scoop test		
6.9.1	Scoop deployed properly and gathers requisite ten milliliters of soil	Demonstration/Test	Incomplete
6.9.2	Soil remains enclosed within rover body after collection	Demonstration/Test	Incomplete
6.10	Remote activation system		
6.10.1	Remote connection can be established in a variety of weather conditions	Demonstration/Test	Incomplete
6.10.2	Remote connection can be established at distance of a mile	Demonstration/Test	Incomplete
6.11	ODAS test		
6.11.1	Object detection camera relays correctly to BeagleBone	Demonstration/Test	Incomplete

6.11.2	Ultrasonic sensor gives accurate distance reading	Demonstration/Test	Incomplete
6.11.3	Object detection software detects objects at least 1 meter away	Demonstration/Test	Incomplete
6.11.4	Object avoidance software maneuvers around detected obstacles	Demonstration/Test	Incomplete

Table 6.9 Physical rover team derived requirements

6.2.2.3 General Requirements

Team Derived General Requirements

#	Requirement Description	Method of Verification	Description of Verification
7.1	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.
7.2	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.
7.3	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.
7.4	Any documents relative to the team will posted for all on the Team Google Drive.	Inspection/ Demonstration	All members will be added to the team Google Drive.

Table 6.10 Team Derived General Requirements

6.2.2.5 Vehicle Requirements

Team Derived Vehicle Requirements

#	Requirement Description	Method of Verification	Description of Verification
8.1	Vehicle will feature an adaptive air-braking system (ADAS).	Inspection	ADAS will be inspected and tested for functionality.

8.1.1.1	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.
8.1.1.2	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
8.1.1.3	The ADAS system will deploy the fins to the correct range.	Demonstration	Optical sensor feedback look reading position of fin deployment.
8.1.2.1	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.
8.1.2.2	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.
8.1.2.3	The ADAS system will follow the flight curve within an error margin of 15%.	Demonstration	Record sensor metric data and calculate deviation.
8.1.3	The ADAS system will adjust itself at a frequency of 20Hz.	Inspection	Set time measurement between beginning of algorithm calculation and motor movement signal.

Table 6.11 Team Derived Vehicle Requirements

6.3 Budget and Timeline

6.3.1 Item Budget

Sub-Scale Budget Table

Sub-Scale Rocket Expenses							
Subsystem	Item	Price Per Unit	Quantity	Total Unit Cost	Shipping	Tax	Total

Thrust	Carbon fiber body	$0.00	0	$0.00			$0.00
	Epoxy Resin 105-A	$39.99	1	$39.99		$3.40	$43.39
	Epoxy Hardener 209-SA	$39.99	1	$39.99		$3.40	$43.39
	75mm Blue Tube Full Length Coupler	$34.19	3	$102.57	$38.14		$140.71
	Standard Airfoiled Rail Buttons (1" 1010)	$7.38	1	$7.38			$7.38
ADAS	Socket Head Cap Screw	$0.25	10	$2.50			$2.50
	3.75in Wood Disk	$1.00	8	$8.00			$8.00
	Eyebolt	$5.00	4	$20.00			$20.00
	All-thread Material	$15.00	1	$15.00			$15.00
	Hex Nuts	$0.10	20	$2.00			$2.00
	Lock Nuts	$0.20	20	$4.00			$4.00
	ADAS Battery GOLDBAT 1300mAh	$14.99	1	$14.99	$0.00		$14.99
	BeagleBone Blue Microcontroller	$82.00	1	79.99	$18.29		98.28
	NeveRest 40 Gearmotor 12V 160RPM	$28.00	1	$28.00	$7.20		$35.20
	Cytron 13A DC Motor Driver	$11.88	1	$11.88	$2.66	$1.10	$15.64
	Carbon fiber body	$0.00	2	$0.00			$0.00
	Acrylic Sheet (11"x14"x0.093")	$5.98	1	$5.98		$0.51	$6.49
	Wiring and connectors	$10.00	1	$10.00	0		$10.00
Avionics	Main Parachute (58”)	$180.00	1	$180.00	$4.50		$184.50
	Drogue Parachute (15”)	$8.31	1	$8.31	$4.50		$12.81
	Perfectflite Stratologger	$49.46	0	$0.00	$0.00		$0.00
	9V Battery	$2.50	10	$25.00			$25.00

	PSP Parachute Repair Tape	$11.45	1	$10.60	$12.77		$24.22
Nosecone	3:1 Fiberglass	$40.00	1	$40.00			$40.00
	Turnigy 800mAh 2S Lipo	$11.72	1	$11.72	0	0	$11.72
	Eggfinder Transmitter & Receiver (GPS)	$98.00	1	$98.00	$6.00	$7.22	$111.22
	AA Battery Pack (x48)	$13.99	1	$14	0	$1.29	$15
Misc.	General Hardware	$150.00	1	$150.00			$150.00
	Bike Pump for Outreach Launcher	9.99	1	$9.99	$0.90		$10.89
Travel	General Travel	$100.00	4	$400.00			$400.00
	Travel	$500.00	8	$4,000.00			$4,000.00
Launch	J420 Motor	$81.36	1	$81.36	$0.00	Included	$81.36
Total				$5712.02			$5680.68

Table 6.12 Sub-scale budget log

Full Scale Budget Table

Full-Scale Rocket Expenses							
Subsystem	Item	Price Per Unit	Quantity	Total Unit Cost	Shipping	Tax	Total
Airframe	Carbon fiber body (approx. 7X3 ft.)	$0.00	0	$0.00			$0.00
	Epoxy Resin 105-A	$39.99	2	$79.98		$3.40	$83.38
	Epoxy Hardner 209-SA	$39.99	2	$79.98		$3.40	$83.38
	5.5" Blue Tube Full Length Coupler	$59.87	2	$119.74	$38.14		$157.88
	Standard Airfoiled Rail Buttons (1" 1010)	$7.38	1	$7.38			$7.38

	5.5" Fiberglass 4:1 Ogive Nose Cone	$88.35	1	$88.35			$88.35
	54MM G12 Fiberglass Filament Wound Tube 48" Long	$67.86	1	$67.86			$67.86
	6061 Aluminum Sheet 1/8" Thick, 6" x 48"	$48.50	1	$48.50			$48.50
	Misc. Bolts	$20.00	1	$20.00			$20.00
ADAS	Chihai 330rpm chr-gm25-370-abhl motor	$10.60	1	$10.60	$3.86	0	$14.46
	Aluminum Sheet	$10	1	$10	0	0	$10
	All-thread Material	$10	1	$10	0	0	$10
	Blue Tube Coupler 5.36”	$20.28	1	$20.28	$10.77	0	$31.05
Payload/ Rover	Pololu Gearmotor 6V 310RPM	$16.95	2	$33.90			$33.90
	LewanSoul Servo Motor	$14.99	1	$14.99	$2.00		$16.99
	BeagleBone Blue Microcontroller	$78.00	1	$78.00	$3.50		$81.50
	Li-ion Battery 7.4V 1Ah	$9.95	3	$29.85	$12.75		$42.60
	Pololu 30T Track Set	$14.95	1	$14.95	$4.00		$18.95
	DigiKey PSoC 6 Pioneer Board	$7.54	2	$7.54			$7.54
	Waveshare XBee USB Adapter USB Communication Board	$13.99	1	$13.99			$13.99
	Xbee Bluetooth USB to Serial Port Arduino Bee Adapter Adapter	$6.99	1	$6.99			$6.99
	Ultrasonic Range Finder - LV-MaxSonar-EZ2	$27.95	1	$27.95	$2.00		$29.95
	Smallest Mini 50.0	$6.29					

	Mega Pixel USB HD Video Camera						
	XBee-PRO 900HP (S3B) DigiMesh, 900MHz, 250mW, Wire Antenna, 200Kbps, 32K Programmable	$41.75	2	$83.50	$7.72		$91.22
Recovery	Iris Ultra 60" Standard Parachute	$180	1	$180	$10.60	$14.85	$206.95
Misc.	Fundraising Merchandise (short socks)	$12.90	1	$12.90			$12.90
	Fundraising Merchandise (long socks)	$19.99	2	$39.98			$39.98
	Fundraising Merchandise (short socks)	$12.99	2	$25.98			$25.98
Travel	Round Trip Competition Flights	$338	15	$5,070			$5,070
	Hotel Stay (per group of four)	$54	4	$216			$216
Launch	K Class Motor	$140	1	$140			$140
Total				$6559.19			$6669.14

Table 6.13 Full scale budget log

6.3.2 Funding Plan

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. The team also plans on presenting to the various college senates at the University of California, Santa Cruz, which offer funding to campus groups. In addition to applying for these grants, the team held a fundraiser selling merchandise and plans to continue hosting these events throughout the year.

The materials will be ordered from the specified vendors. 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.

6.3.3 Timeline

Green events on the timelines represent things that need to be done, orange events are launch dates, and purple events are important due dates.

6.3.3.1 General Timeline

Activity	Start Date	End Date
Design Rocket	Oct 1	Nov 1
PDR Prep	Oct 4	Nov 1
PDR Due	Nov 2	
CDR Prep	Nov 2	Dec 8
Subscale Construction	Nov 2	Dec 8
Subscale Flights	Dec 1	Dec 8
Subscale Analysis	Dec 8	Jan 10
Fullscale Trade Studies	Dec 8	Jan 10
CDR Finalization	Dec 9	Jan 10
CDR Due	Jan 11	
UCSC Giving Day Training	Jan 14	
FRR Prep	Jan 5	Feb 1
Full Scale Construction	Jan 5	Feb 1
Fullscale Flights	Feb 2	Feb 9
FRR Finalization	Feb 3	Mar 3
Fullscale Analysis	Feb 3	Mar 3
UCSC Giving Day	February 27	
FRR Due	March 4	
Competition Preparation	March 4	April 3
Final Flights	April 3	April 4
PLAR Prep	April 5	April 25
PLAR Due	April 26	

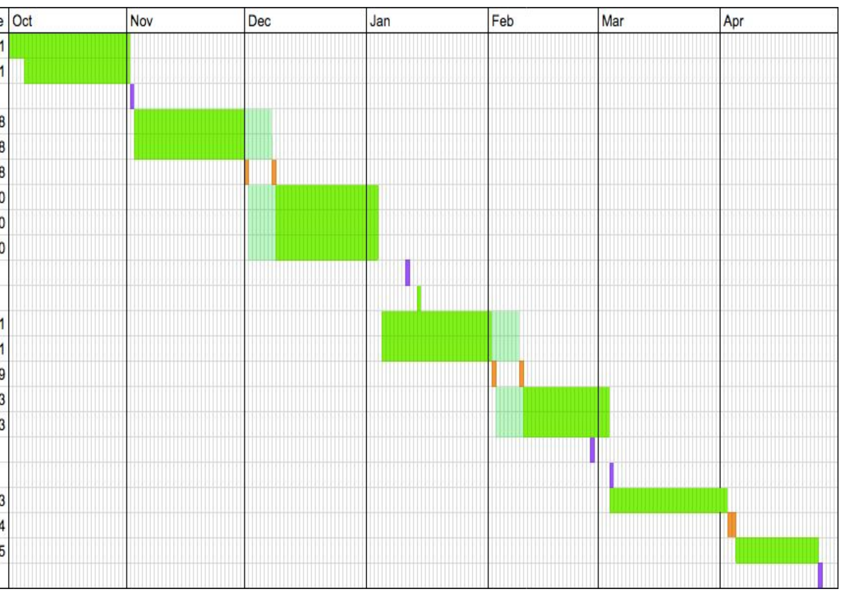


Figure 6.14 General Timeline

6.3.3.2 Vehicle Timeline

Activity	Start Date	End Date
Rolling Thrust Section of Carbon Fiber Frame	Jan 26	Jan 27
Rolling Payload Section of Carbon Fiber Frame	Feb 2	Feb 3
Rolling Recovery Section of Carbon Fiber Frame	Feb 9	Feb 10
Fins, Holding Rings, Motor Section Epoxied	Feb 16	Feb 17
BlueTube, Holes for Bolts and Launch Rails	Feb 23	Feb 24
Vehicle Demonstration Flight	March 4	

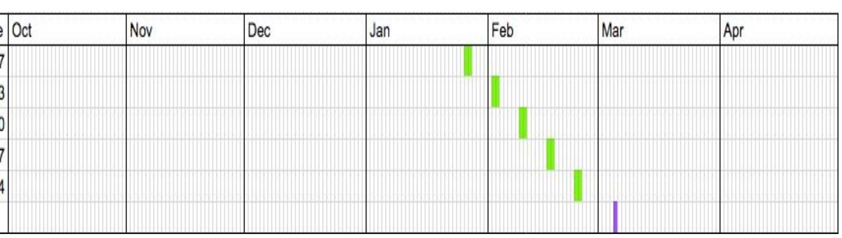


Figure [6.15] Vehicle Timeline

6.3.3.3 ADAS Timeline

Activity	Start Date	End Date	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Design Rocket	Oct 4	Nov 15							
Build Subscale Rocket	Nov 2	Dec 8							
Subscale Flights	Dec 1	Dec 8							
Subscale Analysis	Dec 8	Jan 3							
Fullscale Trade Studies	Dec 8	Jan 3							
Implement Motor Change	Jan 12	Jan 16							
Print Parts	Jan 12	Jan 19							
Code PID Algorithm	Jan 12	Jan 27							
Test Assembly	Jan 20	Feb 8							
Test PID Algorithm	Jan 28	Feb 8							
Fullscale Flights	Feb 2	Feb 9							
Fullscale Analysis	Feb 3	Mar 3							

Figure 6.16 ADAS Timeline

6.3.3.4 Airframe Timeline

Activity	Start Date	End Date	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Rolling Thrust Section of Carbon Fiber Frame	Jan 26	Jan 27							
Rolling Payload Section of Carbon Fiber Frame	Feb 2	Feb 3							
Rolling Recovery Section of Carbon Fiber Frame	Feb 9	Feb 10							
Fins, Holding Rings, Motor Section Epoxied	Feb 16	Feb 17							
BlueTube, Holes for Bolts and Launch Rails	Feb 23	Feb 24							
Vehicle Demonstration Flight	March 4								

Figure 6.17 Airframe Timeline

6.3.3.5 Payload Timeline

Payload									
Activity	Start Date	End Date	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Trade studies	Oct 4	Nov 2							
Select and order bought components	Oct 4	Nov 30							
Design and build ALC	Dec 21	Jan 2							
Design finalized chassis	Nov 2	Jan 11							
All 3D parts printed	Dec 8	Jan 3							
Basic Prototype of Rover (no ODAS)	Jan 12	Jan 16							
Read Camera and Ultrasonic data	Jan 18	Jan 25							
Test Assembly, Rover, Housing	Jan 20	Feb 2							
Separation, Integration, and Exit finalized	Jan 12	Feb 2							
Working ODAS	Feb 4	Feb 23							
All components finalized	Feb 27	Apr 2							

Figure 6.18 Payload Timeline