Rocket Team at UCSC

NASA Student Launch 2018-2019
Flight Readiness Review (FRR)
March 4th, 2019

1 Summary

1.1 Team Summary

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1.2 Vehicle Summary

Table 1.2.1 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*				
104.27	5.52	5.34	18.1	L1000	18	60	5280	Carbon Fiber	59.87	78.89

Table 1.2.1 Full-scale Rocket Parameters

Rail Size: 8ft 10-10

1.3 Payload Summary

Payload Title: *SlugBuggy*

For this year's experimental payload, the soil-collecting rover was chosen. The Actuated Landing Correction System (ALC) employs a bearing-based system to ensure correct orientation of the payload upon landing. After the rover's orientation is corrected, the rover will 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 CDR

Tables 2.1 to 2.5 document a number of changes that have been made to the vehicle, its various subsystems, and the project plan. 2.6 document the CDR action items and the changes made to account for this.

2.1 Vehicle Changes

Change	Rationale
Non-Fiberglass Fins	Fiberglass fins would put the rocket significantly overweight; changing the material to MDF brought the rocket to a more stable weight.
Individual Section Lengths	The payload required more space than planned, increasing the length of the payload section. The recovery section was decreased in length, as it previously had extra space, to retain the same overall height.
*Changing Payload Shear Screw Location	Because of the changes in payload design, the location of the shear screws that fasten the payload section to the recovery section will be altered.
*Greater Shear Screw Size	In our first launch of *Oh Yeah*, the payload section prematurely separated from the recovery section at apogee, due to the weak shear screws designed to hold the sections together. The screws will become a larger size from #2-56, which will ensure that the payload does not detach at apogee.

*Done after launch

2.2 Payload Changes

Change	Rationale
ALC system*	Previous system couldn't handle stress forces experienced during flight and failed in several mission critical areas
Airframe locking system*	New passive ALC system will be secured in place to airframe using structural pins rather than servo
Rover electronics*	More advanced electronics needed to perform vision obstacle detection using OpenCV
Rover vehicle integration section*	A coupler was added to modularize vehicle integration

*Done after launch

2.3 Adaptive Aerobraking System (ADAS)

Change	Rationale
Controlling motherboard*	The previously used BeagleBone board performed very poorly with overvoltage protection and general reliability. The new design switches over to a Raspberry Pi 3 B+ for improved reliability and usability.
Motor driver controller*	Controlling of motor movement has been modularized to a seperate arduino controller board to alleviate points of failure and improve robustness.
Connection wiring*	Wiring of component connections to power as well as each other has been made more robust through soldering due to issues in the previous failed launch.
Power converter*	A USB power converter was added to the design to be able to feed power from the onboard battery to the controlling board and the onboard camera.
Sled mounts*	Components are now secured to the sled through stronger metal screws to prevent dislodging of components from the sled during flight

*Done after launch

2.4 Recovery Changes

Change	Rationale
Layout of Bay*	Batteries are on one side, and altimeters and switches are on the other.
Switches	Screw switches replaced the previous switches because the other switches are susceptible to bouncing in place, whereas the screw switches are more secure once locked into place. There is one switch per altimeter.
Mounts	A U-bolt mount replaced the previous I-bolt mount to ensure strength (accompanied by an additional bulkhead).

Shock cord length*	40ft ⅜" wide kevlar shock cord replaced the 20ft long kevlar shock cord. This allows for pressure to be evenly distributed throughout a longer distance. This is 4x stronger than the previous shock cord.
Battery retention system	Aluminum angles replaced the plastic 3D printed battery cases to prevent the dislocation of the batteries.
Location of battery holes	Prevents wind from one side accidentally triggering the altimeter.

*Done after launch

2.5 Project Plan Changes

Change	Rationale
No changes to the project plan was done.	Nothing needed to be changed.

2.6 CDR Action Items

Action Item	Response
Each altimeter must have it's own switch in case of a switch failure.	A screw switch has been situated and secured to the sled for each of the altimeters.

3 Vehicle Criteria

3.1 Vehicle Design and Construction

3.1.1 Changes Since CDR

Change	Rationale
Non-Fiberglass Fins	Fiberglass fins would put the rocket significantly overweight; changing the material to MDF brought the rocket to a more stable weight.
Individual Section Lengths	The payload required more space than planned, increasing the length of the payload section. The recovery section was decreased in length, as it previously had extra space, to retain the same overall height.
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3.1.2 Safety Features

3.1.2.1 Structural

The thrust section is equipped with some devices to ensure the rocket motor works as intended. In the event the motor fails, we have attached two rings (one circular, one oblong) on the end of the thrust section held by ¼”-20 bolts. If the motor becomes dislodged, it will encounter the rings and stay within the rocket.

3.1.2.2 Electrical

The recovery section features dual altimeters, an EasyMini and StratologgerCF, in an effort to increase redundancy and safety. The altimeters are programmed to ignite the black powder charge for the parachutes at apogee, with one delayed to ensure parachutes are deployed. Each altimeter has an independent power supply and switch.

The vehicle includes an onboard GPS tracker to make sure we able to locate it after it has landed. This GPS transmitter is paired with a receiver that a team member uses to track the vehicle’s location. The GPS receiver is mounted to a fiberglass sled and has its own power supply.

3.1.3 Flight Reliability (Mission Success Criteria)

Mission Success Criteria includes reaching and achieving a maximum altitude of exactly 1 mile (5280'), remain within a 2500' recovery area, and be safely recovered. Through flight tests and OpenRocket simulations, we believe that this vehicle is capable of completing these criteria. The motor used propels the vehicle to above 1 mile, and the onboard aerobraking system (ADAS) will bring the vehicle to exactly 1 mile. The parachutes are chosen to prevent the vehicle from drifting beyond the 2500' limit, by changing parachute size and deployment height. Redundant altimeters and their respective systems will allow for the safe recovery of the vehicle upon landing.

3.1.4 Construction Documentation and Proof

The construction of the vehicle was done between the submission of the CDR on January 4th and the first full-scale launch on February 16th. The construction of the vehicle has been document through pictures and various tests. The vehicle has also been changed and redesigned since the full-scale flight in anticipation of a future, make-up, launch.

3.1.4.1 CAD

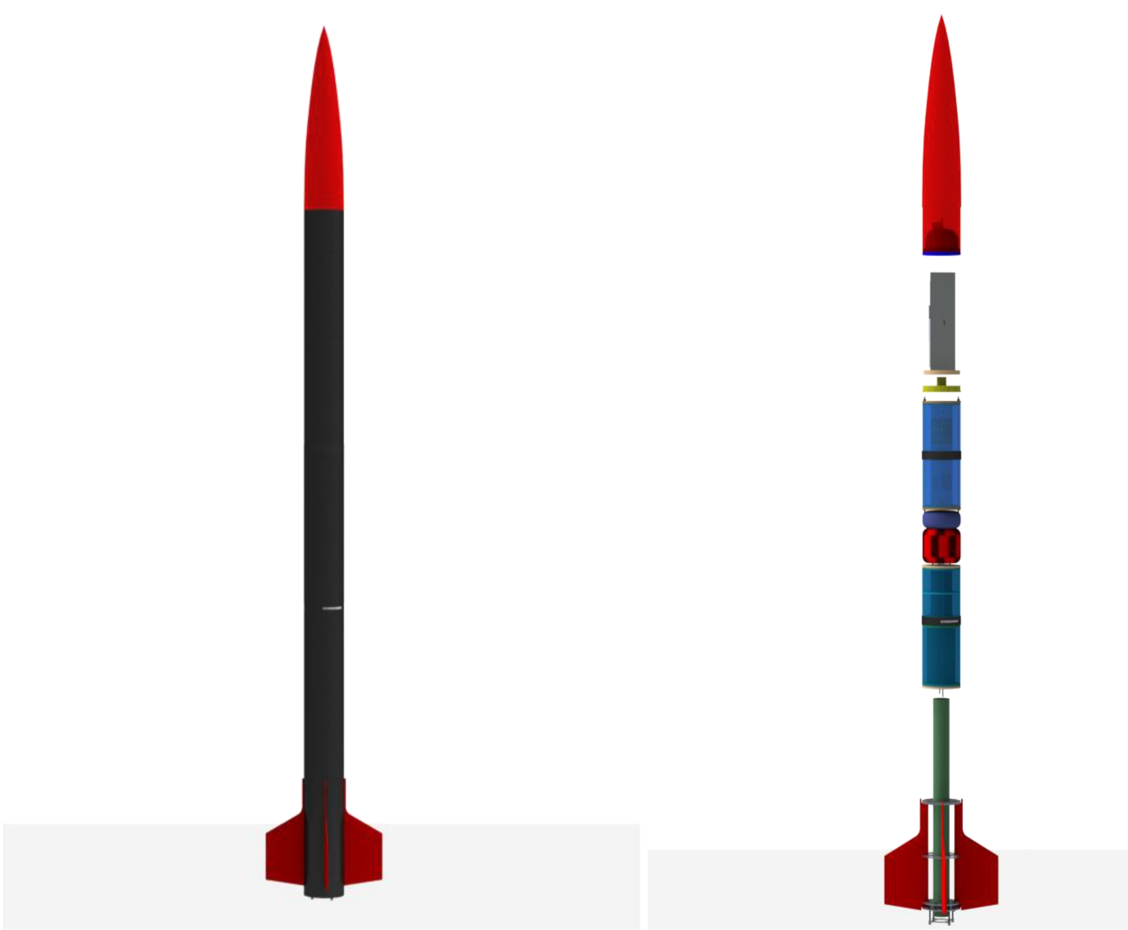


Figure 3.1.1 CAD rendering of Oh Yeah

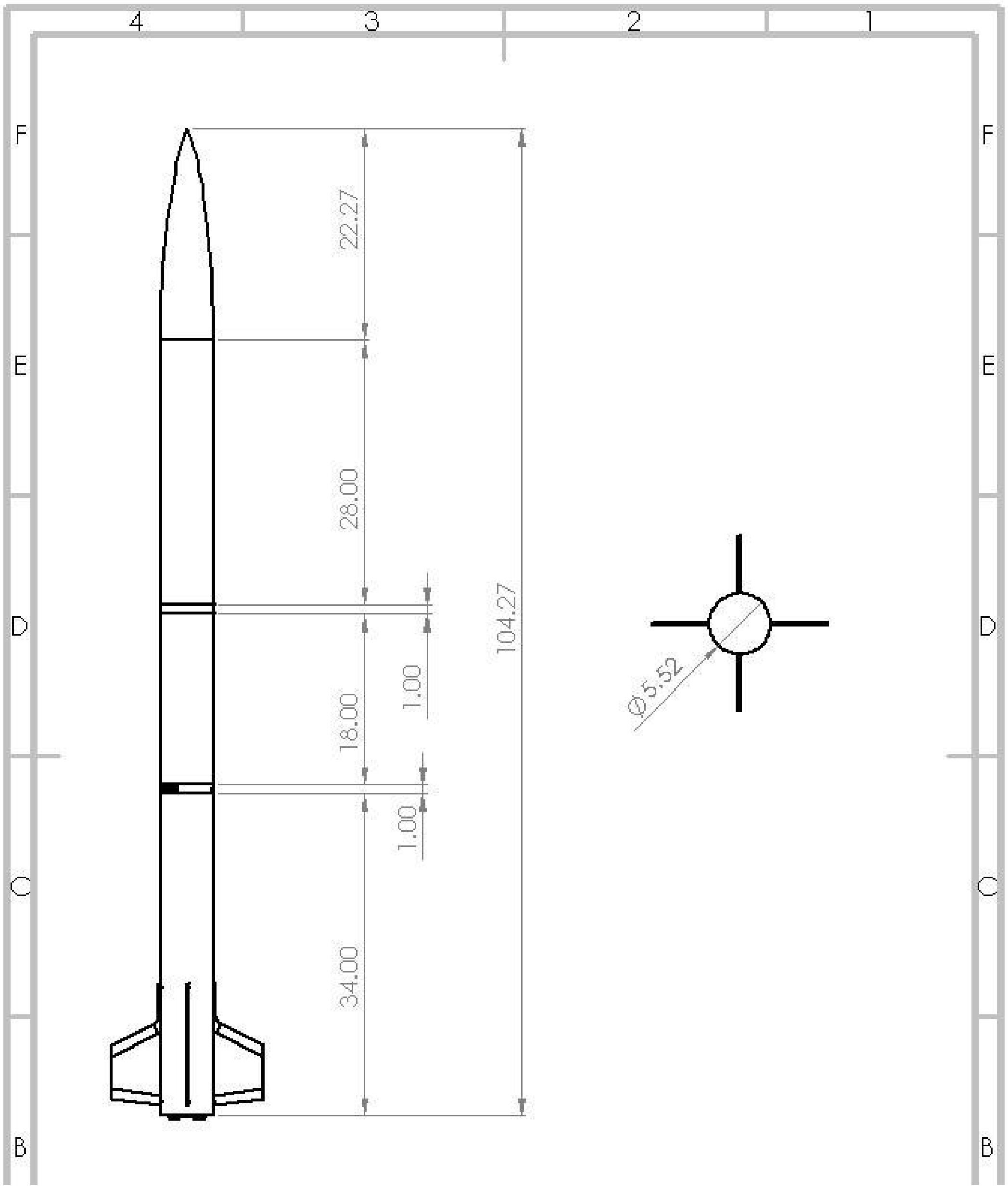


Figure 3.1.2 Measurements of Rocket

Section	Length	Material	Purpose
Nosecone	22.27"	Plastic, fiberglass	Stability, aerodynamics, and

			housing payload GPS radio
Payload	28”	Carbon fiber	Rover Housing
Recovery Bracelet	1”	Carbon fiber	Payload electronics
Recovery	18”	Carbon fiber	Parachute housing
ADAS Bracelet	1”	Carbon fiber	ADAS electronic systems and fins
Thrust	34”	Carbon fiber, aluminum centering rings, and fiberglass motor tube	Houses the motor and fins

Table 3.1.1 Sections of rockets

3.1.4.2 AS-BUILT

Each section of the rocket were hand-rolled in the lab. This was done by cutting the required area of carbon fiber fabric (the length measured to the needed length and width measured to five wraps of carbon fiber when rolling it). Once the carbon fiber was cut with necessary caution to limit any carbon fiber strips for safety, the plastic Mylar was cut and wrapped around the Blue Tube prior to lying the carbon fiber. Peel Ply was cut for one wrap around the carbon fiber once it was rolled. Then the cutted Mylar was wrapped around the Blue Tube mandrel, being precise to cover all parts of the Blue Tube. If the Blue Tube was not fully covered, epoxy would leak onto the Blue Tube and cause difficulty in removal of the carbon fiber section. With the carbon fiber sheet prepared, epoxy; the West System 209 extra slow two-part epoxy, was mixed in the needed ratio of 3.5:1 resin to hardener. The hand-rolling process began by coating an even distribution of epoxy on the myler, than rolling a small section of the cut carbon fiber onto the Mylar and mandrel, which was then held in place by the epoxy. The epoxied sections of the carbon fiber were then squeegeed. As the carbon fiber was turned more onto the mandrel, the squeegeeing served the dual-purpose of condensing the layers of carbon fiber onto each other and allowing the epoxy to seep through the carbon fiber layers, binding them further. Once the carbon fiber was fully rolled onto the mandrel and sufficiently squeegeed, the Peel Ply was added around the carbon fiber to remove any excess epoxy. This process was done for all three sections of the rocket and each section was sit to cure for 24 hours before removal from the mandrel.

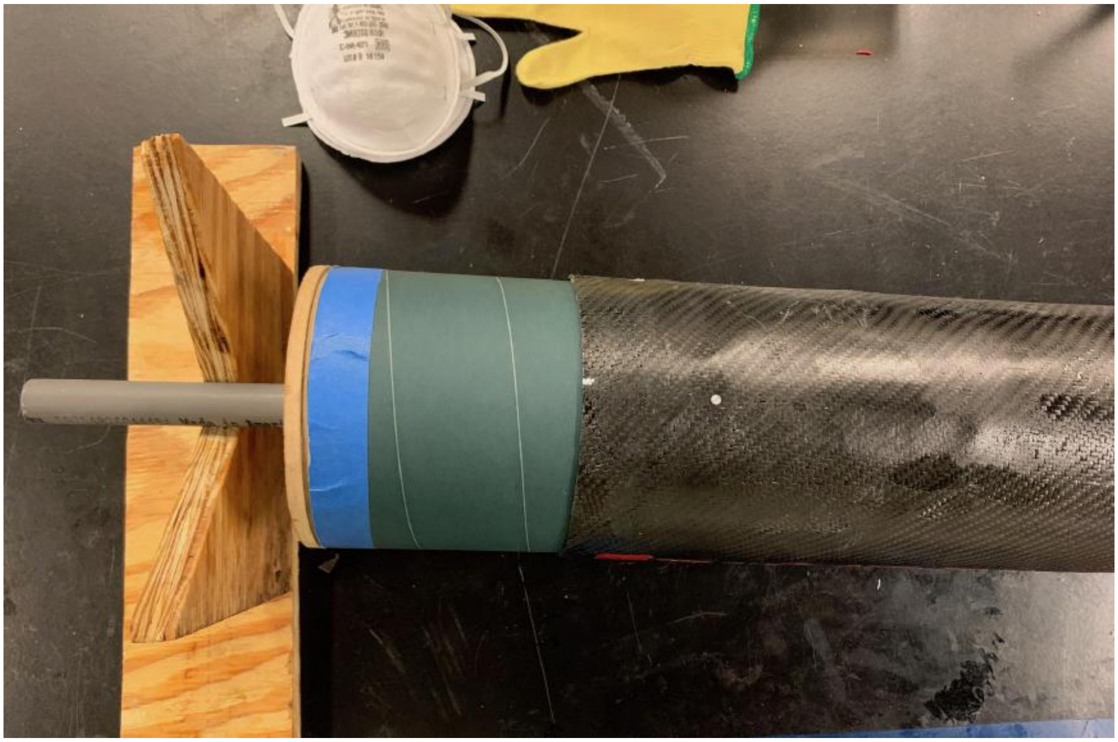


Figure 3.1.3 Carbon fiber section on mandrel

Each carbon fiber section was cut to specifications and needs of the specific section. The thrust, recovery, and payload were cut to 33.875", 22.75", and 28", respectively. Two 1" width carbon fiber rings were also made for the coupling of sections. The BlueTube from the mandrel was then repurposed for the couplers as well. Once the couplers were cut and square, the carbon fiber rings were epoxied (with the same epoxy used in the making of the airframe sections) in the middle of the Blue Tube couplers. In the case of the ADAS coupler, fin slots were cut to the needed width and arc length so the ADAS fins could unwind during launch.

Figure 3.1.4 Thrust section without fins

Figure 3.1.5 Recovery section and semi-permanent threaded hole

Figure 3.1.6 Payload section

The thrust section was then created. The fin slots were cut using an X-carve CNC router for precision. The ¼” drill bit was zeroed at the base of the fin slot, then cut the length of the fin along the length of the thrust section. The aluminum centering rings were cut, epoxied onto the fiberglass motor tube in a linear fashion, and the motor tube was added in the thrust section, oriented so the slots in the centering rings would line up with the previously cut fin slots. The centering rings with motor tube attached were then epoxied in place.

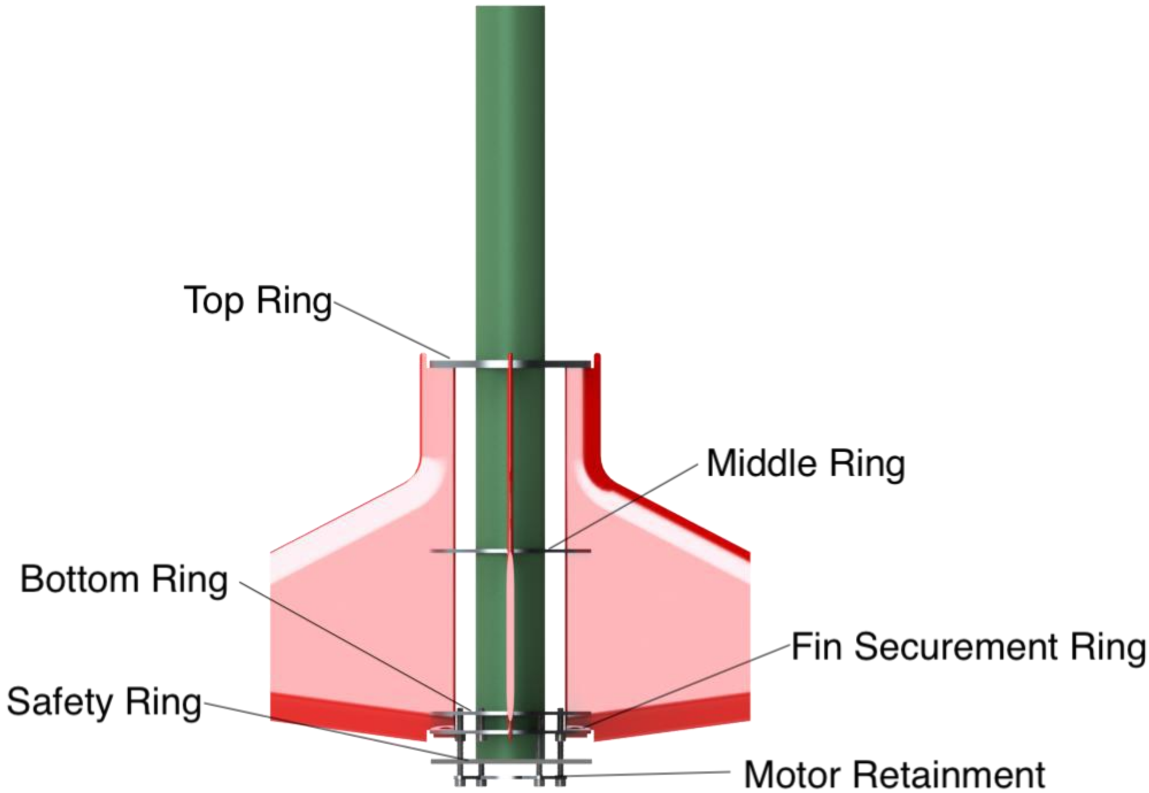


Figure 3.1.7 Motor Containment

The top ring holds the fins in place and transfers most of the force from the motor to the carbon fiber frame. The middle ring provides stability to the fins and keeps the carbon fiber from flexing. The bottom ring contains eight tapped holes that connects to the fin securement ring and offers more stability to the back end of the fins. The fin securement ring locks all the fins in place and is bolted by four bolts to bottom ring. The safety ring holds the motor containment in place in case the epoxy fails and the motor containment becomes detached from the carbon frame. This ring is bolted by two bolts onto the bottom ring. Finally, the motor retainment holds the motor in place and is held by two bolts attached to the bottom ring.

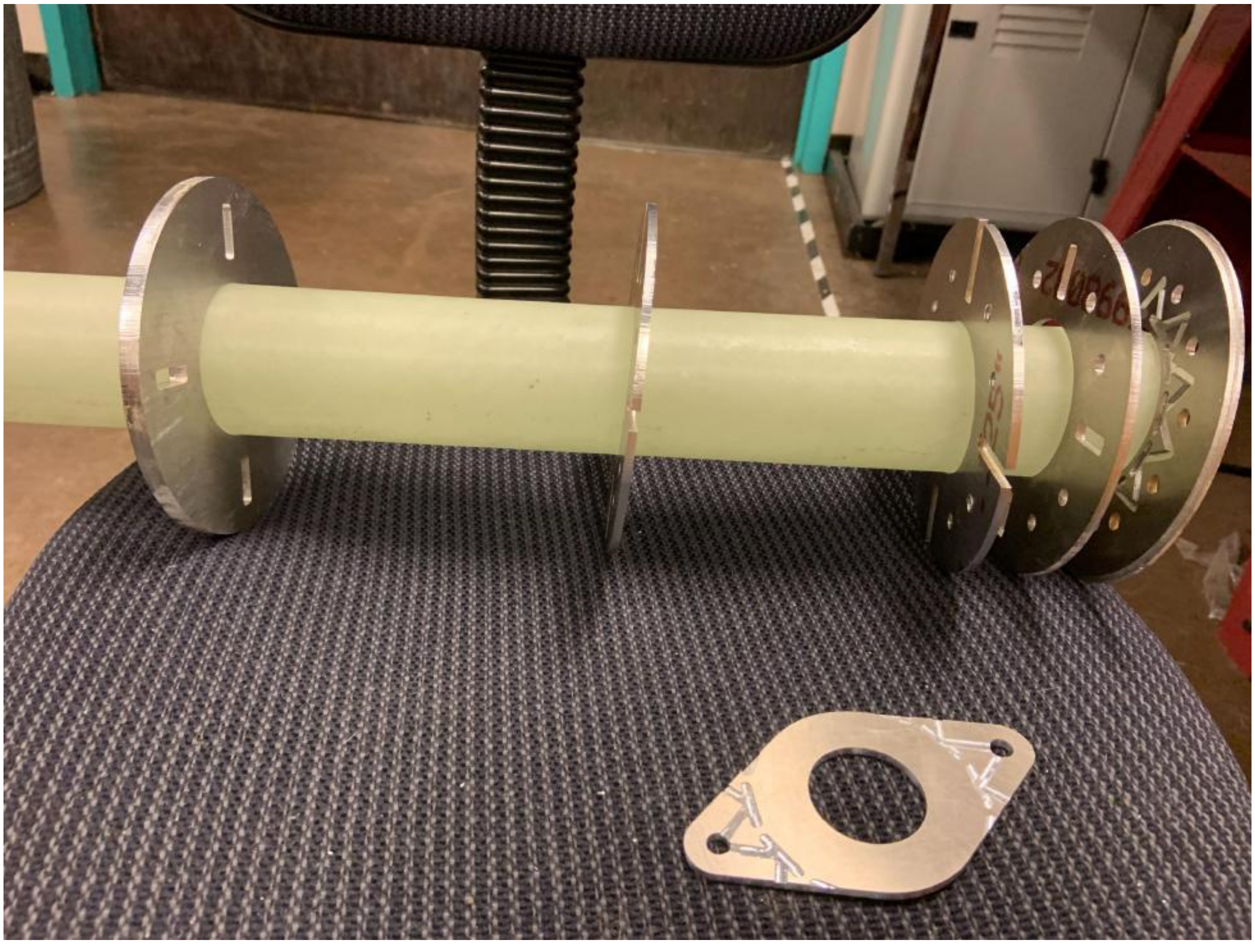


Figure 3.1.8 Motor containment before epoxy

Figure 3.1.9 Centering rings epoxied in thrust section

The top and bottom of each section were then tapped for ¼”-20 screws to hold the sections together for launch. The payload and respective BlueTube coupler were attached with shear screws, set to be released upon landing after launch and allow the payload to drive out of the payload section.

Figure 3.1.10 Nose cone on payload section and size of semi-permanent

3.1.5 Differences from Previous Models

From the recent test flight, the recovery section (the midsection) became damaged during landing. The section had to be rebuilt using previous methods. However, after discovering the minimal amount of BlueTube left used for ADAS (Adaptive Aerobraking System) and recovery couplers, the recovery section will be shorter than the previous model. With the change in length, the height and weight of the rocket will change. However, the function of the recovery section will not change, as there was excess room in the recovery section in the previous model of the rocket.

3.2 Adaptive Aerobraking System

3.2.1 Structural Design

3.2.1.1 Fins

The fins, pictured in Figure 3.2.1, have the teardrop-shaped design that was chosen for the PDR. Simulations proved that this design minimizes turbulence during flight while maximizing drag. The fins are deployed in a constant feedback loop by a DC-actuated spur gear and onboard encoders. Full deployment of the fins corresponds to 90 degrees of rotation from retraction, and 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, and finite element analysis (FEA) showed that the 3D printed fins as-built can withstand this force.

Figure 3.2.1: (Clockwise starting from upper left

ADAS open, ADAS closed, angled 3D open view

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. Solidworks simulations of the rocket's flight at velocities up to an upper threshold of 240 m/s with varying degrees of fin deployment yielded $c_d$data that is interpolatable for use in further simulation and fin control.

3.2.1.2 Assembly

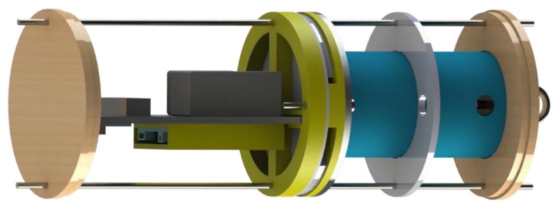


Figure 3.2.2: ADAS without external Blue Tube housing

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 3.2.2. The total mass of the unit, including the Blue Tube coupler is 1.365kg, and the length of the cylinder, measured from the outsides of the endcaps, is 14.08" (35.8cm). The specific assembly steps of the unit is outlined in the safety checklist in section 4. All components will be secured to the electronics sled with metal screws to provide increased security, and connections will be soldered together to ensure strong electrical contact.

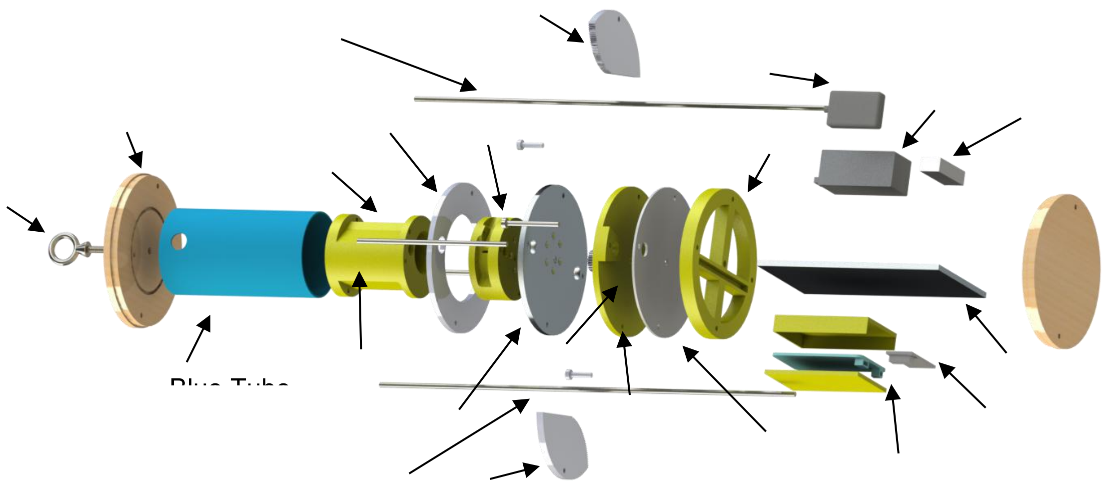


Figure 3.2.3: Exploded view of ADAS with labeled components

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 0.5” Coupler 0.1”
	Bottom Cap	Wood, 2 holes. Sled cutout	73	OD 5.36” ID 5.22” Thick 0.5” Sled 0.25”
Electronics Bay	Sled	Fiberglass plate	120	Length 7” Width 4” Thick 0.2”
	Inner Cap	PLA, 3D Printed, 5 holes, sled cutout	30	OD 5.22” Thick 0.5”

	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 0.58”
	Motor Driver	MD13S Cytron Motor Driver	22.5	Length 2.4” Width 1.3” Thick --
	Power Port	PCB, screw terminals to divert power	15	Length 1.95” Width 0.84” Thick 0.51”
	Power Converter	DC to DC USB Buck Converter	4	Length 1.04” Width 0.60” Thick --
	IMU	GY-521 MPU6050	5	Length 0.83” Width 0.63” Thick --”
	Motor Controller	Arduino Teensy LC	4	Length 1.41” Width 0.69” Thick 0.4”
	Microcont roller	Raspberry Pi B 3+	49	Length 3.43” Width 2.21”

				Thick 0.67”
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, 10 holes	60	Length 3.02” OD 2.87”
	Motor Housing Bottom	PLA, 3D Printed, 4 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	Neverest 40 geared DC motor	100	Length 4” OD 1”
Hardware	Allthreads (4x nut)	Steel, passes through majority of parts, secures entire	60	OD .18” Length 16”

		assembly		
	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 .9 3” OD .18”
	Motor screws (6x screw)	Steel, secures motor to bottom plate and bottom motor housing	2	--
	Motor Allthread s (4x nut)	Steel, secures motor housing to top cap	19	Length 5.75” OD .18”
	Containm ent 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			1364.5	

Table 3.2.1: L[illegible] specifications.

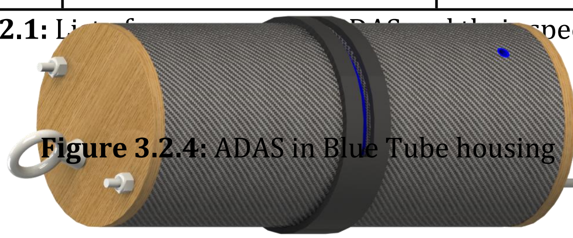


Figure 3.2.4: ADAS in Blue Tube housing

3.2.2 Electrical Hardware

3.2.2.1 Overview

The general design of ADAS remained the same during assembly, however with some slight redesign specifications concerning the onboard computational chips. The overall electrical hardware will function according to the diagram below.

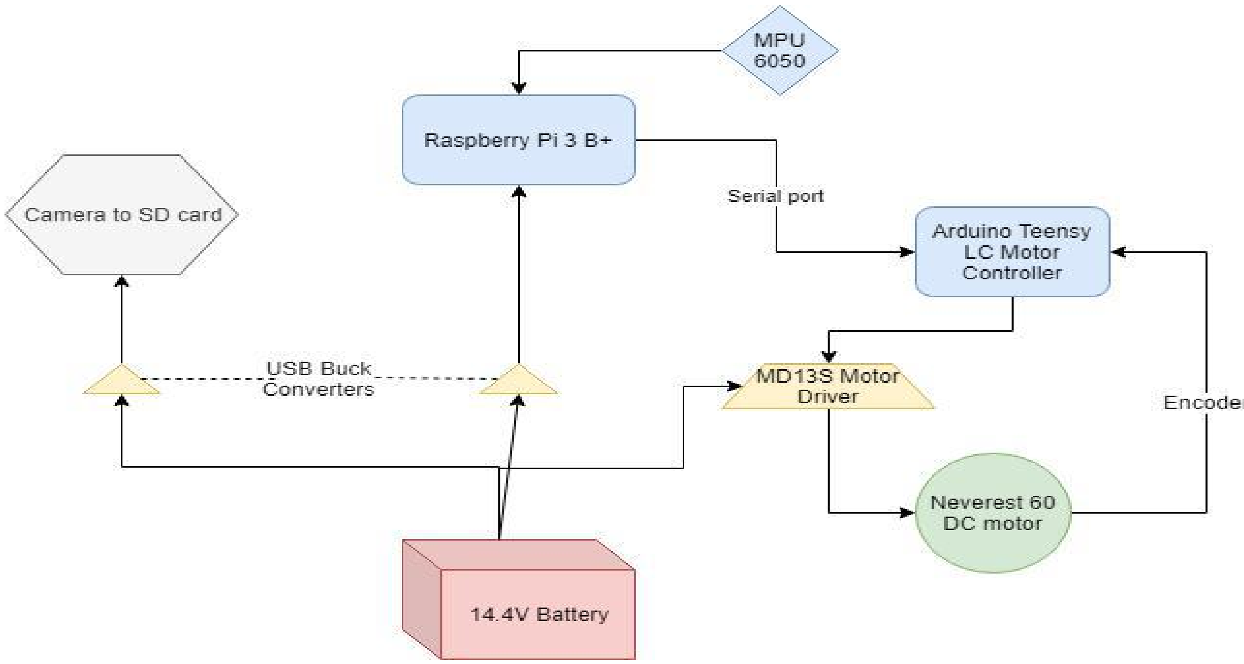


Figure 3.2.5: Electric component overview

Our initial designs from the CDR proposal for the assembly of our rocket are being redone due to a number of hardware failures during prototyping and assembly. Three issues were identified that needed to be addressed in the physical redesign:

- Constant beaglebone issues
- Motor driver shortage
- Loose pin connections

These issues were discovered during the first unsuccessful launch of the full-scale rocket prompting a rapid redesign to address and avoid these issues. The specific shortcomings and their source of each problem are outlined in the following table:

Problems Found in Initial Full Scale Assembly

Task	Responsible hardware	Difficulties
Communication with base team through wifi/ssh	Onboard wifi chip	Wifi was unreliable and difficult to connect to

Running of python PID code to calculate algorithm	Onboard 64 bit processor with full linux code support	Requires somewhat intensive computational power
Powering of onboard camera	Power out pins	Had to make custom power pins from board
Driving of motor driver through gpio pins	Onboard multipurpose pins	Had to create custom wires and libraries Pins had no overvoltage protection
Data logging of sensor data	Onboard SD card connector	Read write mount issues
Reading of IMU sensor data and extrapolation	Onboard IMU module and resulting library	Rewrote code slightly for use
Interface with battery to power itself	Onboard power regulator IC	Frequently blew out despite being in range

Table 3.2.2: Issues with CDR ADAS

The redesign of ADAS will solve these issues by modularizing the hardware to alleviate single points of failure, and using boards with more support over the beaglebone ecosystem. The redesign will be taken care of by the following new parts:

- Raspberry Pi 3 B+ model
- Arduino Teensy
- Mpu-6050 IMU
- Battery to USB power converter with voltage protection and two separate outputs

These improved hardware choices will solve the issues in the following ways:

Task	**Responsible hardware**	**Solution**
Communication with base team through wifi/ssh	Raspberry pi onboard wifi and bluetooth connectivity	Connect to raspberry over wifi or bluetooth
Running of python pid code to calculate algorithm	Raspberry pi onboard Cortex-A53 64-bit 1.4GHz processor	The processor will be running linux as the operating system to handle algorithm calculations
Reading of motor encoder to handle position calculations	Arduino Teensy	Utilizing the prebuilt encoder library and interfaced with the standard IO pins to read encoder data

Powering of onboard camera	Battery to USB power converter	Connect camera to battery through converter, allowing standard connection and voltage protection
Driving of motor driver through gpio pins	Arduino Teensy connected over serial connection to Raspberry pi	The Teensy will be responsible to handling all motor overhead, simply taking in a single position number and driving the motor to that position using the closed encoder feedback loop
Data logging of sensor data	Raspberry pi micro SD card reader	Utilizing the onboard SD card as the main storage system to log data
Reading of IMU sensor data and extrapolation	Mpu-6050 connected to Raspberry pi through standard GPIO pins	Using standard libraries to interface with imu and retrieve data for processing by python program
Interface with battery to power itself	Battery to USB connection	Connecting through a usb interface with power support will alleviate issues with power shorting

Table 3.2.3: ADAS redesign solutions

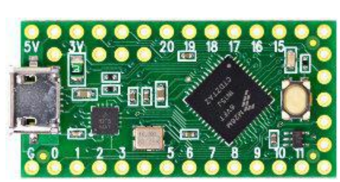
In addition, to combat the issue with the motor driver becoming shorted, the team has installed a 10A fuse between the battery and the connection as well as clearly marked the pin headers. As a backup the team have also purchased multiple copies of the motor driver to have at least one working copy on hand at all times. To combat the issues with the pin connections of components coming loose the team have developed the improved securement methods. In the assembly, the team soldered wire connections together to increase strength, and purchased stronger securement screws to secure pieces to the base plate.

With these new design measures in place, the team has been able to create a more robust and proven ADAS.

3.2.2.2 Microcontrollers

Figure 3.2.6: Raspberry Pi Model 3 B+

Figure 3.2.7: Teensy LC



Raspberry Pi Model 3 B+:

A Raspberry Pi Model 3 B+ will run the python control algorithm, read from an IMU and write to the motor controller. The new board is significantly less expensive and yet has comparable performance housing a 1.4GHZ quad-core arm processor and 1GB of ram. The Raspberry Pi runs Raspbian, a debian based Linux distribution. Communication with the motor controller will be done via serial UART pins and their corresponding linux serial device. Storage for the OS and data logging will be done via the board's micro-sd port, write speed will be limited to 10MB/S which will be sufficient for data logging.

Teensy LC:

Motor control will be done through a Teensy LC. It's 48 MHz single core arm processor and 8K RAM will be ample to run the motor control code. The board will read data from the raspberry Pi via Teensyduino's serial UART library. The motor's encoder and write to the controller using gpio via Arduino Teensy's digital I/O library. Storage will be done on the boards onboard 62K Flash. The Teensy LC has no overvoltage protection so extra care must be taken when working with the board.

Figure 3.2.8: DC-DC Buck converter

3.2.2.3 USB Buck converter

As the Raspberry Pi 3 B+ and the onboard camera only take in standard 5V USB DC input, a buck converter was used to reduce the incoming voltage from the battery, providing a certain level of overvoltage and overcurrent protection. The team decided on the Ailavi DC-DC Buck converter with input tolerances of up to 19V and an output of 5V 3A. The connection to the battery is done through 2 soldered on wires, and the output port is a standard USB connector allowing the flexibility to use standard wires for connection. Several converters were purchased as 2 were needed for the Raspberry Pi and camera, and several left over as a backup.

3.2.2.4 Neverest 40 DC Motor

The motor the team is using is the Neverest 40 DC motor with built in encoder as was proposed in the CDR. The motor itself has ample torque and speed to meet the teams requirements, and has proven reliable in use during the past several launches. The motor itself will be controlled through the motor driver which itself will be controlled through the Arduino Teensy board. The encoder will be powered through the Teensy and will be fed back into the motor controller creating a closed feedback loop for the entire motor actuation system.

3.2.2.5 MD13S Motor Driver

The same motor driver as in the CDR proposal was used for the final rocket build as well. The motor driver functioned well providing the functionality to activate, reverse, and rapidly break the motor while taking in as control input only 3 pins with nominal logic voltage. Taking lessons from the mistakes of the past as any one-time-fool knows, several backups of the driver were purchased from the vendor.

3.2.2.6 MPU 6050 IMU

Previously the BeagleBone's onboard inertial measurement unit (IMU) was used in order to collect accelerometer and gyroscope data. Since the team is now using a Raspberry Pi, which has no onboard IMU, the MPU 6050 IMU will be employed to collect accelerometer and gyroscope data. It is very accurate, as it contains 16-bits analog to digital conversion hardware for each channel. Therefore it captures the x, y, and z channel at the same time. The sensor uses the I2C-bus to interface with the Raspberry Pi 3 B+.

The pin connection is as follows:

Raspberry Pi 3 B+	MPU 6050 IMU
Pin 1 (3.3V)	VCC
Pin 3 (SDA)	SDA
Pin 5 (SCL)	SCL
Pin 6 (GND)	GND

Python, using the smbus package, will be used in order to access the data that the IMU outputs. The data is then used during flight to detect the launch, and MECO, as well as stored in the Raspberry Pi's SD card, for post-flight analysis.

3.2.2.7 Onboard Camera

Monitoring of the component during flight will be done with an onboard keychain camera which records 720p resolution footage at 24Hz. The camera will be set to constantly record upon activation and will monitor the fin bay to check deployment characteristics. The camera will now be connected directly to the batter to maintain power and activation. The limiting factor will now be the onboard memory as opposed to the power supply as previously.

3.2.2.8 Component Wiring

The 14.4V LiPo battery is connected to a XT60 connector which has two small wires soldered onto it. These two wires are connected to a four terminal power distribution block, which distributes the power to all of the components of ADAS. The motor driver and two buck converters are all connected to the power distribution block. There is a 2 Amp fuse between the power distribution block and the USB buck converter that is connected to the Raspberry Pi. There is another fuse, rated at 10 Amps, between the power distribution block and the motor driver. The USB buck converter that does not have a fuse is connected to the camera. An MPU is connected to the Raspberry Pi, which in turn is connected to the Arduino Teensy motor controller. The Arduino teensy is wired to the motor driver, which is then wired to the motor. Finally, the motor's built in encoder is wired back to the Arduino Teensy.

3.2.3 Software

3.2.3.1 Data Filtering and Estimation

The fin-control algorithm compares 6-axis IMU data with reference data to determine necessary fin deployment corrections to successfully attenuate the rocket's apogee to 5280 ft. Acceleration and gyroscope data is read from the IMU and is passed through a Kalman filter for noise reduction and an estimator of velocity and position.

3.2.3.2 Dynamics and Optimization

Optimal control packages and techniques, including Gekko with Python, along with appropriate dynamics and parameters provide reference data for the rocket's flight. This data is computed on-ground and is loaded onto the ADAS computer. The optimized control problem is posed as follows, where the system is solved for the deployment percentage δ that minimizes the objective and matches the boundary conditions $x(t_F) = 5280\ ft$ and $v(t_F) = 0\ ft/s$, with t_E and m_E being the respective time and mass at MECO as predicted by simulations, and t_F is unfixed,

$$\min_{\delta} \int_{t_E}^{t_F} (\delta(t))^2\, dt$$

subject to:

$$\dot{x} = v$$

$$\dot{v} = -g - F_d(t)/m_E\ .$$

Solving this optimization problem results in values for and relations between the position $x(t)$, velocity $v(t)$, and drag fin deployment $\delta(t)$. These states are used as reference by the PID control algorithm that outputs adjustments of the fin deployments to the motor driver program.

3.2.3.3 PID and Implementation

Further optimization is employed to tune the system and obtain gain constants K_P, K_I, and K_D that successfully stabilize the system, as shown in Figure 3.2.9.

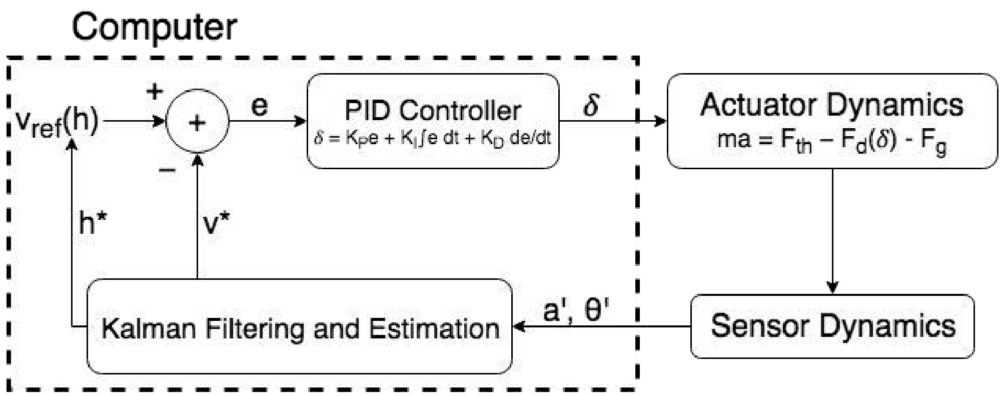


Figure 3.2.9: Control System Block Diagram

Control of the aerobraking fins' deployment is handled by a python program that runs upon boot of the Raspberry Pi. This program provides an interface between the program that acquires and filters data from the 6-axis IMU and the program that writes to and reads from the motor driver. To conserve power between powering-on the ADAS computer and the rocket's launch, the Raspberry Pi will be set to poll the IMU until a vertical acceleration above some threshold (8g) is read indicating the launch event. By setting the board to perform simple polling, the computer will automatically scale the onboard CPU clock to conserve power, and processor intensive tasks will be performed real time and activated only after launch is detected.

3.2.4 Post Flight Results

The results of the previous launch on February 16th exposed deep design flaws within the rocket that are addressed in this redesign. The flight proved that the system functioned structurally well in terms of assembly, however the strength and robustness of components was lacking. Hours before launch both the BeagleBone and motor driver control boards were blown resulting in an non functioning ADAS component. After a rapid redesign with scaled down parameters, the flown system showed structural issues with electrical connections between components, as well as securement to the mounting board. This resulted in the component not deploying during flight. Upon landing however, all physical components remained in functioning order, so while the connections and mounting need to be made stronger the physical components themselves have shown a tolerance to breaking. The newly redesigned system will address these issues as outlined in the previous sections, and will make for a strong and reliable ADAS.

3.3 Recovery Subsystem

3.3.1 Design Robustness of AS-BUILT

3.3.1.1 Structural Bulkheads and attachments

Figure 3.3.1: *Bottom bulkhead*

The ends of the recovery harness attach to the bottom bulkhead of the recovery tube. The stainless steel U-bolt is ¼”-20 thread size and 1 ID. Another endcap was cut out of plywood to add strength. Two nuts secure the U-bolt in place with a mounting plate.

Harnesses

Figure 3.3.2: *Shock cord with chutes,, nomex blanket and jolly logic chute releases*

The kevlar shock cord is ⅜” thick, and has a rate load of 2400 lbs. It’s 40ft in length. It connects the drogue chute, main chute, and nomex blanket.

Battery retention

The batteries are housed by ½" aluminum angles. The angles were cut into six 2.7 in pieces, lined up parallel to house 3 batteries. This is towards the bottom of the avionics sled. Two angles are used for one 9V battery each. A 0.2 in space is left between each set of angles, leaving the fiberglass exposed. Here, there is one hole that is drilled to thread the battery wire connectors through. One 3.65 in piece was cut and faces outward, perpendicular and adjacent to the other pieces. Each aluminum angle has 2 screws that are secured by M3 nuts.

Finally, a piece of tin was bent to act as a cross bar to secure the batteries into place, so they don't fall outward. This is secured onto the plate with 3 screws.

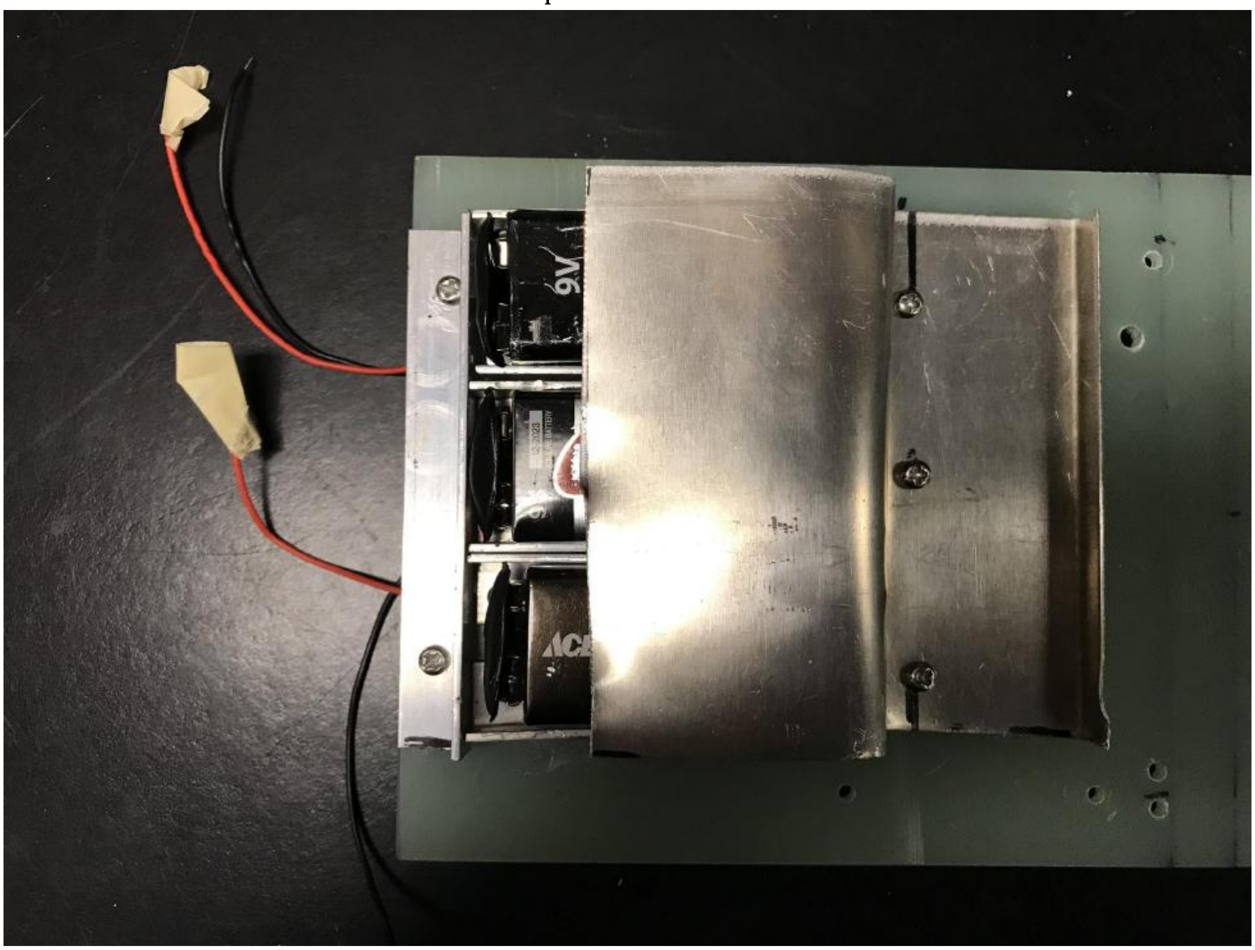


Figure 3.3.3: *Battery retention system*

Shear pins

Two 2-56 X 1/4" long Round Slotted Nylon Machine Screw are tapped through the top of the recovery section and into the nose cone. This allows for the nose cone to stay secure until the detonation of the black powder charges.

Quicklinks

Three quick links are used for convenient assembly of the recovery harness (one for drogue chute, one for main chute) and one to attach to a bulkhead.

3.3.1.2 Electrical

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

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.

Screw switch

Two plastic shell screw switches are secured on each end of the plate facing outward with epoxy. A hex key is used to lock the switch into place before flight. The screw is accessed through a hole.

Mount

A U-bolt is fastened into one of the bulkheads. Connected to the U-bolt is the shock cord that contains the main parachute and drogue parachute.

Terminal block

Figure 3.3.4: *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 altimiters 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.

3.2.1.2.1 Redundancy Features

The StratologgerCF and Easymini altimeters provide an independent dual modular redundancy system. They are powered from different 9V batteries, connect to two different black powder charges, and are connected to different switches to ensure completing the first phase of deployment.

The use of two Jolly Logic Chute Releases is the second stage of redundancy features. The bands that connect them are wrapped around the main chute in series. This will allow the main chute to deploy at 500 ft.

3.3.1.3 Parachute Sizes and Descent Rates

Main chute

Figure 3.3.5: *Iris Ultra 60" Standard Parachute*

The team decided to use an Iris Ultra 60" Standard Parachute from Fruity Chutes that will be released at a height of 500 ft. The toroidal shape was chosen to minimize parachute size and weight, and the diameter was chosen in order to minimize drift.

Specification	**Value**
Shape	Toroidal
Diameter	60 in
Weight	6.8 oz
Packing volume	38.2 in^3
Coefficient of drag	2.2

Table 3.3.1: *Main parachute specifications*

Drogue parachute

Figure 3.3.6: *18" Compact Elliptical Parachute*

For the drogue parachute, the team decided on the 18" Compact Elliptical Parachute from Fruity Chutes that will be released at apogee to meet the descent time requirement. An elliptical parachute was chosen to minimize parachute size and weight, and the parachute diameter was chosen in order to minimize descent time and drift.

Specification	**Value**
Shape	Elliptical
Diameter	18 in
Weight	1.16 oz
Packing volume	6.4 in^3
Coefficient of drag	Between 1.5 - 1.6

Table 3.3.2: *Drogue parachute specifications*

Shock cord

The team will use a 40 ft Kevlar shock cord with a three-quarter inch diameter. This will connect to the main and drogue parachutes using quicklinks, and attach to the Kevlar blanket for wrapping the parachutes. Initially, the team planned to use a 20 ft long and quarter-inch diameter shock cord, but the team decided to use a thicker cord because it was stronger and a longer cord to lessen the force on the rocket as the parachute opens.

Figure 3.3.7: *The Kevlar shock cord used on* *<u>OH YEAH</u>* *with quicklink*

3.3.1.4 Transmitters

StratologgerCF

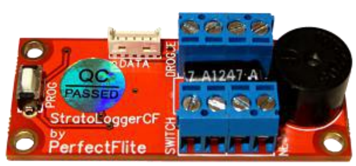


Figure 3.3.8: *PerfectFlite Stratologger CF*

The PerfectFlite Stratologger CF was the team's chosen primary altimeter. It is powered by a 9V battery and helps fire the first ejection charge at apogee.

EasyMini

Figure 3.3.9: *Easy Mini Altimeter*

The EasyMini is the team's secondary altimeter. It is powered by a 9v battery and helps fire the second ejection charge. It has a two second delay time to ensure pressure buildup is not extremely high. It is set on redundancy mode through its settings, making it a redundant feature of the recovery system.

The EasyMini altimeter is connected 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. Hence the two second delay.

Eggfinder TX

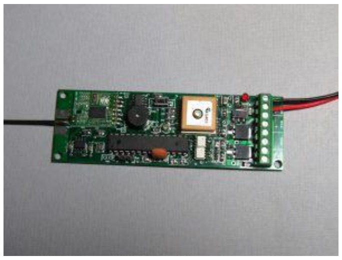


Figure 3.3.10: *Eggfinder TX*

The Eggfinder TX is the team's chosen tracking device. It records the real-time position of the rocket as it lands. The team is using it in conjunction with the Eggfinder RX. The Eggfinder TX allows a range of 10,00 feet and a resolution of 2.5 meters.

Jolly Logic Chute release

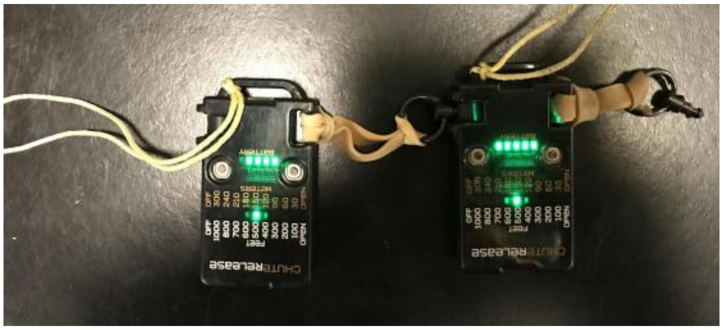


Figure 3.3.11: *Jolly Logic Chute Release*

Two jolly logic chute releases are connected in series, and wrap around the main parachute. The redundancy of wrapping them in series makes it so one chute release will at least work and help aid in deploying the parachute at the correct altitude. The main parachute is set to release at 500 feet.

3.3.1.5 Sensitivity and Interference

Transmitter	Operating Frequency	Receiver
EggfinderTX (Recovery transmitter)	921 MHz	EggfinderRX (Recovery receiver)

Table 3.3.3: *Operating Frequency of Trackers*

3.4 Mission Performance Predictions

3.4.1 Simulation Results

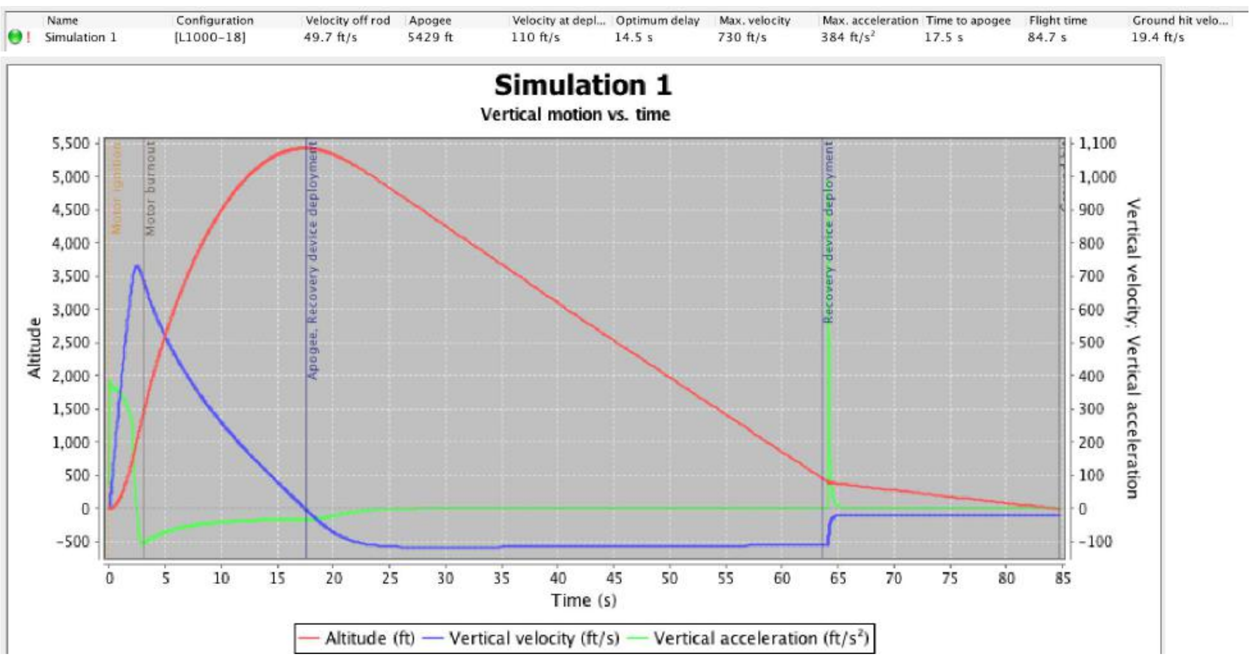


Figure 3.12: *OpenRocket Simulation Results*

3.4.2 Stability and Vehicle Characteristic Relationships

The vehicle's center of gravity with the motor (denoted by the blue dot in the figure below) is located 59.873" from the nose and its center of pressure with the motor (denoted by the red dot in the figure below) is located 78.878" from the nose, as calculated in OpenRocket. This gives a distance of 19.005" between them. Dividing by the outer diameter of the rocket, 5.5", this produces a static stability margin of about 2.28 . Without the motor, the stability margin is 3.43.

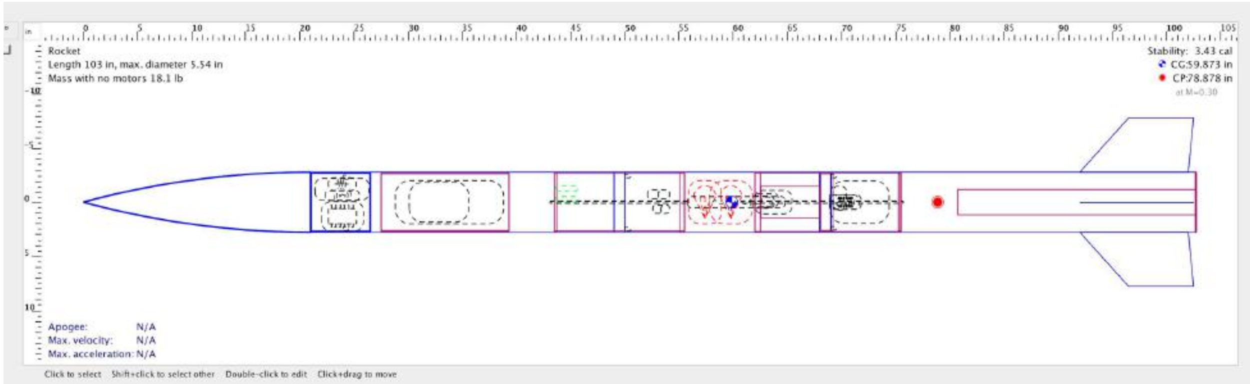


Figure 3.13 *OpenRocket Model of OH YEAH with motor*

OH YEAH has a thrust-to-weight ratio of 9.8, and a predicted rail exit velocity of 61 ft/s.

3.4.3 Kinetic Energy

OH YEAH is designed to not have any independent sections separate from the launch vehicle during flight. A single separation event occurs at apogee, and both sections of the rocket remain tethered for descent.

Tethered Section	Subsystem	Mass
Upper (above ADAS)	Nosecone	757g
Upper (above ADAS)	Payload	1622g
Upper (above ADAS)	Recovery	1956g
Upper Section Total: 4335g		
Lower (ADAS & below)	Thrust (no motor)	1658g
Lower (ADAS & below)	ADAS	1508g
Lower (ADAS & below)	Fins	708g
Lower Section Total: 3874g		
ALL	**Rocket Total: 8209g**	

Table 3.4: *Final predicted rocket mass based on OH YEAH weight measurements*

In order to meet NASA SLI requirements, the rocket must not exceed a landing energy of approximately 100J.

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

KE < 100J (KE cannot exceed 100 joules in order to meet SLI requirements)

Upper: $v = \sqrt{\frac{2(100J)}{4.5kg}}$ = 6.67 m/s

Lower: $v = \sqrt{\frac{2(100J)}{3.8kg}}$ = 7.25 m/s

The tethered rocket must hit the ground at a velocity **less than 6.42 m/s** in order to meet NASA SLI recovery requirements. (*Simulations predict rocket will land at 6.04 m/s*) Another test launch is required to confirm landing velocity.

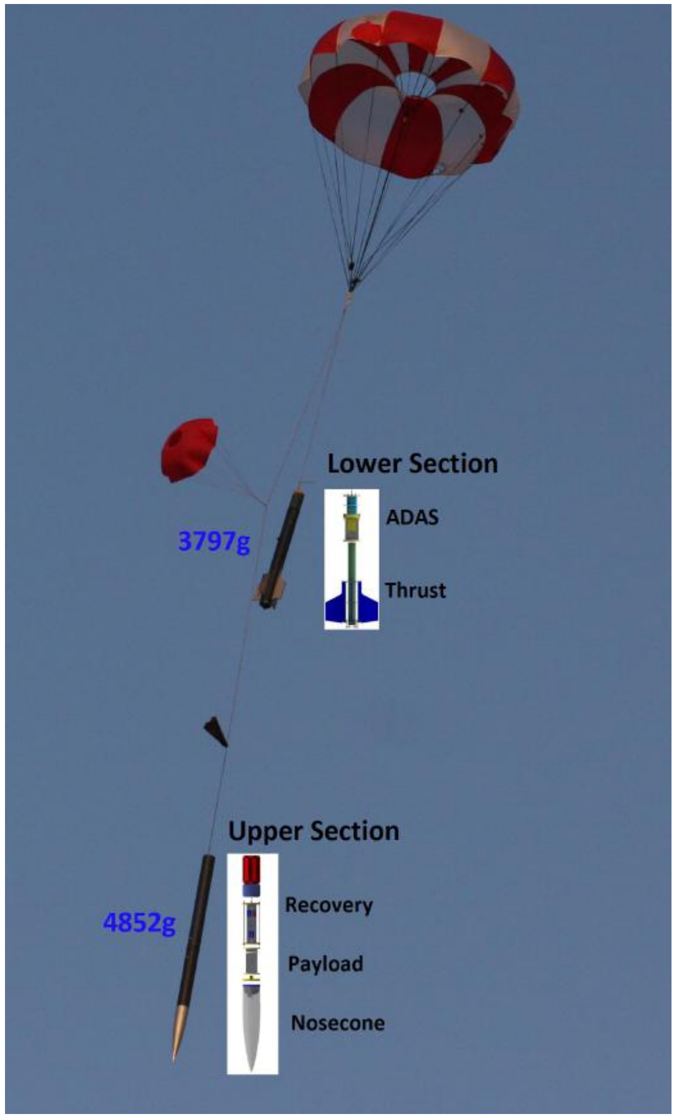


Figure 3.14: *Full Scale mass distributions visualized using* *Take Me Home* *recovery*

3.4.4 Descent Time

The descent time must not exceed 90 seconds in order to satisfy SLI requirements. *OH YEAH's* descending mass is estimated to be 8.2kg.

Descent time is dependent on:

- Rocket mass
- Drogue parachute drag
- Main Parachute drag
- Parachute release time

At apogee (5280 ft) a 24" hemispherical drogue parachute with 4" parachute is released. The drogue will be used to control the descent of the rocket from 5200 ft → 600ft, falling a total of 4600 ft (1402 m) before the main parachute is released.

Calculating descent time of rocket from apogee till main parachute release

Estimating the velocity of descent using only drogue parachute drag. (Not factoring in the drag of the airframe)

$$V = \sqrt{\frac{2F_d}{pC_dA}}$$

$F_d = F_g = ma =$ $\boldsymbol{8.2kg\ (9.81\ \frac{m}{s^2})}$= 80.5N

$$\boldsymbol{\rho\ =\ 1.22\ \frac{kg}{m^3}}$$

$$\boldsymbol{A\ =\ \Pi r^2\ (r = 0.15m) = .07m^2}$$

$$\boldsymbol{C_d\ =\ 0.75\ (estimated)}$$

V = 50.1 m/s

The coefficient of drag for the drogue parachute + rocket was previously unknown. Using data collected from the subscale flight, we determined an approximate coefficient of drag that can be used to roughly estimate descent rate.

$$\boldsymbol{C_d = \frac{2(g)(m)}{(p)(s)(v^2)}} = 5.29$$

g = $9.81\frac{m}{s^2}$

$m =\ 5.19kg$ (subscale weight)

$$\boldsymbol{\rho\ =\ 1.22\ \frac{kg}{m^3}}$$

$$\boldsymbol{s\ =\ \Pi r^2\ (r = 0.15m) = .07m^2}$$

$\boldsymbol{v^2\ =\ (15\frac{m}{s})^2\ = 225\frac{m^2}{s^2}}$

Estimating the velocity of descent using drogue parachute drag and drag of the subscale airframe. (Not factoring in the changes from the full scale airframe)

$$\boldsymbol{V = \sqrt{\frac{2(g)(m)}{(p)(s)(C_d)}}}$$

g = $9.81\frac{m}{s^2}$

$m =\ 8.2kg$ (full scale weight)

$$\rho = 1.22\ \frac{kg}{m^3}$$
$$s = \Pi r^2\ (r = 0.15m) = .07m^2$$
$$C_d = 5.29\ \text{(Drag of rocket + drogue estimated from subscale flight)}$$

V = 18.9 m/s

$$Time = \frac{distance}{velocity}$$

Time = $\frac{1402m}{50.1\frac{m}{s}}$ = 28 seconds

Time = $\frac{1402m}{18.9\frac{m}{s}}$ = 74 seconds

The actual drogue descent time likely lies between the above values (average is **49.6 seconds**), but computer simulations and a test launch will be able to confirm this.

<u>Open Rocket Descent Simulations:</u>

Drogue descent velocity: **36 m/s**

- Main release at 200m **43 seconds** after apogee**.**

Calculating descent time of rocket from main release (200m) till landing

---

Estimating the velocity of descent using only main parachute drag. (Not factoring in the drag of the airframe)

$$V = \sqrt{\frac{2F_d}{pC_dA}}$$

$F_d = F_g = ma = 8.2kg\ (9.81\ \frac{m}{s^2})$= 80.5N

$$\rho = 1.22\ \frac{kg}{m^3}$$
$$A = \Pi r^2\ (r = 0.76m) = 1.82m^2$$
$$C_d = 2.2\ \text{(from manufacturer)}$$

V = 5.8 m/s

$$Time = \frac{distance}{velocity}$$

Time = $\frac{200m}{5.80\frac{m}{s}}$ = **34.48 seconds**

The main descent time is most likely less than 33.8 seconds since airframe drag must be factored in, but computer simulations and a test launch will be able to confirm this.

Open Rocket Descent Simulations:

Main descent velocity: **6.04 m/s**

- Landing after **29 seconds** from main parachute release**.**

The total descent time is estimated to be **72 seconds.** This value was obtained by using Open Rocket simulation data. The Open Rocket data confirms our original predictions done by hand (83.4 seconds).

3.4.5 Drift

NASA SLI requirements state that the recovery area must not exceed a 2500 feet radius.

$$Drift = Descent\ Time * Wind\ Velocity$$

5mph = 2.2 m/s
10mph = 4.47 m/s
15mph = 6.7 m/s
20mph = 8.9 m/s

At 0mph: Drift = 72 sec * 0 m/s = 0m → 0 feet
At 5mph: Drift = 72 sec * 2.2 m/s = 158.4m → 519.7 feet
At 10mph: Drift = 72 sec * 4.47 m/s = 321.84m → 1056 feet
At 15 mph: Drift = 72 sec * 6.7 m/s = 482.4m → 1581 feet
At 20mph: Drift = 72 sec * 8.9 m/s = 640.8m → 2101 feet

Wind Speed	Drift
0 mph / 0 m/s	0m / 0 feet
5 mph / 2.2 m/s	158.4m / 519.7 feet

10 mph / 4.47 m/s	321.84m / 1056 feet
15 mph / 6.7 m/s	482.4m / 1581 feet
20 mph / 8.9 m/s	640.8m / 2101 feet

Table 3.5: *Predicted drift based on hand calculations*

<u>Open Rocket Drift Simulations:</u>
At 0mph: Drift = 2.4m → 8 feet
At 5mph: Drift = 63.5m → 208 feet
At 10mph: Drift = 129m → 423 feet
At 15 mph: Drift = 224.5m → 737 feet
At 20mph: Drift = 320.5m → 1052 feet

Wind Speed	Drift
0 mph / 0 m/s	2.4m / 8 feet
5 mph / 2.2 m/s	63.5m / 208 feet
10 mph / 4.47 m/s	129m / 423 feet
15 mph / 6.7 m/s	224.5m / 737 feet
20 mph / 8.9 m/s	320.5m / 1052 feet

Table 3.6: *Predicted drift based on OpenRocket calculations*

While the drift calculations done by hand and the simulations are off by a factor of 2, both predictions are within the 2500 foot recovery radius at winds up to 20 mph. This is satisfactory, and a test launch can be conducted to confirm actual drift values.

3.4.6 Alternate Calculation Method

3.4.6.1 Calculation Differences

<u>Descent Time</u>

- Hand calculations: **83.4 seconds**
- Open Rocket simulation: **72 seconds**

The descent time differences are not substantial enough to be worrying. Considering that the relatively simplistic calculations done by hand are very similar to the simulation, our prediction is confirmed. A successful test flight is required to obtain the actual descent time data.

Drift
- Hand calculations: @20mph - **2101 feet** drift
- Open Rocket simulation: @20mph **1052 feet** drift

The drift calculations done by hand were very basic. This could be the reason OpenRocket simulates much less drift. The Open Rocket simulation is likely more robust, and predicts much less drift the calculations done by hand. While it may a good idea to improve our drift calculations methods for the future, the rocket drift seems well within the SLI recovery criteria. Accurate drift data is best obtained through a successful test flight.

3.4.6.2 Verification of Simulation Results

As shown by the various methods of calculation of both the drift and flight times, the vehicle will satisfy the drift and landing energy requirements set by NASA. These methods include hand-calculation using various formulas, and the OpenRocket simulation software.

3.5 Vehicle Demonstration Flight

The full-scale flight was carried out on February 16th, 2019 at the Friends of Amateur Rocketry (FAR) launch site in Cantil, CA. Our normal launch site in Snow Ranch, CA was rained out and cancelled on that day. The team was joined by our mentor, David Raimondi, who facilitated all motor and ejection charge assembly.

3.5.1 Launch Day Conditions and Simulations

The launch day conditions were sub-nominal. There were intense and variable winds, with gusts of up to 35 mph. There was little no cloud cover, allowing us to launch when we were ready. Once assembled, we took our rocket to the launch pad and prepared to launch.

Time	Wind Speed	Wind Gusts	Direction	Temperature	Pressure	Conditions
15:55 PST	29 MPH	31 MPH	268° (W)	50° F	29.97 Hg	Little to no cloud cover. High winds.

Table 3.5.1: Weather conditions at time of launch

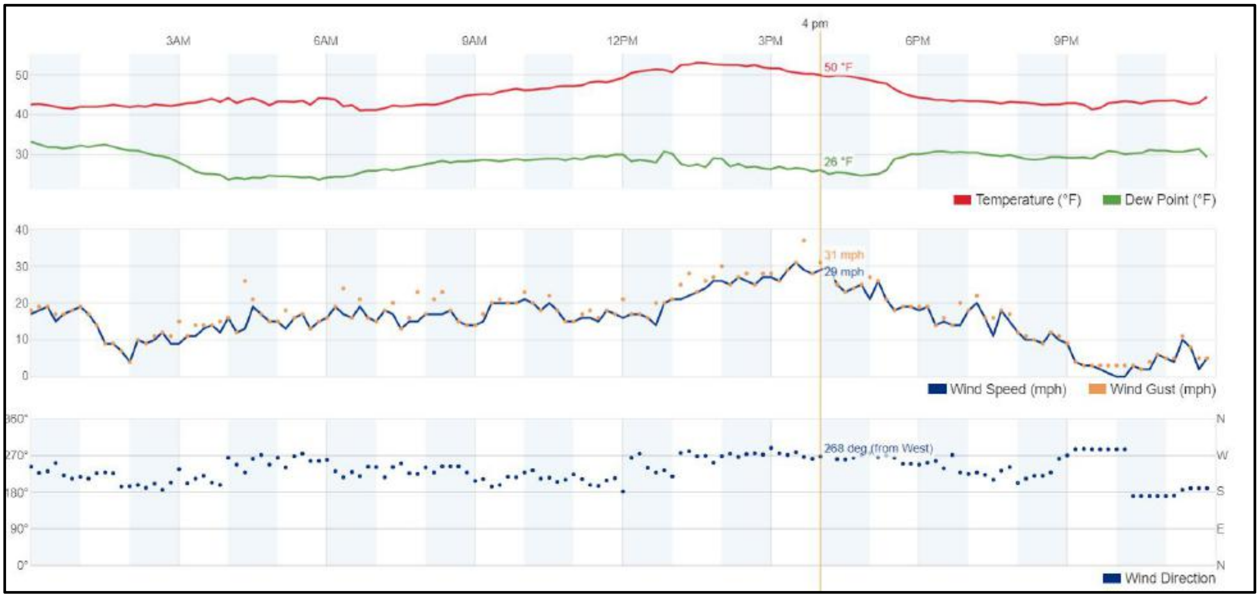


Figure 3.5.1: Launch Day Conditions from a nearby weather station

3.5.2 Vehicle Flight Analysis

3.5.2.1 Flight Failures

There were a number of issues during the launch. These include a failure of the ADAS system, failure of payload/nose cone securement, and failure of full main parachute deployment. We plan on fixing them and have taken actions to redesign the issues.

Failure	Working Rationale	Potential Solutions
ADAS failure to start and function	High acceleration during launch caused wires to come undone, resulting in ADAS from functioning.	Better securement of wires into respective locations, either through solder, electrical tape or a combination of both.
Payload securement failure	The shear pins were sheared prematurely at apogee, pushing the payload section to rely on secondary securement method. This secondary securement method (a rope tied to payload section and recovery section) came	Use stronger shear pins to ensure they do not shear prematurely. Replace rope system and Actuated Landing Correction servo that holds sled with a passive Actuated Landing

	undone, resulting in payload section to freefall to the ground.	Correction system where the center of a bearing is fastened to the edges of a coupler.
Failure of full main parachute deployment	The main parachute was entangled by itself due to the high winds, preventing it from full deployment. This is due to the use of a sub-nominal packing technique leading shroud lines to be loose.	Fold shroud lines to stay contained in main parachute so it is not exposed until deployment.

Table 3.5.2 Failure points during full scale test flight

3.5.2.2 Actual vs Predicted

Due to the failure of the ADAS electronics, the only onboard data recovered from the full-scale flight was from the two barometric altimeters, an EasyMini and StratologgerCF. Below are plots of the vehicle's altitude, velocity and acceleration. The Stratologger acceleration was determined through the derivative of the velocity, which contributed to the very noisy data set. The OpenRocket data is not very accurate for altitude. This is believed to be due to the high winds and gusts and a changed mass between the OpenRocket simulations and the actual flight.

Figure 3.5.2 shows the vehicle's altitude from a number of sources and compares them. The smoothed altitude form the EasyMini and Stratologger are shown, along with the OpenRocket simulated altitude. The discrepancy between the simulated and actual is discussed above but is also caused by the parachute failure at apogee. The main parachute become partially deployed at apogee and never fully deployed. This is evident by the constant rate of descent after apogee.

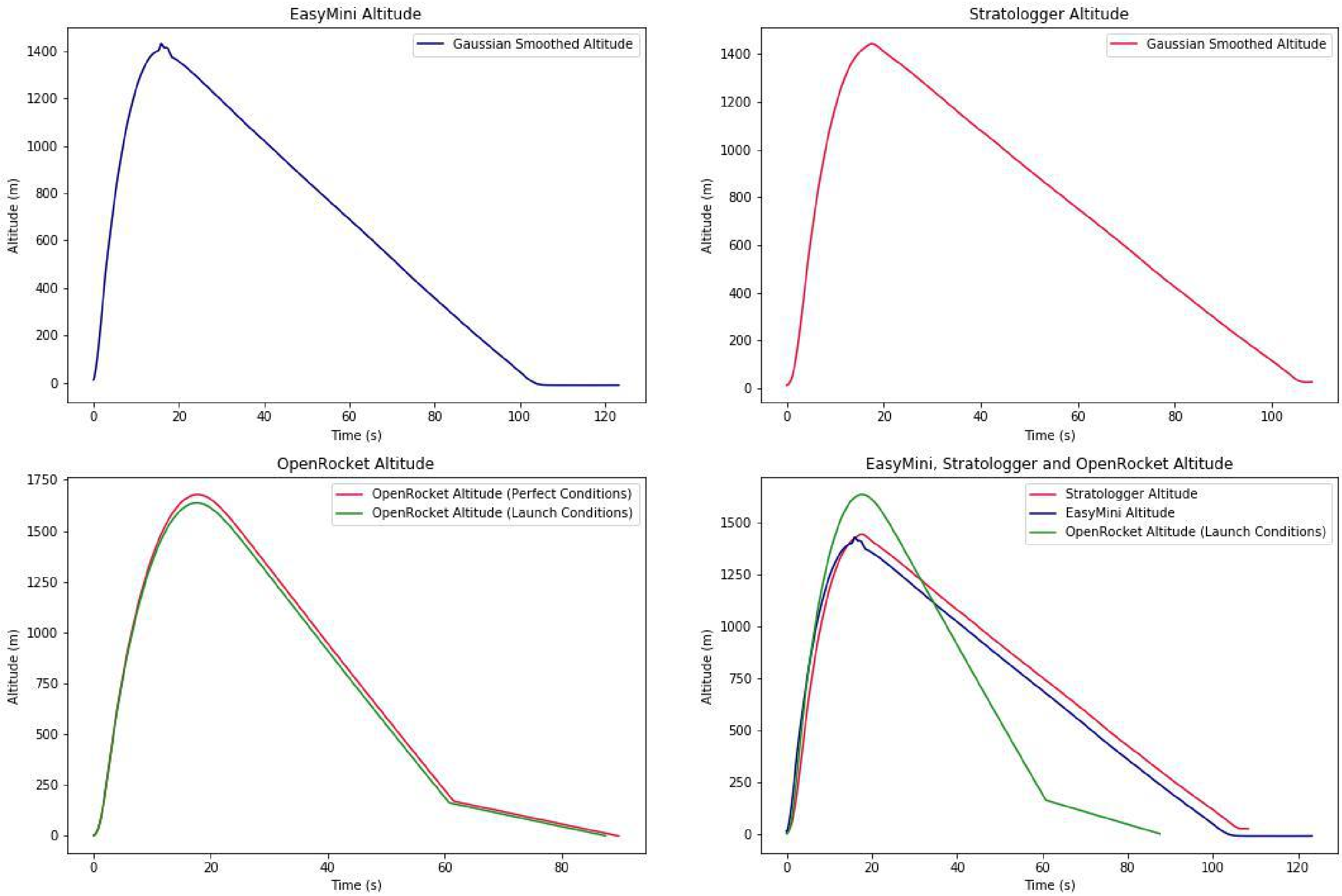


Figure 3.5.2: Altimeter altitude data and OpenRocket simulated altitude plots

The vehicle reached a maximum altitude of 1440 m (4724 ft), a maximum velocity of 180 m/s (591 ft/s) and a maximum acceleration of 100 m/s^s (328 ft/s^2).

Figure 3.5.3 details the vehicle's velocity as given by the EasyMini and Stratologger altimeters. The OpenRocket simulation greatly agrees with the actual, measured, values from the altimeters. However, the discrepancy after apogee is due to the parachute failures, as detailed above. Initially, the vehicle is descending slower than predicted, due to the main parachute being partially deployed. Then, after the simulated main parachute deployment, the vehicle descends much faster, again due to the main parachute not being fully deployed.

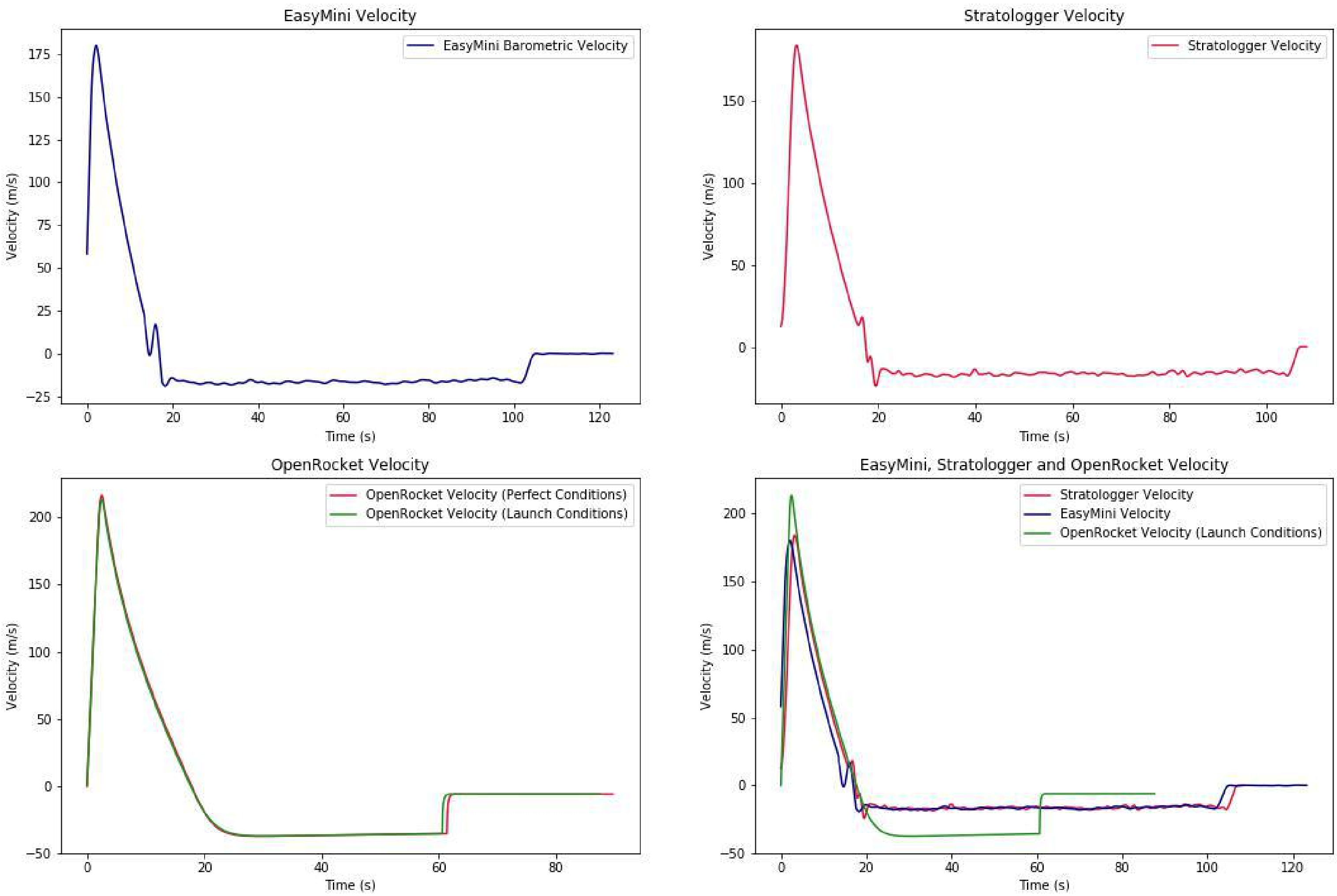


Figure 3.5.3: Altimeter velocity data and OpenRocket simulated velocity plots

Figure 3.5.4 details the vehicle's acceleration given by the EasyMini and calculated from Stratologger-given velocity. The derivative of the Stratologger velocity data produced a very noisy, but relatively accurate data set, as shown in the figure. The OpenRocket simulation agrees very well with the actual data from the altimeters. However, the spike at approximately 60 seconds after launch, due to the predicted main parachute deployment, did not occur during the actual flight.

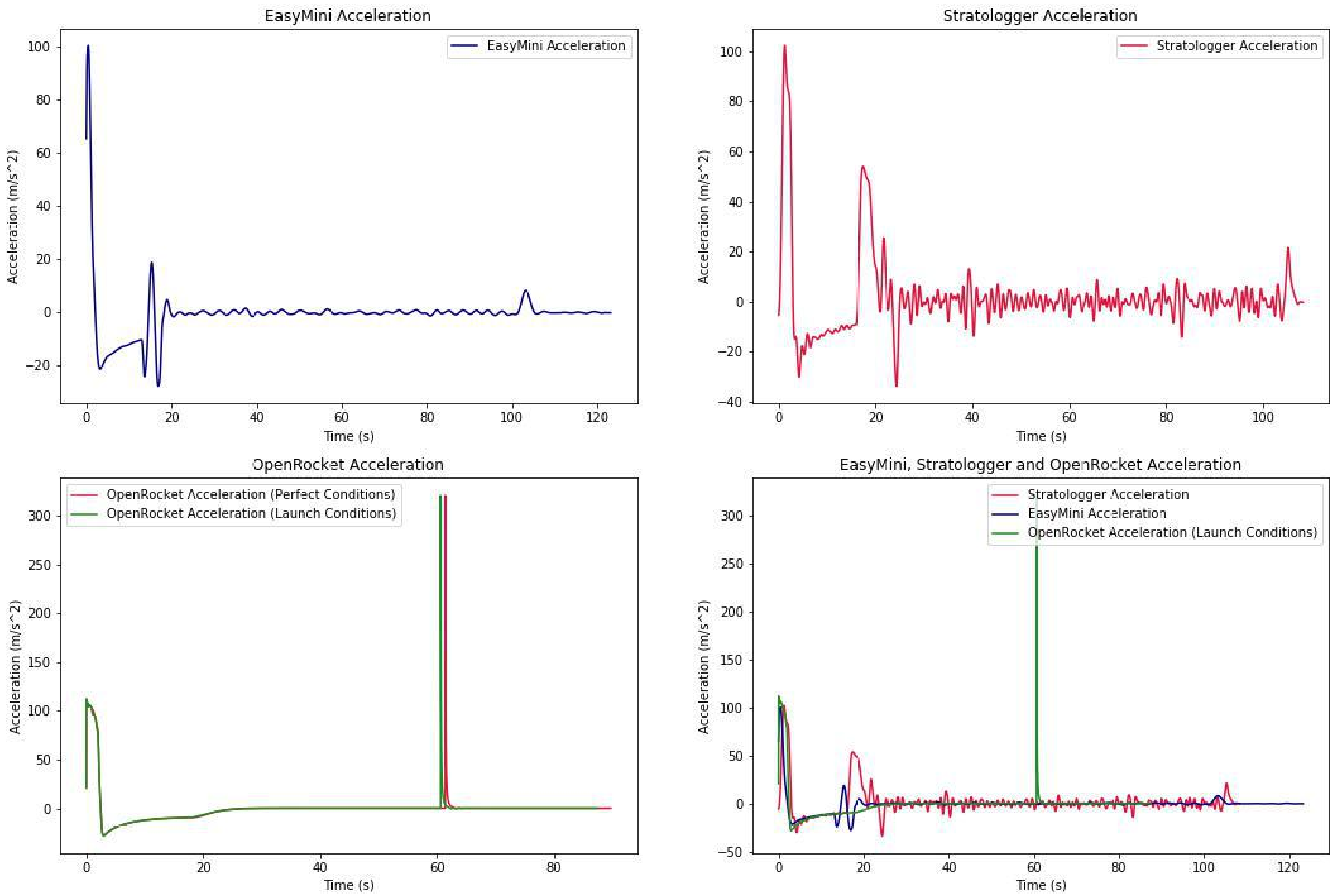


Figure 3.5.4: Altimeter acceleration data and OpenRocket simulated acceleration plots

3.5.2.3 Drag Estimate

To estimate the drag force experienced by the rocket during flight, or the dimensionless coefficient of drag, flight data between engine burnout and flight apogee is considered since

$$F = m(t)a(t) = F_{th}(t) - F_D(t) - m(t)g = -F_D(t) - mg.$$

Combining this information with the well-known drag force relation,

$$F_D(t) = \frac{1}{2} A\, v^2(t)\, \rho\, c_D$$

Which can be rearranged to solve for the drag coefficient,

$$c_D = 2\, F_D(t) / (A\, v^2(t)\, \rho) = 2\, m\, (a + g) / (A\, v^2(t)\, \rho).$$

Obtaining physical estimation of the coefficient of drag, which varies with vehicle velocity and cross-sectional area, would validate the applicability of OpenRocket simulations and is important for tuning the parameters of the algorithm guiding ADAS behavior. Unfortunately calculations with the EasyMini data cannot be resolved to physically meaningful estimates of the drag experienced by the rocket, and the Stratologger data for acceleration is too noisy to be effective in the desired estimation. It is predicted by the team that the next full-scale launch will have resolved its flight and sensor issues so that a reasonable estimate of the coefficient of drag can be obtained.

4 Safety and Procedures

4.1 Team Safety Requirements

4.1.1 Safety Officer

Richard Alves is the Rocket Team at UCSC's Safety Officer for the 2018-19 SLI project season. His experience in electronic and fabrication labs as an Electrical Engineering student provide him with supple knowledge of hazardous materials, risky situations, and the importance of operational manuals and procedures.

4.1.2 Safety Manual and Member Acknowledgement

Additional revisions have been made to the team Safety Manual since the CDR. The changes are summarized as follows:

- Included additional appendices with extra rules, etiquette, and documents to be signed or used throughout lab such that students can print these materials and manual in one document without having to sort through additional content.
- More machinery and tools have been described to identify potential hazards and issues working with those devices.
- A checklist and operating procedures section has been added to provide members with an introduction to launch day activities.
- Updated hazard analysis table to match the risk assessment codes with NASA SLI documentation standards.
- Emphasis on lab and inter-team cooperation in the shared S-Lab space the team occupies with other student groups at UCSC.

More amendments are expected in the Safety Manual between the FRR and Launch Week to better prepare for events away from normal conditions.

The Safety Manual and all other safety documentation is posted on the team's Google Drive and is available to all members free of charge. Members who have read through the Safety Manual and completed the UCSC EH&S lab safety training document (Appendix A), then signed the Safety Acknowledgement Form (Appendix B), demonstrate they are competent lab citizens and gain full privileges to the work space. A running list of members who have signed the Safety Acknowledgement Form, and thus have completed all required training, is maintained by the Safety Officer.

4.1.3 Personnel Safety Measures

In order to quickly and effectively protect personnel from harm when conventional prevention methods and engineering can no longer lower the severity of a hazard, a system of signs and PPE are used in tandem to maximize attention to health and safety. Table 4.1 provides the identifying symbols for the type of PPE or preliminary fulfillment needed when performing certain activities for the team. Section 4.3 makes extensive use of the PPE symbols for when the team is assembling and launching its rocket and payload. Additionally, the team identified a major hazard of spreading epoxy fumes into lab room 360 (see Figure 4.1) when fabricating carbon fiber vehicle parts. The location of this epoxy usage was moved into adjacent lab room 364 within the Sustainability lab space of UCSC Thimann labs, and a flyer (Figure 4.2) created to warn personnel about the hazard created and to use a breathing mask before entering so as to reduce breathing irritation and respiratory health issues.

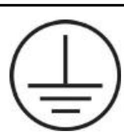
Symbol	PPE Requirement	Situation
	Personnel must wear protective breathing mask	Using epoxy or fiberglass resin, cutting into fiberglass or carbon fiber expected to produce small particles, heavy soldering
	Personnel must use fume extractors and/or fume hood if indoors	Layering epoxy onto carbon fiber airframe parts to fabricate them
	Personnel must wear safety glasses/goggles	Soldering, using saws, using stationary drills, using the X-Carve machine, handling black powder charges
	Personnel must wear nitrile gloves	Using epoxy or fiberglass resins
	Personnel must be electrically grounded	Connecting power supplies to circuits, operating devices rated for 12+ Volts
	Personnel must wear hearing protection (ear plugs or headset)	Using machine saws, drills X-Carve, etc.

Table 4.1 Symbols identifying required PPE and/or personnel awareness and associated situations where used.

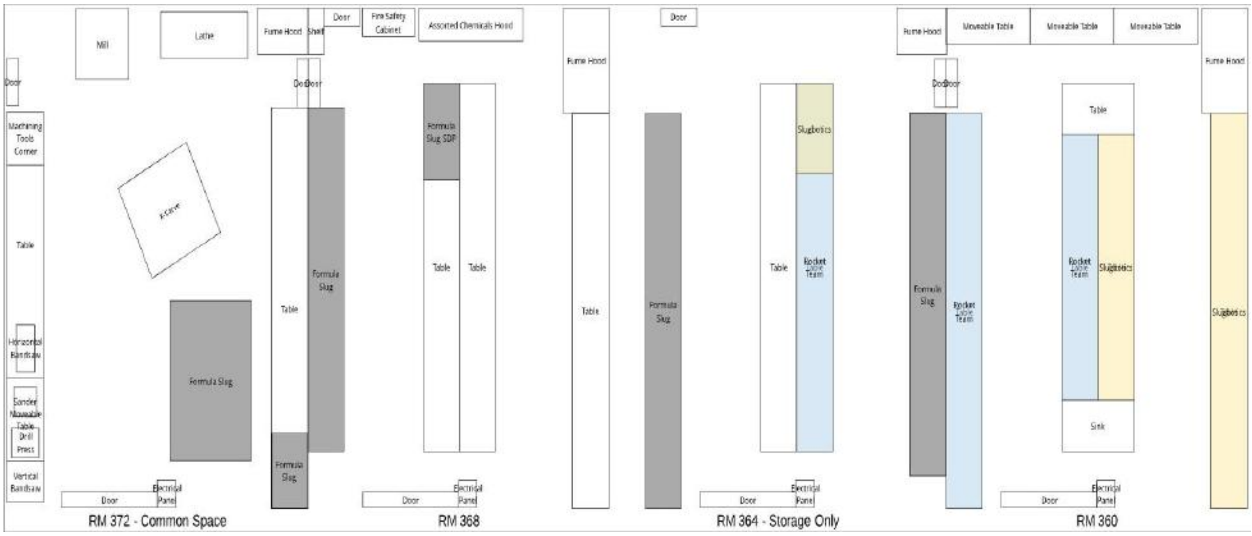


Figure 4.1 S-Lab space distribution across its 4 lab rooms. Note: the team spaces are blue, and fume hoods labeled and other critical lab equipment labeled accordingly.

Figure 4.2: Cautionary flyer visibly that is posted to the door of the room where epoxy is used extensively to fabricate airframe components to alert non-team personnel of the fumes.

4.2 Hazard Analysis

4.2.1 Risk Assessment

Since the CDR, there have been additions and modifications to the team hazard analyses. Effective identification and mitigation of the hazards involved with the activity of personnel, the launch vehicle, and the effects occurring between the vehicle and environment play a critical role in keeping everyone safe. 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 a risk level system that accounts for hazards before and after mitigation has taken place. Sections 4.3.2 - 4.3.4 now prescribe risk assessment codes using a “level before mitigation” (LBM) and “level after mitigation” (LAM) to demonstrate the effect of the team’s safety measures and the 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	Minor damage to vehicle or systems; Minor mission	Between $50 to $200 monetary losses;

			restoration technique; Does not violate any laws or regulations	failure, but non-critical system severely impacted.	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

The hazards facing the team are divided into different sections, with each focusing on a major aspect of the project that could be impacted by the team's SLI project. The separation of sections and tables has remained unchanged since the CDR. Personnel hazards, which are risks affecting team and human life in labs and launch sites, are analyzed in Section 4.2.2. The following section, 4.2.3, lists the failure modes and effects analysis (FMEA) for the recovery, ADAS, payload, and vehicle sections during assembly and operation. Section 4.2.4 then concludes this section by examining the environment's effects on the launch vehicle, as well as the effects the rocket exerts on its surrounding environments. Verifications reference sections of this document, as well as material outside of the document which can be found through the team's web presence and content on UCSC's domain: www.ucsc.edu.

4.2.2 Personnel Hazard Analysis

Hazard	Cause	Effect	LBM	Mitigation	Verification	LAM
Soldering burns	Inattention to task or improper training on equipment	Mild to severe burns on hands and/or exposed extremities	2C	Personnel must verify their soldering capabilities to the Safety Office before being allowed to independently work with soldering equipment. A hand and eye wash station are located within 20 feet proximity of the lab space.	Personnel sign an agreement to abide by the Safety Manual (4.1.2), which dictates soldering usage and training in its briefings. Soldering training is provided for free by UCSC lab safety modules.	3D
Inhalation of soldering fumes	Lead solder usage or melting workstation materials by leaving soldering iron out of its holder on an open surface	Prolonged exposure to soldering fumers leads to asthma attacks and/or sickness resulting from toxic fume inhalation	2B	Personnel must verify their soldering capabilities to the Safety Office before being allowed to independently work with soldering equipment. Soldering will only occur in well-ventilated areas of the lab where fume extractors are available and in use while soldering occurs. Breathing masks are available in the lab.	Personnel sign an agreement to abide by the Safety Manual (4.1.2), which dictates soldering usage and training in its briefings. Soldering training is provided for free by UCSC lab safety modules.	4C
Inhalation of carbon fiber or fiberglass particles	Lack of proper breathing mask	Lung and breathing pain; asthma attack	2C	All activities involving the production of small (<1 millimeter) particles of carbon fiber or fiberglass will	Personnel sign an agreement to abide by the Safety Manual (4.1.2), which dictates	2E

				occur in fume hoods or other well-ventilated areas of lab. Breathing masks are available in the lab.	handling of minute particle production from machinery.	
Flying workshop debris of wood, aluminum, or carbon fiber contacts personnel	Improper securement of component, lack of attention, or lack of proper PPE	Loss of limb or damage to eyes and skin via cuts or bruises	2 C	Only trained individuals will be allowed to operate heavy machinery. Safety glasses/goggles and close-toed shoes will be properly worn at all times.	Personnel sign an agreement to abide by the Safety Manual (4.1.2), which dictates operation of heavy machinery and power tools in shared lab spaces.	2 D
Power tools, such as saws, drills, and Dremel, hit personnel while active	Improper use of equipment or lack of attention	Mild to severe cuts or bruises	2 B	Only trained individuals will be allowed to operate power tools. PPE will be properly worn at all times.	Personnel sign an agreement to abide by the Safety Manual (4.1.2), which dictates operation of heavy machinery and power tools in shared lab spaces.	3 D
Damage to LiPo batteries.	Exposed LiPo battery terminals arcing with short circuit contact, improperly wired circuit operating from lab power supply	Mild to severe burns, muscle spasms, or electrocution	1 C	Personnel will be required to ground themselves and use working outlets when operating with electronics. Hazardous electronic situations not caused by the team must be reported to EH&S and/or lab manager.	Personnel sign an agreement to abide by the Safety Manual (4.1.2), which dictates operation of high-power electronic equipment and devices. UCSC EH&S provides training on electronic safety.	4 D

Extended exposure to RF signals	Radio transmitter device emits RF signals in close range to personnel	High power (>10 Watts) RF radiation can burn the epidermis when exposed for extended periods of time in close proximity	2 C	All RF transmitters used by the team are rated for wattages well below high power thresholds (<10 Watts). Additionally, usage will be limited to specific time limits for testing and launches and distances to avoid personnel from excessive exposure.	Personnel sign an agreement to abide by the Safety Manual (4.1.2), which dictates operation of RF equipment and devices. Also, the team is using the devices listed on the UC Santa Cruz Transmitter Data Form, which show that the devices do not exceed harmful limits of radiative power.	4 D
Rechargeable battery explosion	Improper storage, circuit configuration, overcharging, or punctured casing	Moderate to severe burns	2 A	All batteries must be checked visually for damage and all personnel must demonstrate skills with charging and discharging batteries to the Safety Officer. A hand and eye wash station are located within 20 feet proximity of the lab space.	Personnel sign an agreement to abide by the Safety Manual (4.1.2), which dictates handling of rechargeable batteries and interfacing with them. A manual is included with the team battery chargers.	3C
Inhalation or contact with noxious adhesives	Lack of necessary PPE, improper handling of epoxy or fiberglass resins	Skin, eye, and breathing irritation or damage	2 B	PPE such as breathing masks and nitrile gloves will be readily available for use in lab. All personnel will have access to MSDS online and be properly trained to handle chemicals.	Personnel sign an agreement to abide by the Safety Manual (4.1.2), which dictates handling of toxic and harmful chemicals. UCSC EH&S provides training on hazardous materials.	3 D

Extended exposure to high decibel noises	X-Carve, drills, saws, and other lab machinery can exceed 90 dB of noise levels	Chronic ear and hearing damage	1 D	Hearing protection will be provided for louder machinery at all times. Signs will be posted notifying personnel of rooms or spaces with loud sounds and machines.	Personnel sign an agreement to abide by the Safety Manual (4.1.2), which dictates operation of heavy machinery and power tools in shared lab spaces. Hearing protection will be shown during lab introduction tours for all new personnel.	3 D
Moving parts of rover or machinery harm personnel	Improper training or incorrect control algorithms	Bruises, cuts, loss of limb	1 B	Moving equipment will be handled with proper training and tested for correct operation frequently. Failure of a machine to operate safety will be reported to the lab manager immediately. Rover testing will be done away from bodily extremities.	Personnel sign an agreement to abide by the Safety Manual (4.1.2), which dictates operation of heavy machinery and power tools in shared lab spaces. Rover testing will occur outdoors, away from populations.	2 D
Detonation of black powder separation charges	Improper assembly in recovery or payload systems, or improper storage causing excess heat and/or electricity in black powder charge	Severe burns, loss of limb, eye damage, trauma	1 C	Black powder charges will only be acquired at launch events from certified vendors or other qualified personnel/mentors, and only handled by trained members. During installation of charges onto rocket, safety glasses will be worn. No black powder charges will be stored in campus labs.	Personnel sign an agreement to abide by the Safety Manual (4.1.2), which dictates handling of pyrotechnics. UCSC EH&S provides training on hazardous materials.	1E

Viewing distance not observed for launch	Lack of attention to launch protocol or failure of launch event operators to provide adequate clearance	Severe burns, loss of limb, trauma, death resulting from motor/ignition system	1 C	All personnel will be required to stand back at least 100 feet from the launch pad. Cooperation with RSO will determine specifics for safe distances and viewing provisions.	Personnel sign an agreement to abide by the Safety Manual (4.1.2), which dictates minimum viewing distances specifications and launch event activities. The team mentor, Safety Officer, and RSO must approve the launch conditions as per the procedures (4.3.)	1E
Rocket lands with higher than expected velocity	Unstable flight trajectory, recovery system failure, or launching under unsafe weather conditions	Moderate to severe injuries to personnel and surrounding property; death from high velocity impact with rocket	1 C	A thorough checklist will be used to determine if electronics are working properly and the launchpad setup correctly. If a rocket is actively landing unsafely, the RSO must verbally warn crowds via intercom system.	The launch procedures specify the recovery checklists and tasks to prepare the landing of the launch vehicle. A working intercom system will be verified to be active at the launch sites before choosing such locations for launches.	3 D
Failure to adhere to lab rules and requirements	Untrained personnel enter lab space and do not follow etiquette posted online	Loss of equipment, loss of lab privileges, potential health threats	2 B	Only certified team members can access the team materials and there will be accountability held for all persons who occupy the lab spaces simultaneously.	Personnel sign an agreement to abide by the Safety Manual (4.1.2), which dictates behavior in the shared S-Lab spaces. Other engineering teams will report issues and grievances to the team leads as needed.	2 D

Prolonged exposure of personnel to weather and direct sunlight	Inattention of launch event personnel and team members to account for locations experiencing an excessively warm, cold, or wet climate	Sunburns (potential of melanoma), frostbite, heat syncope, or high winds causing flying debris to strike personnel	2C	All launch sites the team will travel to will be identified at least 1 week before and the weather reports scoured and reviewed thoroughly during days leading into designated launch day. Sunscreen and water will be provided for all trips.	Personnel sign an agreement to abide by the Safety Manual (4.1.2), which dictates launch conditions. Team mentor will determine safety of launch conditions with Safety Officer.	4D
Team drives to launch site with inadequate sleep	Staying up late to complete rocket launch preparation	Unsafe driving potentially leads to vehicular crashes, resulting in serious injury, death, and loss of rocket components and SLI project feasibility	1A	All personnel responsible for driving the team must earn at least a 6 hour rest before operating a vehicle.	Personnel must notify the team of sleeping times and patterns to ensure all drivers are capable of handling the long drives to remote launch sites. Multiple members are capable of driving, as proven by licenses.	2E

Table 4.6: Personnel Hazard Assessment

4.2.3 Failure Modes and Effects Analysis

Hazard	Cause	Effect	LBM	Mitigation	Verification	LAM
Computer	Wire or other	Cannot be	3	Allot adequate space in the	BBB is programmed to	3

(BBB) is turned off while contained in rocket	component is pressed against power button	turned back on without opening rocket, ADAS will fail	C	electronics bay to avoid crammed components	chirp at regular intervals to verify that it is powered on	D
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	3 D	The battery will be charged within 12hrs of flight and tested before integration	Measure the battery voltage immediately before assembly pre-flight	3 E
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	3 C	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	3 D
Fins extend over upper	Algorithm error or motor	Fins are no longer	3 C	Set the upper threshold below the maximum deployment by	Test sufficiently pre-flight. Use interior	3 D

threshold	over-rotation	actuated by gear and will not retract. Potential damage to ADAS or airframe on landing		a comfortable margin, potentially add hardware to limit deployment	camera to assess performance	
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	3 D	Protect the BBB with a 3D printed case, test cases that may contribute to failure to mitigate risk	Assess BBB function before assembly	3 C
Overcharged battery	Charged battery with too-high voltage	Battery is compromised, could combust, may not provide sufficient power	1 D	Use charge controller	Assess battery before integration (should be able to visually detect)	1 E
Poor/no cable connection	Incorrectly connected or strained during assembly	Could short a component on the board causing failure	2 B	Ensure that connection site is clean and secure	Double check each connection	2 D
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)	3 D	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	3 E

Table 4.7: ADAS FMEA

Hazard	Cause	Effect	LBM	Mitigation	Verification	LAM
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 after housing opens	Airframe component prohibits rotation of ALC	The rover would be unable to exit the airframe, resulting in mission failure	1C	The payload has been designed so all components responsible for rotating the rover and its securement devices are free of obstructions during all parts of launch.	The free rotation and integrity of rover housing will be tested.	3E
Black powder residue on sensitive rover parts	A black powder charge will detonate not far from the rover, blasting residue on exposed surfaces.	The camera may not function properly when afflicted by residue.	3B	The black powder charge can be covered by a piece of fire retardant cloth to retain residue.	Black powder charges must be used while covered by fire retardant cloth.	3D

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	1 D	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.	1 E
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.	1 D	A unique deployment signal will be sent by a team member.	Unique deployment signals will be confirmed before launch.	1 E
Premature deployment (mid-flight)	Separate signal sets off the black powder charge pre-landing safely. Extreme care will be taken when wiring black powder activation and	Payload section is tethered to airframe, and rover is tethered to payload section, so it is unlikely any parts will	1 D	A unique deployment signal will be sent by a team member.	Unique deployment signals will be confirmed before launch.	1 E

	radio and handling radio.	separate 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.	3 D	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.	3 E
Batteries not fully charged.	Batteries installed before fully charging or are damaged sometime between assembly and flight.	Insufficient power, resulting in rover failure.	3 D	Full charge of batteries is to be confirmed before installation.	Launch procedures will require batteries to be checked before integration.	3 E
Electrostatic discharge to sensor or control electronics.	Electrostatic build up on team member.	Potential shorts and component failure.	3 C	Grounding mats and wrist straps must be used when testing electronics.	Test procedures require grounding mats and wrist straps.	3 E

Table 4.8: Payload FMEA

Hazard	Cause	Effect	LBM	Mitigation	Verification	LAM
Entanglement	Improper	Rocket lands	1B	Team members use a	The launch procedures	1

of drogue/main parachute	preparation of parachute inside airframe	with higher velocity than allowed		wooden jig to assist them in getting the strings untangled during preparation. Help will be provided by the team mentor at the launch site.	describe the correct process to prepare the recovery parachutes so that they do not tangle (4.3.1).	E
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	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

	cloth.					
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.	3 D
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	1 E

Table 4.9: Recovery FMEA

Hazard	Cause	Effect	LBM	Mitigation	Verification	LAM
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.	1 E
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.	1 E
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.	2 E

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	Carbon fiber or fiberglass material blocks radio signal propagation	Potential to lose track of rocket when landing farther away from launch site	1C	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

4.2.4 Environmental Hazard Analysis

Hazard	Cause	Effect	LBM	Mitigation	Verification	LAM
Launch pad not level for takeoff	Soft soil due to damp weather conditions or rocky terrain	Unpredictable takeoff leading to erratic flight	1C	Launch pad will be visually inspected and leveled correctly before installing launch vehicle with the team mentor and Safety Officer available for assistance and verification.	Both the team mentor and Safety Officer must sign off on the launch pad preparation stage of the launch procedures (4.3.6)	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 any movement	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 assembly of vehicle in unsafe conditions	Rain, fog, snow, high-winds, hot and cold temperatures	Airframe components expand and contract due to thermal expansion, electronics fail to work due to inclement water	1C	All vehicle assembly will 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	The full-scale vehicle contains a sled that allows for all component to enter based on a	1E
Overheating of rocket pyrotechnics	High temperatures in direct sunlight create overheating elements inside rocket	Motor detonation or	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 trees or launch site buildings	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.	3 D
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.	2 E

Table 4.10 Environmental Hazards on Rocket Analysis

Hazard	**Cause**	**Effect**	**LBM**	**Mitigation**	**Verification**	**LAM**
Rocket debris	Component lands excessively hard, failure to secure components exposed from vehicle separation during flight	High impact velocity causes splintering of rocket and/or its systems into untraceable parts	1C	Thorough checklists will be made to ensure all components of the vehicle are secured prior to launch.	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.	1 E

Motor CATO	Improper packing of motor or ignition system	Nearby 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	1 D
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	1B	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	1 E
Rechargeable battery leaks or explodes	Extreme high or low temperatures, inattention to charging battery	Toxic substance may pose risk to personnel, environment, or vehicle, and electrical fire may occur	2D	Batteries will be stored at allowed room temperatures and care will be taken to monitor electronics behavior.	Batteries tested before flight	2 E
Improper disposal of e-waste	Lack of attention by personnel, falling electronic debris from failed launch	Release of lead and other toxic metal compounds into potentially sensitive habitats	2B	All team members will be briefed on where e-waste may be disposed of and how to identify specific types of e-waste.	Team members hold each other accountable for proper safety practice and lab checks are conducted regularly	2 D
Chemical spill	Lack of attention by personnel	Epoxy or fiberglass resins leak into ground and	2C	Completion of safety lab trainings and extreme care when handling chemical substances. Contact	Routine safety checks and extra caution are put in place when chemical substances are in use	2 D

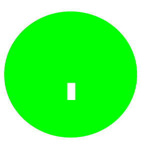
		waterways, potentially harming wildlife		appropriate resources to resolve in event		
Trash and debris littering by team personnel	Lack of attention by personnel or unavailable disposal containers	Harmful plastics and other compounds are left in active habitats, potentially harming wildlife	1C			2 E

Table 4.11: Vehicle Hazards on Environment Analysis

4.3 Safety Checklists and Launch Operations Procedures

Sections 4.3.1 through 4.3.10 outline the team's matured launch procedures and checklists, which have been revised since the CDR. The procedures now outline material checklists on a per subteam basis, and additional details have been added across all subsections. Current estimates place the time requirement for completion of all procedures by about 15 team personnel to be between 120 - 150 minutes, depending on conditions at the launch site. All operations involving rocket preparation are to be done on flat surfaces where available (tables and workbenches brought by team or provided onsite) and in a controlled environment, assuming no adverse weather occurs that could jeopardize electronic systems or tamper with substances such as epoxy and black powder charges.

Throughout the lists are a variety of symbols highlighting relevant information, warnings, and PPE where required. Table 4.1 documented the team's PPE requirements, and those symbols can be seen throughout the procedures listed herein. When an important or critical piece of information needs to be mentioned while following the procedures outlined, the notation described in Table 4.13 will be used to reliably highlight the content. Additionally, the checklists must be signed off by certain individuals now for multi-factor verification and authorization to continue with launch procedures. Table 4.14 denotes when and which specified personnel must sign their initials to authenticate the step has been completed. A printed and digital version of the checklists will be made available for launch day, with pens or other writing utensils provided, so the signing may commence without issue. Besides just identifying personnel, Table 4.14 also designates the acronyms that delineate tasks and procedures to each stage of preparation and subsystem requirement. This improves the organization and specifics of each task as it can be identified from a specific part of the vehicle assembly and launch preparation.

Symbol	Significance	Description
	NOTE	Labels relevant, but non-critical information for personnel to consider or remind themselves about
	CAUTION	Identifies steps requiring PPE or other preventive measures and explains the reasoning behind it

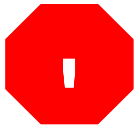
	WARNING	Used to caution personnel on procedures involving potentially lethal hazards, and how to avoid creating unnecessary risk

Table 4.13: Images and their symbolic meanings that are used to inform personnel of unique situations that arise during launch procedures.

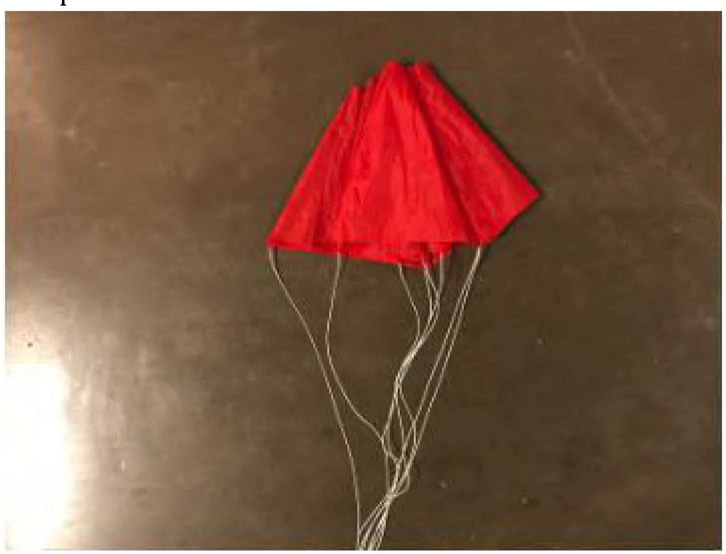
Personnel or Name of Launch Procedure Section	Abbreviation
Team Safety Officer	TSO
Range Safety Officer	RSO
ADAS Subteam Lead	ADL
Payload Subteam Lead	PSL
Airframe Subteam Lead	AFL
Recovery Subteam Lead	RSL
Team Mentor/Advisor	TMA
Recovery Procedures	RLP
ADAS Procedures	ALP
Payload Procedures	PLP
Vehicle Preparation	VLP
Motor Preparation	MLP
Preparation on Launch Pad	PRE

Igniter Installation	IGN
Launch Procedure	LLP
Troubleshooting	TSP
Post-Flight Inspection	PFI

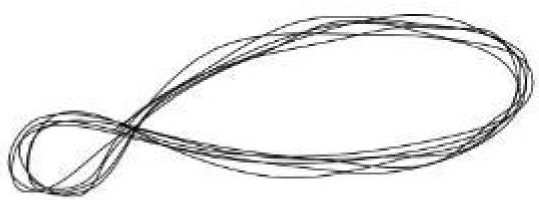
Table 4.14: Abbreviations for specific personnel and launch preparation steps seen in Sections 4.3.1 through 4.3.10.

4.3.1 Recovery Procedures

Recovery Equipment and Material Checklist				
Personnel Initials		**Item Name (x Quantity of items)**		
RSL ___	TSO____	❏ Multimeter	❏ ⅛ inch hex key	❏ 9-Volt battery (x3)
		❏ Jolly Logic Chute Release Kits (x2)	❏ Main Parachute	❏ Drogue Parachute
		❏ Kevlar shock cord	❏ Nomex blanket	❏ E-match (x2)
		❏ Wooden jig	❏ Quicklink (x3)	❏ Screwdriver
		❏	❏	❏
Recovery Preparation Checklist				
Personnel Initials		**Recovery Sled Preparation**		
RSL ___	TSO____	❏ Check voltage of 9V battery with multimeter (make sure it's 9V)		
RSL ___		❏ Insert batteries in battery holders. Leave the middle battery holder open for Payload battery		

RSL ___		❏ Secure battery pads that are housed in the battery holders onto the batteries
RSL ___		❏ Test if altimeters are working by turning the screw switch in place with the hex key
RSL ___		❏ Unscrew the screw switch
RSL ___		❏ Secure sled in coupler, then in airframe
Personnel Initials		**Drogue Chute Preparation**
RSL ___	TSO____	❏ Lay out drogue so shroud lines are extended and rest of chute is expanded 
RSL ___		❏ Fold shroud lines back into the chute so they are not exposed

RSL ____		❏ Fold drogue chute into thirds vertically
RSL ____		❏ Fold drogue chute into thirds horizontally
Personnel Initials		**Main Chute Preparation**
RSL ____	TSO_____	❏ Lay down the shock cord, drogue parachute, main parachute, and nomex protector separately.
RSL ____		❏ Clamp wooden jig on table. Sort parachute strings by left main, center pull, and right main.
RSL ____		❏ 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.
RSL ____		❏ Fold back canopy gores. Flake a gore starting from an indicator on the chute that it's the bottom left side.
RSL ____		❏ 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.
RSL ____		❏ Keep folding fabric away from the center and flattening it.
RSL ____		❏ 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

RSL ___		❏ Remove the wooden jig, and then make an accordian, or Z fold with the remaining chute
RSL ___		❏ Wrap strings around the chute
RSL ___		❏ 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.
RSL ___		❏ Set altitude for Jolly logic chute release by configuring the buttons to desired measurement
RSL ___		❏ Wrap Jolly logic chute releases around diameter of main parachute once it's packed.
Personnel Initials		**Tether and Shock Cord Preparation**
RSL ___	TSO____	❏ Spread out 40 ft. kevlar shock cord
RSL ___		❏ [Recovery]=X=13ft==(Blanket)=X=13ft==(Main)=X=13ft==(Drogue)=X=13ft==[ADAS] Where ever there's an X, wrap the shock cord (looped 6-8 times back and forth), then put a piece of masking tape on each end 

		
RSL ___		❏ Put a piece of masking tape on each end of one of those loops
RSL ___		❏ Secure drogue chute to harness via quicklink
RSL ___		❏ Secure main chute to harness via quicklink
RSL ___		❏ Secure kevlar blanket to harness
RSL ___		❏ Tie harness to recovery U-bolt (main chute side)
RSL ___		❏ Thread harness through recovery airframe section

RSL ___		❏ Tie harness to ADAS U-bolt (drogue side)
RSL ___		❏ Attach Ematch leads to recovery terminal blocks
RSL ___		❏ Ensure that each Ematch is connected to independent altimeter

4.3.2 ADAS Preparation

ADAS Equipment and Material Checklist				
Personnel Initials		**Item Name (x Quantity of items)**		
ADL ___	TSO____	❏ Laptop (x3) ❏ Multimeter ❏ Zip ties ❏ Electrical tape ❏ Fuse (1 a mp, 12V) ❏ Battery Connectors (x6) ❏ Screws (x6) + small screws to attach motor to	❏ Plastic Box ❏ Breadboard ❏ JST Jumpers (x10) ❏ USB 2.0 to Network Adapter ❏ Bag of Resistors (~100) ❏ Buttons (x2)	❏ ADAS System ❏ ADAS Coupler and Bracelet ❏ Top Cap ❏ Bottom Cap ❏ Eye Bolt ❏ Washers (3) ❏ Hex Bolt LARGE ❏ 14.8 V Battery ❏ Beaglebone

<table>
<tr><td></td><td></td><td>housing
❑ Screwdriver
❑ Screw Nuts (x8)
❑ Wire Cutters/Strippers
❑ Dial Caliper
❑ Tweezers/Pliers</td><td>❑ LED
❑ SD Adapter for microSD
❑ Micro SD (32gb✓) + (8gb✗) + (2gb✓)
❑ Raspberry Pi Camera</td><td>❑ NeveRest Motor
❑ Motor Driver
❑ Fins (x2)
❑ Gear
❑ Wire to power beaglebone
❑ Wire Connectors for motor and motor driver
❑ Wire connector for motor encoder
❑ Sled
❑ Middle Cap
❑ Top Fin Plate
❑ Bottom Fin Plate (Acrylic)
❑ Allthreads (x2)
❑ Camera
❑ Camera charging cord</td></tr>
<tr><th colspan="5">ADAS Preparation Checklist</th></tr>
<tr><th colspan="2">Personnel Initials</th><th colspan="3">ADAS Launch Preparation</th></tr>
<tr><td>ADL ___</td><td>TSO____</td><td colspan="3">❑ Ground oneself before handling any ADAS equipment
❑ Flip power switches to “off” +</td></tr>
</table>

<table>
<tr><td></td><td></td><td>❏ 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</td></tr>
<tr><th colspan="2">Personnel Initials</th><th>ADAS Assembly Preparation</th></tr>
<tr><td>ADL ___</td><td>TSO_____</td><td>❏ 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</td></tr>
</table>

		❏ 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
Personnel Initials		**ADAS Launchpad Preparation**
ADL ___	TSO_____	❏ Listen for initialization chirps from BeagleBone to ensure program running
Personnel Initials		**ADAS Post-Launch Inspection**
ADL ___	TSO_____	❏ Unscrew ADAS from airframe ❏ Assess condition of ADAS ❏ Disassemble ❏ Turn off Camera ❏ Remove sd cards and store safely ❏ Cut Power to System ❏ Store electronics

4.3.3 Payload Preparation

Payload Equipment and Material Checklist

Personnel Initials		**Item Name (x Quantity of items)**		

PSL ____	TSO____	❑ Radio
		❑ Perf board with Arduino Uno and radio circuit
		  ❑ Sled to hold above board
		  ❑ E matches
		  ❑ Black powder charges
		  ❑ 2X Xbee Radio modules for receiver/transmitter
		  ❑ Laptop (for transmitting radio signal)
			❑ Rover Electronics
			  ❑ 2x 2-cell Lipo batteries
			  ❑ 9V battery (as backup)
			  ❑ Pololu A-*Star* 32U4
			  ❑ MD08A motor driver board
			  ❑ MPU 6050 IMU
			  ❑ 2x DC motors
			  ❑ 2x Servo motors
			  ❑ Wires
			  ❑ Reverse kill switch
				❑ Rover body
				  ❑ Scoop
				  ❑ Chassis
				  ❑ Sled to rover connector
				  ❑ Wheel holders
				  ❑ Bolts for wheel holders
				  ❑ Plastic wheels

		❑ Payload housing
		  ❑ Coupler
		  ❑ Bearings attached to coupler
		  ❑ Sled
		  ❑ Hook attachment
		  ❑ Rope for reverse kill
			❑ Miscellaneous building supplies
			  ❑ Pliers
			  ❑ Scissors
			  ❑ Wire
			  ❑ Wire strippers
			  ❑ Soldering iron + solder
			  ❑ Resistors	

		switch ❏ Wood door between nose cone and payload section	❏ Duct tape ❏ Lipo charger ❏ Electrical tape	

Payload Preparation Checklist		
Personnel Initials		**Rover Preparation**
PSL ____	TSO_____	❏ Ensure that Arduino board is wired according to the schematics found in Payload section 6
		❏ Ensure that both Lipo batteries are charged at > 8.2V
		❏ Ensure that the Arduino micro microcontroller is flashed with the latest software version on the Github
		❏ Run all software tests (found on Github)
		❏ Test function of all motors ❏ Ensure that at default, both motors are driving in a counter-clockwise direction
Personnel Initials		**Rover Integration Preparation**
PSL ____	TSO_____	❏ Attach reverse kill switch with batteries to the -Bat+ pins on the Arduino micro board (with ground and + going to their respective pins)

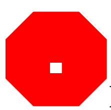
		❏ Attach a rope with one end on the reverse kill switch piece through the rover door, with two sturdy knots on each side of the door ❏ Test reverse kill switch function by ensuring the Arduino is powered off by default, and powers on upon switch pull ❏ Slide the scoop cap to the slot on the front of the rover ❏ Attach the scoop to the servo in the front ❏ Place assembled rover (with scoop side facing door) on the sled ❏ Place the ES 9051 servo on the rover back compartment and fasten hook to the servo and sled ❏ Test that the hook securely holds the servo onto the sled by holding sled and rotating it around 360˚ with the rover attached. If it is fastened correctly, the rover will stay on ❏ Place sled into the ALC rotating bearing system ❏ Bolt the ALC, sled, and rover to the coupler ❏ Gently shake and rotate the Payload section in all directions, ensuring that all components are secure ❏ Secure the Payload coupler in the top of the Payload section
Personnel Initials		**Radio Module Preparation**
PSL ____	TSO____	❏ Fasten the perf board with the Arduino Uno, Radio receiver, and circuit to activate e-matches to the sled ❏ Test that the circuit is powered off by default and test radio transmit to ensure e-matches are lit ❏ Place black powder charges ❏ Secure the sled containing the perf board in the nose cone ❏ Attach the wood door to the bottom of the nose cone, between the charges and the Payload section

4.3.4 Vehicle Preparation

<table>
<tr><th colspan="5">Vehicle Equipment and Material Checklist</th></tr>
<tr><th colspan="2">Personnel Initials</th><th colspan="3">Item Name (x Quantity of items)</th></tr>
<tr><td>VSL ___</td><td>TSO____</td><td>❏ ¼”-20 bolts (x6)</td><td>❏ Aluminum centering rings (x3)</td><td>❏ #8 bolts (x4)</td></tr>
<tr><th colspan="5">Payload Preparation Checklist</th></tr>
<tr><th colspan="2">Personnel Initials</th><th colspan="3">Vehicle Preparation</th></tr>
<tr><td>VSL ___</td><td>TSO____</td><td colspan="3">❏ Grab three aluminum rings (two circular, one oblong) and six ¼”-20 bolts. Add the circular ring in the bottom of the thrust section and orient so the outer notches align with the fin slots.
❏ Bolt in the aluminum ring to the centering ring.
❏ Add the other circular ring and “cap” it onto the end of the thrust section. Add in the same manner as the previous ring.
❏ Finally, add the oblong piece to the end of the outer ring and screw it in.
❏ Add the four fins into the fin slots.
❏ Attach the thrust section to the ADAD coupler, orienting so the ¼”-20 holes four inches down the top of the thrust section align with the ¼”-20 holes three inches up the ADAS coupler.</td></tr>
</table>

		❏ Add bolts to the threaded holes to secure the thrust section and ADAS coupler. ❏ Attach the recovery section to the ADAS coupler, orient so the shear screw holes align (1.75 inches down the coupler and 3.75 inches up the recovery section). ❏ Once the parachutes are added into the recovery section, attach the other Blue Tube coupler and add in the #8 bolts to the holes (four inches down the recovery section and one inch up the coupler). ❏ Push the payload section over the shoulder of the nose cone (the side with larger holes), align the semi-permanent holes, and add in #8 bolts. ❏ Add the combined payload and nose cone section over the recovery Blue Tube coupler, align the shear screw holes, and add shear screws.

4.3.5 Motor Preparation

Motor Preparation Checklist		
Personnel Initials		**Motor Installation Procedure**
TMA__	TSO____	❏  Inspect motor for external damages like punctures or loose components, and discard if faulty ❏ Install motor into motor housing of lower end of airframe ❏ Secure motor in with bolts and process describe for vehicle

4.3.6 Preparation on Launch Pad

- ❏ 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

Motor Preparation Checklist		
Personnel Initials		**Motor Installation Procedure**
TMA__	TSO____	❏ Inspect launch pad for uneven alignment, and attempt to relocate until pad is above solid, flat, dry ground ❏ Install rocket onto rail with rail button and mounts ❏ Activate recovery systems using

4.3.7 Igniter Installation

Motor Preparation Checklist		
Personnel Initials		**Motor Installation Procedure**
TMA__	TSO____	❏ Inspect igniter for faulty connections before proceeding

		❏ Install igniter to motor ❏ Ensure process is complete with RSO and launch perrsonnel

4.3.8 Launch Procedure

Launching Checklist		
Personnel Initials		**Rocket Launch Procedure**
TMA___	TSO_____	❏ Ensure all personnel and spectators are outside of the clearance range of the pad before starting countdown sequence ❏ Allow for RSO to handle loudspeakers to announce team's participation and launch attempt ❏ RSO detonates igniter ❏ Track rocket visually throughout entire launch and with GPS tracking system

		❏ Acquire line of sight to landed rocket before proceeding ❏ Wait for touchdown and all clear signal from RSO to activate radio signal to deploy rover ❏ Trask rover progress from at least 50 feet away at all times ❏ Wait for rover mission to conclude before proceeding to post-launch inspection

4.3.9 Troubleshooting

Troubleshooting Checklist		
Personnel Initials		**Procedure**
TMA___	TSO_____	❏

4.3.10 Post-Flight Inspection

Post-Flight Inspection Checklist

Personnel Initials		**Post-Flight Inspection Procedure**
TMA__	TSO____	❏ Remove all undetonated black powder charges from the vehicle and ensure they are safely stored away before continuing with post-flight inspection of vehicle ❏ Recollect rover from its resting location and disconnect battery ❏ Disconnect remaining batteries of Payload, recovery, etc. ❏ Unscrew ADAS, Payload, and Recovery hardware from airframe after opening vehicle sections up ❏ Assess condition of rocket and systems ❏ Turn off cameras ❏ Remove sd cards and store safely ❏ Cut Power to System ❏ Store electronics

5 Payload Criteria

5.1 Changes from CDR Overview

On the team's February 16th launch, the entire payload section was destroyed. This gave the Payload team an opportunity to rebuild the rover.

5.1.1 Rover Retention System

The rover retention system experienced a catastrophic failure in the previous flight. Therefore the entire system was redesigned for structural integrity and simplified. The main point of failure was in the load bearing servo of the ALC system and the primary and secondary retention system. To combat these failures the ALC has been redesigned into a passive component that utilizes the natural righting ability of gravity to stabilize the rover. The securement system was also changed and moved to the front just behind the nose cone. It features a locking pin that secures the ALC system to the rocket body in flight in order to prevent the component from moving within it and throwing the rocket off course due to weight oscillations. Finally, the separation point was moved to just behind the nose cone. The securement shear screws have been upgraded to a higher force tolerance as well to combat premature separation. The redundant securement method was kept as is with the addendum that securement will be done with a proper bowline self-clinching knot.

5.1.2 Chassis

Wanting to maintain the stacked design from the CDR, Payload team redesigned the chassis so that its largest components, the microcontroller and battery, were stacked next to each other horizontally rather than vertically. We also moved the scoop mechanism to the front of the rover utilizing the fact we are only constrained with the front facing diameter of the chassis but not its depth. The new chassis was now 3.8 inches in diameter and 8 inches long and utilized as much space as possible with a compact and sleek design.

5.1.3 Electronics

Before the Payload main computer was the BeagleBone Blue, which powered the dc motors, servo motors, and had a built in IMU. Due to the hardware failures that came from using the BeagleBone, the team decided to go with more predictable and reliable hardware. A Raspberry Pi Zero is employed to interface with the sensors, and to interface with the new microcontroller that will control the tank motors. The Raspberry Pi Zero will take in sensor data from a CSI Camera, an Ultrasonic sensor, and an external Inertial Measurement Unit (IMU), process the data, and delegate to the pololu microcontroller how to move the motors. The pololu microcontroller connects to a motor driver, which then drives the motors accordingly.

5.2 Payload Design Overview

5.2.1 Rover Chassis

Originally, the chassis was built to have every component stack on top of each other vertically, but after discussions and debates with the Payload team, it was decided to flip the components sideways to save more space. Many of the previous decisions were kept though, and only refurbished in the latest model by adjusting tolerances to allow for tighter fits, thinning walls to minimize material usage, and redesigning angles to be 3D printer friendly. Another key idea that was kept from the previous design was having sliding features that would interlock with each other to hold components together via tension rather than screws or bolts. This idea was used in designing the scoop cap by creating a dovetail joint end for the cap and a matching shaped slot on the rover that, when connected, restricts the cap’s movement in almost all directions; the roof also utilized this design and restricted most movement as well.

5.2.1.1 Design

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. PLA is sturdy enough to withstand the journey with the rocket, yet flexible enough to bend and to fit the motors in place. Much of the design remains the same as was proposed in the CDR with only several small changes in dimensions for efficiency reasons. The design was able to pass a number of the lab tests and proved its reliability in conditions it is projected to face in the future.

5.2.1.2 Changes since CDR

There have been a number of small changes since the CDR to accomodate for the physical limitations of creating the rover and to save on space and weight. Firstly all components were turned to mount vertically to the walls of the rover as this allowed for more integration space of electronics. Secondly walls were decreased in width to save on weight, add extra space, and speed up printing time. Finally, mounts of electronics including servo slots, mounting screw holes, and piece joints were reinforced to add an extra layer of structural integrity.

5.2.1.3 Construction Documentation and Proof

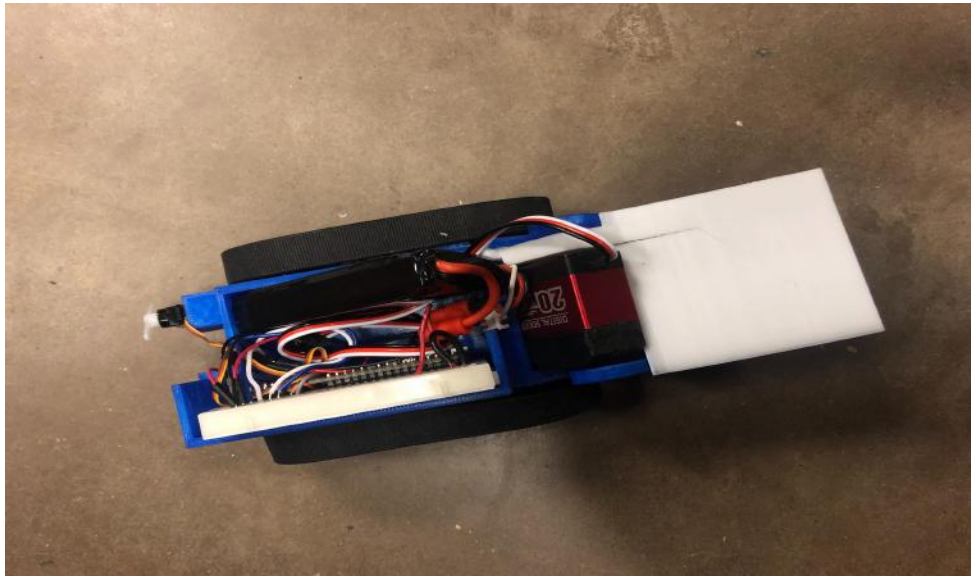


Figure 5.2.1: Payload chassis as built

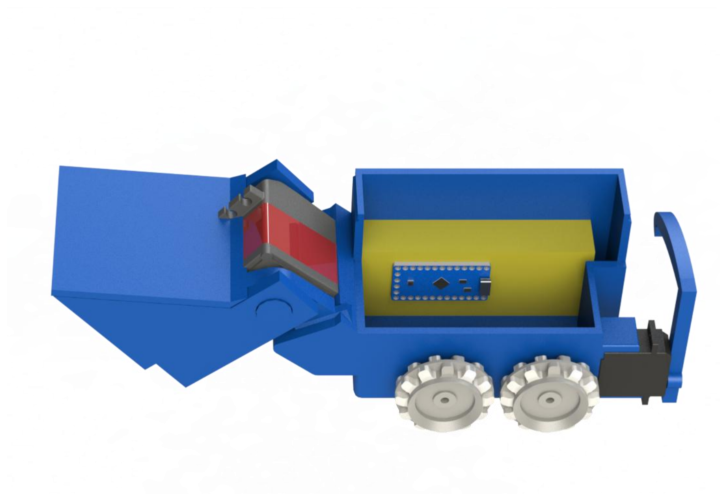
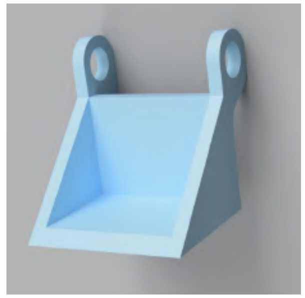


Figure 5.2.2: Final CAD of chassis



5.2.2 Soil Collection Method (SCM)

Figure 5.2.3*:* Bulldozer scoop

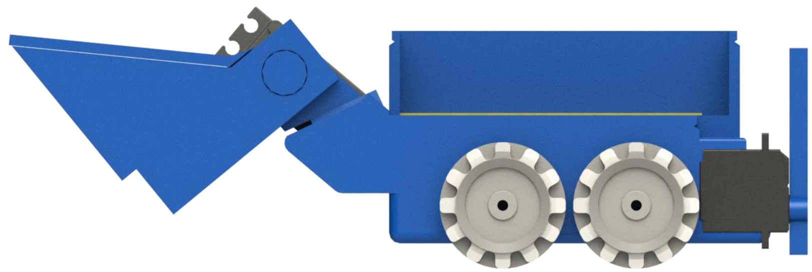


Figure 5.2.4: CAD of scoop and assembly

5.2.2.1 Design

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.

5.2.2.2 Changes since CDR

The rover was manufactured largely according to the specifications as outlined in the CDR. printing the parts proved to be simpler and more straight forward than feared. The only change between the CAD parts presented in the CDR document and the physical end product was a slight bevel on the lip of the scoop to allow for a cleaner retraction and securement compartment.

5.2.2.3 Construction Documentation and Proof

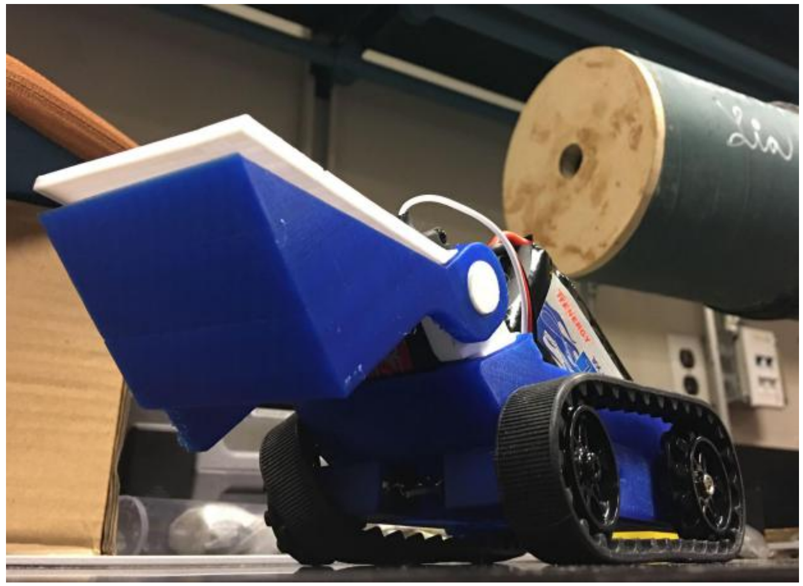


Figure 5.2.5: As constructed payload scoop

The final as built rover is able to feature the full scoop and assembly as can be seen in the figure presented above. The rover was subjected to a number of tests to test the efficacy of the design, the results of which are outlined later on in section 6.

5.2.3 Radio

5.2.3.1 Radio System Design

5.2.3.1.1 Objective

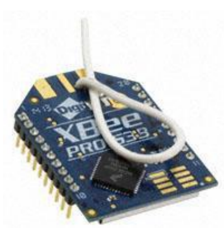
For the rocket's releasing of the rover, the radio's responsibility rests in routing and receiving a signal to set off the separation of the rocket with a black powder charge with a radio frequency of 900MHz.

5.2.3.1.2 Components

To transmit and receive the signal, we are using two XBee-PRO 900HP radio modules which will be connected to Waveshare USB XBee Communication Boards, which were selected for ease of access to the XBees' digital/UART pins and USB connectivity. The signal will be sent from a computer with the XCTU software.

Connected to the receiver XBee module is an Arduino Uno, which reads AT input from the transmitter module. Upon receiving the command to confirm circuit activation, the Arduino sends 5.0V to the gate of a Power MOSFET, activating an E-Match circuit that ignites the black powder charge.

Components of onboard Payload radio

 **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

<table>
<tr><td>
Waveshare XBee USB Adapter</td><td>UART communication board supporting XBee connectivity
includes UART and USB interfaces
includes buttons and LEDs for testing and debugging</td></tr>
<tr><td>
Arduino Uno Rev3</td><td>Connected to receiver XBee via SoftwareSerial
Sends and receives messages to and from the transmitter XBee
Configured to send 5.0V to digital output pin for 5 s after receiving activation signal</td></tr>
</table>

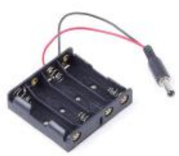
 **9V Battery**	● 3.2 grams ● 9V Alkaline ● Using one to power an e-match to set off a black powder charge
 **4x AA Battery Holder for Arduino**	● Holds 4 AA batteries ● Used to power the Arduino Uno Rev3 and the Waveshare Xbee USB adapter by consequence midflight

Table 5.2.1: Payload onboard radio components

5.2.3.2 Changes Made Since CDR

The receiver XBee was originally designed to send voltage directly to the transistor. However, because the digital output voltage of the receiver XBee is not sufficient for toggling the MOSFET, the Arduino Uno was added as a “middleman” between the receiver XBee and the Power MOSFET, reading serial input from the receiver to send a stronger voltage from its digital output.

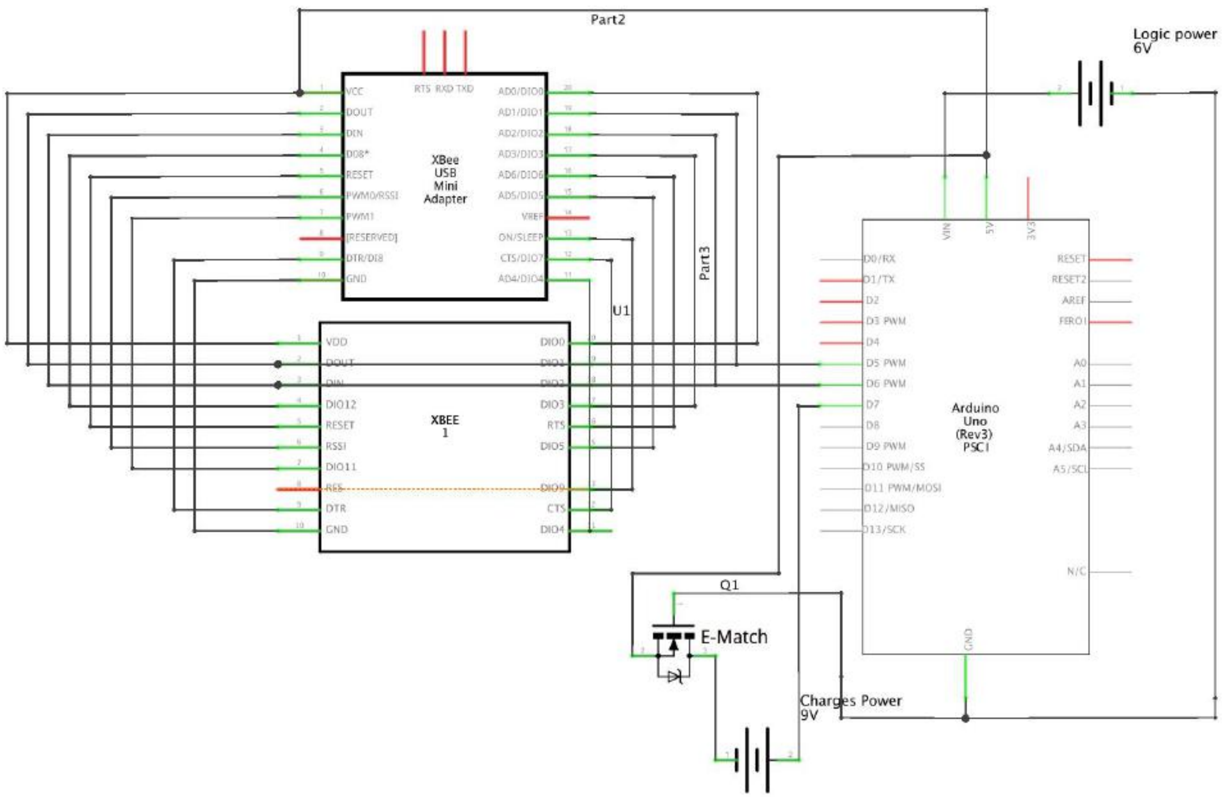


Figure 5.2.6: *Schematic for Radio System*

5.2.4 Actuated Landing Correction (ALC)

5.2.4.1 Objective

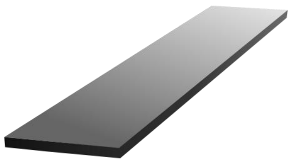
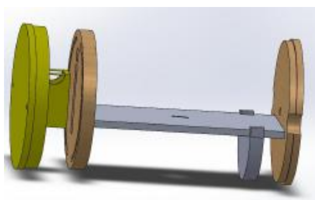
The objective of the ALC system is to secure our rover to the rocket in flight and ensure the rover is deployed upright. The previous flight showed deep structural issues with the ALC system in terms of securement and structural integrity. The new system now relies on a passive righting system utilizing gravity and the inherent imbalance of our rover system to deploy it upright. A redundant securement system was also kept in place to hold the rover housing to the rocket body in case of failure.

5.2.4.2 Components

ALC component table

 **Blue tube coupler**	● 10'' blue tube coupler ● 5.36'' diameter ● Used to hold rover chassis in flight ● Will sit within airframe coupler

 **Ball bearings**	● 8 x 0.5" ball bearings ● Will sit evenly distributed on top and bottom ends of blue tube coupler ● Tolerance weight of several hundred pounds ● No need for lubrication
 **L-bolts**	● 4 x 1" l-bolts ● Used to hold blue tube coupler in place laterally ● Will be secured directly to airframe section

 **Aluminium sled**	● 10'' section of CNC machined aluminum ● ⅛'' thickness ● Same design as CDR ● Will be machined with keyhole slit for rover securement
 **3D printed key system**	● Same design as in CDR ● Key system will be 3D printed to match custom made hole on sled ● FEA of 3D printed PLA piece shows withstanding tolerance of several kilograms

 **Nose cone pins**	● 1.5'' securement pin ● Permanently secured to nose cone using epoxy ● Slides into lock with payload bay ● Secures rotating bay to airframe

Table 5.2.2: ALC components list

5.2.4.3 Changes made since CDR

Since the proposed system presented in the CDR failed upon the test launch, the entire ALC system was overhauled. The redesign began with the housing assembly. The securement was changed from an active load bearing servo into a passive ball bearing assembly. This led to the sled also being redesigned. The new sled is secured to the housing directly through epoxy and the end caps. The securement method was also changed to include another locking mechanism to the airframe in flight.

5.2.5 Drive

5.2.5.1 Drive System Design

5.2.5.1.1 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.

5.2.5.1.2 Rover Mobility

Figure 5.2.7: The Pololu 30T Track Set

To maximize traction, the Drive system implements 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.

5.2.5.1.3 Axle and Bolt

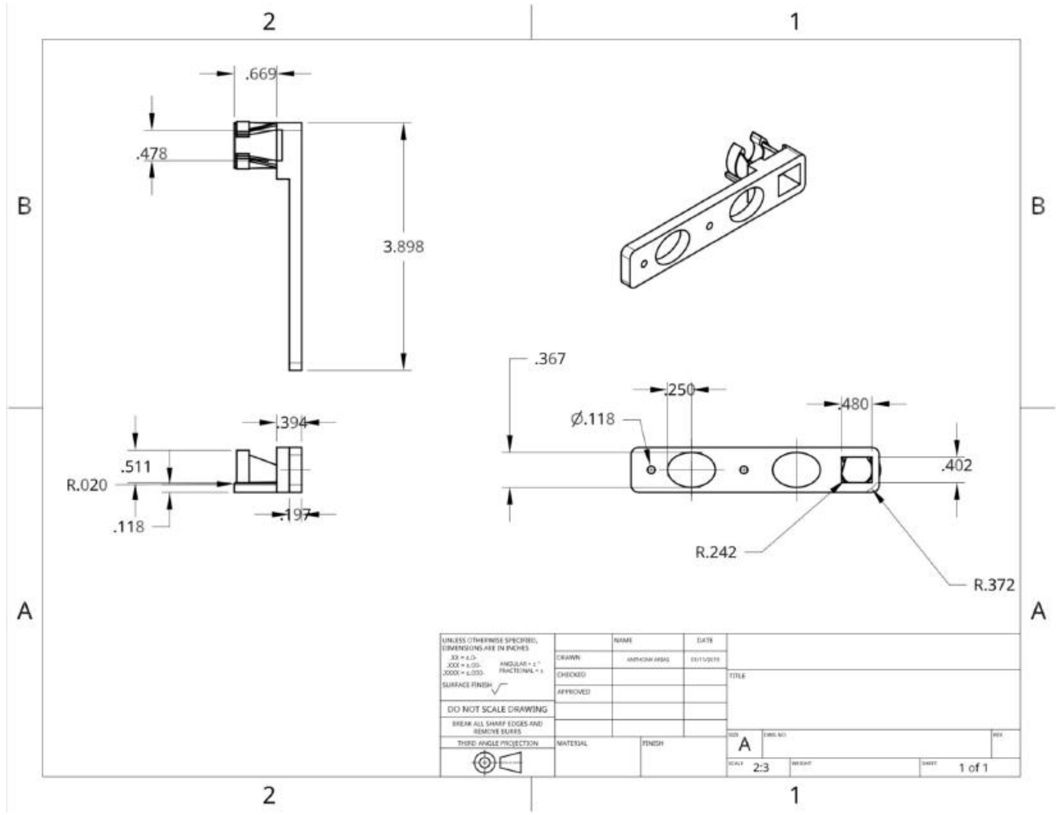


Figure 5.2.8: Drive system diagram

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. This holder of the wheels ensures that the motors are held completely stationary and spaced correctly.

5.2.5.1.4 Main Drive Motors

Figure 5.2.9: 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

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

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.

After thorough testing, (detailed further in section 6.1.1), we have concluded that motors supply sufficient torque to power the rover, and that the treads are able to traverse a wide variety of terrain types.

5.2.5.1.1 Changes since CDR

Besides the wheel holders changing from slightly curved to straight edges, no changes to the drive system have been made since CDR. The team is still using the same motors, wheel holders, wheels, and treads.

5.2.5.1.1 Construction Documentation and Proof (CAD and as-built)

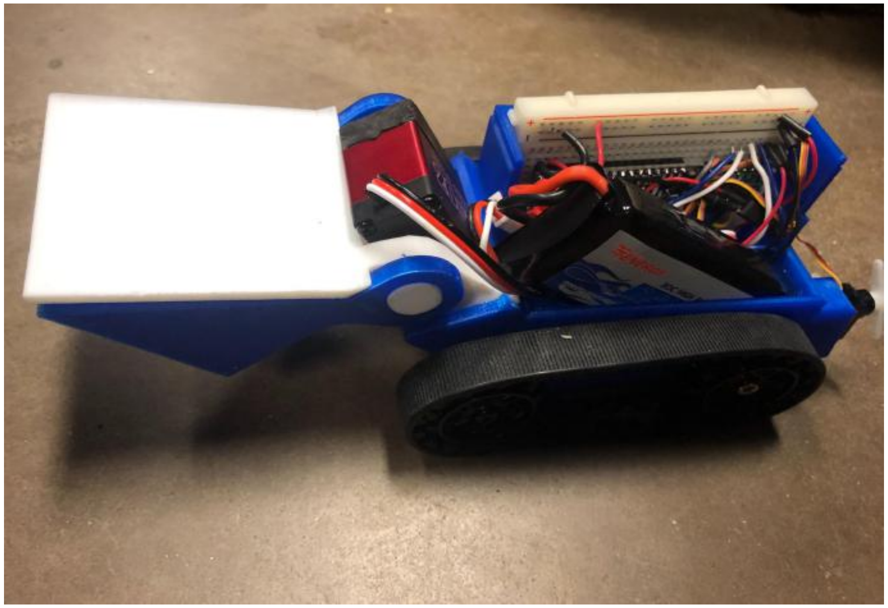


Figure 5.2.10: As constructed payload scoop

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. ODAS uses a camera for vision detection, in addition to the Ultrasonic Rangefinder. The sensors will be connected to a Raspberry Pi Zero, which will then process the data, and send a signal to the Pololu A-star microcontroller to adjust the driving motors accordingly. The Raspberry Pi Aero will be using OpenCV, a python library, in order to analyze the camera data in real-time and make decisions to avoid obstacles. 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).

5.2.6.2 Changes From CDR

The team has changed ODAS to break its dependency on the Beaglebone and switched to the ATmega32U4 board and a Raspberry Pi Zero. The Raspberry Pi Zero will take care of the object detection and movement algorithm, sending signals to the ATmega32U4 to control the motor actuation.

5.2.6.3 HC-SR04 Ultrasonic Ranging Sensor

Figure 5.2.11: 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 is functional and will provide the accuracy needed to detect obstacles. Additionally, it is a popular and reputable sensor.

5.2.6.4 Raspberry Pi Zero CSI Mini Camera Module

Figure 5.2.12: Raspberry Pi Zero CSI Camera Module

For computer vision, ODAS will use a 5MP CSI Camera Module that connects to the Raspberry Pi Zero through the Camera Serial Interface port. 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 Raspberry Pi Zero 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.

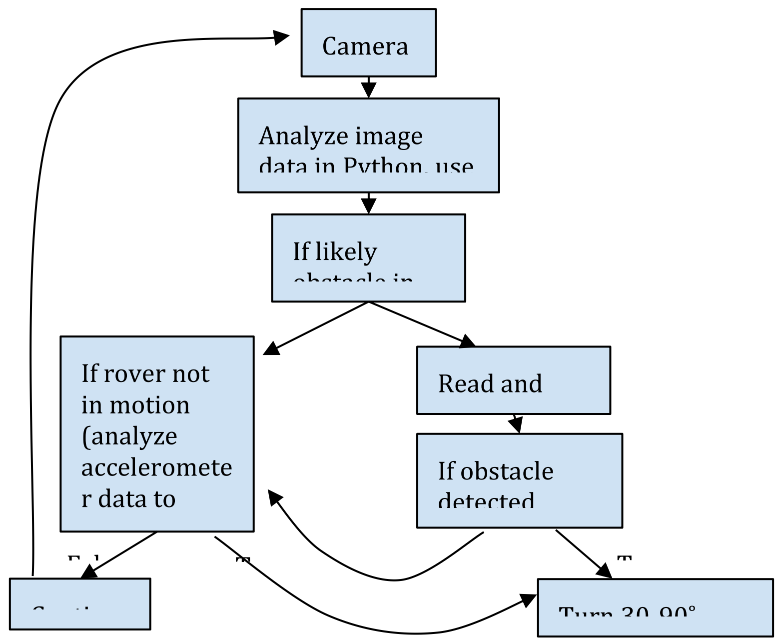


Figure 5.2.13: ODAS Software overview

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 processing and analyzing image data. Edge detection and color histogram representation will be used to identify problematic terrain and obstacles through computer vision.

5.2.6.6 Construction Documentation

After having to rebuild and re-design the rover on a tight timeline, the team has decided to focus effort on tasks deemed more essential, including redesigning retention system and porting the software and electronics to the ATMega32U4 board. Consequently, construction on the ODAS system has not been started yet. The team will will begin construction in late March.

5.3 Rover Securement and Housing

5.3.1 Design

The rover securement system was redesigned following our previous launch, and has eliminated the load bearing servo and electronic component of the ALC. The new design distributes the weight and support force of the component across a much larger cross section of the airframe and eliminates the single point of failure in a load bearing servo. Securement of the payload assembly inflight will be done with mounting pieces on the airframe nose cone and a secondary retention failsafe. The primary lock system holds the housing unit in place to the airframe during flight using locking pins connected to the nose cone. Once the rocket has landed the nose cone ejects, releasing the locking pins and allowing the housing assembly to rotate freely and right itself. In case of nose cone failure as was experienced in the previous launch the secondary retention system will hold the payload bay to the rocket. The nose cone will be secured to the payload bay through a similar retention system incorporating a high tensile strength paracord and secure U-bolts on both the payload bay and nosecone.

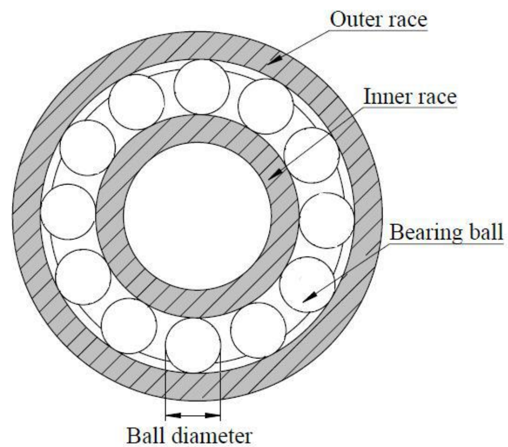


Figure 5.3.1: Sample schematic of rover ALC housing

The rover itself is connected to the coupler and bay through a lock and key mechanism. The key sits on the rover and is controlled by an actuating servo. Once the activation signal is received by the payload assembly, the key turns to disengage from the lock discoupling the rover from the sled assembly. This securement method is passive by default as per NASA specifications. This means that on unexpected failure the rover will default to connected to the sled. The only way to release the rover is to activate power through the blowing of the black powder charges and initiate the undocking procedure.

5.3.2 Changes made since CDR

Several changes were made to the payload section since the CDR and first unsuccessful launch. The issues along with their stemming component are addressed in the following table:

Previous retention system sources of failure

Issue	Responsible component	Reason for failure
Sled came unsecured	ALC servo	Load bearing servo was single point of failure for holding rover to airframe. Came apart due to higher than expected g's in flight.
Rover came unsecured	Lock and key mechanism	When sled came undone from payload bay, retention system flew off from sled.
Shear pins broke prematurely	Airframe shear pins	Shear pins were smaller than needed for experienced forces during flight.
Payload bay opened up mid air	Door locking system	3D printed parts were damaged upon high velocity impact with ground.
Secondary retention system failed	Failsafe retention system	Line became undone when put under stress.

Table 5.3.1: Sources of payload bay failure

These issues are addressed with the redesign as described above. Each issue is addressed by a newly designed component in the following way:

Previous retention system addressed issues and solutions

Issue	Redesigned component	Introduced solution

Sled came unsecured	Ball bearing ALC system	The new system will distribute the weight across the airframe section. This removes the single point of failure and means the bay will only slide out due to multiple concurrent structural failures on the airframe.
Rover came unsecured	Lock and key system	The previous lock and key system disengaged the rover due to catastrophic failure of the bay system. However the system proved effective in lab tests up to the specified tolerances and therefore will be used in the redesign.
Shear pins broke prematurely	Higher force rated shear pins	The new shear pins are set to a higher breaking tolerance than was experienced in the previous flight.
Payload bay opened up mid air	Isolated payload bay design from airframe	By decoupling the payload bay from the airframe a failure in the airframe component will no longer be directly tied to failure of the payload bay.
Secondary retention system failed	Securement of failsafe through bowline knot	The new securement will feature a stronger tie down to the payload bay using a self clinching bowline knot.

Figure 5.3.2: Solutions introduced in new redesign

5.3.3 Construction Process

5.3.3.1 ALC

The new ALC system has done away with the previous servo system in favor of a solution that distributes the weight of the rover and associated housing across a large section of the airframe. The new ALC system will be passive rather than active, and will utilize the force of gravity to right the rover in the correct orientation. A secondary payload bay coupler was introduced in the design that houses the physical rover. Securement to the sled will be done through this coupler, and will be done through a permanent epoxy as well as end cap securement. This is a much stronger and more permanent attachment than the previous ALC servo implementation.

This bay will then be connected to the surrounding carbon fiber housing through the use of integrated ball bearings. The ball bearings will sit on the newly incorporated BlueTube coupler through permanent screws, providing 3mm of buffer space between the coupler and airframe. These ball bearings are free rotating, and in the case of an unsecured ALC coupler will automatically drop the heaviest part of the coupler to the lowest point. Since our assembly will be vastly weighted in favor of the rover, this will cause the rover to naturally slide to the upright orientation much like a weight on an unbalanced bicycle wheel. The coupler itself is secured into the payload bay by use of L-bolts that hold the coupler in place. The back and front ends of the couplers will be secured to the airframe using semi permanent bolts, with the front couplers being removable to add and remove the coupler housing.

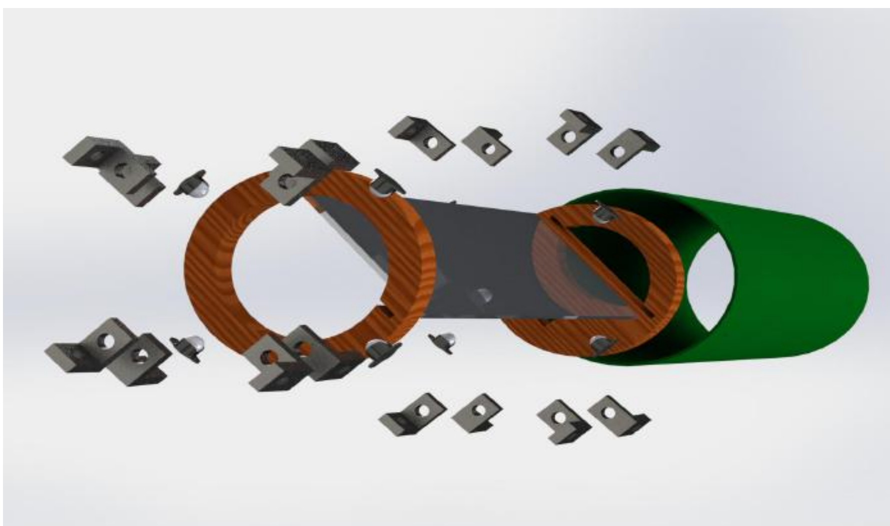


Figure 5.3.2: ALC

5.3.3.2 Sled to Airframe

In flight there is the risk that the ALC system throws the rocket off balance if not properly secured. In the case where it is free rotating in flight, small oscillations run the risk of resonating the rotation of the rover. If left unchecked, this rotation would in effect become an unbalanced gyroscope and could very quickly throw our rocket off course. To combat this the ALC coupler will be locked in place during flight thanks to a protruding pin from the nose cone assembly. This pin will sit off center from the nose cone and will fit into a corresponding off center hole on the payload bay. In flight, as the nose cone is attached to the airframe due to shear pins the payload bay will also be attached to the nose cone and hence the airframe. Once the black powder charges detonate and release the nose cone, it will release the pin from its lock disengaging the ALC coupler from the air frame and allowing it to right itself.

Figure 5.3.3: Sled to Airframe

5.3.3.3 Hook to Sled

The rover will remain attached to the sled through the use of a lock and key system. The previous lock and key system remained attached to the rover despite multiple drop tests as well as active stress and failsafe tests. The slot in the sled will sit under an actuated key attached to the rover chassis through a servo. While it was acknowledged that this created a second load bearing servo, the weight of the servo and the decreased g forces experienced by the rover and hook assembly proved to be small enough to be handled by the hook.

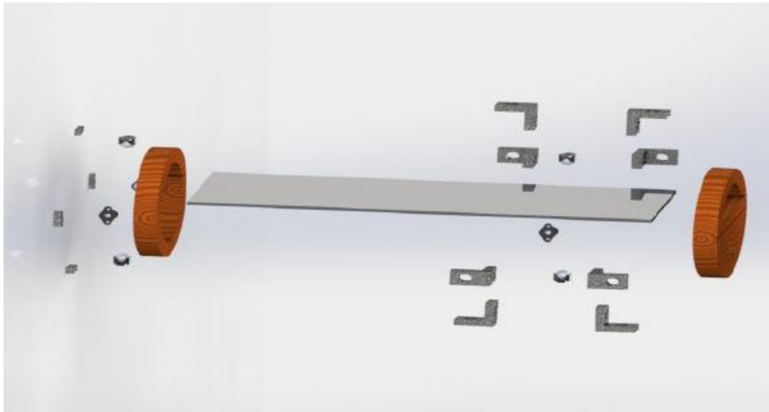


Figure 5.3.4: Hook to Sled

5.4 Electronics

5.4.1 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 Raspberry Pi Zero integrated computer was chosen for its computing strength and ease of use and a Pololu A-Star was chosen to drive the motors themselves. The drivetrain utilizes 2 independent high speed geared dc motors driving a tank tread to provide actuation. To accomplish soil collection 2 servos were used for their high torque and precision. The task of object detection was accomplished by using an CSI connection camera and ultrasonic range detector in conjunction both fed into the Raspberry Pi. 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. Distance and movement verification will be done using an MPU 6050 IMU module fed into the Raspberry Pi as well.

5.4.1.2 As-built Schematics

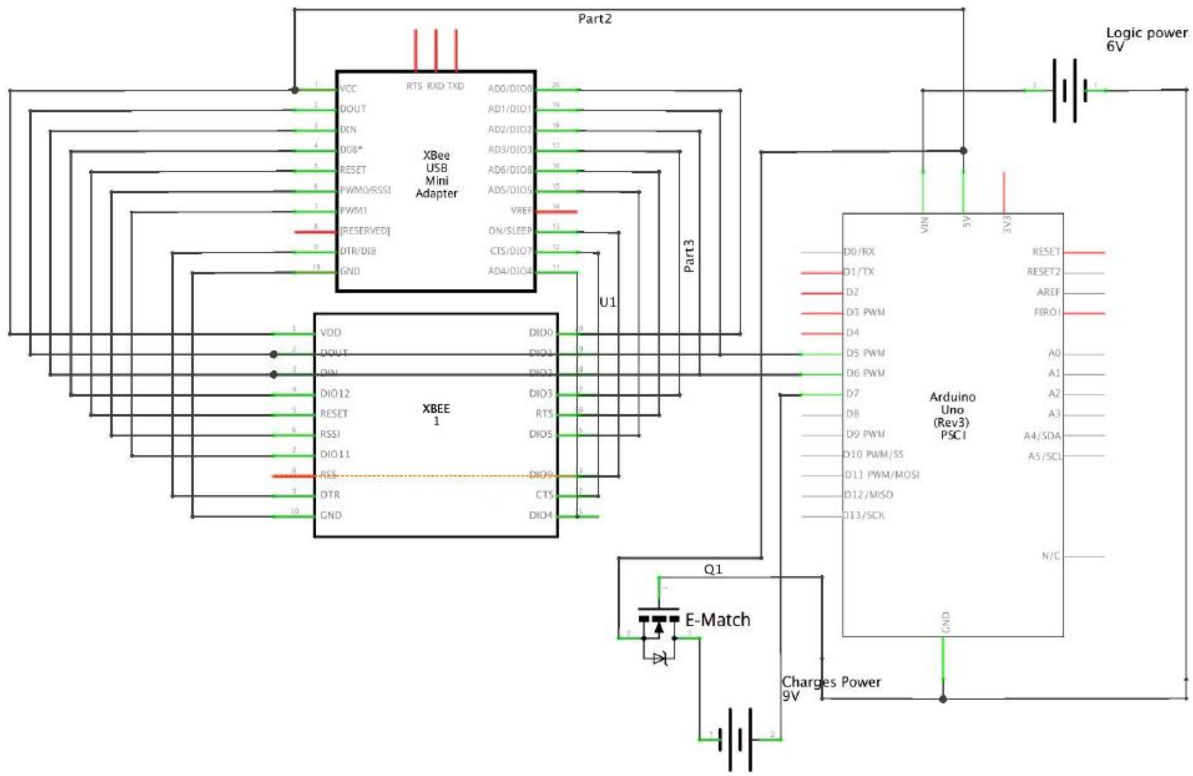


Figure 5.4.1: Schematic for the Radio

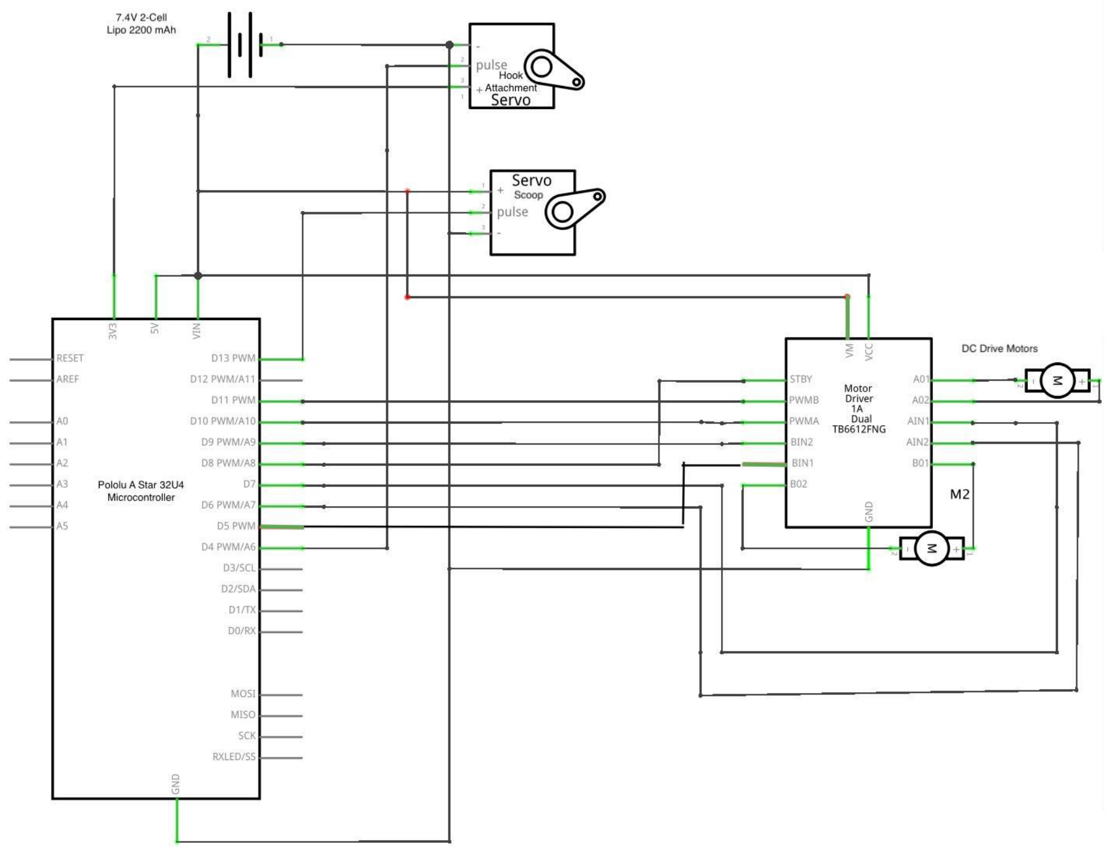


Figure 5.4.2: Schematic for the Rover and Microcontroller

Payload rover electronics components

 **Pololu A-Star 32U4 Mini LV**	● ATmega32U4 16 MHz processor ● Size: 18mm x 50mm x 6mm ● 2.5 kb RAM, 32 kb program memory ● 2.7 V to 11.8 V input range ● Up to 1.5 A output current, 5 V logic voltage ● Reverse voltage protection ● Cost: $19.95	 **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: 0.5ms~2.5ms ● Pulse Period: 20ms ● Cost: $14.99	 **Li-ion Battery 7.4V 1Ah**	● Size: 85.0mm x 33.0mm x 17.0mm ● 7.4V 2-cell pack ● Cost: $9.95
 **Pololu Gearmotor 6V 310RPM**	● Size: 10 × 12 × 26 mm ● Gear Ratio: 51.45:1 ● Shaft Diameter: 3 mm ● Cost: $16.95	 **Raspberry Pi Zero CSI Camera Module**	● Weight: 0.17 oz ● Camera Serial Interface ● 5 MegaPixel Image ● 1080p Video ● 2592 x 1944 pixel static images

 **Emax ES9051 4.3g Digital Mini Servo**	● Size: 19.74 × 8.34 × 23.25 mm ● Weight: 4.1g ● Speed: 0.09 s/60^0 @ 4.8V ● Stall torque: 0.8 kgf.cm @ 4.8V ● Cost: $4.56	 **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
 **Pololu TB6612FNG Dual Motor Driver Carrier**	● 2 Motor channels ● 4.5-13.5 V operating voltage range ● 1 A continuous output current per channel ● 2.7-5.5V logic voltage range ● Reverse voltage protection	 **Raspberry Pi Zero**	● Size: 65mm x 30mm ● 1GHz single-core CPU ● 512MB RAM ● Micro USB power ● HAT-compatible 40-pin header ● CSI camera connector (v1.3 only)

Table 5.4.1: Rover electronics

5.4.2 Changes since CDR

The team has decided to switch from the BeagleBone Blue to the Pololu A-star 32U4 and Raspberry Pi Zero. This decision was made due to the high cost ($80), lack of documentation, board issues, and lack of availability of the BeagleBone; it was decided that the benefits of switching to a more standard board configuration would outweigh the time taken to port the board's electronics and software over to the new microcontroller. Another motor driver, the Pololu TB6612FNG, was also required in the current design of the rover and rover housing

Additionally, the SpringRC SM-S4303R Continuous Rotation Servo was removed, as the ALC is now passive and not controlled electronically. The smaller Emax ES9051 Digital Mini Servo was added to the hook to sled retention system.

5.4.3 Construction Process

Overview

The electronic components of the Payload section can be separated into two different sections: The payload rover, and a detachment system. Firstly, the detachment system is composed of an Arduino UNO Rev3 that is in charge of separating the rover from the rocket once it lands on the floor and it is no longer moving. It does so by receiving a 900Mhz radio signal with a radio module, and activating black powder charges. Secondly, we have the electrical components that drive the rover itself. The main component is a Raspberry Pi Zero that takes environment data through a CSI Camera, an IMU, and an Ultrasonic Sensor. It then delegates how to control the motors to a pololu microcontroller, which then moves the motors of the rover by interfacing with a Pololu motor driver.

5.4.3.1 Radio and base telemetry

The radio utilizes the Xbee transmitter/receiver pair to communicate with the base station and listen in for the deployment signal. The receiver module is connected to an Arduino Uno to process the received signal and execute the black powder charge. Upon confirmed landing on the ground by the base crew, a signal is sent through the transmitter using a computer connected to the transmitter and running the XBee's XCTU program. The received signal triggers an event, which is intercepted by the arduino module which in turn activates the black powder charge blowing the nose cone from the remaining assembly.

5.4.3.2 Drive

The electric portion of the drive component of Slug Buggy is split into 2 main sections. There is the drivetrain which will be responsible for the physical actuation of the rover scoop mechanism, and lock and key securement system. Then there is ODAS which is the "brain" of the rover and controls the movement input to the drivetrain. The input to ODAS also takes in the IMU sensor.

Motor movement

The rover movement is controlled by 2 pololu geared DC motors each individually one of a pair of tank treads. By having the treads move independently, it give our rover full control over the direction of movement. The dc motors are controlled by our pololu motor driver chip, which controls the power and polarity flowing to the motors. This in effect controls the direction and speed of the motors.

In addition to the drivetrain there are 2 servos controlling the scoop mechanism and lock and key securement system.

Obstacle Detection and Avoidance
The main component of this system is the Raspberry Pi Zero. The CSI Camera, The Ultrasonic Sensor, and the Inertial Measurement Unit (IMU), will be connected to the Raspberry Pi Zero, feeding it data. The Raspberry Pi Zero then analyzes the data, and sends signals to the Pololu A-Star in order to control the two DC motors that move the tank threads. The components will be powered with the Li-ion Battery.

5.4.3.3 Soil Collection

Figure 5.4.3: 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. The servo will be connected to the motor driver, which will in turn control the power and actuation of the servo using signals from the onboard microcontroller. On signal from the microcontroller to activate the scoop system. It will trigger the power on pins to the motor driver, activating the servo and opening the scoop. The power from the drive system will provide the torque necessary to scoop up the soil. Once a predefined distance has been traveled, the scoop will then be retracted on signal from the microcontroller and lock into place sealing our sample.

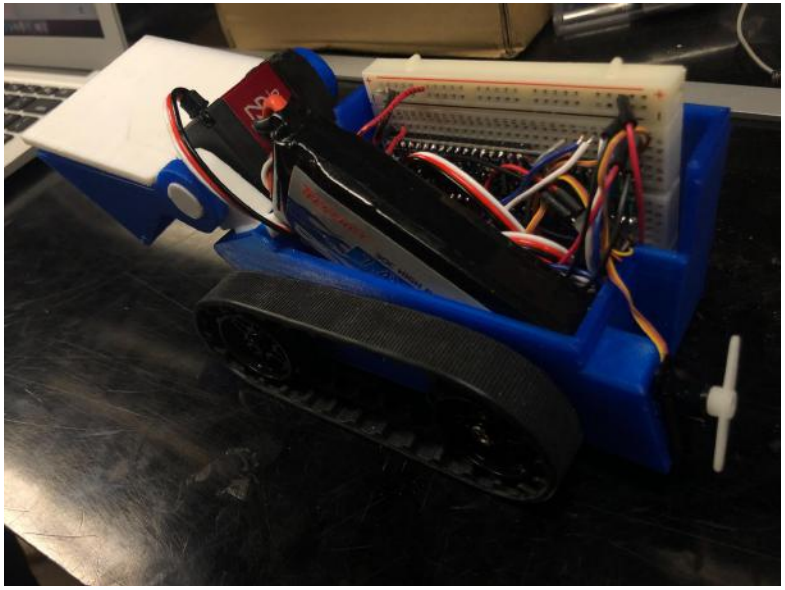


Figure 5.4.4: Current rover electronics

5.4.4 Planned Construction

In addition to the schematic in figure 5.13, a Raspberry Pi Zero will be added with a CSI Camera Module, an IMU, and an Ultrasonic Sensor, in order to successfully implement the obstacle avoidance system. The Raspberry Pi Zero will interface with the Pololu microcontroller in order to tell it how to drive the motors. We expect to encounter difficulties regarding the communication between the Raspberry Pi Zero and the Pololu microcontroller.

5.5 Payload Demonstration Flight

5.5.1 Date

Our full scale rocket was launched on February 16th on a sunny, windy day in the center of the Mojave desert. Launch time was late in the afternoon. Hopes were high, unfortunately the wind was higher.

5.5.2 Success Criteria

The payload was deemed to have been successful if it was able to perform the necessary soil collection upon landing. In order for this to happen several important aspects of the payload design would be tested and function correctly. The securement and landing system would need to keep the rover in place throughout launch, safely delivering the rover to its final destination. Upon landing the ALC system would need to correctly right the rover to deliver it to the correct orientation. Finally, once deployed the rover would be required to function as described and correctly implement the ODAS, drive, and soil collection systems.

5.5.3 Results

After a slightly skewed launch from the pad our OH YEAH rocket launched to apogee and deployed the recovery drogue as expected. Unfortunately, due to an underestimation of force expected during the flight the shear pins securing the payload bay to the rocket were prematurely sheared. This led to a catastrophic failure of the payload bay dislodging the internals and sending the entire upper portion of the rocket into free fall. The majority of the pieces comprising payload were lost to the eternal forces of the Mojave sand and wind. Several servos and 3D printed sections of the chassis were recovered, as well as the airframe bay. However the rover itself was dislodged from the payload bay at apogee and was one of the components entering free fall losing the remainder of the components. No lives were lost.

This result prompted a structural redesign of the securement system. The load bearing servo was deemed unreliable and is replaced with a ball bearing system that distributes the weight across a larger section of the airframe. The retention system is updated to be more secure and distribute the force to a larger section of the retainment bay eliminating the point of failure present in the previous launch.

5.5.4 Analysis of Retention System Performance

The previous retention system proved insufficient to handle the load of the forces experienced in flight during the previous launch. At apogee, the premature ejection of the payload bay due to shear pin failure caused a large impulse on the cable retention system. This impulse caused the secondary retention system to fail at the cable point of securement as all the force was focused on a single small area. It also sheared the load bearing servo holding the payload in place in the rocket. As a result the section came unseparated, leading to a failure of the door and spilling out the unsecured payload rover into the sky. The cable strength and all other parts of the retention system itself performed fine, and the cable and other retention systems on the airframe remained intact. Due to this point of failure on the retention system, the new system was redesigned to distribute this force so as to remain under the breaking point of the utilized particle board and remove compounding ladders of failure within the design.

6 Project Plan

6.1 Testing

6.1.1 Test Results

6.1.1.1 Payload Test Results

6.1.1.1.1 Radio Tests

#	Requirements Fulfilled	Description of test	Criteria for success	Status
1	Team: 6.8.1., 6.8.2.	Digi XBee Radio Communication Test (detailed below in 6.1.1.1.1.1)	Receiver successfully	Complete

	NASA: 4.3.3.	Activate radio transmitter from a distance of a mile in the following environments: ● Open field (OPERS field at UCSC) Each in the following conditions ● Clear ● Rain/fog With the receiver in the following housing ● Inside nose cone ● In nose cone, with complete airframe	received signal with reasonable packet receiving success rate.	
2	NASA: 4.3.3	Activate test E-match circuit from a distance of a mile in open field, in both clear and rainy/foggy conditions	Receiver successfully receives signal, igniting E-match	Planned for 3/9/19 launch
3	Team: 6.8.1., 6.8.2. NASA: 4.3.3.	Test radio receival inside complete assembled carbon fiber airframe at 500 feet from transmitter	Receiver successfully received signal with sufficiently strong connection (>-85 - -90dBm)	Failed

6.1.1.1.1.0 Preliminary Radio Testing

<u>Test Objective</u>

Ensure that the materials the radio is placed in and the radio module the team uses is functional.

Tested Items

- XBee modules
- Carbon fiber airframe placement

Success Criteria

Receiver successfully received signal with sufficiently strong connection (>-85 - -90dBm)

Results

Test 3 failed (at a distance of 500 feet) because the radio was unable to communicate through carbon fiber airframe. The team moved the radio section from the carbon fiber to the fiberglass nose cone in order to accomodate this issue.

6.1.1.1.1.1 Digi XBee Radio Communication Test

Test Objective

The objective for this test is to confirm that our Digi Xbee radio modules can be capable of consistent, continuous communication through an encasement of fiberglass from over 2,500 feet to a mile away.

Tested Items

- Communication consistency at long range
- Communication consistency through fiberglass
- Communication consistency through carbon fiber

Success Criteria

- Signal successfully received under connection stronger than -85 dBm while receiver is inside fiberglass nose cone.
- Radio modules do not experience downlink throughout the test

Procedure

This test will conducted to analyze the radio's performance as it is intended to be used. The environment will be that of a simulation of the conditions in which the system is expected to perform during the mission.

1. Acquire the following:

a. Nose cone used in full-scale rocket
b. 2 XBee modules with USB interfaces
c. A laptop for the transmitter
d. Power source for the receiver.

2. In an open field, modules will be placed 0.5-1 mi apart. The receiver is then connected to power and placed in the full-scale nose cone, and the transmitter is connected to a laptop with XCTU installed.
3. Using XCTU's built-in range test, the connection between the transmitter and the receiver is tested.

<u>Results</u>

The transmitter's signal was received inconsistently when the receiver was inserted into the nose cone of the full-scale rocket. The radio connection when the receiver was removed from the nose cone was stable at a sufficiently strong connection ranging from -70 - -80 dBm. The results of range tests before and after insertion are shown below.

Figure 6.1. Open field range test; receiver is removed from nose cone.

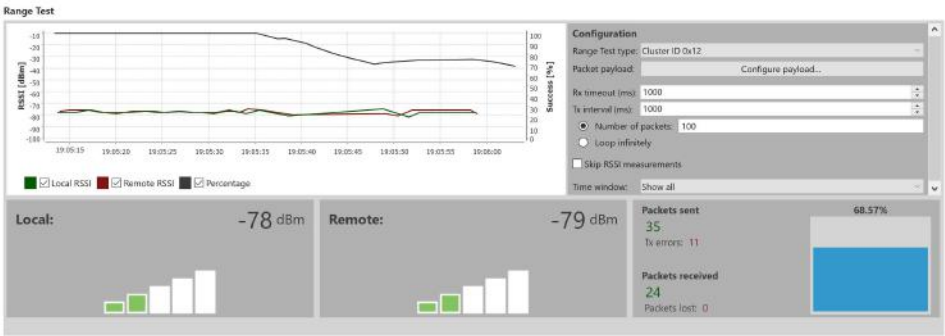


Figure 6.2. Open field range test; receiver inserted in nose cone at time 19:05:35.

Given that the black powder activation circuit requires continuous communication between the radio modules, the receiver as is cannot be situated in the nose cone in the final design. Therefore, the signal of the radio modules must be amplified to maintain a strong connection if the current design of the activation circuit is to be maintained.

6.1.1.1.1.2 E-Match Activation Test

<u>Test Objective</u>
This test's objective is to ensure that the radio system activates the E-Match to trigger rover deployment upon receiving an activation signal from the transmitter XBee module.

<u>Tested Items</u>
- Connection of radio modules in full-scale rocket
- Serial communication between receiver XBee module and Arduino Uno
- Ignition of E-Match activated by digital output of Arduino

<u>Success Criteria</u>
- XBee modules successfully communicate with each other with receiver in full-scale rocket
- Arduino successfully receives commands from XBee modules and outputs activation voltage for a limited time.
- E-Match ignites after signal is sent.

Procedure
This test will be conducted following the launch of the full-scale rocket, when the rover is intended to deploy from the rocket. Following the current design of the rocket, the rover deployment circuit will be placed in the nose cone, while the transmitter XBee module will be connected to a laptop approximately 1 mile from the landing site. The activation signal is then sent through the serial console interface in XCTU.

Results
Test planned for Mar 9, 2019 launch.

#	Requirements Fulfilled	Description of test	Criteria for success
1	Team: 6.3.3, 6.4.1 NASA: 4.3.3	After launch, send radio signal ~1 mile from landing site to activate E-match	The radio receiver will complete the circuit, the E-match will go off

6.1.1.1.2 Chassis and Rover Body Integrity Tests

Objective
The objective for the Chassis and Rover Body Integrity Tests is to ensure that the rover is durable, so that it can be reused for future flights and can withstand any expected and minor unexpected conditions during the mission, transportation, or building process.

Items/Variable to be Tested
- Integrity of rover build
- Durability of electronics

Procedure

With the fully assembled rover, with attached electronics, complete the following tests. After tests, run test scripts to ensure all connections are strong and still in place, and visually inspect the rover (including electronic parts and batteries) for damage)

#	Requirements Fulfilled	Description of test	Criteria for success	Status
1	Team: 6.5.1., 6.5.3. NASA: 4.3.2.	Shake rover while fully assembled with fitted treads then place rover down on ground surface and attempt to drive	Treads remain on rover and in working condition Rover moves across ground, without issue	Planned
2	Team: 6.6.2 NASA: 4.3.7	Drop rover from 4 feet	The rover body and electronics are intact and undamaged	Planned

6.1.1.1.3 Rover Soil Collection Method Tests

Objective

The objective for the Rover Soil Collection Method Tests is to ensure that the rover is able to collect 10 mL of soil on a variety of terrains, given that the soil type the rover will land on is unknown. These validate the team's design of the bulldozer scoop design.

Items/Variable to be Tested

- Scoop design dimensions
- Durability of scoop material

#	Requirements Fulfilled	Description of test	Criteria for success	Status
1	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	Planned
2	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	Planned

6.1.1.1.4 Actuated Landing Correction Tests

<u>Objective</u>

The objective for the Actuated Landing Correction Tests is to assure the security of the payload until its upright landing it also responsible for. If successful, the positioning of the payload upon launch will prove to be perfected.

<u>Items/Variable to be Tested</u>

- Payload landing position
- Security of payload position during flight

<u>Success Criteria</u>

- Payload lands in upright position no matter what orientation it is initially in
- Payload remains inside Actuated Landing Correction system even during harsh conditions

#	Requirements Fulfilled	Description of test	Criteria for success	Status
1	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	2/16/19 Success (under old design) Planned 3/7/19 (new ALC design)
2	Team: 6.3.1	Pull on inside ring inside sled bearing towards outside the airframe	The ring remains secure in place	Planned 3/7/19

6.1.1.1.5 Rover Drive System Tests

Objective

The objective for the Rover Drive System Tests is to affirm our rover's proficiency in driving across various types of terrain in preparation for whatever flavor of environment a launch site may present itself with, whether the ground be rocky, grassy, wet, or steep, our rover must be able to traverse through all to ensure that it can travel ten feet away from our rocket. In addition, the Rover Drive System Tests ensure the rover can be dropped safely from a distance of one foot.

Items/Variables to be Tested

- Rover's proficiency in crossing various terrain
- Rover's durability in withstanding dropping a distance of one foot

#	Requirements Fulfilled	Description of test	Criteria for success	Status
1	Team: 6.5.1., 6.5.3. NASA: 4.3.2, 4.3.4, 4.3.7	Drop rover from distance of 1 foot.	Treads remain on rover and in working condition Rover moves across ground, without issue	Planned 3/7/19
2	Team: 6.4.2 NASA: 4.3.4	Deploy rover on mud with at least 25% water content	Rover is able to drive a distance of 10 feet, rover is not damaged by water, rover travels across.	Complete
3	Team: 6.4.2 NASA 4.3.4	Deploy rover on grass	Rover is able to drive a distance of 10 feet, rover is not damaged by water, rover travels across.	Planned 3/7/19
4	Team: 6.4.2	Deploy rover on gravel with average	Rover is able to drive a distance of 10 feet, rover is	Complete

	NASA: 4.3.4	granularity of 5mm	not afflicted by gravel, rover travels across.	
5	Team: 6.4.2 NASA: 4.3.4	Deploy rover on rocky terrain with rocks at least 2cm in average	Rover is able to drive a distance of 10 feet, rover is not afflicted by rocks, rover travels across.	Planned 3/7/19
6	Team: 6.4.2 NASA: 4.3.4	Deploy rover on inclined soil (30% grade)	Rover is able to drive a distance of 10 feet over incline.	Planned 3/7/19

<u>Results</u>

The only terrain our rover can surely traverse is mildly gravely terrain and muddy terrain. Tests for other terrain such as grassy, rocky, and inclined soil are planned on a date before the next launch. The test for the rover's withstanding of a foot long fall is also planned on a date before the next launch.

6.1.1.1.6 Rover Attachment and Housing Tests

<u>Objective</u>

The objective for the Rover Attachment and Housing Tests is to ensure that the rover is securely fastened to the rest of the airframe during the entirety of the flight, even in unexpected conditions (including premature black powder activation). Additionally, the Rover Attachment tests verify that the rover is only powered on upon black powder activation.

<u>Items/Variables to Be Tested</u>

- Durability of door in protecting against black powder
- Integrity of shear pins
- Activation of kill switch upon separation
- Strength of sled attachment

#	Requirements Fulfilled	Description of Test	Criteria for Success	Status
1	Team: 6.1, 6.1.1 NASA: 4.3.1, 4.3.3	Activate black powder charge using electronic switch	Black powder charges detonate and separate rocket without damaging other components	Planned 3/9/19
2	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	Planned 3/9/19
3	Team: 6.1.2	Pull on payload assembly tethers from rocket body with force of 10N	Shear pins will not shear upon application of 15N force.	Planned 3/9/19
4	Team: 6.4.3	Pull on payload assembly tethers from rocket body with force of 20N	Shear pins will shear upon application of 20N force.	Planned 3/9/19
5	Team: 6.6.1	Secure rover to housing, then execute detachment sequence and attempt drive motion	Rover will detach from housing and begin driving	Planned 3/7/19
5	Team: 6.6.1, 6.4.3, 6.1.2, 6.4.2, 6.4.4	Flight demonstration: In a test flight, secure the rover to ALC and attachment system	Rover stays in place on sled during duration of rocket flight	Failed 2/16/19 Planned 3/9/19

<u>Results</u>
The Payload section came undone and was lost during the February 16th flight, therefore failing test 5. The team has entirely redesigned the housing system to avoid a repeat occurrence (refer to section 5.3).

6.1.1.1.7 Rover Electronics

<u>Objective</u>
Rover Electronics tests ensure that all electronics on the rover are correctly and safely assembled before flight. The team is aware that LiPo batteries can be dangerous and wiring mistakes can be costly if not careful, and tests extensively to prevent any electronics issues.

<u>Items/Variables to Be Tested</u>

- The LiPo battery is fully charged and undamaged
- The microcontroller, motors, and all other connections are correctly wired
- No wiring is exposed

#	Requirements Fulfilled	Description of test	Criteria for success	Criteria for success
1	Team: 6.8.1.	Run test battery of all motors before flight to ensure all connections are properly made	All motors move at expected speeds	Complete
2	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	Complete
3	Team: 6.7.2.	Record battery temperature and visual	Temperature will be below 30 degrees celsius and no	Complete

	NASA: 4.3.8.	characteristics before use in launch	observable swelling Battery will be brightly colored and clearly marked as fire hazard while clearly distinguishable from other parts	
4	Team: 6.8.1.	Visual inspection then tactile inspection of rover to ensure no exposed wiring and cables secure	Cables secure and no wiring is exposed	Complete
5	Team: 6.3.3, 6.4.1	Connect reverse kill switch to microcontroller and pull	Microcontroller is not powered on when switch is not pulled Reverse kill switch powers on microcontroller when pulled	Complete

6.1.1.1.8 Rover Software

Objective

The team believes in test-driven software development and the importance of unit and integration tests in ensuring a successful and reliable software system for the payload.

Items/Variables to Be Tested

- Software
- Sensors (IMU and Ultrasonic)
- Control of motors

#	Requirements	Description of test	Criteria for success	Status

	Fulfilled			
1	Team: 6.5.2	Run motor test script for DC motors (drive both motors forward at high speed, one forward one backward, the other backward one forward)	Motors move in the directions specified at sufficient power	Complete 2/10/19
2	Team: 6.6.1	Run servo motor test script (drive servos to specified positions)	The servos move to expected position Servos have sufficient voltage and torque	Complete 3/3/19
3	Team:	Microcontroller reads accurate data off MPU		Complete 2/15/19

6.1.1.1.9 Black Powder Containment Tests

Objective

The objective for the Black Powder Containment Tests is to ensure that the black powder charge will successfully separate the rocket and deploy the payload without damaging other components of the rocket.

Items/Variables to Be Tested

- Durability of black powder container
- Integrity of shear pins
- Activation of kill switch upon separation

#	Requirements Fulfilled	Description of Test	Criteria for Success	Status

1	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 without damaging other components	Planned
2	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	Planned
3	Team: 6.4.3	Pull on payload assembly from rocket body with force of 20N	Shear pins will shear upon application of 20N force.	Planned

6.1.1.1.9.1 Black Powder Activation Test

<u>Test Objective</u>
This test's objective is to assess the black powder charge's capabilities in separating and deploying the rocket.

<u>Tested Items</u>
- Successful communication between radio transmitter and black powder activation circuit
- Deployment of black powder charge
- Separation of rocket
- Protection of other components from detonation

<u>Success Criteria</u>
- Black powder charge is successfully detonated, separating the rocket
- No components of payload housing are damaged after detonation

<u>Procedure</u>

This test will be conducted during the launch of the full-scale rocket. Black powder charges will be used to deploy the recovery system as the rocket descends and the rover housing after the rocket lands.

Results

Test planned for Mar 9, 2019 launch. Due to safety regulations, the team will wait until the next launch before testing the black powder.

6.1.1.1.9.2 Housing Deployment Test

Test Objective

This test's objective is to ensure that the black powder detonation applies sufficient force to open rover housing, and that the black powder detonation circuit is opened following deployment of the rover housing.

Tested Items

- Door of housing assembly opens from force of black powder detonation (20 N)
- Kill switch activation upon housing deployment

Success Criteria

- Housing deploys upon simulated force of detonation at 20N, and is unaffected by smaller forces
- Housing deployment activates kill switch
- Kill switch opens test black powder activation circuit

Procedure

With rover housing enclosed, pull on the door of the rover housing with 10, 15, and 20N of force.

Results

Test planned for Mar 9, 2019 launch

6.1.1.1.9.3 Shear Pin Integrity Test

Test Objective

This test's objective is to assess the black powder charge's capabilities in shearing the shear pins upon activation.

Test Items

- Shear pins shear upon applied simulated detonation force

Success Criteria

- Shear pins shear when (and only when) the simulated detonation force of 20N is applied

Procedure

With payload housing and airframe secured by shear pins, pull the housing from the airframe with a force of 10, 15, and 20 N.

Results

Incomplete, test planned for Mar 9, 2019 launch

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 6.2.1 to Table 6.2.5 describe how the team will comply with these stipulations, using the following four methods of verification:

- **Inspection** - Examination of the object or system using the senses and tools available to the team. This method is very unobtrusive and does not require much interaction or modification of the object or system being examined.

- **Demonstration** - Making the system or object perform its intended purpose under scrutiny to ensure that it functions as desired.
- **Analysis** - Verification that the system or object performs as intended through a set of calculations, models, and simulations.
- **Test** - Verification of the system or objects by means of controlled inputs, and comparison of output to the intended output of the object or system.

General Requirements

#	Requirement Description	Method of Verification	Description of Verification	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 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).	Inspection	There will be constant inspections to ensure that all work is being done solely by students members, with the exception of operations that must be performed by team mentors (i.e. motor assembly, black powder handling, preparing/installing electric matches).	In Progress	The team continues to be 100% student run and plans on continuing to be so.
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,	Inspection	The project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks/mitigations will	Complete	Timelines and budgets have been completed by all subteams.

	checklists, personnel assignments, STEM engagement events, and risks and mitigations.		be inspected and discussed weekly at team meetings.		
1.3	Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during certain activities.	Inspection	All members of the team will be asked if they are Foreign Nationals and will be identified by the PDR.	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.	Complete	A list consisting of members who will attend launch week activities has been made and submitted.
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 will be identified by the CDR. The mentor will	Complete	David Raimondi has been identified as the team's mentor

			ensure that all attending personnel meet the necessary requirements.		
1.4.3	No more than two adult educators	Inspection	No more than two adult educators will attend launch week, and will identify themselves by the CDR.	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.	Complete	STEM Engagement activities have been completed and their relevant info has been sent to NASA.
1.6	The team will establish a social media presence to	Inspection	Any team social media will be inspected and updated		All social media aspects have

	inform the public about team activities.		regularly to inform and engage the public about team activities.	Complete	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 milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient.	Inspection	Team members will inspect all deliverables to ensure they are completed and emailed by their respective deadlines. In the event that a deliverable exceeds the maximum file size, a link to a download of the file will be sent.	In Progress	Derivables are continually emailed to NASA by the deadline and will continue to stay 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	Inspection	All necessary equipment		Use of library

	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.		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	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 and 12 foot 1515 rails will be provided. The launch rails will be canted 5 to 10 degrees away from the crowd on launch day. The exact cant will depend on launch day wind conditions.	Inspection	The team's launch vehicle will be inspected to ensure that it is compatible with the launch pads provided by Student Launch's launch service provider.	Incomplete	The vehicle will be built to use the provided rails.
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)	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		David Raimondi has been identified as the team's mentor

	throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to launch week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attend launch week in April.		mentor will accompany and supervise the team at launch week.	Complete	

Table 6.2.1: 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	Further 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.	Complete	Fullscale flights demonstrated that the recovery altimeters are activated by a dedicated arming switch
2.5	Each altimeter will have a dedicated power supply.	Inspection	Dedicated batteries will be supplied and planned for in the design.	Complete	Inspection of the full-scale reveals 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.	Complete	Inspection of the recovery bay reveals 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	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	Complete	The vehicle is designed and will be constructed to have a maximum of 4 independent sections

	separately from the main vehicle using its own parachute.		a connection to the parachute(s).		
2.8.1	Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length.	Inspection	Every shoulder will measured and verified of its length compared to the body diameter.	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 for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	Demonstration	A comprehensive flight checklist will be made and tested before launch to verify the preparation time.	Incomplete	At the launch site, the team will 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.	Demonstration	The motor mount and chosen motor will be made and fit in order to be capable of being launched by a standard 12-volt direct current firing system.	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 Design Review (CDR) milestone.	Demonstration	From simulations, a final motor choice will be made by the CDR and presented clearly.	Complete	Final motor choice is the 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.	Complete	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.	In Progress	Past and future fullscale flights will verify a rail exit velocity of 52 fps
2.19	All teams will successfully	Demonstrati	Team will successfully		Subscale flight

	launch and recover a subscale model of their rocket prior to CDR. Subscales are not required to be high power rockets.	on	launch and include a flight report of the subscale model in the CDR.	Complete	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 project.	Inspection	The subscale model will be built entirely during the school year and solely for NASA 2019 SLI.	Complete	Subscale was built Fall 2018
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.	Vehicle Demonstration	Demonstrati	The vehicle will be flown in		The final full

1	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:	on/ Inspection	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	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 rocket, designed and built specifically for this year's	Inspection	The full-scale model will be built entirely during the school year and solely for NASA 2019 SLI.	Complete	The full-scale rocket has been crafted from this year's original

	project.				design and materials
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.	Complete	Payload will be built to exist without any external hardware
2.20.1.5	Teams shall fly the launch day motor for the Vehicle	Inspection/ Demonstrati	The chosen motor will be purchased and used during		The L1000 is available at local

	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.	on	the full-scale demonstration flight.	Incomplete	stores and is not rare
2.20.1.6	The vehicle must be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the launch day flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.	Demonstration/ Inspection	The final chosen amount of ballast from simulations will be flown during the full-scale demonstration flight. The flight checklist will verify that the ballast is added.	Incomplete	Full-scale 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.	Demonstration	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.	Demonstration/Inspection	Planned launch dates for the full-scale demonstration flight will be before the FRR submission deadline. Any backup dates will be verified and changes will be made if necessary.	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 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	Demonstration/ Inspection	The payload will be completed and flown with the full-scale vehicle during the demonstration flight. All aspects of the payload will be verified to have been successful from data and post-launch analysis.	Incomplete	Full-scale demonstration flight has not yet been completed

	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:				
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 Addendum are not required.	Inspection	A FRR Addendum will not be included should all flights be completed before the FRR deadline.	Complete	An FRR Addendum will be needed

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
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.	Complete	An FRR Addendum has been approved
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	Inspection	The team will petition the NASA RSO if the payload		Contact with the NASA RSO will be

	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.		demonstration flight is unsuccessful in any way.	Incomplete	made when needed.
2.22	Any structural protuberance on the rocket will be located aft of the burnout center of gravity.	Inspection/ Analysis	The design of the rocket will feature all protuberances behind the burnout center of gravity.	Complete	The rocket is designed to have 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	Inspection/ Analysis	Should the vehicle feature forward canards, simulations will show a minimal aerodynamic	Complete	Simulations ensure that extraneous canards will not

	team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.		effect.		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 6.2.2: 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	Demonstration/ Inspection	The vehicle design will be made to deploy a drogue parachute at apogee and a		The full scale rocket will be launched at a

	drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the RSO.		main parachute at a lower specific altitude. This will be verified through inspection of the systems and demonstration flights.	Incomplete	later time to 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 overseen 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	Inspection	The vehicle design will feature shear pins for attaching any section of the vehicle that detaches,	Complete	The vehicle features shear pins

	compartment.		including the parachute compartments.		
3.9	Recovery area will be limited to a 2,500 ft. radius from the launch pads.	Analysis/ Demonstration	OpenRocket simulations and numerical analysis will verify that the vehicle does not exceed a drift of 1250 ft.	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.	Complete	The full-scale vehicle contains a GPS device that fulfills this requirement
3.11.1	Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic tracking device.	Inspection	Addition GPS Trackers will be included on any section that lands untethered from the launch vehicle. Verification that is functional will be completed before the flight.	Incomplete	Will be verified 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.	Complete	Design configuration tested in subscale successfully, design was functional during fullscale test flight 1
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	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

	inadvertent excitation of the recovery system				
3.12.4	The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	Inspection/ Demonstration	The vehicle design will include shielding from any other electronics to verify the functionality of the recovery electronics.	Completed	Design configuration tested in subscale successfully, design was functional during fullscale flight 1

Table 6.2.3: 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.	Completed	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.	Completed	No additional experiments will be flown
4.2.2	If the team chooses to fly an	Inspection	The team will not include	Completed	No additional

	additional experiment, they will provide the appropriate documentation in all design reports so the experiment may be reviewed for flight safety.		any additional experiments in the launch vehicle.		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	Demonstrati on	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 experienced.	Demonstrati on/ 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
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.	In Progress	Remote connection and radio tests have been are continually being done in various locations and configurations
4.3.4	After deployment, the rover will autonomously move at	Demonstrati on	The rover has been designed to autonomously		Rover treads will be tested to

	least 10 ft. (in any direction) from the launch vehicle. Once the rover has reached its final destination, it will recover a soil sample.		move a minimum of 10 ft. from the launch vehicle, then collect a soil sample.	Incomplete	ensure design meets requirements
4.3.5	The soil sample will be a minimum of 10 milliliters (mL).	Demonstration	The rover has been designed to collect a minimum of 10 milliliters of soil before stopping soil collection.	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.	Demonstration	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.	Demonstration	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	Demonstration	Batteries will be marked with a bright color separate from any other color found on the rover, and will have labels marking it a fire hazard.	Incomplete	Rover battery will be wrapped in a single layer of neon duct tape with warning labels written on

Table 6.2.4: 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.	Complete	Safety checklist is made and is used for launch day operations.
5.2	Each team must identify a student safety officer who will be responsible for all items in section 5.3.	Demonstration	Richard Alves will act as the team's student Safety Officer and has accepted responsibility for all items in section 5.3.	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	In Progress	Continuation of procedure will occur all the way to the flight.

			and observe all major vehicle development.		
5.3.3	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data,	Demonstration	A safety manual will be maintained by the Safety Office such that it contains all pertinent information on the team's protective measures, and a spreadsheet will track compounds stored in the lab spaces and beyond.	In Progress	Maintenance of safety manual will guide safety procedures moving forward.
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	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.

	communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.				
5.5	Teams will abide by all rules set forth by the FAA.	Inspection	All team members will be informed of all rules set forth by the FAA, and regular inspections will be made to ensure that all rules are abided by.	In Progress	

Table 6.2.5: 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	Description of Verification	Complete
6.1	Housing is securely fastened to airframe assembly throughout flight	Demonstration /Test	Flight test will prove the in situ securement of the payload bay	Incomplete
6.1.1	Semi permanent fasteners securely attached to nose cone	Demonstration /Test	Structural integrity of fasteners tested before	Incomplete

			launch	
6.1.2	Shear pins and safety ropes securely attached to rest of air frame	Demonstration /Test	Structural integrity of shear pins and safety ropes tested before launch	Incomplete
6.2	Strength testing of physical rover to housing assembly	Demonstration /Test	Conduct a drop test and pull tests	Incomplete
6.2.4	Rover lock and key attachment to sled	Demonstration /Test	Conduct a drop test and pull tests	Incomplete
6.2.5	Rapid acceleration securement during flight	Demonstration /Test	Conduct a drop test and pull tests	Incomplete
6.3	Rover orientation correction component	Demonstration /Test	Rotate payload bay to verify orientation is maintained	Incomplete
6.3.1	Successfully accomplishes landing correction	Test	After successful landing, verify rover corrects landing orientation	Incomplete
6.3.2	Sled locks in place during flight and will not move	Test	After landing, verify sled did not move	Incomplete
6.3.3	System is powered off until signal is received for activation	Demonstration	Verify through tests of electronic system	Incomplete
6.4	Deployment			
6.4.1	Black powder charge detaches	Demonstration /Test	Verify black powder detonation detaches	Incomplete

	housing successfully		housing	
6.4.2	Door disengages from coupler	Demonstration /Test	Verify 20N force disengages door	Incomplete
6.4.3	Shear pins detach coupler from rest of rocket body	Demonstration /Test	Verify 20N force shears shear pins	Incomplete
6.4.4	Kill switch activates onboard electronics	Test	Test activation through disengaging door of housing assembly	Incomplete

Table 6.2.6: 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	Description of Verification	Complete
6.5	Tread testing			
6.5.1	Treads are securely fastened and won't malfunction in flight	Demonstration /Test	Verify treads remain on rover in working condition following applied expected force and terrain traversal	Incomplete
6.5.2	Motors actuate treads correctly and move rover body	Demonstration /Test	Demonstrate forward movement of rover upon activation of	Incomplete

			motors	
6.5.3	Rover can navigate various inclines with various terrains	Demonstration /Test	Deploy rover on various terrains and inclines, maintaining forward motion without damage to rover	Incomplete
6.5.3.1	Angles varying from 0, 10, 20, 30, 40, 50 degree inclines	Demonstration /Test	Deploy rover on aforementioned inclines, demonstrating forward motion	Incomplete
6.5.3.2	Terrains ranging from grassy, compact, muddy, gravel, large rocks, and sandy	Demonstration /Test	Deploy rover on aforementioned terrains, demonstrating forward motion	Incomplete
6.6	Chassis testing			
6.6.1	Rover can detach lock and key securement system and deploy	Demonstration /Test	Verify deployment from housing after rover activation	Incomplete
6.6.2	Rover body will be able to handle stresses of flight and use	Demonstration /Test	Verify rover is intact and undamaged after subjected to forces simulating impact and acceleration	Incomplete
6.7	Battery test			
6.7.1	Battery will not overheat	Inspection	Battery temperature	Incomplete

	during mission		inspected before integration and launch	
6.7.2	Visual inspection for swelling to ensure battery hasn't been overcharged	Inspection	Battery visually inspected before integration and launch	Incomplete
6.7.3	Battery has capacity needed to carry out mission	Demonstration /Test	Verify battery is able to power rover for expected mission duration.	Incomplete
6.8	Electronics test			
6.8.1	Electronics are secured and no wires are exposed	Inspection	Visual and structural inspection of electronics	Incomplete
6.8.2	Servo motors actuate correctly	Demonstration /Test	Verify software correctly adjusts position of servos	Incomplete
6.8.3	Sensors all function and read distance data correctly	Demonstration /Test	Sensor readings tested before integration	Incomplete
6.8.4	Linux subsystem			
6.8.4.1	Logs are cleared	Inspection	Conduct a faux flight and verify logs are cleared afterward	Incomplete
6.8.4.2	Services are started	Inspection	Power system on and verify services are started	Incomplete

6.8.4.3	Sensors are reading accurate data	Demonstration /Test	Conduct an in lab test of all electrical components and verify data matches real world experiences	Incomplete
6.9	Scoop test			
6.9.1	Scoop deployed properly and gathers requisite ten milliliters of soil	Demonstration /Test	Verify scoop contains at least 10 mL of soil after proper deployment	Incomplete
6.9.2	Soil remains enclosed within rover body after collection	Demonstration /Test	Verify no soil escapes rover body when shaken.	Incomplete
6.10	Remote activation system			
6.10.1	Remote connection can be established in a variety of weather conditions	Demonstration /Test	Conduct range tests of radio modules in varying weather conditions	Incomplete
6.10.2	Remote connection can be established at distance of a mile	Demonstration /Test	Conduct range tests of radio modules at distance of a mile with receiver in full-scale airframe	Incomplete
6.11	ODAS test			
6.11.1	Object detection camera relays correctly to motor drivers	Demonstration /Test	Verify motor drivers respond to object detection	Incomplete

6.11.2	Ultrasonic sensor gives accurate distance reading	Demonstration /Test	Test in the lab with a predetermined distance and compare with ultrasonic sensor data	Incomplete
6.11.3	Object detection software detects objects at least 1 meter away	Demonstration /Test	Verify response to objects placed at least 1 meter away	Incomplete
6.11.4	Object avoidance software maneuvers around detected obstacles	Demonstration /Test	Verify rover maneuvers through simulated obstacle course	Incomplete

Table 6.2.7: Physical rover team derived requirements

6.2.2.3 General Requirements

ADAS Team Derived General Requirements

#	Requirement Description	Method of Verification	Description of Verification	Complete	Details
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.	In Progress	Meetings continue to be held but instead on Tue/Wed.

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.	In Progress	Team communication is done through slack.
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.	In Progress	All ADAS code is kept on the teams 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.	In Progress	All documents have been posted to the Team Google Drive

Table 6.2.8: Team Derived General Requirements

6.2.2.4 Adaptive Aerobraking Requirements

#	Requirement Description	Method of Verification	Description of Verification	Complete	Details
8.1	Vehicle will feature an adaptive air-braking system (ADAS).	Inspection	ADAS will be inspected and tested for functionality.	In Progress	Full ADAS functionality will be tested at the next full scale launch.
8.1.1.	The ADAS will regulate drag	Inspection	ADAS fins will be inspected	In Progress	Fins met

1	with the help of two retractable fins.		to fit inside the launch vehicle frame and to have a minimum and maximum protrusion that allows for adequate drag control during flight.		requirements for the first full scale launch, will be tested with the redesigned rocket.
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	In Progress	Fins met requirements for the first full scale launch, will be tested with the redesigned rocket.
8.1.1.3	The ADAS system will deploy the fins to the correct range.	Demonstration	Hall effect sensor feedback loop reading position of fin deployment.	In Progress	Initial tests successful, will be tested with redesign.
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 an actual apogee within 50 of the target.	In Progress	Will be tested at next full scale launch.
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.	Complete	Aerodynamic simulations for the fins have been calculated.
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.	In Progress	Test will be run during next full scale launch.
8.1.3	The ADAS system will adjust itself at a frequency of 15Hz.	Inspection	Run deployment profile that performs multiple full	In Progress	Test will be run during next full

			deployments at rate of 15 Hz.		scale launch.
8.1.4	The ADAS system will be able to withstand an impact velocity of 35mph	Demonstration	Drop component from 15 feet onto grassy ground and inspect for damage	In Progress	Test will be run with redesigned system before next full scale launch.

Table 6.2.9: Team Derived ADAS Requirements

6.2.2.5 Team Derived Vehicle Requirements

#	Requirement Description	Method of Verification	Completion
9.1	In house, hand rolled carbon fiber airframe	Inspection/demonstration	Complete
9.2	Detachable fins	Inspection/demonstration	Complete

Table 6.2.10: Team Derived Vehicle Requirements

6.3 Budget

6.3.1 Item Budget

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" BlueTube 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
	Chihai 330rpm chr-gm25-370-abhl motor	$10.60	1	$10.60	$3.86		$14.46
	Aluminum for sled and rings			$0.00			$0.00
	all threads			$0.00			$0.00
	Blue tube coupler			$0.00			$0.00
	MD13S motor Driver	$9.90	2	$19.80	$2.99		$22.79
	Arduino Teensy	$11.62	2	$23.24	$9.00		$32.24
	Rapberry pi 3 B+	$38.20	1	$38.20	free		$38.20

	Pin connectors	$12.92	1	$12.92	free		$12.92
	Ailavi USB Buck converter	$9.90	2	$19.80	free		$19.80
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-	$27.95	1	$27.95	$2.00		$29.95

	EZ2						
	Smallest Mini 50.0 Mega Pixel USB HD Video Camera	$6.29					
	XBee-PRO 900HP (S3B) DigiMesh, 900MHz, 250mW, Wire Antenna, 200Kbps, 32K Programmable	$41.75	2	$83.50	$7.72		$91.22
	Pololu Gearmotor 6V 310RPM	$16.95	2	$33.90	$1.95		$35.85
	HiLetgo 3pcs GY-521 MPU-6050 MPU6050 3 Axis Accelerometer Gyroscope Module	$8.99	3	$26.97	$0.00		$26.97
	Adafruit Motor/Stepper/Servo Shield for Arduino v2.3 Kit	$23.39	1	$23.39	$0.00		$23.39
	Arduino Uno	$23.00	1	$23.00	$0.00		$23.00
	Royitay Universal Boat Outboard Engine Motor Kill Stop Switch and Safety Tether	$11.90	1	$11.90	$0.00		$11.90
	TB6612FNG Dual Motor Driver Carrier	$3.33	3	$9.99	$4.95		$9.99

	A-Star 32U4 Mini LV = 19.95	$19.95	1	$19.95	$0.00		$13.99
	Pololu Ball Caster with 3/8″ Metal Ball	$1.99	5	$9.99	$0.00		$9.99
	Adafruit Perma-Proto Half-Sized Breadboard PCB	$12.50	1	$12.50	$0.00		$6.99
	Toggle Switch: 3-Pin, SPDT, 5A	$1.75	1	$1.75	$0.00		$1.75
	3pcs of Tenergy 30C 7.4 V 2200mAh Replacement LiPO Battery for Syma	$36.99	1	$36.99	$0.00		$36.99
	HiLetgo 3pcs Pro Micro Atmega32U4 5V 16MHz Bootloadered IDE Micro USB Pro Micro Development Board Microcontroller	$20.89	1	$20.89	$0.00		$20.89
	5xPairs XT60U (XT60 Upgrade) 3.5mm Banana Connector Gold Plated	$6.99	1	$6.99	$0.00		$6.99
	Smallest Mini 50.0 Mega Pixel USB HD Video Camera	$6.29	1	$6.29	$0.00	0	$6.29

	GOLDBAT 1300mAh 4S 100C 14.8V Softcase Lipo Battery Pack with XT60 Plug for RC Car Truck Boat Heli Airplane UAV Drone FPV Racing (1 Pack)	$16.99	1	$16.99	$0.00		$16.99
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	$227	18	$4086			$4086
	AirBnB Stay	$1814	1	$1814			$1814

	Rental Vehicles	$1220	1	$1220			$1220
Launch	L1000 Motor	$240	2	$480			$480
Total				$9108.61			$9248.35

6.3.2 Funding Plan

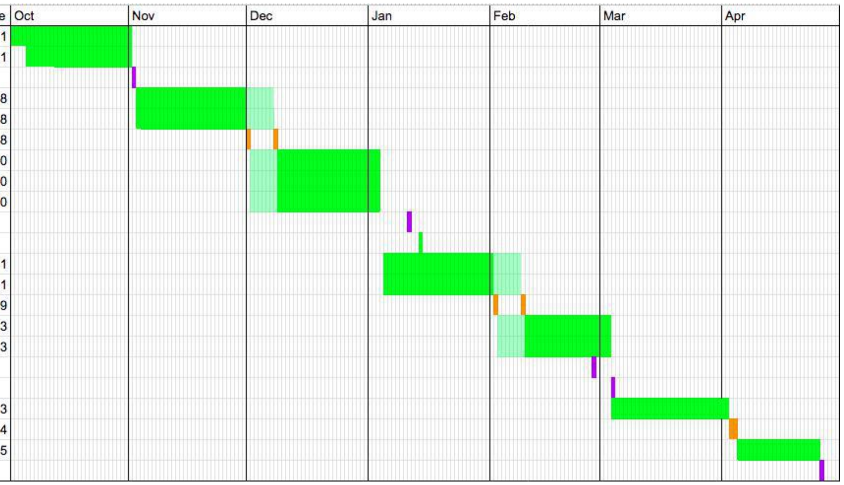
The team's funding comes largely from crowdfunding events. The two events that made up the bulk of the team's funding last year are the yearly University of California, Santa Cruz's Giving Day event and the team's GoFundMe campaign, which combined to over $5,000. The team once again participated in the Giving Day event, raising $4,356. We plan to have another GoFundMe campaign, as well as 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.

6.4 Timeline

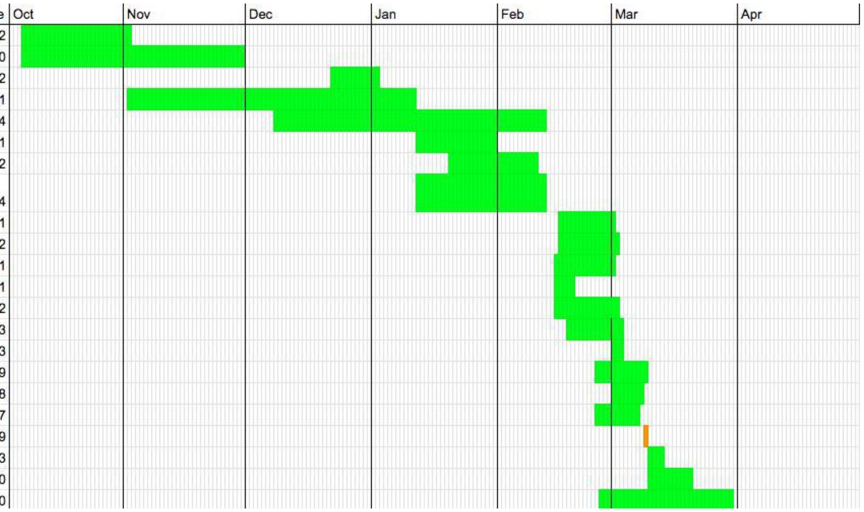
6.4.1 General Timeline

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	

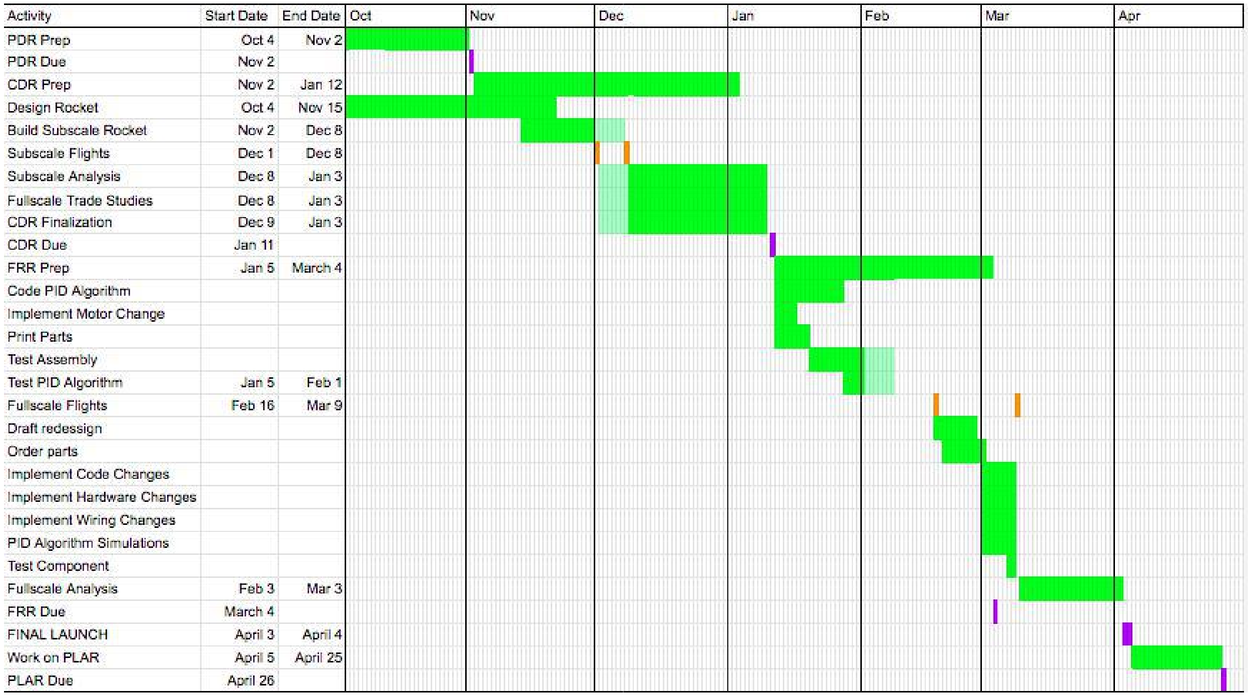


6.4.2 Payload

Activity	Start Date	End Date
Trade Studies for design choices and PDR	Oct 4	Nov 2
Select and order 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	Feb 14
Finish basic prototype of rover (no ODAS)	Jan 12	Jan 31
Test assembly, rover, housing	Jan 20	Feb 12
Finalize separation, integration, and exit	Jan 12	Feb 14
Re-print parts after crash	Feb 18	Mar 1
Re-design servo connector to payload sled	Feb 18	Mar 2
Re-design ALC and payload retention	Feb 17	Mar 1
Re-order all lost components	Feb 17	Feb 21
Finalize all design changes	Feb 17	Feb 2
Assemble re-designed and re-built payload	Feb 20	Mar 3
Test rover scoop and drive	Mar 1	Mar 3
Test radio and black powder separation	Feb 26	Mar 9
Test payload retention	Mar 1	Mar 8
Finalized Payload (sans ODAS software)	Feb 27	Mar 7
Payload flight demonstration	Mar 9	Mar 9
Read camera and ultrasonic data	Mar 10	Mar 13
Working ODAS	Mar 10	Mar 20
Finalize entire Payload section	Feb 27	Mar 30



6.4.3 ADAS


Activity
Start Date
End Date
Oct
Nov
Dec
Jan
Feb
Mar
Apr
PDR Prep Oct 4 Nov 2
PDR Due Nov 2
CDR Prep Nov 2 Jan 12
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
CDR Finalization Dec 9 Jan 3
CDR Due Jan 11
FRR Prep Jan 5 March 4
Code PID Algorithm
Implement Motor Change
Print Parts
Test Assembly
Test PID Algorithm Jan 5 Feb 1
Fullscale Flights Feb 16 Mar 9
Draft redessign
Order parts
Implement Code Changes
Implement Hardware Changes
Implement Wiring Changes
PID Algorithm Simulations
Test Component
Fullscale Analysis Feb 3 Mar 3
FRR Due March 4
FINAL LAUNCH April 3 April 4
Work on PLAR April 5 April 25
PLAR Due April 26

6.4.4 Airframe

Activity	Start Date	End Date
PDR Prep	Oct 4	Nov 2
PDR Due	Nov 2	
CDR Prep	Nov 2	Jan 12
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
CDR Finalization	Dec 9	Jan 3
CDR Due	Jan 11	
FRR Prep	Jan 5	March 4
Code PID Algorithm		
Implement Motor Change		
Print Parts		
Test Assembly		
Test PID Algorithm	Jan 5	Feb 1
Fullscale Flights	Feb 16	Mar 9
Draft redessign		
Order parts		
Implement Code Changes		
Implement Hardware Changes		
Implement Wiring Changes		
PID Algorithm Simulations		
Test Component		
Fullscale Analysis	Feb 3	Mar 3
FRR Due	March 4	
FINAL LAUNCH	April 3	April 4
Work on PLAR	April 5	April 25
PLAR Due	April 26	

6.4.5 Recovery

Activity	Start Date	End Date
Order Parachute	Jan 29	
Start Building Recovery Bay	Feb 4	Feb 8
Connect Wires on Switches and Altimeters	Feb 8	Feb 12
Delegate Roles for FRR	Feb 12	Feb 17
Order Stand Up Screws	Feb 17	Feb 19
Complete Electrical and Structural Sections of FRR	Feb 20	Feb 24
Complete Drift Calculations and Openrocket Simulations	Feb 25	Feb 28