NASA University Student Launch Initiative

Payload Fairing Design and Deployment of Atmospheric Measurement Probe

Prepared for:

NASA Marshall Space Flight Center Academic Affairs Office

By:

Astro Cats - University of Cincinnati Senior Design Team

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ACRONYM DICTIONARY

NAR = National Association of Rocketry

PPE = Personal Protective Equipment

STEM = Science, Technology, Engineering, and Mathematics

TRA = Tripoli Rocketry Association

AGL = Above Ground Level

ASL = Above Sea Level

CNC = Computer Numerical Control

FAA = Federal Aviation Administration

GPS = Global Positioning System

GSM = Global System Mobile Communication

IR = Infrared

LSO = Launch Safety Officer

MPH = Miles Per Hour

OSGC = Ohio Space Grant Consortium

PCB = Printed Circuit Board

PIL = Planetary Investigation Lander

RSO = Range Safety Officer

SLI = Student Launch Initiative

SMS = Short Message Service

UC = University of Cincinnati

UFB = University Funding Board

UML = Unified Modeling Language

UV = Ultraviolet

HPR = High Powered Rocket

JSON = JavaScript Object Notation

1 SUMMARY

1.1 TEAM SUMMARY

Team Name: Astro Cats - University of Cincinnati Senior Design Team

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1.2 LAUNCH VEHICLE SUMMARY

The main purpose of the Astro Cats' launch vehicle is to deliver a scientific payload to an altitude of 5,280 ft. (AGL). The vehicle will utilize a custom fairing design that will house the payload. The Rocket will consist of four subsections: The fairing, electronics bay, tracking bay and fin system. At apogee, the fairing will split in to two pieces and the payload will be deployed.

The electronics bay will contain three StratoLogger altimeters connected to ejection charges located on the outside of the top and bottom of the bay. One altimeter will deploy the fairing at apogee and the main parachute. The second altimeter will separate the drogue parachute and the main chute. The final altimeter will also separate drogue parachute. The tracking bay will contain an Arduino microcontroller, a radio transceiver and a GPS module. The tracking bay will communicate the launch vehicle's position back to our ground station in real time.

The total length of the rocket will be 84.4 inches. The outer diameter of the airframe is 5.54 inches. Without the payload or engine loaded, the rocket will weigh approximately 12 lbs. When the rocket is loaded with the payload and engine, it will weigh approximately 19 lbs. In this configuration, the center of gravity will be located at 46.79 inches from the tip of the nose cone and the center of pressure will be located at 57.99 inches from the tip. This gives the rocket a margin of 2.04 inches.

The launch vehicle will use a Cesaroni – P54-5G Classic (K570) rocket motor to obtain the desired altitude. Recovery will be completed by deploying a drogue parachute at apogee and then deploying a main chute at approximately 700 feet slowing it down to a safe decent rate of 14.2 ft/s.

1.3 PAYLOAD SUMMARY

The main objective of the payload is to record atmospheric measurements of earth's atmosphere from an altitude of 5,280 feet. The PIL is designed to record data including, but not limited to, Pressure, Temperature, Relative Humidity, UV Radiation and Solar irradiance. The PIL will also capture at least 2 images in the air, as well as 3 images on the ground. In order to accomplish all of these tasks, multiple sub-systems have been integrated into the PIL. Among these systems, includes a landing module for the PIL to remain upright for photos, and an electronics sub-system to capture the data and send it to ground control in real time. Along with the successful deployment of the PIL, the fairing shall also successfully deploy in-order for complete mission success. The fairing is designed to split in half with a powder charge ignited at apogee, with the 2 fairing sections attached to the PIL itself with shock cord. The PIL will be separate from the rocket, and will fall separately under its own parachute at a rate of 21.95 ft/s.

Milestone Review Flysheet

Institution	University of Cincinnati

Milestone	PDR

Vehicle Properties

Total Length (in)	84.4
Diameter (in)	5.54
Gross Lift Off Weigh (lb)	19
Airframe Material	Cardboard
Fin Material	G-10 plastic
Drag	0.3 (Cd)

Motor Properties

Motor Manufacturer	Cesaroni
Motor Designation	K570
Max/Average Thrust (lb)	200.85 / 129.15
Total Impulse (lbf-s)	465.4
Mass Before/After Burn	58.98 oz / 22.82 oz
Liftoff Thrust (lb)	200.85

Stability Analysis

Center of Pressure (in from nose)	57.99
Center of Gravity (in from nose)	46.79 (before burnout) / 43.15 (after)
Static Stability Margin	2.04 / 2.70
Static Stability Margin (off launch rail)	2.04
Thrust-to-Weight Ratio	6.77
Rail Size and Length (in)	1.5" x 1.5" / 84 in
Rail Exit Velocity	64.22 ft/s

Ascent Analysis

Maximum Velocity (ft/s)	659.24	
Maximum Mach Number	0.59	
Maximum Acceleration (ft/s^2)	311.7	
Target Apogee (From Simulations)	5280	
Stable Velocity (ft/s)	44	
Distance to Stable Velocity (ft)	3.3	

Recovery System Properties

Drogue Parachute

Manufacturer/Model		LOC		
Size		7.1 ft^2		
Altitude at Deployment (ft)		5280		
Velocity at Deployment (ft/s)		0.0249		
Terminal Velocity (ft/s)		44.97		
Recovery Harness Material		nylon		
Harness Size/Thickness (in)		1/4"		
Recovery Harness Length (ft)		5.5		
Harness/Airframe Interfaces		Swivel eye hook / eye bolt		
Kinetic Energy of Each Section (Ft-lbs)	Rocket			
	370			

Recovery System Properties

Main Parachute

Manufacturer/Model		SkyAngle		
Size		57 ft^2		
Altitude at Deployment (ft)		600		
Velocity at Deployment (ft/s)		44.97		
Terminal Velocity (ft/s)		14.2		
Recovery Harness Material		nylon		
Harness Size/Thickness (in)		5/8" in		
Recovery Harness Length (ft)		6.6		
Harness/Airframe Interfaces		Swivel eye hook / eye bolt		
Kinetic Energy of Each Section (Ft-lbs)	Rocket	Payload		
	35.3	44.6		

Recovery Electronics	
Altimeter(s)/Timer(s) (Make/Model)	PerfectFlite StratoLogger SL 100
Redundancy Plan	Multiple altimeter, backup ejection charges
Pad Stay Time (Launch Configuration)	250 Hours

Recovery Electronics	
Rocket Locators (Make/Model)	Custom GPS
Transmitting Frequencies	902-928 MHz
Black Powder Mass Drogue Chute (grams)	1.5 g (2g backup)
Black Powder Mass Main Chute (grams)	1.5 g (2g backup)

Milestone Review Flysheet

Institution	University of Cincinnati	Milestone	PDR

Payload	
Payload 1	**Overview** The main task of the Payload is to record atmospheric measurements of earth's atmosphere from an altitude of 5,280 feet. The PIL is designed to record data including, but not limited to, pressure, temperature, relative humidity, UV radiation and solar irradiance. The PIL will also capture at least two images in the air, as well as three images on the ground. In order to accomplish all of these tasks, multiple sub-systems have been integrated into the PIL. Among these systems, includes a landing module for the PIL to remain upright for photos.
Payload 2	**Overview** The fairing shall also successfully deploy in-order for complete mission success. The fairing is designed to split in half with a powder charge ignited at apogee, with the two fairing sections attached to the PIL itself with shock cord.

Test Plans, Status, and Results	
Ejection Charge Tests	The team will conduct multiple ground ejection "pop" tests to see the amount of black powder we need to use in our charges. We will be testing the fairing separation charge, the drogue charge and main charge individually. We will start with a small amount of black powder and gradually increase the amount from there if needed.
Sub-scale Test Flights	Our scale rocket will be constructed from the Iris rocket kit from LOC Precision. The outer diameter of the rocket is 3.10" and has a 38mm motor tube. This model is a 0.56 scale of our full scale launch vehicle. This rocket model was chosen as our scale rocket because it was the kit that most closely resembled our full scale vehicle and would minimize any customization needed. Our first scheduled subscale test will take place on November 21st of 2015. The subscale will be loaded with ballast as needed in order to most closely match mass placement of the full scale. We will also be using this subscale model in the wind tunnel in our university's Aerospace laboratory. The rocket will be loaded on a sting mount and connected to a force balance. The values obtained from our wind tunnel tests will help to give us a more accurate estimation for the coefficient of drag for our full scale vehicle.
Full-scale Test Flights	Once the team has proven with the subscale model that our design works, we will do full scale testing of the launch vehicle using a simulated mass as our payload. Our full scale tests will also test our fairing separation system.

2 CHANGES TO PROPOSAL

2.1 VEHICLE CHANGES

The main design change of the launch vehicle was to the fairing design. The two clamshell pieces will be made using fiberglass instead of machining or 3D printing them. This decision was made in because the design proved two difficult to machine and 3D printing would be too costly to make multiple parts. Using fiberglass would allow us to make multiple fairing models quickly and cheaply. The reinforced fiberglass will also be more structurally sound and can be much more easily formed to the shape that is desired. It will also allow the team to make repairs on a damaged part rather than making a completely new part.

The next design change made to the rocket was to the removable fin design. The team has decided to forgo the removable fin design and fix the fins permanently to the launch vehicle. This decision was made to reduce the overall complexity of the rocket and improve reliability of the fins. The fins will be made with a G-10 fiberglass plastic core sandwiched by two pieces of 5 lb. divinycell foam and shaped into an airfoil shape. The shape of the fins also changed. The fins were slightly swept back in order to move back the center of pressure. This decision was made to increase the stability margin of the rocket. This will then be reinforced with a fiberglass shell on the outside. The fins will be permanently attached to the motor mount tube within the rocket and will be capable of withstanding far greater loads than it would see in the field. Two retaining walls on either side of the fin will prevent any tangential movement. In the event that one of the fins are damaged, if we are not able to repair it using more fiberglass, we will remove the lower section, salvage the undamaged fins and replace it with a new lower section.

2.2 PAYLOAD CHANGES

Payload electronics changes that have been made include changing the temperature and humidity sensor, changing the pyranometer, changing the radio antennas and removing the SMS module.

The SHT15 temperature and humidity sensor was changed for the RHT03 temperature and humidity sensor. The RHT03 has a 2 second response time compared to the 8 second response time of the SHT15. This will allow the payload to utilize 2 RHT03 sensors, alternately polling for each sensors current data every second. The accuracy of the humidity is equal on both sensors at ±2% accuracy. The accuracy of the temperature on the RHT03 is ±0.5°C, compared to ±0.3°C of the SHT15. The benefits in the response time of the RHT03 make up for the decreased temperature accuracy compared to the SHT15.

The Kipp and Zonen SP Lite 2 Pyranometer was changed to the Apogee Instruments SP-215 Pyranometer. The SP-215 is cheaper than the SP Lite 2. The SP-215 costs $235.00 and the SP Lite 2 costs 378.75, saving $143.25. The spectral range is greater for the SP-215 at 360nm to 1120nm wavelengths, compared to 400nm to 1100nm for the SP Lite 2. The directional response error is about equal for both sensors, with the SP Lite 2 slightly better at a 3% error at a 75° zenith angle, compared to a 5% error at 75° zenith angle for the SP-215.

The Ground antenna was changed from the L-COM 900 MHz 8dBi Flat Patch Antenna to a Digi International A09-HSM-7. This was changed for FCC regulations. The radio used is the Digi International XTEND 900, and the AO9-HSM-7 is FCC approved for use at full 1 watt transmit power with this radio. Because ground control will be sending commands to the atmospheric payload, the antenna must be FCC approved for limiting transmitting power.

The SIM900 GPRS/GSM Board was removed to conserve space and weight in the atmospheric payload and rocket tracking bay, and to reduce costs. The radios with selected antennas will have more than enough power to steam the data and GPS coordinated of the atmospheric payload and rocket tracking bay. The radios will be able to communicate at distances between 2 and 3 miles, and with uncertain GSM service in the area, the SIM900 GPRS/GSM Board was removed. A micro SD card on board the payload will act as a backup data logger in case of radio failure.

2.3 PROJECT PLAN CHANGES

Project plan changes that have been made are update the schedule, lower the travel expenses, add parts to rocket and payload expenses, changing overhead, and complete the educational engagement. The project schedule was updated to meet the current state of the project. This will accurately reflect our current state of work. Using university vehicles as car rentals lowered the travel expenses instead of previous enterprise. This reduces cost from using an outside agency for rental. Additional parts were added to the rocket and payload budget lists. In addition the overhead was modified to keep total budget the same. Educational engagement was completed on November 4. The educational engagement plan was updated to reflect this change. Additional updates will occur after the high school and NASA are contacted with follow-up surveys and documentation respectively.

3 MISSION STATEMENT

3.1 MISSION MOTIVATION

In attempt to compete and win the NASA University Student Launch the University of Cincinnati Astro Cats will develop vehicle capable of deploying a planetary probe to approximately 1 mile above ground level and then will be deployed via a fairing nose cone section. The probe will be equipped with a suite of sensors to capture valuable atmospheric data such as UV radiation, solar irradiance, temperature, humidity, pressure, and pictures during decent. The data will then be transmitted via radio to the ground station where it will be stored, interpreted and plotted in real time. After the competition we will further investigate the trends in the data and provide a report stating the results and conclusion drawn from the mission.

In summary the team aims to:

- Develop and construct a high-powered rocket capable of delivering our probe to an altitude of 5,280 ft.
- Develop and construct a custom fairing design to deploy the payload.
- Develop and construct a probe that contains a suite of sensors to measure basic atmospheric data.
- Take descent and landing images, and use image processing to correctly orient the images.
- Analyze atmospheric data transmitted back to ground station during decent and after landing.
- Generate a report stating results and conclusions drawn from the atmospheric data collected.

3.2 MISSION OPERATIONS

The mission we choose to complete consist of four separate phases. The first phase or Launch phase begins after the rocket is armed on the launch pad and continues until the rocket reaches apogee. During this time all electronics will be in low power mode and only transmission will include status of electronics and battery if we choose from the ground station. Once at apogee the first set of altimeters will trigger a black powder charge to deploy the fairing sections, and the payload with its parachute. The electronics of the payload will be become active and will begin collecting data from the sensor package and storing it onboard. The radio will become active and begin transmitting only the location of the payload at a specified time interval. Five seconds after apogee the rockets drogue parachute will be ejected by a second charge. The next phase occurs when the rocket reaches 600 feet and the second set of altimeters trigger the black powder charge to separate the upper and lower body sections and deploy the main parachute. The tracking electronics in the rocket remain in low power mode and the payload continues the same operation as in phase 2. Phase 4 or the recovery phase occurs as the payload and rocket reach the ground. The rocket tracking electronics turn on and begin to transmit the location of the rocket via a text message, which is received by team members so the rocket can be found and recovered. Upon landing the payload will continue to collect data from its sensors at a rate of 1 sample per minute and begin. After 10 minutes the radio will begin to transmit all the data back to the ground station so it can be analyzed.

4 VEHICLE DESIGN

4.1 MISSION SUCCESS CRITERIA

The launch vehicle will be considered successful if it meets the following criteria:

- Launch vehicle reaches an altitude as close to 5,280 ft. while reaching a minimum altitude of 5,030 ft. (AGL) and not exceeding a maximum altitude of 5,405 ft. (AGL)
- The fairing separates at apogee and deploys the payload
- The drogue parachute deploys at apogee
- The main parachute is deployed at 600 ft. (AGL), +/- 100 ft.
- Launch vehicle returns to Earth in reusable condition
- Tracking bay reports position data back to ground station

4.2 SUBSYSTEM DESIGN

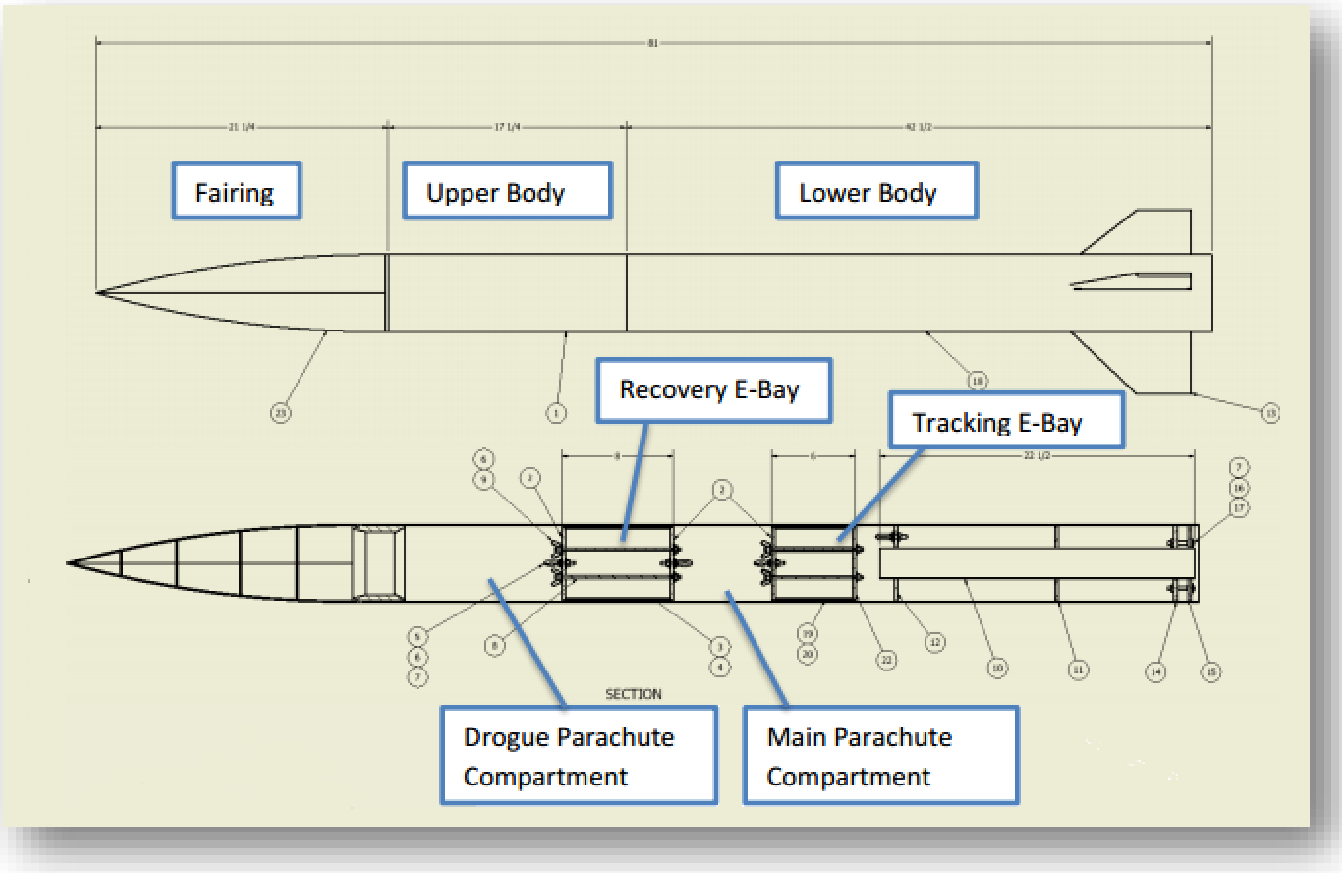


Figure 1: Vehicle Subsystems Overview

4.2.1 Tracking Bay

The rocket-tracking bay will be located between the motor mount and the Electronics bay. The inner components will consist of an Arduino Mega 2650 board, a SparkFun Venus GPS module, an XTEND-900 radio transceiver, a battery and both a radio and GPS antenna. The tracking bay will be constructed out of a LOC Precision 5.38" electronics bay and will be permanently attached to the lower body tube with the use of epoxy. The bay's electronics will be accessible through a removable bulkhead on the in the main chute compartment.

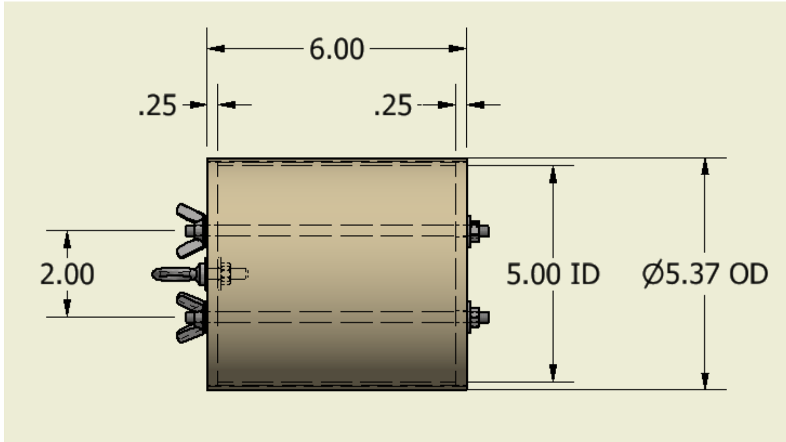
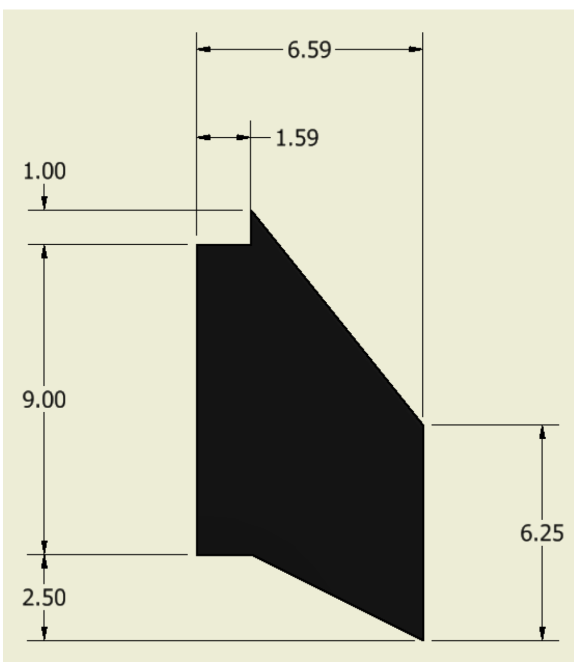


Figure 2: Tracking Bay Details

4.2.2 Fins

The fins are designed to be slightly swept back in order to move back the center of pressure. The chosen material for the fins will be 1/16" G-10 fiberglass plastic in order to provide core strength to the design. Two pieces of 5lb Divinycell vinyl foam will be placed around the core and shaped into an airfoil design. Epoxy and fiberglass will be used over the whole design to create a light shell around the core. The fins themselves will be permanently attached to the rocket in order to allow them to withstand stronger loads than detachable fins.



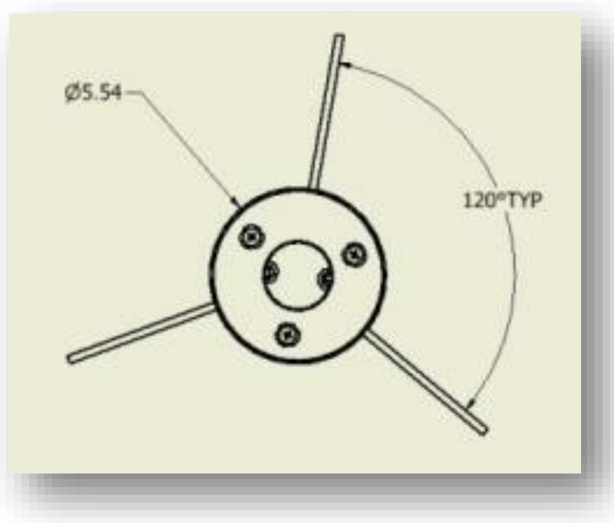


Figure 3 (Left) and Figure 4 (Right): Details of fins and their attachment to the body

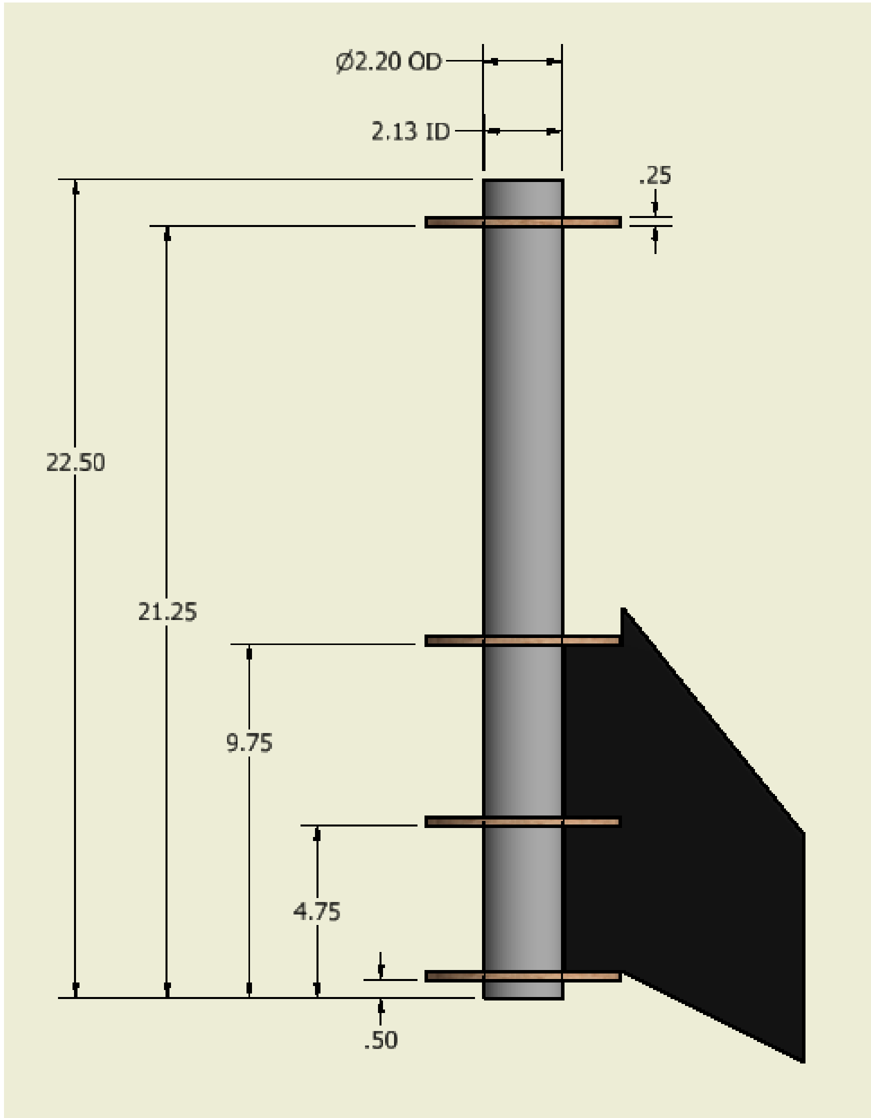


Figure 5: Details of the Motor Mount

4.2.3 Recovery Bay

The rocket recovery bay is located between the fairing and the tracking bay. The inner components will consist of three Stratologger altimeters, three 9v batteries, four blast tubes, an altimeter sled and the Payload assembly. The recovery bay will be constructed out of a LOC Precision 5.38” electronics bay.

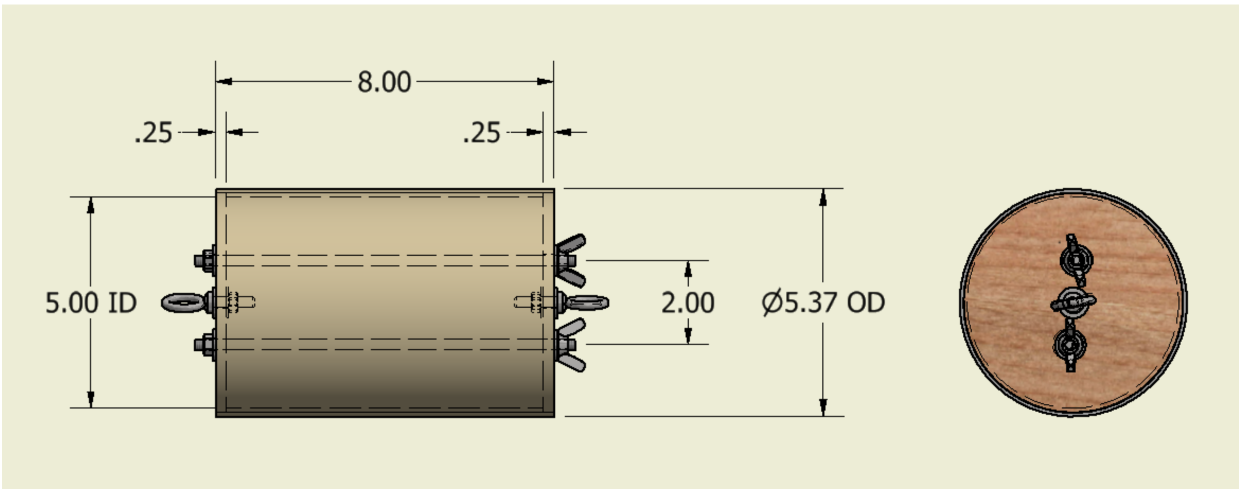


Figure 6: Recovery Bay Details

4.2.4 Fairing Design

The fairing will be a clamshell model, designed to blow apart with a similar powder charge separating that will separate the main body from the lower body. The fairing was designed using Autodesk Inventor, and will be made out of 4 oz. and 6 oz. fiberglass fabric and epoxy resin. The clamshell pieces will be supported by ribs made from 3D printed material and reinforced with more fiberglass. The ribs will also interlock via nylon shear screws. Four additional shear screws will bolt the base of the fairing to the rocket body. Both fairing shells are designed to be identical, with an overlapping “tab” along the edge to prevent airflow from leaking into the payload section. The fairings will be loaded with a single powder charge, located in a pressure cylinder, fabricated from aluminum, in the tip of the nose cone. This pressure will cause the fairing to break free of the shear pins and release the payload. The fairings will separate at apogee, and will be tethered to the same shock cord as the PIL parachute.

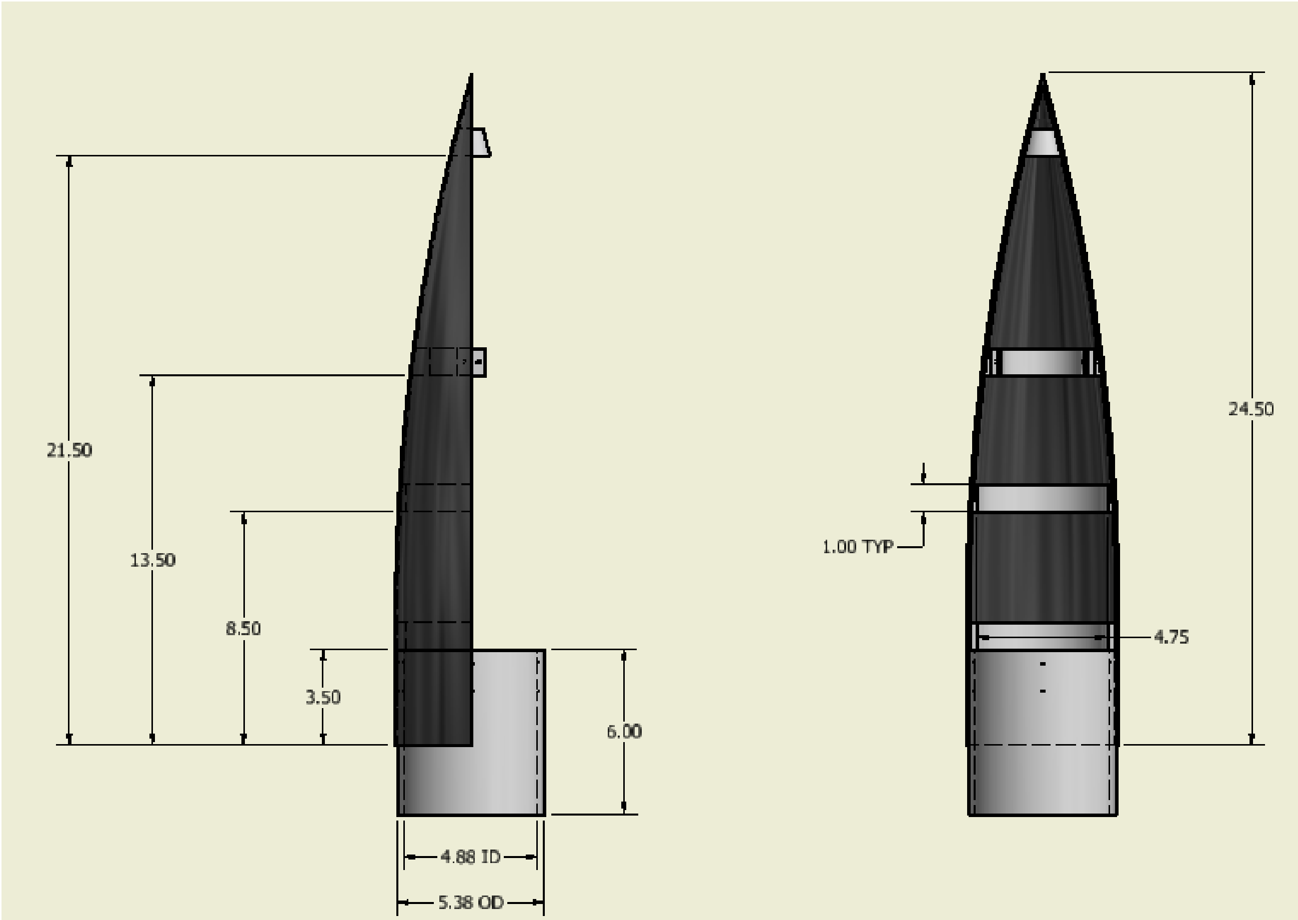


Figure 7: Fairing Design Details

4.3 Overview of Scale Rocket

Our scale rocket will be constructed from the Iris rocket kit from LOC Precision. The outer diameter of the rocket is 3.10" and has a 38mm motor tube. This model is a 0.56 scale of our full scale launch vehicle. This rocket model was chosen as our scale rocket because it was the kit that most closely resembled our full scale vehicle and would minimize any customization needed. Our first scheduled subscale test will take place on November 21st of 2015. The subscale will be loaded with ballast as needed in order to most closely match mass placement of the full scale. We will also be using this subscale model in the wind tunnel in our university's Aerospace laboratory. The rocket will be loaded on a sting mount and connected to a force balance. The values obtained from our wind tunnel tests will help to give us a more accurate estimation for the coefficient of drag for our full scale vehicle.

Figure 8: Details Scale Model Kit Purchased

4.4 Testing Plan

4.4.1 Pop Testing

The team will conduct multiple ground ejection pop-tests to see gauge the amount of black powder to use in our charges. We will be testing the fairing separation charge, the drogue charge and main charge individually. We will start with a small amount of black powder and gradually increase the amount from there if needed.

4.4.2 Vehicle Testing

In accordance with the requirements for the NASA a subscale model of our rocket will be launched to test to see if our design is sound. Once the team has proven with the subscale model that our design works, we will do full scale testing of the launch vehicle using a simulated mass as our payload. Our full scale tests will also test our fairing separation system.

4.4.3 Drop Testing

To test our parachutes, we will perform drop tests from a designated building on campus. We will time the descent and use our data to improve our simulation results. The drogue, main and PIL parachute will be tested separately.

4.4.4 Wind Tunnel Testing

Our subscale model will be used in our University's wind tunnel to gather data on the flight characteristics of our launch vehicle. The goal of these tests are to help us get more accurate values for our drag calculations.

4.4.5 Tracking Bay Radio Testing

The tracking bay radio communication will be tested by sending data from the ground station equipment to the tracking bay radio at various distances and checking for signal strength and data loss. This will ensure that our radio transceivers are capable of communicating with each other at the distances they will encounter.

4.5 Recovery and Electronics

4.5.1 Recovery Electronic Summary

The recovery bay will consist of three StratoLogger altimeters for reference see section 5.5.2 Recovery Electronic Diagram. StratoLogger-1 (Strat-1) will deploy the main ejection charge for the faring and main parachute. Strat-2 will deploy the main charge for the drogue parachute and also the back-up charge for the main parachute. Strat-3 will be connected to the back-up drogue parachute charge. Each StratoLogger will have its own isolated 9-volt power supply in case of failure and have a designated lock-on arming switches.

5.1.1.1 StratoLogger SL 100 Details

The StratoLogger is “A miniature, high accuracy, extreme range altimeter with two event deployment and flight data logging” device. The logger is capable of both post-flight data retrieval, real time data output and time-delay settings. It is capable of calculating an instantaneous and smoothed velocity of the rocket which it uses to determine when apogee is reached within +-.02 seconds.

4.5.2 Recovery Electronic Diagram

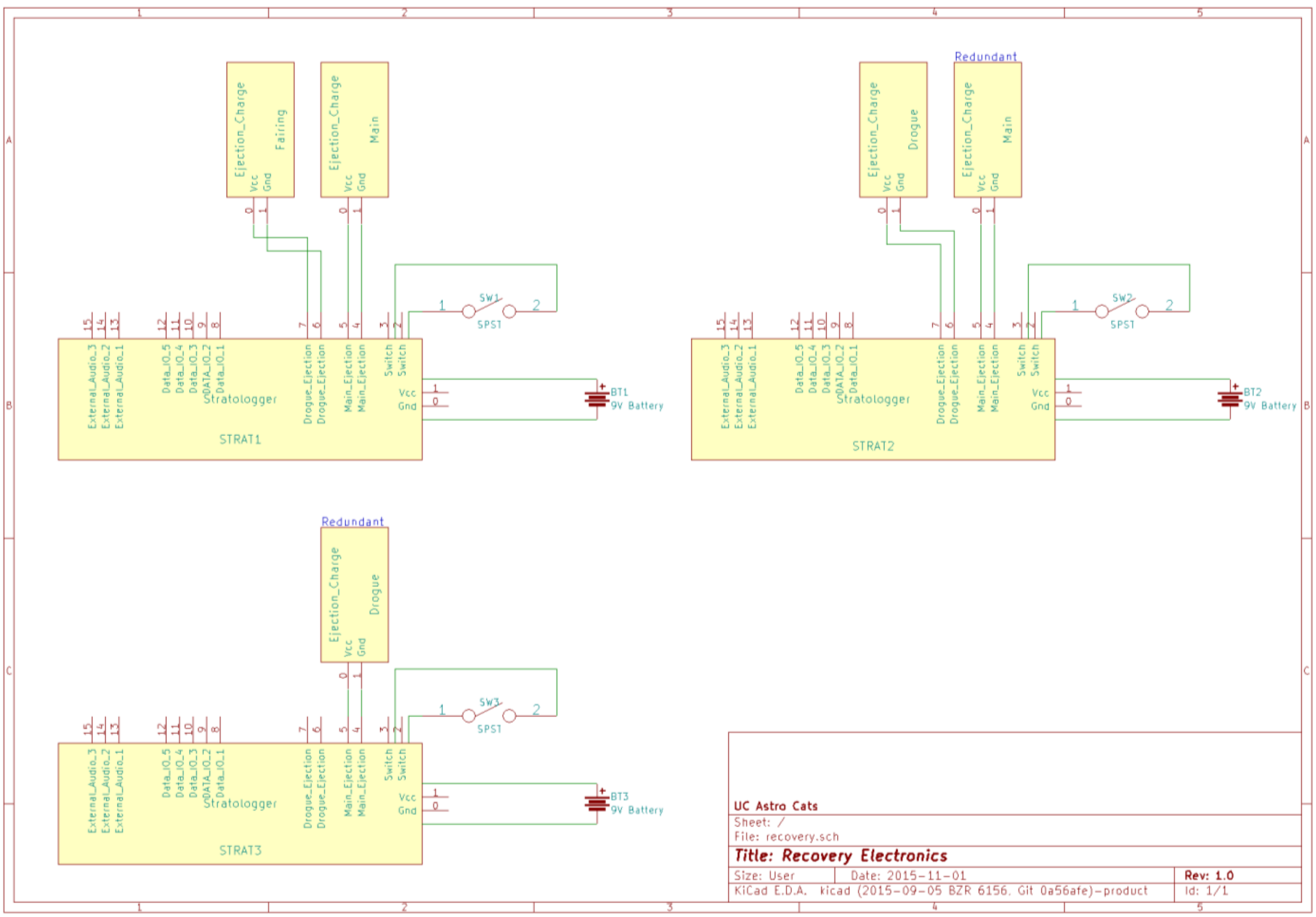


Figure 9: Rocket Recovery Electronics Diagram

4.5.3 Ejection Charges

Previous rocket launches used a 1.5-gram ejection charge. For initial testing the rocket recovery system will utilize a 1.5-gram charge and a 2-gram back up charge for both the drogue and main parachute. Initial values are based on ejection charge calculators using the given length of the tube, diameter and estimated pressure. These values will be refined as pop-tests are conducted prior to the first test launch.

4.5.4 Parachute Sizing

Using the mass table in section 5.8, descent rates were calculated using:

Variables:

S – Surface area of the parachute

g - Acceleration due to gravity

m – Mass

ρ –Density of air

C_d – Coefficient of drag

V – Descent rate velocity

D – Diameter

Descent Rate:

$$S = \frac{2 * g * m}{\rho * C_d * V^2}$$

Kinetic Energy:

$$K.E. = \frac{1}{2} * m * V^2$$

To meet desired descent rates and kinetic energy limits the following parachutes will be used:

Main— SkyAngle CERT-3 large parachute, 57 sq. feet, 1.26 Cd, descent rate: 14.2 ft/s

Consists of four 5/8” mil-spec suspension lines (2,250 lbs.), a 1,500 lb. swivel and zero-porosity 1.9 oz. balloon cloth. Per suppliers specifications. Load capacity is 36 lbs. and suspension line length 80”.

Drogue— 36” LOC LHPC-36 parachute, 7.1 sq. feet, 0.75 Cd, descent rate: 44.97 ft/s

Uses 10 nylon braided shroud lines in 155 lb. and 210 lb. tensile strengths. 66” suspension line ¼” thick.

PIL— Public missiles PAR-60HD parachute, 12.6 sq. feet, 0.75 Cd, descent rate: 21.95 ft/s

60” nylon rip-stop conical parachute with ~12” spill hole. Load capacity is 5.6-10 lbs.

4.5.5 Attachment & Deployment Process

Upon reaching apogee, the fairing will separate releasing the payload. The payload and fairing halves will descend with a single PAR-60HD parachute. After a delay at apogee the drogue LOC LHPC-36 parachute will deploy connected to the main rocket. After descending to approximately 600 feet AGL, the main SkyAngle parachute will deploy. The rocket will then descend via a drogue parachute attached to the recovery bay and a main parachute attached to both the recovery bay and rocket body. Each parachute will be attached using rip-stop nylon cords and additional nylon suspension supports. The cords will then be attached to eyebolts embedded into the bulkheads of the Recovery Bay. Figure 10: PublicMissiles.com shows the attachment method we plan to use.

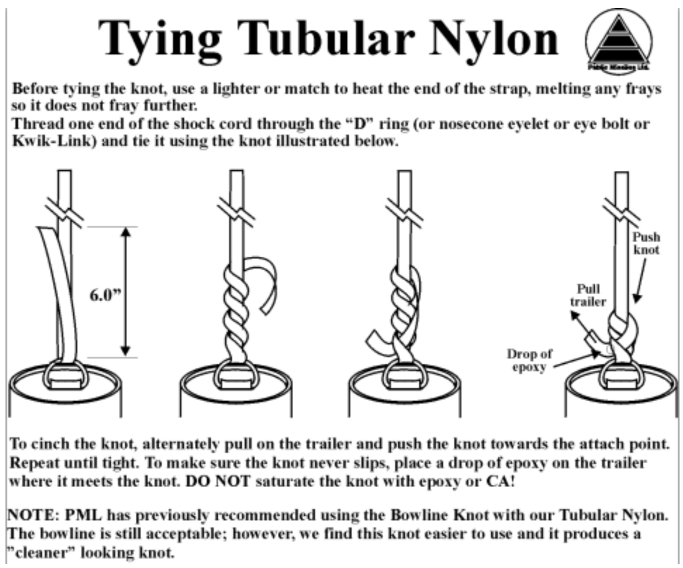


Figure 10: Knots being used to secure recovery systems

4.5.6 Tracking Bay Electronics

The rocket tracking bay will provide ground control with GPS Coordinates of the rocket. The GPS data will be sent in real time, to provide real time tracking of the rocket body as it descends back to ground. GPS Data will be stored in a JSON string, and the JSON string will be sent to ground over the serial stream radio. The rocket tracking bay will consist of an Arduino board, a GPS module and a radio transceiver which can be seen in Figure 11 below.

- Arduino Mega 2650 - Microcontroller that interfaces the GPS module and the radio.
- SparkFun Venus GPS - GPS Module that outputs GPS Coordinates over a serial connection.
- XTEND-900 - Radio transceiver that receives and transmits an asynchronous serial stream.

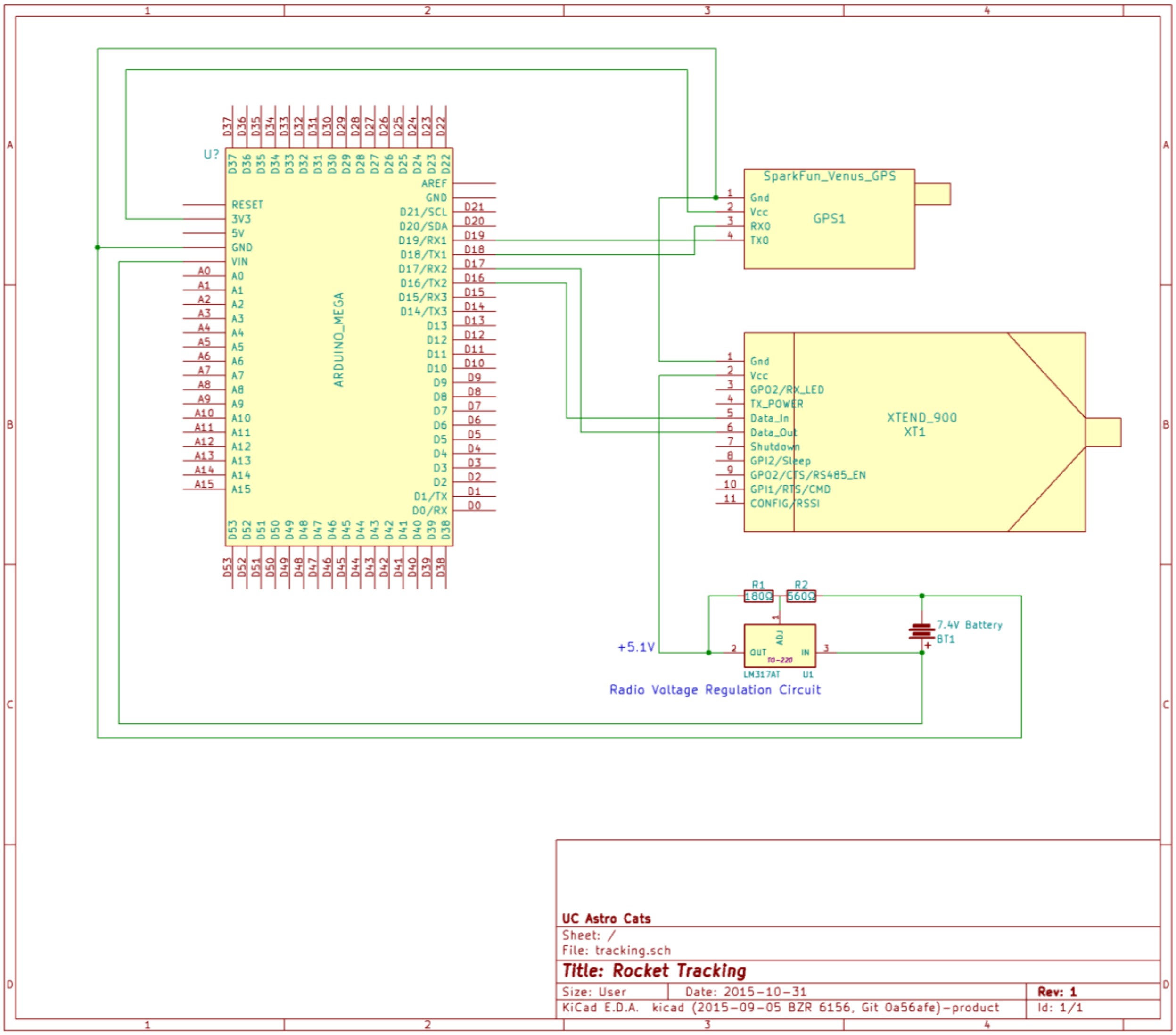


Figure 11: Tracking Bay Electronics Schematic

4.6 Recovery Requirements & Verification

Table 1: List of Recovery Requirements and Verification Plan

Requirements	Design Features to meet Requirement	Verification
The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and main parachute is deployed at a much lower altitude. Tumble recovery or streamer recovery from apogee to main parachute deployment is also permissible, provided the kinetic energy during drogue-stage descent is reasonable, as deemed by the range safety officer.	This requirement will be met through a two stage parachute recovery system.	This will be verified through the full scale test.
Teams must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full scale launches.	This test will be carried out at a launch site where the ejection charges will be tested.	This will be verified through testing.
At landing, each independent section of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.	This will be met through the use of drag equations and the mass of the rocket to keep the kinetic energy of each rocket section below 75 ft-lbf.	This will be verified through the full scale test.
The recovery system electrical circuits shall be completely independent of any payload electrical circuits	This will be met by designing the system to be completely independent. This payload (PIL) is on a completely separate circuit.	This will be verified through analysis.
The recovery system shall contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers. One of these altimeters may be chosen as the competition altimeter	The system is designed with two altimeters for the recovery system.	This will be verified through analysis.
Motor ejection is not a permissible form of primary or secondary deployment. An electronic form of deployment must be used for deployment purposes.	The system removes the delay charge and uses an altimeter based recovery system.	This will be verified through analysis.

A dedicated arming switch shall arm each altimeter, which is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	The system is design in such a way to have external switches arming switches for each altimeter.	This will be verified through analysis.
Each altimeter shall have a dedicated power supply.	The system is designed with 3 separate batteries for each altimeter.	This will be verified through our design analysis.
Each arming switch shall be capable of being locked in the ON position for launch.	The switches are of a key type that can be locked into position.	This will be verified through design analysis.
Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.	The compartments for the parachutes are designed with shear pins.	This will be verified through design analysis.
An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.	The system consists of radios and GPS to transmit the position to the ground.	This will be verified through system design.
Any rocket section, or payload component, which lands untethered to the launch vehicle shall also carry an active electronic tracking device.	The PIL section, separate from the main rocket, contains a separate tracking system.	Verified through system design.
The electronic tracking device shall be fully functional during the official flight at the competition launch site.	The system will transmit during the official launch by design.	This will be verified through system design.
The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	The recovery system will have a shield to prevent interference.	This will be verified through system design.
The recovery system altimeters shall be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device	The system is designed to physically separate the recovery system from any interfering component.	This will be verified through inspection.

The recovery system electronics shall be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.	The system is designed with a metal foil shield between the recovery system and the radios.	This will be verified through inspection.
The recovery system electronics shall be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	The system is design with a metal foil shield between the recovery system and other rocket electronics.	This will be verified through inspection.
The recovery system electronics shall be shielded from any other onboard electronics which may adversely affect the proper operation of the recovery system electronics.	The system is design with a metal foil shield between the recovery system and other rocket electronics.	This will be verified through inspection.

4.7 Vehicle Requirements

Table 2: List of Vehicle Requirements and Verification Plan

Requirement	Design Features to meet Requirement	Verification
The apogee of the rocket shall be as close to 5280 feet (AGL) as possible.	The motor chosen has enough power to reach the required height and will be calibrated to do so.	Will be verified through flight testing.
The rocket must carry one NASA approved altimeter for recording altitude used in competition scoring.	The PIL is designed to hold a NASA approved altimeter.	Will be verified through inspection.
The rocket must be designed to be recoverable and usable meaning it is able to launch the same day with no repairs of modifications.	The rocket is designed to be recoverable.	Will be verified through design.
The rocket may not have more than four independent sections.	The rocket is designed to have four independent sections.	Will be verified through design.
The rocket is limited to single stage.	The rocket is designed to be single staged.	Will be verified through design.
The rocket must be able to be built and ready to launch within two hours.	The rocket is made to be assembled within the required time limit of two hours.	Will be verified through design.
The rocket must be able to be launched through NASA-designated 12 volt direct current firing system.	The rocket is designed to launch through a 12 volt direct firing system.	Will be verified through design.
Only commercially available, NRA/TAR/CAR approved motors may be used to propel the rocket.	The motor used meets required approval.	Will be verified through design.
Total Impulse may not exceed 5,120 Newton-seconds.	The motor is designed to cap at the required force.	Will be verified through testing.
All pressure vessels must be RSO approved and have a minimum of 4:1 Safety factor, pressure relief valve, and full pedigree.	The pressure vessels used are designed to meet requirements.	Will be verified through design.
A full-scale model of the rocket must be flown prior to the FRR.	A test launch will be scheduled.	Will be verified through testing.

4.8 Rocket Mass List

Table 3: Vehicle Mass List

Component Mass List			
Lower Section	**qty.**	**weight (g)**	**total (g)**
5.5" Motor mount tube (per inch)	42.75	18.29	781.90
2.25" Motor mount tube (per inch)	20	5.68	113.6
centering ring	4	46	184
Fins	3	150	450
Rail Buttons	1	14	14
Main Chute	1	76	76
Shock Cord (Main)	1	106	106
Motor	1	1685	1685
Motor Casing	1	163.9	163.9
Motor Retainer	1	39	39
Total Lower Section Mass			**3613.40**
Upper Section	**qty.**	**weight (g)**	**total (g)**
5.5" Body Tube (per inch)	7.25	18.29	132.60
Body tube Coupler	1	106	106
Nose Cone	1	570	570
Shock Cord (drouge)	1	73	73
Drouge Chute	1	16	16
10.5" Stiffy Tube (per inch)	10.5	22.95	241
Total Upper Section Mass			**1138.60**
Electronics bay	**qty.**	**weight (g)**	**total (g)**
Stratologger	4	15	60
Payload Assm.	1	690	690
Altimeter Sled	1	112	112
9volt Battery	4	46	184
Blast tube	4	20	80
Total Electronics Bay Mass			**1126.0**
Tracking Bay	**qty.**	**weight (g)**	**total (g)**
Radio - XTEND 900	1	18	18
Radio Antenna	1	100	100
Stiffy tube	1	510	510
GPS - SparkFun Venus GPS	1	10	10
GPS Antenna	1	18	18
Battery	1	280	280
Total Tracking Bay Mass			**936.0**

Total Mass	**Kilograms**	6.81
	Lbs.	14.99

4.9 Mass Summary

All of the off-the-shelf parts we are going to be using have been weighed individually using a digital scale. Since the fins and nose cone will be custom made, estimated masses were used based off of components from the lab that were of similar size and material. In addition, we will include a 1 pound reserve to account for additional unforeseen weight.

4.10 Confidence in Design

Overall, the team is strongly confident in the design we have chosen. Some minor modifications may need to occur as we progress through the project. Once we get a working model of our rocket and payload, we will be able to obtain a more accurate mass description and find our actual center of pressure and center of gravity and compare it to our theoretical values. This will in turn give us better simulation results. From there we will be able to refine the design if need be. The custom fairing will prove to be the most difficult part to produce. Multiple attempts to may be needed produce the right one. If from our tests we deem the fairing design to be too unsafe to fly, we will either redesign it or replace the fairing in place of a standard fitted nose cone.

4.11 Vehicle Performance & Simulations

4.11.1 Mission Performance Criteria

The criteria for a successful mission are: The launch vehicle must reach an altitude of 5,280 feet above ground level. At apogee, a fairing design shall deploy a payload. The launch vehicle will have a dual deployment recovery system. A drogue parachute shall be deployed at apogee, and a main parachute shall be deployed at an altitude of 600 feet. The payload and the rocket will both be recoverable and reusable, and will land with a kinetic energy under the maximum of 75 ft-lbs.

4.11.2 Thrust Profile, Altitude Model, Flight Profile

Using RockSim 9's simulation tool we were able to select the Cesaroni K570 motor. With a total impulse of 2070.258 N-Sec and a 3.90 sec burn time, the average thrust is relatively low so that the rocket is not subject to unnecessary high forces during launch that come with short burn motors. Using data from thrustcurve.org we were able to simulate the thrust curve in Matlab. Our simulation gave us the figure below. The thrust curve from thrustcurve.org can be seen on the right.

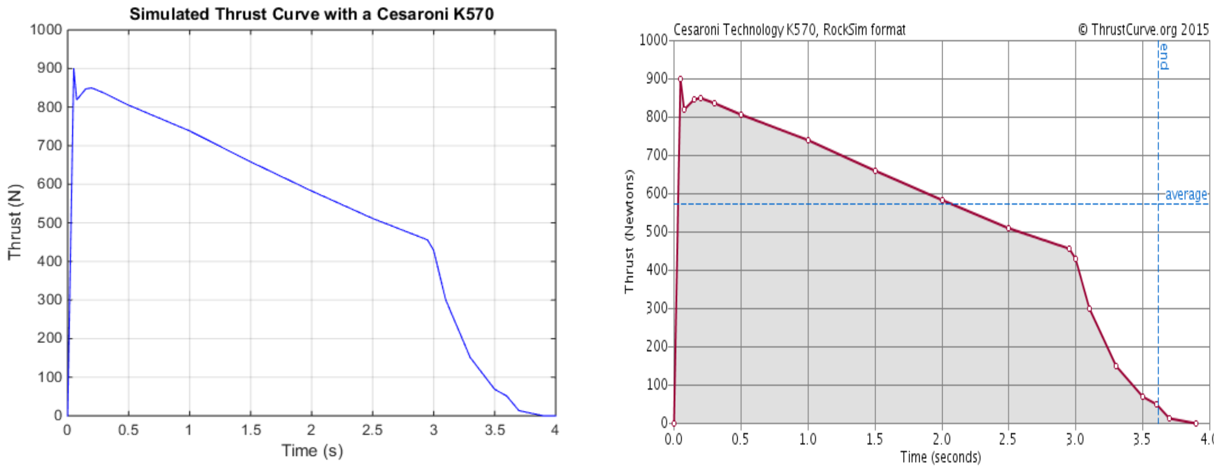


Figure 12: Graph of Actual Thrust Curve and Matlab Code Thrust Curve

Two different methods were used to determine the altitude of the rocket. First, a Matlab script was used to solve for the acceleration, velocity, and position. Using Force=mass*acceleration, an equation for acceleration was created, and the derivation can be seen below.

$$F = m\ddot{y} \qquad (1)$$
$$m\ddot{y} = T - D - W \qquad (2)$$

Equation two was derived from the summation of forces. T=Thrust, D=Drag, W=weight, m=mass

$$\ddot{y} = (\frac{1}{m})(T - D) - g \qquad (3)$$
$$D = \frac{1}{2}\rho\dot{y}^2 SC_d \qquad 4)$$

S=cross-sectional surface area of the rocket, v=velocity, rho=density, Cd=drag coefficient.

$$\ddot{y} = (\frac{1}{m})(T - \frac{1}{2}\rho(\dot{y})^2 SC_d) - g \qquad (5)$$

Equation 5 was the acceleration modeled in Matlab. Mass, thrust, and density are not constants. All three were modeled separately and indexed, so when the program ran through for each step in time it pulled the data from those functions. Mass and thrust are dependent on time, and density is dependent on altitude. The density function was created using the international standard atmospheric model. The mass function was created under the assumption that the burning rate is constant. Thrust was generated by the process stated above. Cd is not constant as it changes with Reynolds number. To get accurate data for the coefficient of drag you must find it experimentally. We are in the process of getting a scale model together to put into a wind tunnel. Once this data is collected the function will be added into the program. Until that time a Cd of .30 was used. This number was chosen based on inputs from previous rocket teams and grad students at the University of Cincinnati. Using this method, with zero wind, and all simulated masses and cross-sectional surface areas inputted into the program, a max altitude of 5,476.60 feet. The flight profile simulation data from Matlab can be seen below.

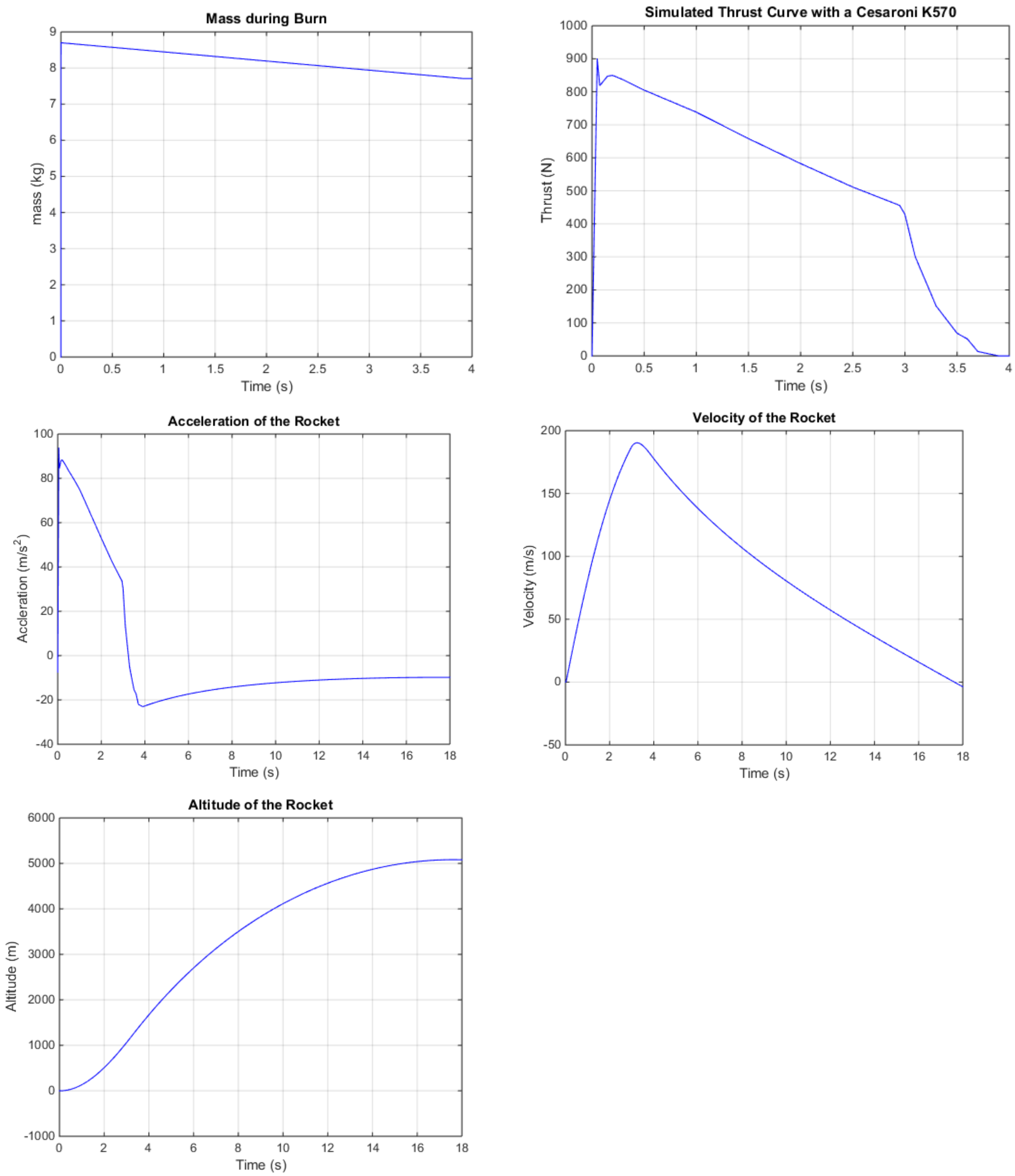


Figure 13: Simulated Flight Profile of the Rocket

Until we can get accurate Cd vs. Reynolds number data we will be using the altitude predictions from Rocksim. Currently the altitudes for a no-wind scenario are very different. We are working to finalize the Matlab model and get accurate coefficient of drag data. The second method is using Rocksim, and this is also where CP, CG, and stability margin data are gathered from are. Figure 5 shows that the K570 is able to send our proposed rocket in no-wind to a max altitude of 5,740.30 feet AGL which is shown in simulation 0. Simulation 1 is the same rocket with light winds (0-2 MPH) and in Simulation 2 the rocket is subject to medium winds (3-7 MPH). These altitudes are much higher than needed. Simulation 3 is the result of using 1.44 lb. ballast placed near the center of gravity, as not to affect the rocket's stability, to reach the desired altitude of 5,280 feet above ground level. The flight profile for simulation 3 can be seen in Figure 6. The team plans to use this tactic along with two test launches to accurately predict the needed ballast weight to reach the desired altitude at differing wind conditions.

Figure 14: Rocket Diagrams & RockSim 9 Simulation Results

Table 4: Results of Rocksim Simulations

Simulation	Max Altitude Feet	Max Velocity Feet/Sec	Ballast Weight Pounds	Wind Speed MPH
0	5,740.30	659.24	0	0
1	5,739.90	659.24	0	0-2
2	5,728.75	659.19	0	3-7
3	5281.27	610.26	1.44	0

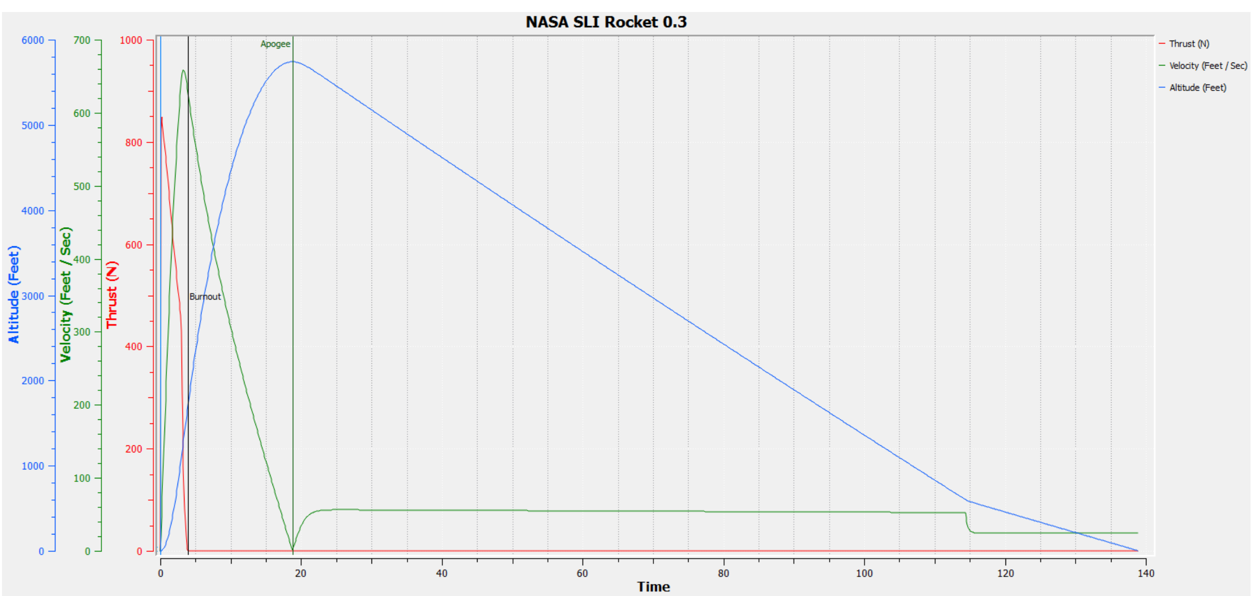


Figure 15 : RockSim 9 rocket flight profile with Cesaroni K570

The graph above is the flight profile simulation of the rocket without the ballast, using Rocksim 9. The max altitude reached, with no wind is 5,740.30 feet. There is a clear discrepancy between our two models, and fortunately, we know what it is and we know how to correct it. Once we can get into the wind tunnel to get experimental coefficient of drag data, our model will be much more accurate.

4.11.3 Drift Calculations

Drift Calculations were simulated in Matlab. This data is simulated from apogee and is a simple vector addition. If an object is falling with X speed over Y time and the wind is Z speed, then the total drift is Y*Z. Our simulated descent rates are currently 14.2 ft/s for the rockets main parachute which gets deployed at 600 feet, and 44.97 ft/s for the drogue parachute. The payload falls with a constant descent rate of 21.95 ft/s. Seen below are below are simulated drift for 5 different wind speeds, 0, 5, 10, 15, and 20 MPH. Since wind is not constant, a range was applied to the mean wind speed for each step in time in the simulation. The range was calculated by adding a standard deviation of ±2 ft/s. This gives us wind speeds in a normal distribution which more accurately models true wind behavior. Having the wind distribution modelled as a normal distribution is an assumption based around a sustained wind. The next step is to get experimental wind data to more accurately model its behavior. A plot of the distribution of wind speeds for a single run, with the mean at 7.33 ft/s (5MPH), can be seen below. (Distributions for other wind speeds can be found in the appendix.)

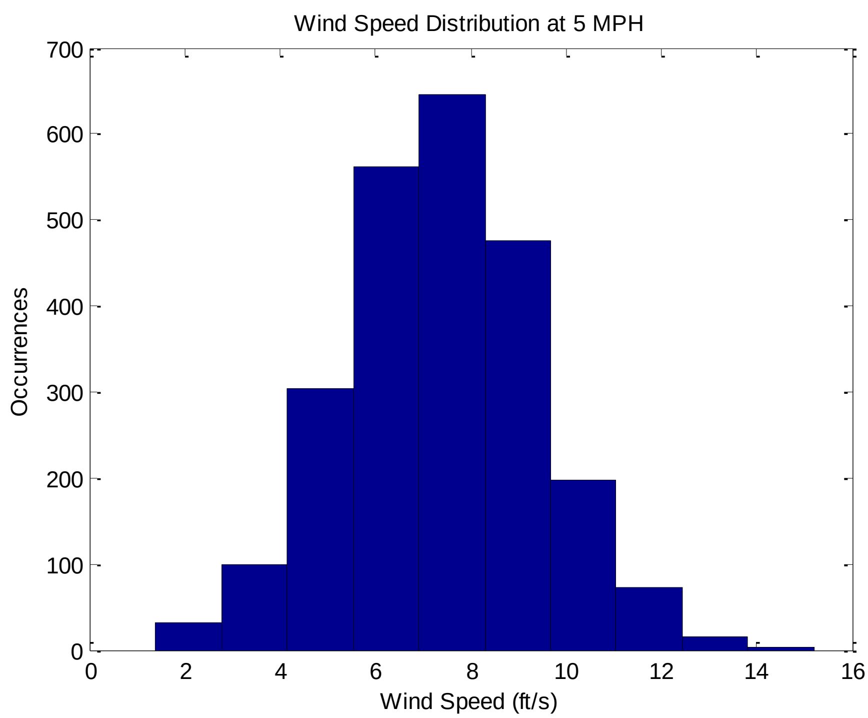


Figure 16: Wind Speed Distribution used in Simulation

Now that we have determined the change of wind speed given a mean, we can use that data to accurately calculate drift. Using 0 MPH (0 ft/s) for our first calculation, a total drift of 0 feet was calculated. Our second input is 7.33 ft/s (5 MPH). The graph of drift from apogee can be seen below. (This graph for other wind speeds can be seen in the appendix.)

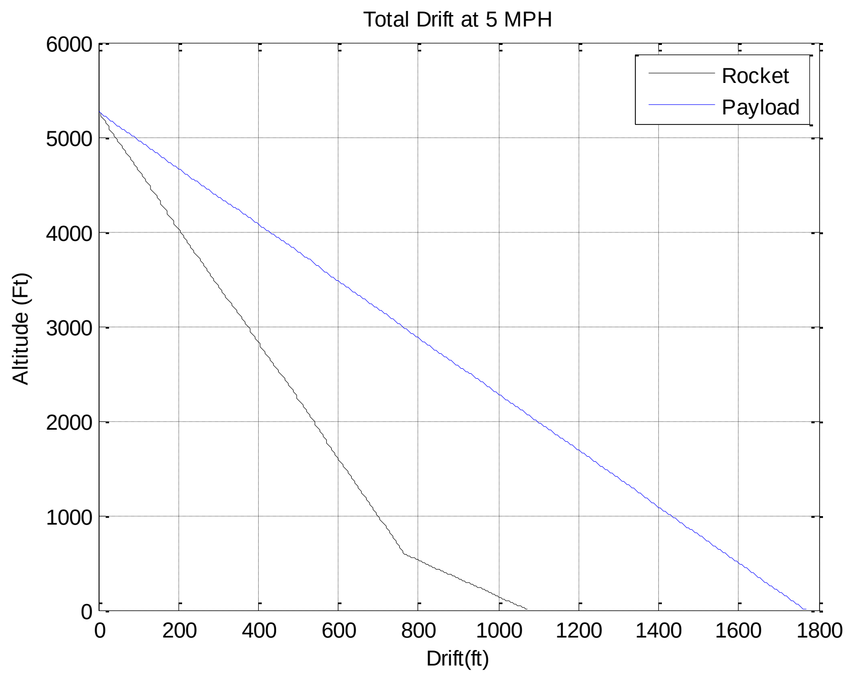


Figure 17: Calculated Total Drift in 5 MPH Wind Conditions

As can be seen above, the slopes of the descent vary as the wind speed varies. At 600 feet of altitude our main parachute is deployed, which slows the rockets descent to 14.2 ft/s. Each mean wind speed was run 10,000 times to get a distribution of the total drift for the rocket and the payload.

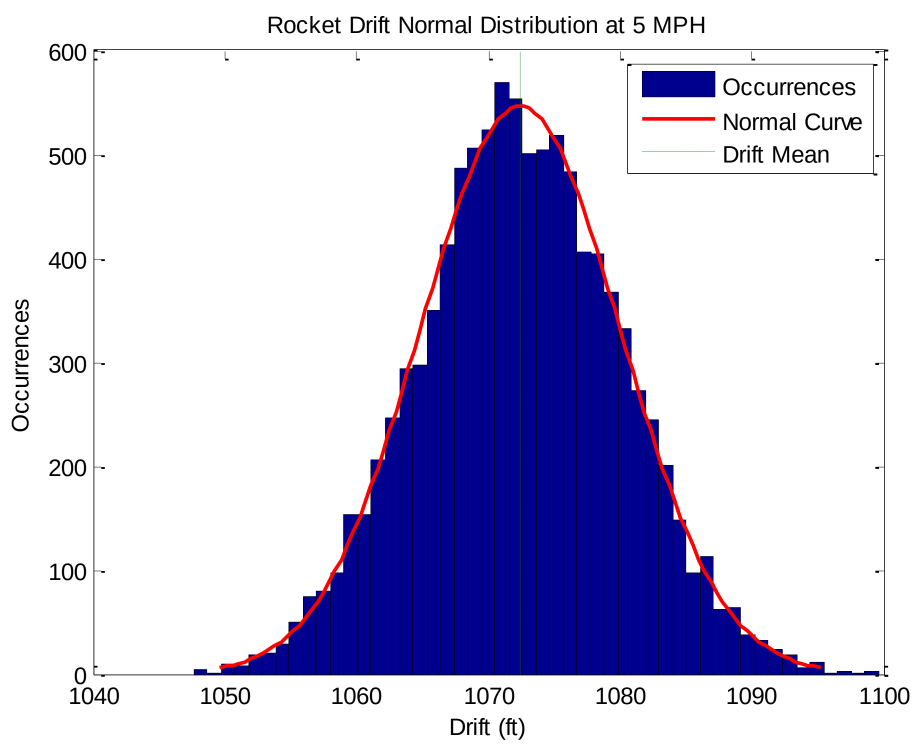


Figure 18: Calculated Rocket Drift Using 5 MPH Variable Wind Speeds

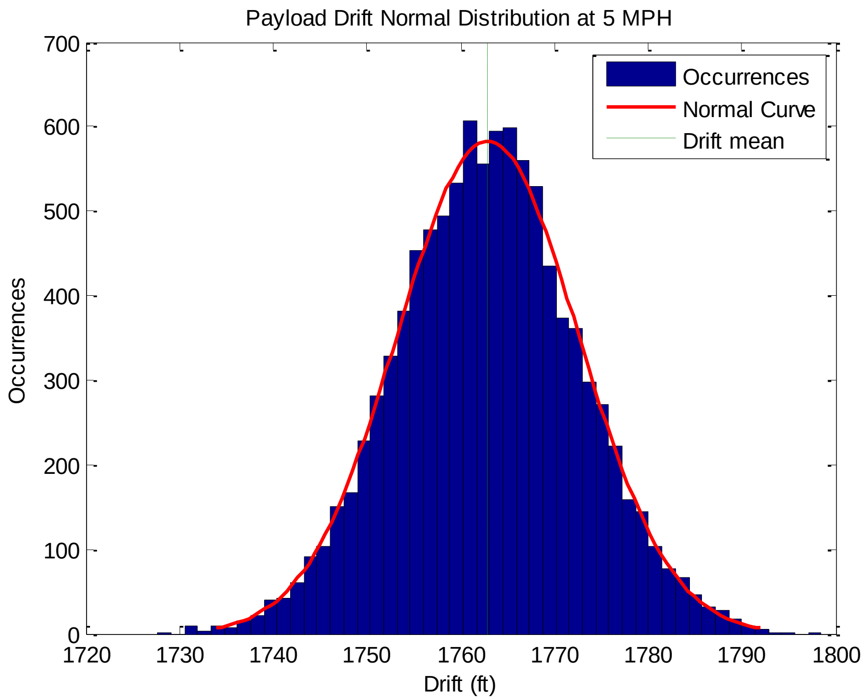


Figure 19: Calculated Payload Drift Using 5 MPH Variable Wind Speeds

The mean for the rocket drift was calculated to be 1,072.31 feet, with a standard deviation of 7.60. When we go out ±3 sigma, we can get the range that 99.7% of our data falls in. For our Rocket Drift at 5 MPH that range is calculated to be 1,049.51 feet to 1,095.11 feet. For the payload, the mean drift is 1,762.82 feet with a standard deviation of 9.67. The drift range for our payload extends from 1,733.81 feet to 1,791.83 feet. Data for wind at 14.67 ft/s (10 MPH) can be seen below.

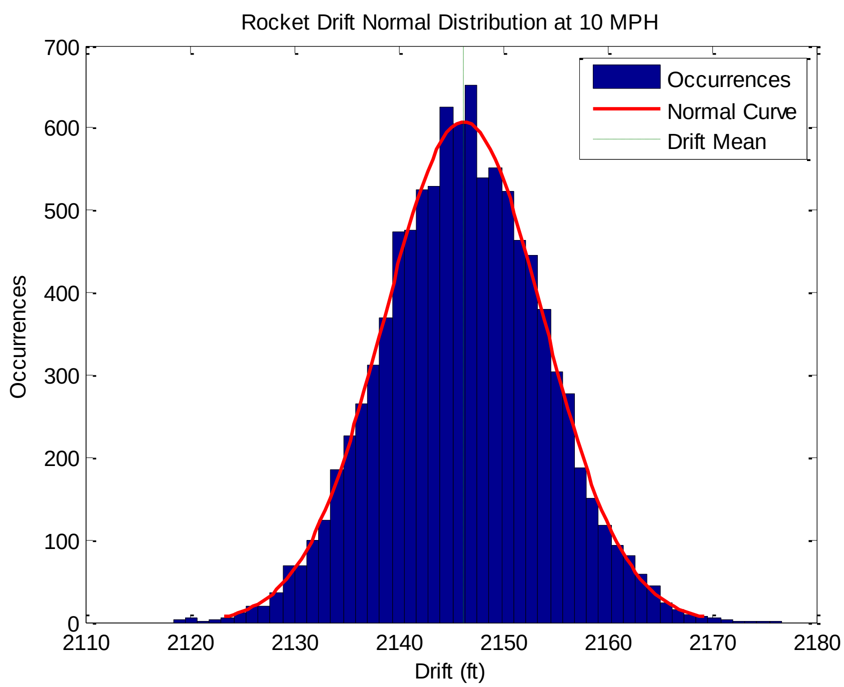


Figure 20: Calculated Rocket Drift Using 10 MPH Variable Wind Speeds

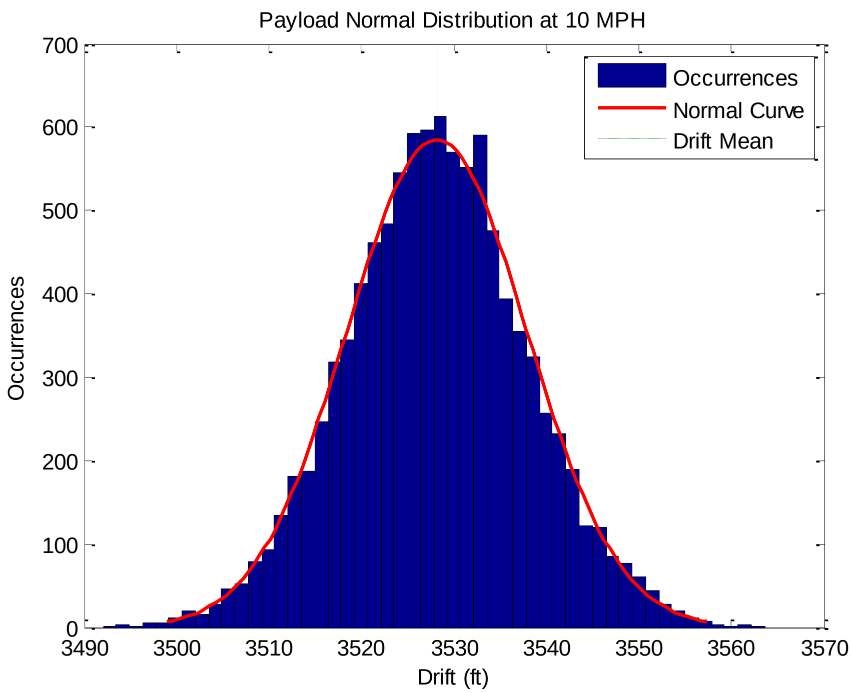


Figure 21: Calculated Payload Drift Using 10 MPH Variable Wind Speeds

The mean drift for the rocket at 10 MPH is found to be 2,146.19 feet with a standard deviation of 7.65. Our rocket should fall within 2,123.24 feet and 2,169.14 feet 99.7% of the time. The mean drift for the payload at 10 MPH is found to be 3,528.05 feet with a standard deviation of 9.76. Our payload should fall within 3,498.77 feet and 3,557.33 feet 99.7% of the time. Drift at 15 MPH can be seen below.

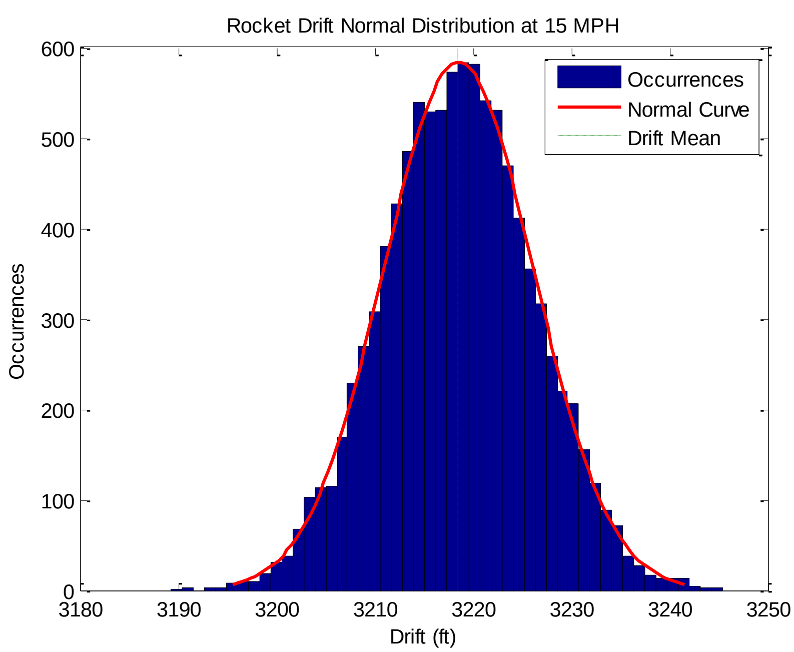


Figure 22: Calculated Rocket Drift Using 15 MPH Variable Wind Speeds

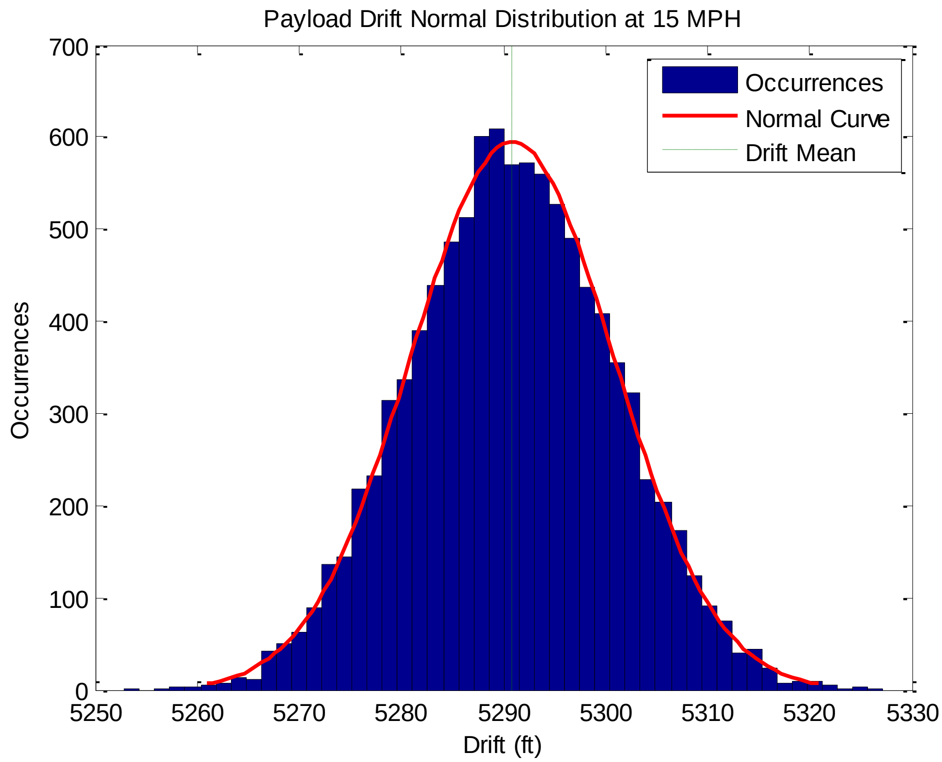


Figure 23: Calculated Payload Drift Using 15 MPH Variable Wind Speeds

The mean drift for the rocket at 15 MPH is found to be 3,218.56 feet with a standard deviation of 7.66. Our rocket should fall within 3,195.58 feet and 3,241.54 feet 99.7% of the time. The mean drift for the payload at 15 MPH is found to be 5,290.97 feet with a standard deviation of 9.97. Our payload should fall within 5,260.97 feet and 5,320.79 feet 99.7% of the time. Drift at 20 MPH can be seen below.

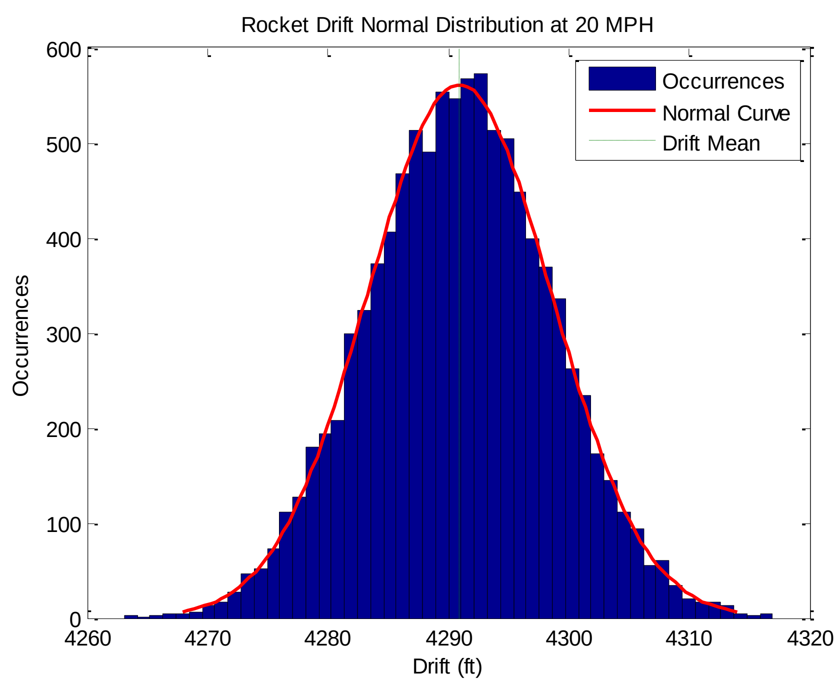


Figure 24: Calculated Rocket Drift Using 20 MPH Variable Wind Speeds

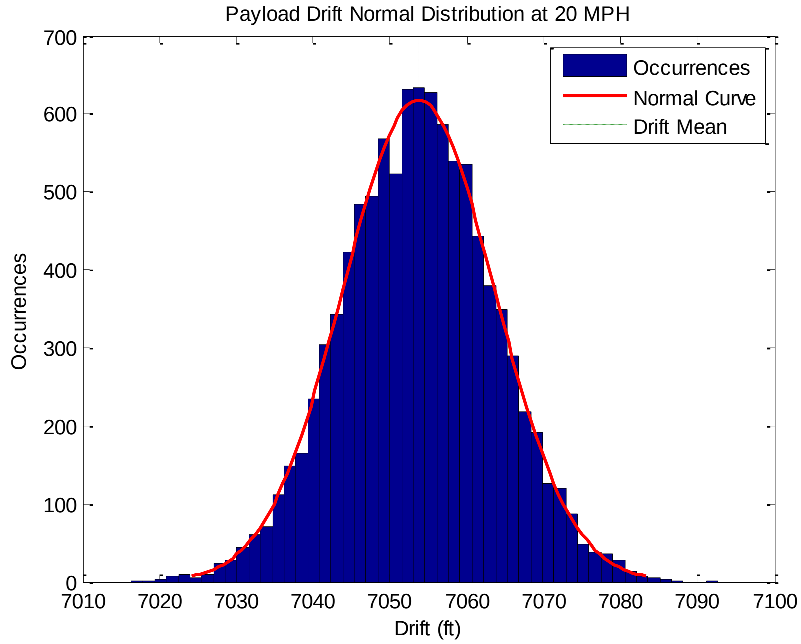


Figure 25: Calculated Payload Drift Using 20 MPH Variable Wind Speeds

The mean drift for the rocket at 20 MPH is found to be 4,290.98 feet with a standard deviation of 7.66. Our rocket should fall within 4,268 feet and 4,313.96 feet 99.7% of the time. The mean drift for the payload at 20 MPH is found to be 7,053.87 feet with a standard deviation of 9.86. Our payload should fall within 7,024.29 feet and 7,083.45 feet 99.7% of the time.

4.11.4 CP, CG, Static Margin and Kinetic Energy

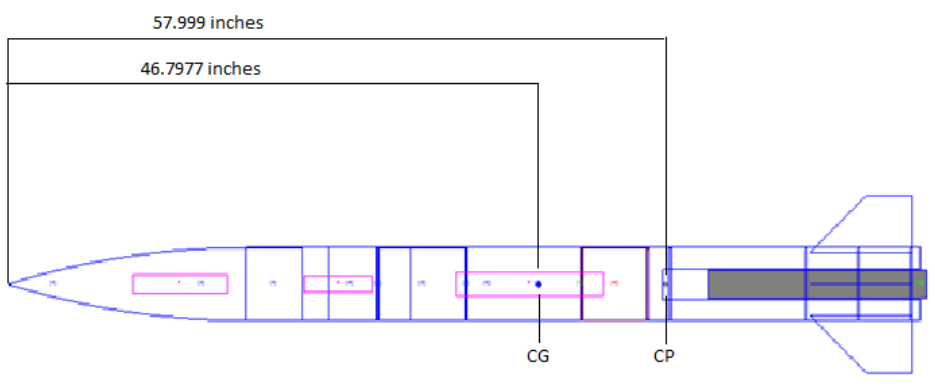


Figure 26: Rocket Static Stability Diagram

Our Center of Gravity was found to be 46.7977 inches from the tip of the nose. The center of pressure is located 57.999 inches from the tip. Our margin is 11.22 inches and given our diameter of 5.5 inches we get a static margin of 2.04. Changes to CG and static margin before and after burnout can be seen in the table below.

Table 5: Stability Values for the Rocket

	On Launch Pad	After Burnout
CP (from tip)	57.99 in.	---
CG (from tip)	46.79 in.	43.15 in.
Static Margin	2.04	2.70

The Kinetic Energy Equation is listed below.

$$KE = \frac{1}{2} m\dot{x}^2 \qquad (1)$$

KE= Kinetic Energy, m=mass, $\dot{x}$=speed. The speed is directly related to the wind speed and the descent rate. Descent rate is constant so we made the equation for speed below.

$$speed = \sqrt{descent\ rate^2 + wind\ speed^2} \qquad (2)$$

Using these two equations we modeled wind speed vs. Kinetic Energy.

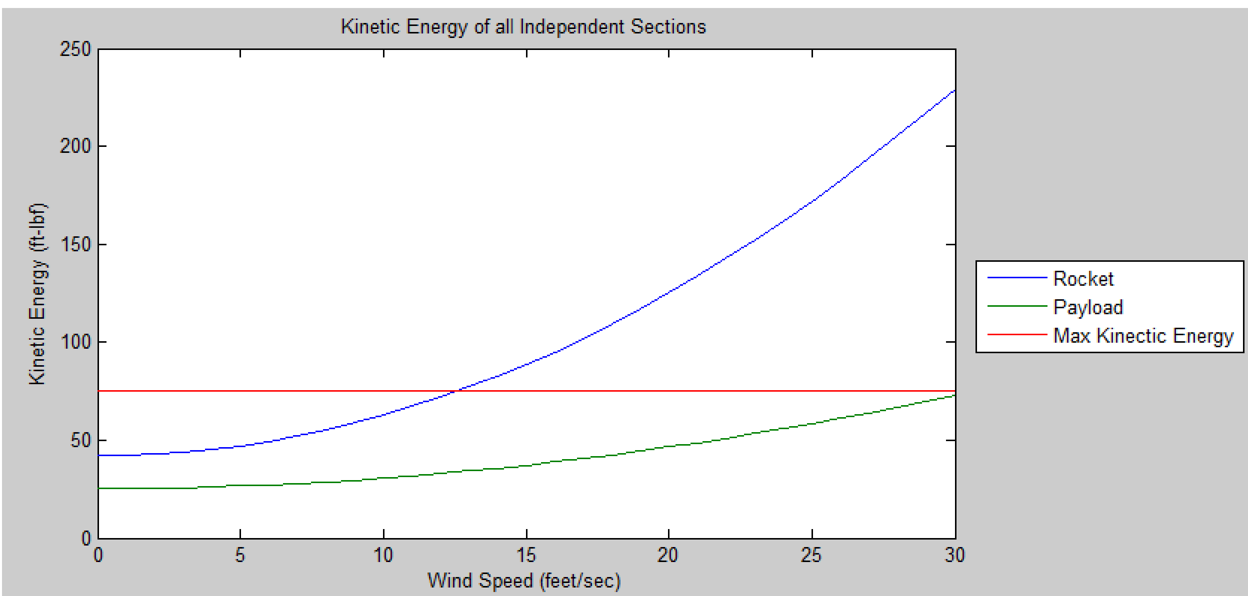


Figure 27: Kinetic Energy Plot for the Various Sections

Using this relationship, the max wind speed that we can launch into is 12.5 ft/s (8.5 MPH) and still stay under the competition requirement for a kinetic energy less than 75 ft-lbf. This graph shows a worst case scenario. This is working off of the assumption that wind speed is 100% effective on our falling rocket and payload. That is a very hefty assumption to make, but by our CDR we should have a more accurate model.

4.11.5 Next Steps and Motor Selection

Based on our current weight, the K570 has more than enough thrust to get us to apogee. Based on Rocksim 9, and under the condition of no wind, our team can add 1.44 lbs. to our current weight of 19 lbs. before this motor does not allow us to reach 5,280 feet. If we exceed this limit, or our full scale test shows that our altitude models are wrong and that we are not reaching expected altitudes we will jump up to a Cesaroni K750-RL, which has more thrust, approximately 200 N. This engine would add approximately 900 feet to our altitude (without ballast), or would all us to add approximately 5.75 lbs. to our design if needed. Currently we are using a Cesaroni K570 which has a total impulse of 2070.258 N-Sec and a 3.9 sec. burn time. Preliminary test show a total altitude of 5,740.30 feet, with no wind. The motor has a thrust-to-weight Ratio of 6.77 and a max velocity of 660 feet/second. We are also considering using a Cesaroni K750-RL which has a total impulse of 2361.966 N-Sec and a 3.14 sec. burn time. Preliminary test show a total altitude of 6,638.85 feet, with no wind and a thrust-to-weight ratio of 8.53 and a max velocity of 765 feet/second.

There are some immediate things that need to happen to make our simulations more accurate. Number one priority is to get our scale model into the wind tunnel, and get accurate coefficient of drag data. Second is to do more research into wind distribution and behavior, as well as more accurately model its effect on a falling mass. After this, more degrees of freedom will be added to both models. This will always to calculate not only distance travelled, but also direction of travel.

4.12 Interface and Integration

The rocket is composed of 5 main components: The fairing, upper body tube, electronics bay, tracking bay and the lower body tube/fins section. The lower body tube & fins will be attached to the tracking bay and will remain attached throughout the flight. The rocket will separate at the fairing and below the recovery bay module.

The PIL will sit slightly above the electronics bay and will be enclosed within the fairing. The fairing pieces will be attached to the parachute of the PIL. The drogue parachute will be attached to the top of the recovery bay and will be deployed using altimeters 1 & 2 of in the recovery bay. The main parachute will be attached to a shock cord that runs between the bottom of the recovery bay and the top of the tracking bay and will be deployed via altimeters 3 & 4 in the recovery bay. The shock cords between each section will be made long enough to minimize damage from the individual sections smashing into each other during descent.

The tracking bay will consist of a radio transceiver, a GPS module and an Arduino board. The Arduino board will retrieve GPS coordinates from the GPS module, and put the coordinates into a JSON string. Once the JSON string is built, it will be sent to the radio transceiver over a serial connection. The tracking bay radio will then send this data over radio. The ground control radio transceiver will receive this data, and send it to the ground control Arduino over a serial connection. The custom ground control software will get the JSON string from the ground Arduino, and extract the GPS coordinates from the JSON string. Once the coordinates are extracted, they will be updated in the user interface, and the coordinates will be plotted visually in the ground software. GPS Coordinates of the ground control will be referenced, and a graphic showing where the rocket is with respect to ground control will be displayed.

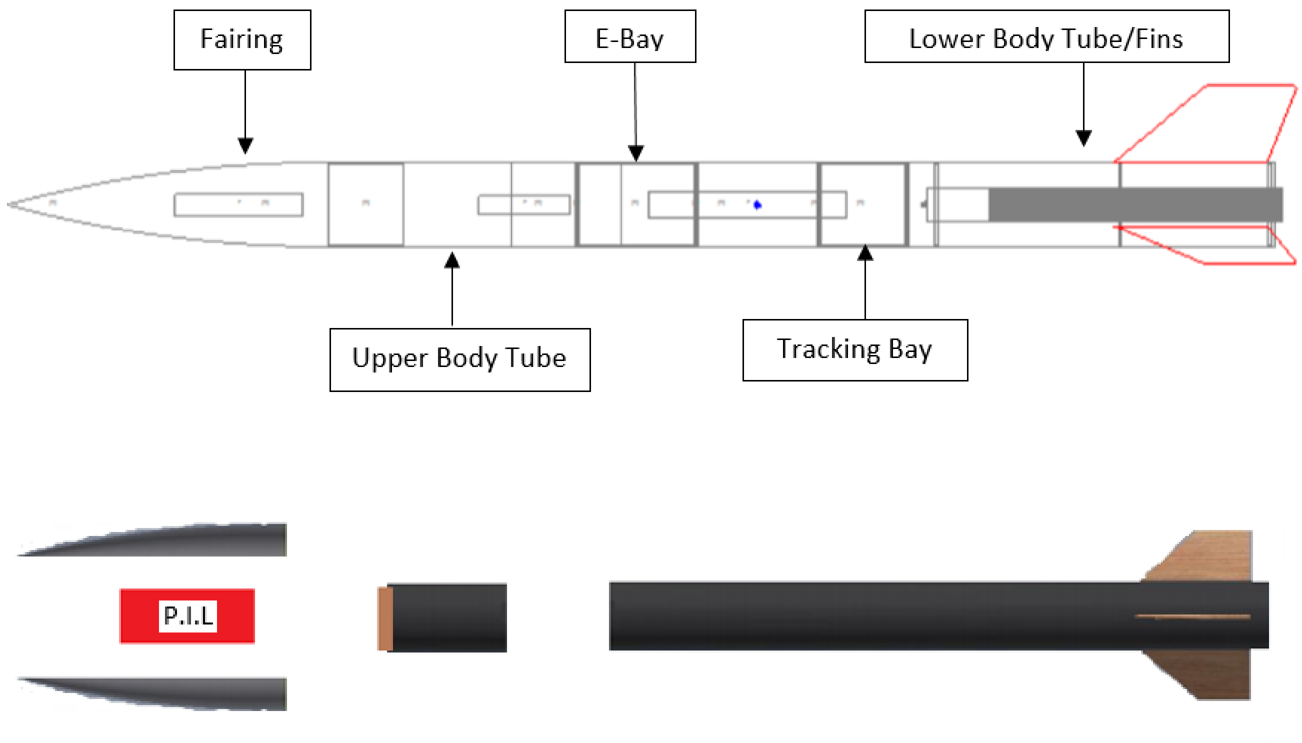


Figure 28: Rocket Sections and Integration

4.13 HAZARD ANALYSIS

RAC CLASSIFICATIONS

The following tables and charts explain the Risk Assessment Codes (RACs) used to evaluate the hazards identified in this report. RACs are established for both the initial hazard, that is; before controls have been applied, and the residual/remaining risk that remains after the implementation of controls. Additionally, table 2 provides approval/acceptance levels for differing levels of remaining risk. In all cases individual workers should be advised of the risk for each undertaking.

TABLE 1 RAC				
Probability	**Severity**			
	1 Catastrophic	**2 Critical**	**3 Marginal**	**4 Negligible**
A – Frequent	**1A**	**2A**	**3A**	**4A**
B – Probable	**1B**	**2B**	**3B**	**4B**
C – Occasional	**1C**	**2C**	**3C**	**4C**
D – Remote	**1D**	**2D**	**3D**	**4D**
E - Improbable	**1E**	**2E**	**3E**	**4E**

TABLE 2 Level of Risk and Level of Management Approval	
Level of Risk	**Level of Management Approval/Approving Authority**
High Risk	Highly undesirable, and require addition controls and safety measures before the launch of the rocket.
Moderate Risk	Undesirable, and depending on what kind of hazard it will still require additional engineering controls and safety measures before the flight of the rocket.
Low Risk	Acceptable risks, but certain safety measures must take place to become a low risk hazard.
Minimal Risk	Acceptable risk and no additional safety measures must be taken to ensure safe launch of rocket.

TABLE 3 Severity Definitions – A condition that can cause:			
Description	**Personnel Safety and Health**	**Facility/Equipment**	**Environmental**
1 – Catastrophic	Loss of life or a permanent-disabling injury.	Loss of facility, systems or associated hardware.	Irreversible severe environmental damage that violates law and regulation.
2 - Critical	Severe injury or occupational-related illness.	Major damage to facilities, systems, or equipment.	Reversible environmental damage causing a violation of law or regulation.
3 - Marginal	Minor injury or occupational-related illness.	Minor damage to facilities, systems, or equipment.	Mitigatable environmental damage without violation of law or regulation where restoration activities can be accomplished.
4 - Negligible	First aid injury or occupational-related illness.	Minimal damage to facility, systems, or equipment.	Minimal environmental damage not violating law or regulation.

TABLE 4 Probability Definitions		
Description	**Qualitative Definition**	**Quantitative Definition**
A - Frequent	High likelihood to occur immediately or expected to be continuously experienced.	Probability is > 0.1
B - Probable	Likely to occur to expected to occur frequently within time.	0.1≥ Probability > 0.01
C - Occasional	Expected to occur several times or occasionally within time.	0.01 ≥ Probability > 0.001
D - Remote	Unlikely to occur, but can be reasonably expected to occur at some point within time.	0.001≥ Probability > 0.000001
E - Improbable	Very unlikely to occur and an occurrence is not expected to be experienced within time.	0.000001≥ Probability

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Personnel exposure to moving saw blade	Improper placement of personnel body or objects near saw blade	Death or severe personnel injury	1C	1. During a pre-job brief, all hazards with using a saw will be made aware. 2. Inspection of saw and saw blade must be done before use to ensure that the machine is safe to use. 3. Unless given proper training and authorization by the proper people, no individuals will be allowed to use a saw. 4. All PPE must be worn while working with or nearby a saw. 5. Take steps to ensure that you have eliminated all outside hazards while working near a saw (i.e. tripping hazards from cords)	1. A written pre-job brief must be done to verify planned work. 2. Safety officer must give proper approval to use saw, and the safety officer must have all signed authorization sheets for the individual to use a saw. 3. Personnel must ensure that they have all the proper PPE on and that they remove any loose or baggy clothing or jewelry. 4. A visual verification must occur that power to the saw has been turned off while saw is not in use	1E
Personnel exposure to rotating drill bits	Improper placement of personnel body or objects near rotating drill bits	Death or severe personnel injury	1C	1. During a pre-job brief, all hazards with using a drill or drill press must be made aware. 2. An inspection of the drill and drill bits must occur before every use of the machine to ensure that it is safe to use. 3.Unless given proper training and authorization by the proper people, no individuals will be allowed to use a drill or drill press. 4. All PPE must be worn while working with or nearby a drill or drill press. 5. Take steps to ensure that you have eliminated all outside hazards that could effect you while working with or nearby a drill or drill press.	1. A written pre-job brief must be done to verify planned work. 2. Safety officer must give proper approval to use saw, and the safety officer must have all signed authorization sheets for the individual to use a drill or drill press. 3. Personnel must ensure that they have all the proper PPE on and that they remove any loose or baggy clothing or jewelry. 4. A visual verification must occur that power to the drill or drill press has been turned off while drill or drill press is not in use	1E
Personnel exposure to pinch points from a press brake	Improper placement of personnel body or objects near press brake	Death or severe personnel injury	1C	1. During a pre-job brief, all hazards with using a press brake must be made aware. 2. An inspection of the press brake must occur before every use of the machine to ensure that it is safe to use. 3.Unless given proper training and authorization by the proper people, no individuals will be allowed to use a press brake. 4. All PPE must be worn while working with or nearby a press brake. 5. Take steps to ensure that you have eliminated all outside hazards that could effect you while working with or nearby a press brake.	1. A written pre-job brief must be done to verify planned work. 2. Safety officer must give proper approval to use saw, and the safety officer must have all signed authorization sheets for the individual to use a press brake. 3. Personnel must ensure that they have all the proper PPE on and that they remove any loose or baggy clothing or jewelry. 4. A visual verification must occur that power to the press brake has been turned off while the press brake is not in use	1E

Personnel injury while using common hand tools	Improper placement of body, or improper use of tool	Severe personnel injury	**2B**	1. During pre-job brief, all hazards will be made aware while using hand tools. 2. Inspection of the hand tool must occur before each use. 3. Personnel must have the proper training and know how to use the hand tool. 4. All proper PPE must be worn to avoid all injuries associated with improper use of a hand tool. 5. Personnel must ensure that they are using the right hand tool for the job.	1. A written pre-job brief must be done to verify planned work. 2. Personnel must have proper training from the safety officer. 3. Personnel must perform a visual inspection of the tool before use. 4. Personnel must ensure that they are wearing all the proper PPE while using hand tools.	**2D**
Personnel injury while using soldering iron	Improper placement of body near soldering irons	Minor burn injury	**3D**	1. Always ensure that the tip of the soldering gun is away from you while you are using it. 2. When you place the soldering gun down, make sure that it is in a location that you will not accidently touch. 3. After you are finished with the soldering gun, ensure that it has been unplugged from the wall and has been turned off.	1. Visually verify that the soldering gun is in a position that you will not get burned from it. 2. After use, visually verify that the soldering gun is turned off and in a position where it can cool down without anyone being able to touch it.	**3E**
Personnel exposure to low voltage source (12 Volt DC)	Improper placement of hands while using or holding electronics	First aid injury	**4E**	1. When working with batteries, make sure that you do not touch the two leads together to short circuit the battery. 2. Never put yourself in between the circuit, to potentially cause damage to yourself.	1. Physically verify that you are not touching both sides of a battery and potentially causing it to short circuit through you.	**4E**
Personnel exposure to high voltage source (120 Volt AC)	Faulty power cords or frayed power cords	Death or severe personnel injury	**1C**	1. Before using anything that uses a 120 volt power source, always inspect the power cord before plugging the device in. 2. If the cord frays or has exposed wires, never plug in the device. 3. If the cord frays or has exposed wires while you are using the device, make sure you unplug the device and wait 30 seconds to ensure that all capacitors within the device have discharged before handling the cord. 4. Electrical tape around exposed wires is a temporary fix, but the device should not be used until the cord has been fully repaired.	1. Visually inspect all power cords before plugging them in. 2. If cords are damaged, visually verify that the cord is unplugged and wait 30 seconds before touching any part of the cord that could potentially electrocute you.	**1E**

Personnel exposure to small particles from belt sander	Improper use of PPE while using belt sander	Critical injury to eyes, or lungs if inhaled	**2C**	1. During pre-job brief, all hazards will be made aware while using belt sanders. 2. Inspection of the belt sander must occur before each use. 3. Personnel must have the proper training and know how to use the belt sander. 4. All proper PPE must be worn to avoid all injuries associated with improper use of a belt sander.	1. A written pre-job brief must be done to verify planned work. 2. Personnel must have proper training from the safety officer. 3. Personnel must perform a visual inspection of the tool before use. 4. Personnel must ensure that they are wearing all the proper PPE while using belt sanders.	**3D**
Personnel exposure to pinch points from a kick shear	Improper placement of personnel body or objects near kick shear	Death or severe personnel injury	**1C**	1. During pre-job brief, all hazards will be made aware while using a kick shear. 2. Inspection of the kick shear must occur before each use. 3. Personnel must have the proper training and know how to use the kick shear. 4. All proper PPE must be worn to avoid all injuries associated with improper use of a kick shear.	1. A written pre-job brief must be done to verify planned work. 2. Personnel must have proper training from the safety officer. 3. Personnel must perform a visual inspection of the tool before use. 4. Personnel must ensure that they are wearing all the proper PPE while using kick shears.	**1E**
Personnel injury from tripping hazards in a room	Improperly placed objects or a lack situational awareness	Severe personnel injury	**2B**	1. During the pre-job brief a thorough inspection of the room will be made to assess any potential tripping hazards. 2. If tripping hazards exist in the room, try to eliminate them by picking them up or moving them into a location that no one could potentially trip over. 3. While doing the pre-job brief, plan a route around and away from the tripping hazards in the event that you would need to evacuate that area.	1. Visually verify any potential tripping hazards in the room. 2. Physically remove any tripping hazards that you can. 3. Vocally verify the tripping hazards in the room with everyone else.	**2D**
Personnel injury from falling ceiling tiles	Improperly placed or loose ceiling tiles	Severe personnel injury	**2E**	1. During the pre-job brief, a thorough visual inspection of the ceiling will be made. 2. If any ceiling tile is deemed unsafe, personnel will need to move to a different location. 3. If ceiling tiles need to be replaced, maintenance or the respective authority will be notified that it needs to be replaced or fixed.	1. The pre-job brief will require a visual inspection of the ceiling to ensure that it is safe to work under.	**2E**

Personnel exposure to fumes while soldering	Inadequate ventilation of room	Minor lung damage	**2C**	1. Before working with these chemicals, always read the MSDS for information on what PPE you need to wear and what to do in the event of an emergency. 2. Always make sure you wear the proper PPE that is stated in the MSDS sheets. 3. When working with chemicals that produce fumes, ensure that you are either outside or in a well ventilated room to prevent any build of toxic vapors.	1. Visually verify that you are in a room that is adequately ventilated. 2. Physically verify that you have on all the proper PPE. 3. Physically read the MSDS sheet before any work with that chemical can occur.	**2E**
Personnel exposure to chemical fumes and burns while creating PCB boards	Inadequate ventilation of room or lack of PPE	Severe personnel injury	**2C**	1. Before working with these chemicals, always read the MSDS for information on what PPE you need to wear and what to do in the event of an emergency. 2. Always make sure you wear the proper PPE that is stated in the MSDS sheets. 3. When working with chemicals that produce fumes, ensure that you are either outside or in a well ventilated room to prevent any build of toxic vapors.	1. Visually verify that you are in a room that is adequately ventilated. 2. Physically verify that you have on all the proper PPE. 3. Physically read the MSDS sheet before any work with that chemical can occur.	**2E**
Personnel exposure to chemical fumes and burns while working with epoxys or resins	Inadequate ventilation of room or lack of PPE	Severe personnel injury	**2C**	1. Before working with these chemicals, always read the MSDS for information on what PPE you need to wear and what to do in the event of an emergency. 2. Always make sure you wear the proper PPE that is stated in the MSDS sheets. 3. When working with chemicals that produce fumes, ensure that you are either outside or in a well ventilated room to prevent any build of toxic vapors.	1. Visually verify that you are in a room that is adequately ventilated. 2. Physically verify that you have on all the proper PPE. 3. Physically read the MSDS sheet before any work with that chemical can occur.	**2E**
Personnel exposure to small fiberglass strands while working with fiberglass	Lack of PPE and lack of experience while working with fiberglass	Severe personnel injury	**2C**	1. Before working with fiberglass ensure that you have the proper PPE on. 2. Ensure that you have read the MSDS and know how to work with fiberglass. 3. Try to stay in a confined area so that clean up of the area after you have completed is very easy. 4. Use a vacuum to clean up the area after using fiberglass to ensure you pick up all the small fibers. 5. Never use compressed gas to clean off anything when working with fiberglass. This could cause the fibers to become airborne and much more dangerous.	1. Physically read the MSDS sheet before using fiberglass. 2. Physically verify that you have on the proper PPE. 3. Physically clean up the area with a vacuum after completing all work with fiberglass.	**2D**

Potential injury from wildlife while driving	Lack of situational awareness while driving	Death or severe personnel injury	**1C**	1. While driving, ensure that all your attention is focused on driving. 2. The use of cellular phones or other electronics is prohibited while operating the vehicle. 3. During night time conditions, ensure your vehicles lights are on, and when possible use the vehicles bright lights to illuminate any wildlife in the road way. 4. When driving through an environment that contains large wildlife (i.e. deer) drive slowly. 5. Avoid swerving if there is an animal in the roadway, this could cause more damage to nearby personnel or you could potentially go off the road and hit a tree or rock.	1. Pay attention to your speedometer to verify the speed that you are going. 2. Maintain visual verification with the road and be aware of any wildlife that could potentially walk into the road.	**1E**
Potential injury from other drivers while driving	Lack of situational awareness while driving	Death or severe personnel injury	**1C**	1. Always make sure that you keep your eyes on the road, and pay attention to all other drivers on the road. 2. Always follow the rules of the road when driving. 3. Use your turn signals and your mirrors before making any kind of maneuvers while driving. 4. Always be a defensive driver.	1. Maintain visual confirmation with the other drivers on the road. 2. Use auditory ques from your environment to understand the positions of other cars.	**1E**
Potential injury from sleep deprivation while driving	Not getting a good nights sleep or nap before driving for extended amounts of time	Death or severe personnel injury	**1C**	1. Before driving for prolonged amounts of time, ensure that you have had a good nights sleep before or have taken a nap before you drive. 2. If you become tired and do not have another driver, then pull off of the road into a safe location and take a nap or go to sleep for the night. 3. If you become tired and do have another non-tired driver, then pull over into a safe location and switch drivers.	1. If driving habits are deemed unsafe by other personnel through visual verification or by the driver, then the driver will be forced to pull over and sleep or switch drivers.	**1E**
Potential injury from distracted driving due to passengers in car	Not paying attention to the road while other passengers are in the car	Death or severe personnel injury	**1C**	1. Always pay attention to the road and never get distracted from the passenger within the car. 2. If passengers in the car become too distracting, pull off of the road and wait until conditions become better.	1. Mentally verify that you are okay to drive, and physically pull over if conditions become too bad.	**1E**

Potential injury from distracted driving due to cellular devices	Using a cellular device while operating a vehicle	Death or severe personnel injury	**1B**	1. Never use a cell phone or other electronic device while you are driving. 2. If you have to use your cell phone have a passenger use it for you, or use a hands free device. 3. Place the drivers cell phone in back seat or trunk so that it is far enough away that the driver cannot get to it without having to pull over. 4. If you do not have a passenger or a hands free device, make sure that the driver pulls off of the road to take any calls or texts	1. Visually verify that the drivers phone is in the trunk or back seat. 2. If the phone is still on the driver, visually verify that the driver does not use it while driving.	**1E**
Potential injury due to unsafe road conditions because of weather or construction	Lack of situational awareness while driving	Death or severe personnel injury	**1C**	1. When road conditions are bad, make sure that you drive slowly and cautiously. 2. Abide by the speed limit in a construction zone. 3. If weather conditions are deemed to unsafe, pull off of the road and wait until conditions become better.	1. Visually check your speedometer to ensure that you are driving the speed limit in a construction zone. 2. Visually check your speedometer to ensure you are driving at a safe speed for the given road conditions.	**1E**
Potential injury due to car breaking down	Car could potentially break down and you could not stop the car	Death or severe personnel injury	**1D**	1. Before every use of a vehicle, and 360 degree inspection of the vehicle will occur to ensure that it is safe to operate. 2. If something is found that makes the vehicle unsafe to drive, then the vehicle shall not be driven and the proper authorities will be notified that the vehicle needs to be repaired before it can be used.	1. In order to use a UC vehicle personnel must follow strict visual inspection guidelines provided by the school.	**1D**
Personnel exposure to rocket chemicals while transporting the motors	If rocket motor breaks during transportation due to hard impacts	Severe personnel injury	**2D**	1. A explosion proof portable magazine has been purchased to allow our team to transport rocket motors safely and legally. This magazine will prevent and chemical releases from happening if the motor broken inside of the magazine. 2. When opening up the magazine we will assume that the motor broke apart and have all PPE on that the MSDS sheet recommends to use when handling the Ammonium Perchlorate chemical propellant. 3. All possible ignition sources will be kept far away from the magazine to not allow any possible rogue ignitions	1. Visually verify that the motor has been placed in the portable magazine before transportation, and that the magazine has been sealed tight. 2. Visually verify that no igniters or other possible ignition sources are inside the magazine or nearby the magazine while transporting the rocket motor.	**2E**

Personnel exposure to payload battery explosion while transporting it	Hard impact to the battery while driving could cause the battery to explode	Death or severe personnel injury	**1D**	1. When transporting the payload battery, it will need to wrapped up in a soft material (i.e. blanket) and placed in spot that cannot roll around in the car. 2. Make sure that the battery leads are not touching anything that would allow the battery to short circuit and cause a fire.	1. Perform a visual inspection that the battery is completely wrapped up and in a secure location. 2. Perform a visual inspection the battery leads do not have the ability to short circuit.	**1E**
Personnel exposure to fire while transporting rocket	Sparks or hard impacts could potentially cause the rocket motor to burn or the LiPo batteries to explode	Death or severe personnel injury	**1D**	1. Ensure that all flammable materials are far away from any ignition sources. 2. Make sure that batteries are not capable of being short circuited and are wrapped in soft material to prevent penetration of the battery. 3. Ensure that the portable rocket magazine is closed and sealed tight. 4. All team members will have proper training on how to handle a fire in the event of an emergency, and the team will bring a fire extinguisher inside of the car.	1. Visually verify that the portable rocket magazine is closed and seal tight. 2. Visually verify that the fire extinguisher is in the car, and that it is charged with the right material and at the right pressure. 3. Physically verify that the LiPo batteries are in a safe spot that will not take any hard impacts while driving.	**1E**
Potential risk of hypothermia from cold weather related activities	Lack of proper PPE or long exposure times to the cold weather	Death or severe personnel injury	**1C**	1. When working in cold conditions, ensure that you have the proper PPE on. 2. Depending on how cold it is, take breaks often and go into a warm dry location. The colder it is the more frequent you will need to take breaks, and the breaks will need to be longer so that you can adequately warm up. 3. Remove any wet clothing and replace with dry clothing as soon as you can.	1. Take breaks in a timely fashion so that you warm up before going back out into the cold. 2. Physically verify that your clothes are dry, if they are wet replace them. 3. Physically verify that you have cold weather PPE on.	**1E**
Potential risk of hyperthermia from warm weather related activities	Lack of hydration, strenuous activities, or prolonged exposure times to hot weather	Death or severe personnel injury	**1C**	1. Stay hydrated throughout the day to avoid becoming over heated. 2. Take breaks frequently and go to cool location to avoid overheating. 3. Always have the right PPE on, but if you have multiple layers then make sure you remove those articles of clothing so that your body can cool itself down.	1. Take breaks in a timely fashion so that you cool down before going back into the warmth. 2. Physically verify that you have taken off as many layers or clothing as possible so that your body can cool down naturally. 3. Physically verify that you are getting enough water into your system to stay hydrated.	**1E**

Environmental hazard, if vehicle is left in idling while not in use	Car is left running when not in use, when it could be turned off	Minimal environmental damage	**4C**	1. All vehicles will need to be turned off when not in use to ensure that we minimize any greenhouse gas emissions.	1. Driver of the vehicle will need to perform a visual inspection of the dashboard to ensure that the vehicle is off. 2. An auditory inspection of vehicle must also occur to make sure that the motor is turned off.	**4D**
Environmental hazard, from rocket flame during launches	If flammable material is kept near to the rocket flame on lift off	Irreversible severe environmental damage	**1D**	1. Before launch of the rocket, ensure that there is no flammable material nearby where the rocket launches (this includes looking for dry brush, paper, flammable fuels, etc.). 2. Make sure that before launching a rocket, that the launch pad that it is on has no flammables on it, and make sure that the flame from the motor cannot spread past the launch pad.	1. Before launch a visual verification will occur to ensure no flammables at or nearby the launch pad. 2. If in the event of a small fire, once the rocket lands we will use a fire extinguisher to put it out completely (visual verification to ensure that the fire is completely out by waiting nearby the place of the fire for 30 minutes). 3. If the fire is too large to handle, the fire department will need to be called to handle it (calling 911).	**1E**
Potential risk of injury due to tornados	From tornado causing damage to a building or to a personnel	Death or severe personnel injury	**1D**	1. A tornado cannot be controlled, nor do we have an influence in where it goes. The best way to prepare is to know where to go if one happens. 2. In the pre-job brief explain where to go in the event of an emergency. 3. Prior to doing work, check the weather to see if there is a possibility of a tornado. 4. In the event that a tornado were to actually happen, never panic and be prepared to move to a safe location as soon as possible.	1. On the written pre-job brief have the location that you would go to in the event of inclement weather.	**1E**
Personnel risk of slipping while snow or ice is on the ground due to bad weather	Lack of situational awareness while walking during cold weather or improper PPE	Severe personnel injury	**2B**	1. During bad weather conditions, personnel will need to ensure that they walk slowly and cautiously through snow or on top of ice. 2. Personnel will need to wear closed toe shoes with slip resistant rubber soles. 3. Individuals should also avoid any or all steps, uneven surfaces, or ramps while walking through the snow or ice. 4. Ensure that when you enter a dry building, that you wipe your feet off of any water to prevent slipping and falling indoors because of the water still on your shoes	1. Keep your eyes on the ground and avoid bad walking surfaces using visual verification. 2. Check to make sure you are using the proper shoes through visual verification. 3. Ensure your shoes are wiped off once you enter a building using a physical touch verification.	**2D**

Personnel risk of dehydration working during warm weather conditions	Prolonged strenuous activities or lack of nearby water source	Death or severe personnel injury	**1D**	1. While working in warm weather, ensure that you drink plenty of water throughout the day. 2. Make sure that you take plenty if breaks to allow your body to cool down to avoid excessive sweating. 3. Avoid any drinks with caffeine or any drinks with excessive electrolytes (i.e. coffee, soda, sports drinks).	1. Ensure that you drink plenty of water. Your body will tell you when you need water. 2. If working for prolonged amount of time, take a break every 30 to 45 minuets to allow you to get some water and avoid excessive sweating.	**1E**
Lack of situational awareness due to being hungry	Not eating a good meal before a job can take your mind off of any potential hazards	Death or severe personnel injury	**1D**	1. Ensure that you eat at least 3 meals a day that have a mixture of carbohydrates and proteins. 2. If during the competition a team member becomes hungry and cannot concentrate on the task at hand, small snacks will be brought with us to ensure that no one becomes irritable or unsafe.	1. Physically verify that you have eaten a good meal at least 3 times a day.	**1E**
Personnel risk of sunburn if exposed to the sun for too long	Prolonged exposure to UV rays, or lack of sunscreen	First aid injury	**4B**	1. Personnel will apply sunscreen (preferably 50 SPF or greater) every couple of hours (or less depending on the manufacturers recommended use) when exposed to UV rays given off by the sun. 2. Personnel may forgo sunscreen if they are wearing protective clothing, but will need to wear sunscreen on any part of their body that is not covered up by protective clothing.	1. Personnel will be responsible for their own physical verification that they have applied sunscreen. 2. If the safety officer deems that the protective clothing of an individual is not adequate (through visual verification) then the individual will need to apply sunscreen.	**4C**
Personnel risk of disease from wildlife	Main risk comes from mosquitos from lack of bug repellant or lack of protective clothing	Minor occupational illness	**3D**	1. Always wear protective clothing to avoid contact with any mosquitos. 2. If protective clothing is not enough, bring some sort of insect repellant and apply it based on the manufacturers application times. 3. Be cautious of stagnant water because this is the breeding location of the mosquitos.	1. Physically verify that you have put on insect repellant and are wearing enough protective clothing. 2. Always visually inspect an area for stagnant water and avoid it, to stay away from mosquitos.	**3D**

Personnel risk of injury from feral wildlife	Injury caused by a wild animal attacking an individual	Death or severe personnel injury	**1D**	1. Avoid any contact with any wildlife. 2. If wildlife is in your way, try to find a new route around it.	1.Visually verify that no wildlife is nearby to you so that it cannot harm you.	**1E**
Personnel risk of disease from other personnel	Disease spread from human to human through unsanitary conditions	Minor occupational illness	**3D**	1. If you notice that someone is sick, make sure you try to avoid any contact with that person. 2. Always wash your hands after touching objects that could be infected with potentially harmful diseases (i.e. bathroom door handles, public computer keyboards, etc.). 3. If you are sick, take time off and stay at home so that you minimize the risk of spreading the disease.	1. Physically wash your hands after touching something that could be potentially harmful. 2. Physically stay at home when you are sick to avoid spreading the disease.	**3E**
Personnel risk of eye damage if looking at bright objects for too long	Looking at the sun for too long especially during rocket launches	Severe personnel injury	**2E**	1. If you have to look toward the direction of a bright object, never stare directly into that object. 2. Wear polarized lens to help mitigate the damage from looking at a bright object. 3. Never look into the sun using a set of binoculars or other focusing lenses.	1. Physically verify that you are wearing polarized lenses before looking at anything bright.	**2E**
Personnel risk of injury from potential fire inside a building	A fire that is consuming a building or a fire in a small confined space	Death or severe personnel injury	**1D**	1. In the pre-job brief always discuss the meeting location in the event that you would need to evacuate the building. 2. If a fire were to occur stay as low to ground as possible to avoid and noxious gases that rise up to the ceiling. 3. Before touching any doors while escaping a fire, test to see if the door is hot before you open it up. 4. If a fire extinguisher is nearby and it is a small fire, use the extinguisher to put the fire out. 5. If there is a legitimate fire, pull the fire alarm and call 911.	1.Verbally verify a meeting location if a fire were to break out in the pre-job brief. 2. Physically pull a fire alarm and escape the building as quickly as possible. 3. Physically verify the temperature of a door before opening it.	**1E**

Personnel risk of burn while using any tool that can create sparks or hot pieces of metal	Improper use of PPE while using any tool that could create sparks or hot pieces of metal	Minor personnel injury	**3C**	1. Always make sure that you wear the proper PPE when working with anything that can create sparks or hot pieces of metal. 2. Ensure that there are no flammable materials near where the sparks are created.	1. Physically verify that you are wearing the proper PPE. 2. Visually verify that there are no flammable materials near the source of sparks or hot pieces of metal.	**3D**
Personnel risk of injury from uneven walking surfaces	Lack of situational awareness while walking on an uneven surface	Severe personnel injury	**2C**	1. When walking on uneven surfaces, ensure that you take your time and maintain full focus on the ground you are walking on. 2. Never become distracted with an electronic or something else while walking on an uneven surface. 3. Always wear shoes that will maintain an adequate grip on the surface you are walking on.	1. Visually follow the path you are walking and avoid any other obstacles. 2. Physically verify that you shoes have enough traction to prevent you from falling.	**2D**
Personnel risk of injury from slipping on small pools of water	Lack of situational awareness while walking or near a wet surface	Severe personnel injury	**2C**	1. Avoid walking on any wet surface, or try to find a path with the least amount of water on it. 2. If you have to walk over a wet surface, make sure that you do it slowly and have full attention on getting past the wet walkway. 3. Make sure that you have shoes with rubber soles that can provide as much traction as possible under these conditions.	1. Visually verify the best path to take. 2. Physically slow down how fast you walk.	**2D**
Personnel risk from falling rockets	Failure to release a parachute, or tangled parachute and a lack of situational awareness could lead to a rocket landing on someone or something	Death or severe personnel injury	**1D**	1. Maintain the minimum safe distance when launching a rocket. 2. Always try to keep eye contact with the rocket while it is falling back to the ground. 3. If shelter is available stay under that so that the falling rocket cannot hit you. 4. If you believe that the rocket is going to fall on you, make sure you get out of the way as fast as you can.	1. Physically verify that you are the minimum safe distance away from the launch of the rocket. 2. Maintain visual contact with the rocket as it is coming down, and get out of its way as fast as you can (if the rocket is heading in your general direction).	**1E**
Personnel risk from falling payloads or small objects	If rocket or payload were to break apart in flight, small objects would come down	Death or severe personnel injury	**1D**	1. Maintain the minimum safe distance when launching a rocket. 2. Always try to keep eye contact with the payload or small pieces while it is falling back to the ground. 3. If shelter is available stay under that so that the falling objects cannot hit you. 4. If you believe that the payload or small pieces is going to fall on you, make sure you get out of the way as fast as you can.	1. Physically verify that you are the minimum safe distance away from the launch of the rocket. 2. Maintain visual contact with the payload or small pieces as it is coming down, and get out of its way as fast as you can (if the rocket is heading in your general direction).	**1E**

Personnel risk from exploding rockets on the launch pad	If minimum safe distance isn't adhered to or improper handling of rocket while setting it up could cause an explosion	Death or severe personnel injury	**1C**	1. Ensure that you are the minimum safe distance away from the launch pad at launch time. 2. When placing the igniters in, ensure that the electronic ignition system is disconnected or turned off to avoid any accidental ignitions. 3. Ensure that you have gone through a pre-launch safety checklist and have been approved by the RSO before launching your rocket, to minimize risk.	1. Verify that the PLS sheet has been filled out. 2. Physically verify that the RSO has given you the go ahead to launch. 3. Physically verify that the ignition system is off when going near the rocket. 4. Physically verify that you are the safe distance away from the launch pad during launch.	**1E**
Environmental hazard from prolonged rocket motor launches	If launching many rockets, there will be an increase in greenhouse gas emissions	Minimal environmental damage	**4B**	1. There will be increased greenhouse gas emissions from launching rockets. Nothing can be done to avoid this except for potentially changing fuel sources (which is not allowed)	1. No verifications are required.	**4B**
Environmental hazard to chemical releases due to rocket explosion	If rocket or payload were to explode, any chemicals inside the rocket would be scattered across the ground	Mitigatable environmental damage	**3D**	1. If rocket explodes any and all chemicals contained within the rocket will be dispersed throughout the area. Make sure you are at the minimum safe distance away when the rocket launches to avoid contact with any of those chemicals. 2. Understand and read all MSDS sheets for all chemicals on your rocket so that in the event that it blows up, you can be prepared to start the clean up process.	1. Physically read the MSDS sheets and have adequate supplies to clean up the area in the event that the rocket were to blow up on the launch pad.	**3E**
Personnel injury from exploding battery of payload on landing or takeoff	If LiPo batteries take a large impact, they have the potential to explode and cause damage to property or personnel	Death or severe personnel injury	**1D**	1. Always maintain minimum safe distance when launching the rocket. 2. Avoid having your battery come in contact with anything that could potentially pierce it. 3. If payload is coming down near your location make sure that you stay away from, just in case the battery would land on something sharp and cause it to explode.	1. Physically verify that you are the minimum safe distance away from the launch pad. 2. Physically verify that the design our battery placement, will not be able to be physically pierced by any object on takeoff and on landing.	**1E**
Personnel exposure to exploding powder charges	Improper handling of black powder charges can cause them to explode	Death or severe personnel injury	**1D**	1. When working with the powder charges, ensure that no sparks can be created that could light off the ignition system. 2. When placing the ignitors into the powder charges, make sure that the electronic ignition system has been turned off and the batteries have been pulled out.	1. Physically verify that the batteries have been pulled out of the ignition system before putting the ignitors in the powder charges.	**1E**

Personnel exposure to accidental takeoff of rocket	If rocket is misfired and launched early without personnel at the proper safe distance, could cause an injury or death	Death or severe personnel injury	**1D**	1. Ensure that you are the minimum safe distance away from the launch pad at launch time. 2. When placing the igniters in, ensure that the electronic ignition system is disconnected or turned off to avoid any accidental ignitions. 3. Ensure that you have gone through a pre-launch safety checklist and have been approved by the RSO before launching your rocket, to minimize risk.	1. Physically verify that the electronic ignition system is turned off and unplugged before connecting it to the rocket motor.	**1E**
Personnel injury from prolonged posture while sitting or standing	Prolonged sitting and sitting with the wrong posture can cause prolonged minor injuries	Minor personnel injury	**3E**	1. When setting up the ignition system, ensure that the electronic ignition system is turned off and unplugged from the power source. 2. Avoid creating any kind of sparks that could accidently ignite the rocket motor.	1. Physically verify that the electronic ignition system is turned off and unplugged before connecting it to the rocket motor.	**3E**
Personnel lack of situational awareness at rocket launch due to sleep deprivation	Personnel that have sleep deprivation could fall asleep at the launch and not be aware of any hazards that do exist	Death or severe personnel injury	**1D**	1. Always ensure that you receive a good nights sleep prior to the competition. 2. If a nap is required ensure that you are inside a building and inside a safe location (during off times) before taking as nap.	1. Physically get a good nights sleep before coming to the competition.	**1E**
Environmental hazard, bird strikes with rocket or payload	Launching a rocket when a bird is flying by (bird could potentially be endangered)	Irreversible severe environmental damage	**1D**	1. Prior to launch of the rocket, and all clear signal will be given by the safety officer to ensure that the sky is cleared of any birds that could potentially be within the launch path of the rocket. 2. If too many birds are in the way of the rocket, then the rocket launch will need to be delayed to allow for the birds to clear out of the way.	1. Safety officer is to use a visual verification that the sky is clear of any birds or flying objects, before the launch of the rocket.	**1E**

4.14 Environmental Concerns

Environmental Hazards	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Wildlife strikes when launching the rocket	Launching a rocket when a bird is flying by (bird could potentially be endangered)	Irreversible severe environmental damage	1D	1. Prior to launch of the rocket, and all clear signal will be given by the safety officer to ensure that the sky is cleared of any birds that could potentially be within the launch path of the rocket. Double check right before countdown occurs. 2. If too many birds are in the way of the rocket, then the rocket launch will need to be delayed to allow for the birds to clear out of the way.	1. Safety officer is to use a visual verification that the sky is clear of any birds or flying objects, before the launch of the rocket.	1E
Chemical releases at launch pad due to rocket explosion	If rocket or payload were to explode, any chemicals inside the rocket would be scattered across the ground	Mitigatable environmental damage	3D	1. If rocket explodes any and all chemicals contained within the rocket will be dispersed throughout the area. Make sure you are at the minimum safe distance away when the rocket launches to avoid contact with any of those chemicals. 2. Understand and read all MSDS sheets for all chemicals on your rocket so that in the event that it blows up, you can be prepared to start the clean up process.	1. Physically read the MSDS sheets and have adequate supplies to clean up the area in the event that the rocket were to blow up on the launch pad.	3E
Dispersed chemical release due to mid air rocket explosion	If rocket or payload were to explode, any chemicals inside the rocket would be scattered across the ground	Mitigatable environmental damage	3D	1. If rocket explodes any and all chemicals contained within the rocket will be dispersed throughout the area. Make sure you are at the minimum safe distance away when the rocket launches to avoid contact with any of those chemicals. 2. Understand and read all MSDS sheets for all chemicals on your rocket so that in the event that it blows up, you can be prepared to start the clean up process.	1. Physically read the MSDS sheets and have adequate supplies to clean up the area in the event that the rocket were to blow up on the launch pad.	3E

Increased greenhouse gases due to rocket launches	If launching many rockets, there will be an increase in greenhouse gas emissions	Minimal environmental damage	**4B**	1. There will be increased greenhouse gas emissions from launching rockets. Nothing can be done to avoid this except for potentially changing fuel sources (which is not allowed)	1. No verifications are required.	**4B**
Increased greenhouse gases while traveling to competition	This cannot be avoided while traveling to the competition or traveling to other launch sites	Minimal environmental damage	**4A**	1. When renting or driving a vehicle, select a vehicle that is more fuel efficient. 2. Once we are at the designation, turn off the vehicle to save fuel and reduce emissions.	1.Visually verify that the car is turned off at we get to our destination.	**4A**
Increased greenhouse gases if car is left idling when not needed	Car is left running when not in use, when it could be turned off	Minimal environmental damage	**4C**	1. All vehicles will need to be turned off when not in use to ensure that we minimize any greenhouse gas emissions.	1. Driver of the vehicle will need to perform a visual inspection of the dashboard to ensure that the vehicle is off. 2. An auditory inspection of vehicle must also occur to make sure that the motor is turned off.	**4D**
Accidental chemical spills while constructing the rocket	Improper handling while working with chemicals	Reversible severe environmental damage	**2C**	1. Always keep focus on the task at hand. 2. Read the MSDS sheets prior to use and ensure that we have the proper supplies to clean up the chemical spill.	1. Visually read the MSDS sheet. 2. Physically verify that you have the proper clean up supplies in the event of a spill.	**1D**
Improper disposal of chemicals after working with them	Improperly disposing of chemicals	Reversible severe environmental damage	**2B**	1. Prior to using the chemicals read the MSDS sheet and read how to dispose of the chemicals properly. 2. In the event of an accidental chemical disposal, if the situation is still able to be clean up then follow the MSDS sheet on how to clean it up properly. If the chemical is not able to be cleaned then notify the local authorities immediately.	1. Visually read the MSDS sheet. 2. Physically verify that you have the proper clean up supplies in the event of a spill.	**1E**

Brush fire from launching a rocket	If flammable material is kept near to the rocket flame on lift off	Irreversible severe environmental damage	**1D**	1. Before launch of the rocket, ensure that there is no flammable material nearby where the rocket launches (this includes looking for dry brush, paper, flammable fuels, etc.). 2. Make sure that before launching a rocket, that the launch pad that it is on has no flammables on it, and make sure that the flame from the motor cannot spread past the launch pad.	1. Before launch a visual verification will occur to ensure no flammables at or nearby the launch pad. 2. If in the event of a small fire, once the rocket lands we will use a fire extinguisher to put it out completely (visual verification to ensure that the fire is completely out by waiting nearby the place of the fire for 30 minutes). 3. If the fire is too large to handle, the fire department will need to be called to handle it (calling 911).	**1E**
Accidental fire while constructing the rocket	If flammable material is kept nearby a source of sparks while constructing the rocket	Irreversible severe environmental damage	**1D**	1. Prior to using any tool that can create sparks or excessive heat, inspect the area for any flammable materials. 2. Always have a fire extinguisher and know how to extinguisher. 3. Call 911 if the fire can not be handled, pull a fire alarm, and leave the building immediately.	1. Physically verify that a fire extinguisher is nearby while working. 2. Mentally verify an evacuation route and meeting location in the event of an emergency.	**1E**

4.15 ROCKET FAILURE MODES

Rocket Failure Modes	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Structure failure from deploying a parachute at too high of a velocity	Late deployment of parachute while moving at a high velocity	Causes rocket body to fall back to earth at terminal velocity	1C	1. Test that ejection charges to see if they fire at the proper time. 2. Test the altimeters and place new batteries in the altimeters prior to launch. 3. Ensure that the altimeters are programmed properly	1. Verify that ejection charges work by doing pop tests. 2. Inspect and verify all batteries and altimeters work properly.	1E
Motor failure due to faulty ignitor	Damaged ignitor, not connected to electronic ignition source, or electronic ignition source does not have power	Motor fails to ignite when expected	4C	1. Prior to launch inspect the ignitor for damage. 2. Ensure that it is properly connected to the electronic ignition system and that the system has power. If ignitor fails wait 1 minute, and the electronic ignition system is off before approaching the rocket.	1.Visually inspect ignitor for damage. 2. Physically verify that all connections to ignitor are made properly and that no wires are shorting out.	4D
Unintentional rail button detachment	Loose attachment to the rails	If motor ignites it will launch in a random direction	1D	1. Prior to launch check the rail attachments to ensure that they are firmly secured	1. Visually inspect the rail attachments to ensure a tight connection with the rail before launch.	1E
Shock cord failure	Damaged or frayed shock cord	Rocket body will come back down	1B	1. When inserting the parachute into the correct sections of the rocket, ensure that there is not physical damage to the shock cord, it is attached properly, and has no potential chance of becoming snagged.	1. Visually verify that the cord is not damaged and that it is packed properly in the rocket.	1E
Tangled parachute	Improperly packed parachute	Rocket will come down faster than intended and potentially take damage on landing	2B	1. When packing parachute ensure that it is folded and assembled properly. 2. Double check to make sure that the cords of the parachute cannot become snagged when deploying	1. Prior to launch visually inspect that the cords of the parachute are packed properly and that they will not get snagged during ejection.	2C

Fin damage on landing	Rocket coming down on a single point, or coming down too fast	Broken fins will not allow the rocket to be reusable	**1C**	1. Ensure that the parachute is properly packed and has no damage. 2. Check the altimeters to make sure that they work properly and fire the ejection charges at the set altitude prior to launch of the rocket.	1. Visually verify that the parachutes are packed properly. 2. Prior to launch physically verify that the altimeters work and that they have new batteries.	**1D**
Premature ejection charge ignition	Faulty altimeter or short circuit	Parachute could take damage and cause damage to rocket	**1D**	1. When connecting the ejection charges ensure that there are no possible shorts in the system. 2. Check that the altimeters are functioning properly and that the electronic matches are not damaged prior to launch.	1.Visually inspect that all connections cannot short and that the electronic match is not damaged. 2. Physically verify that the altimeters are set at the proper altitude and work properly prior to launch.	**1E**
Unstable launch pad	Unleveled ground, or poorly made launch platform	Rocket will fly off in an unintended location	**1D**	1. Ensure that the launch pad properly and on an even surface.	1. Visually verify that the launch pad is safe to use prior to launch.	**1E**

Minor parachute tear	Faulty parachute, or during ejection it snags on part of the rocket	Potential damage to rocket from additional descent velocity	**2B**	1. Inspect the parachutes for any damage prior to launch. 2. Ensure that all fire blankets are in place so that the ejection charges cannot burn the parachute during ignition. 3. Ensure that the parachute cannot snag on the rocket during deployment.	1. Visually inspect the parachute and that all engineered safety devices are in place prior to launch of the vehicle.	**2C**
Ejection charge failure to ignite	Faulty altimeters or batteries in altimeters fail	Sections won't separate and the rocket will come down at terminal velocity	**1E**	1. Double check that new batteries have been installed and that the altimeters work properly before launch of the vehicle.	1. Physically verify that all new batteries are connected properly and that the altimeters work properly prior to launch.	**1E**
Main motor ignition failure	Failed ignitor or electronic ignition system	Rocket will not fire	**4B**	1. Prior to launch check that the ignitor isn't damaged and that it is connected properly. 2. Ensure that the electronic ignition system is properly turned on and connected.	1. Physically verify that all connections have been made properly and that there are no shorts in the system.	**4D**
High wind conditions	Weather conditions	Cannot launch rocket in high wind conditions and launch will need to be delayed	**4B**	1. There is nothing that can be done to avoid bad weather conditions.	1. Visually inspect the weather prior launch to see if it could potentially turn worse than intended.	**4B**

4.16 PAYLOAD FAILURE MODES

Payload Failure Modes	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Battery dies during mission	Uncharged battery or battery takes damage during takeoff or ejection	Total failure of the payload	1D	1. Charge the battery the night before launch day. 2. Never connect the battery until you are ready for launch and size the battery to last at least 1 hour on the launch pad before launching.	1. Physically verify that the battery is charged prior to launch and that the connections to the battery are not made until right before the launch.	1E
Arduino board failure	Damage from takeoff or power disconnection	Total failure of the payload	1E	1. Ensure that all connections a have been made properly and that it is properly attached to the payload structure.	1. Visually inspect that the Arduino for damage, that all connections are made properly, and that it is secured to the PIL structure.	1E
Battery explodes on takeoff or landing	High G's on the system and the battery could have an impact point	Total failure of the payload	1D	1. Never overcharge or place the battery in an unsecure location. 2. Check to see that no sharp objects near the battery before launch and that all electrical connections are secure.	1. Visually verify that there are no sharp impact points for the battery and that it is properly secured to the PIL frame.	1E
Parachute gets tangled	Improperly packed parachute	Payload could potentially take damage on landing	2B	1. When packing parachute ensure that it is folded and assembled properly. 2. Double check to make sure that the cords of the parachute cannot become snagged when deploying	1. Prior to launch visually inspect that the cords of the parachute are packed properly and that they will not get snagged during ejection.	2C
Minor parachute tear	Faulty parachute, or parachute burns from ejection charge	Payload could potentially take damage on landing	2C	1. Inspect the parachutes for any damage prior to launch. 2. Ensure that all fire blankets are in place so that the ejection charges cannot burn the parachute during ignition. 3. Ensure that the parachute cannot snag on the rocket during deployment.	1. Visually inspect the parachute and that all engineered safety devices are in place prior to launch of the vehicle.	2D

Radio communication partial or complete failure	Battery failure, grounds ops communication failure, transmitter failure, or Arduino failure	Vital information could be lost and mission could be a failure	**1C**	1. Test the electrical connections to ensure that they receivers are getting power at the grounds ops. and in the payload. 2. Run our test program software from the grounds ops to ensure that the receivers are properly transmitting and receiving data properly. 3. Ensure that there is no damage to the receivers prior to launch.	1. Visually verify that there is no damage to the receivers and that they are properly plugged in. 2. Run the test program from the ground ops. station to ensure that the PIL is sending and receiving data properly.	**1D**
Landing gear failure	Landing gear fails to deploy properly due to bad servo or stuck legs	Payload could potentially take damage on landing	**3B**	1. Test the servo to make sure it works prior to use, and ensure that it has power from the battery prior to launch. 2. If lubrication is required to release the legs, make sure that prior to launch they are properly lubed and can move freely when released from their locked position.	1. Physically verify all connections were made properly and that altimeters work prior to launch. 2. Physically test the servos to ensure that it can release the legs at the right time during the testing phase of the payload.	**3C**
Payload fails to separate from fairing	Shear pins fail to break	Fairing and payload will come down ballistic	**1B**	1. It is important to test the ejection charge connections prior to launch. 2. During pop tests, ensure that the fairing will have adequate pressure to break the shear pins on the fairing. 3.Ensure that the altimeters are working properly and have new batteries to minimize risk.	1. Physically verify all connections were made properly and that altimeters work prior to launch. 2. Physically test the shear pins and ejection charge inside the fairing to see if the shear pins will break and deploy the payload properly.	**1E**
Ground Ops. software failure	Computer crashes or battery dies	No data will be received by the computer and the mission will be a failure	**1D**	1. Ensure that there aren't too many programs running at once. 2. Attempt to have a full battery at all times or stay plugged into a power source to avoid power failures.	1. Physically charge your battery the night before and if possible plug the computer directly into a power source to ensure that it works properly for as long as possible.	**1E**

4.17 PRE-LAUNCH AND LAUNCH CHECKLISTS

Pre-Launch and Launch Checklist

Pre-Launch Checklist

This is to be used on launch day to ensure the rocket is and payload is ready for launch.

Safety Preparation

- ☐ Had a meaningful PJB and filled out PJB form
- ☐ Ensure that everyone is wearing the proper PPE

Motor Preparations

- ☐ Before opening the portable magazine, ensure that there are no open flames within 25 feet of rocket motor
- ☐ Prepare the motor per manufacturers' instructions
- ☐ Inspect igniters by checking continuity, resistance, and visually inspect for any cracks or damage
- ☐ Once prepared, place motor back in portable magazine and wait till all inspections and approvals have occurred before placing the motor into the rocket

Recovery Systems

- ☐ Inspect shock cords for cuts, abrasions, tangles, or fraying
- ☐ Inspect shroud lines for cuts, abrasions, tangles, or fraying
- ☐ Inspect main chutes for cuts, holes, abrasions, or fraying
- ☐ Inspect drogue chute for cuts , holes, abrasion, or fraying
- ☐ Inspect all connection points on payload and rocket body for damage
- ☐ Fold all parachutes as per engineer's design
- ☐ Insert parachutes into recovery sections of rocket body, while ensuring that no lines become tangled
- ☐ Place fire blankets above necessary chutes to prevent damage from powder charges

Electronics for Avionics

- ☐ Install all batteries into all altimeters
- ☐ Confirm that all altimeters are working properly
- ☐ Confirm that altimeters are programmed properly to set off powder charges at designated altitudes
- ☐ Install altimeters into avionics bay
- ☐ Wait till final assembly steps before connecting altimeters to powder charges

Electronics for Payload

- ☐ Plug in battery to the electronics in the PIL
- ☐ Turn on Ground Ops. and verify that all data is being sent properly from the PIL
- ☐ Place all coverings and frames around the electronics and wait for final assembly

Rocket Airframe

- ☐ Visually inspect rocket body for any damage
- ☐ Visually inspect fins and motor mounts for any damage
- ☐ Visually Inspect fairing for damage

Final Assembly

- ☐ Place PIL in fairing and secure in place
- ☐ Assemble all other sections of the rocket ensuring a snug fit
- ☐ Secure all sections with the proper hardware
- ☐ Double check that rocket is assembled properly

Motor Installation

- ☐ After final assembly has occurred take motor back out of the portable magazine
- ☐ Check for no open flames within 25 ft.
- ☐ Install motor as per manufacturer's instructions and ensure a tight fit

Pre-Launch and Launch Checklist

Launch Checklist

This is to be used right before launch to that the rocket will be safe and will launch properly

Safety Preparations

- ☐ Ensure that PJB has occurred and been filled out
- ☐ Ensure that everyone is wearing the proper PPE

Preparing Rocket on Launch Pad

- ☐ Visually inspect launch pad to ensure that it is flat and clear of any debris
- ☐ Visually inspect surrounding area for any potential flammable material
- ☐ Place rocket assembly on the pad an ensure it is mounted properly to the rail

Ignitor Preparation

- ☐ Before handling the ignitor, ensure that it is disconnected from the electronic ignition system and that the system is off
- ☐ Secure the ignitor in place
- ☐ Attach all necessary connections to ignitor ensuring that no wires are touching to prevent any shorting
- ☐ Wait till final launch preparations before connecting battery to the electronic ignition system

Arming

- ☐ Arm all devices on the rocket, and ensure that they are locked in place

Final Launch Preparations

- ☐ Move to minimum safe distance away from rocket (for K class rocket 200ft)
- ☐ Connect the battery to the electronic ignition system
- ☐ Signal to the RSO that the vehicle is ready for launch and wait till you have been given proper approval

Launching the Rocket

- ☐ Wait till RSO has given proper approval to launch rocket
- ☐ Turn on electronic ignition system (RSO)
- ☐ Double check that no wildlife can be injured on launch of rocket
- ☐ Double check that no new hazards have arisen
- ☐ Signal to crowd using and everyone that rocket is ready for launch (RSO)
- ☐ Provide a verbal countdown 5 seconds prior to launch (RSO)
- ☐ Activate electronic ignition system after countdown has occurred (RSO)

Misfire Procedure

- ☐ Turn off and disconnect electronic ignition system
- ☐ Wait at least 1 minute after disconnecting the electronic ignition system before approaching the rocket
- ☐ Approach the rocket and redo the *"Ignitor Preparation, Arming, Final Launch Preparations, and Launching the Rocket"* steps

Recovery

- ☐ Wait 10 minutes after rocket and payload have landed to ensure all data has been sent properly
- ☐ Double check GPS location to pinpoint where both sections have landed
- ☐ Check to ensure that they are recoverable in safe locations and that no other rockets are in the air.
- ☐ Approach rocket and payload
- ☐ Disarm all switches on the rocket
- ☐ Check to ensure that all powder charges detonated
- ☐ Remove any undetonated powder charges
- ☐ Bring back rocket and payload to safe location and remove battery in the payload

5 PAYLOAD DESIGN

5.1 PAYLOAD CONCEPT FEATURES AND DEFINITION

5.1.1 System overview

The PIL system consists of many different sub-systems including the structural, landing module, electrical, and fairing. These sub-systems must work together to achieve the PIL's overall mission. The structural component of the PIL must hold everything together during ascent, deployment, descent, and landing. The landing module must deploy for the best photography results, and the electrical sub-system must remain in working condition and collect the data needed at the correct sample rate. It is crucial the fairing deploys as intended, however there are redundant charges above the electronics bay that will force the deployment of the PIL, in the event of a fairing separation failure. Each component must work to insure the greatest chance of mission success, however there are redundancies planned into the more crucial systems, to increase chance of mission success.

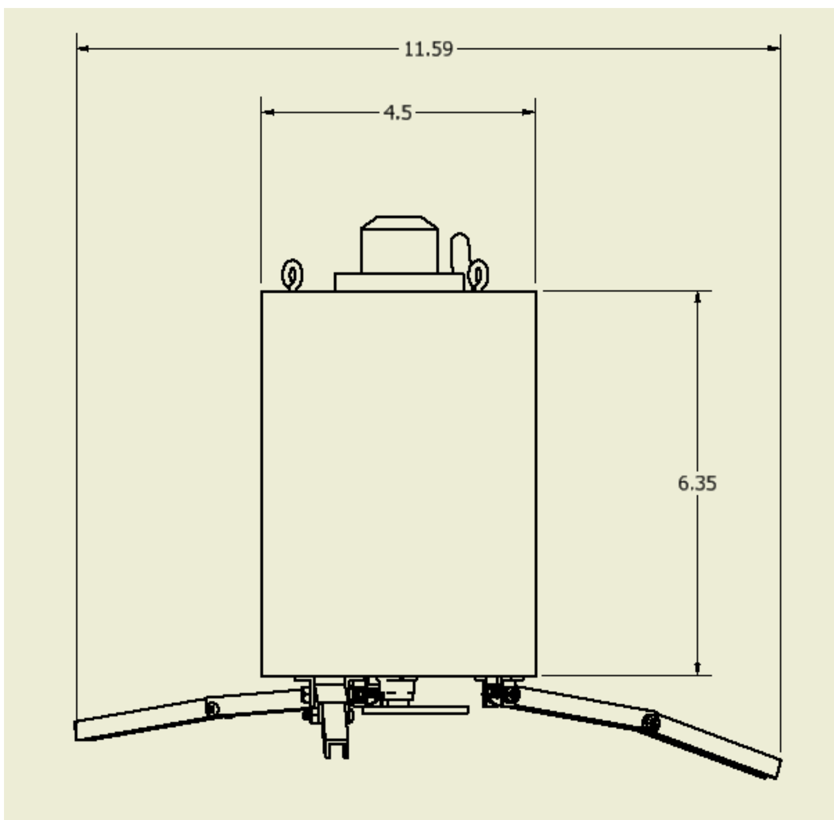


Figure 29: Genera PIL Dimensions

5.1.2 PIL Structure

The payload section of this mission took quite a bit of ingenuity. The first unique design that is implemented is the literal backbone of our payload: the tri-structure. The tri-structure is the triangle-like structure in which every electrical, mechanical, and recovery device is attached to. It is unique because it allows for maximum mounting surface area for the electronics, while still keeping height clearance between the mounting surface and the protective shell. There is some level of challenge to manufacturing this component, but the benefit of using this structure greatly out weights the fabrication challenge. The highest level of challenge would be electronic systems that are mounted to the tri-structure.

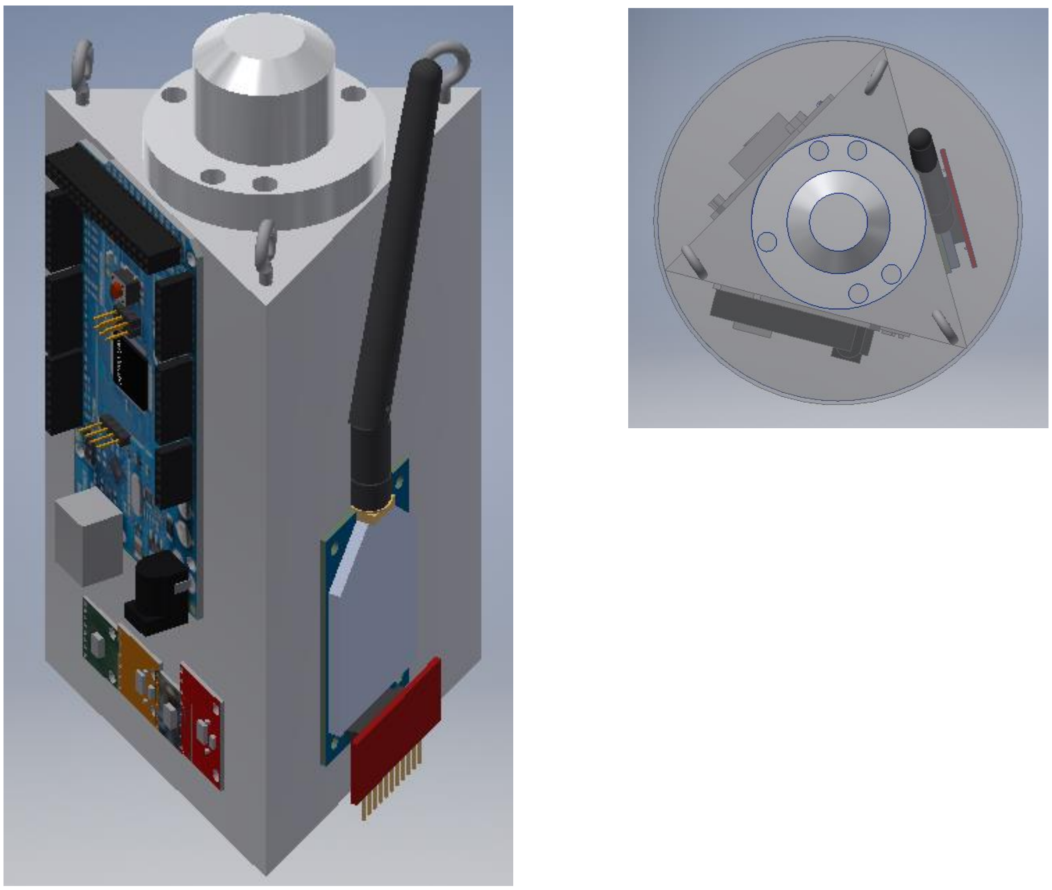


Figure 30 & 31: Drawings of the PIL's Structure

5.1.3 Landing Module

Another unique design of the PIL, is that it has an integrated landing module attached to the tri-structure. This module is designed to help the PIL stabilize upon landing. It is designed to fold up flush to the bottom of the PIL, and deploy outward once out of the rocket. The legs will deploy by rotating a servomotor, which will be fixed to a retaining triangle, blocking the legs from deploying. Once the retaining triangle frees the landing legs, the legs will spring open and be held by 2 torsion springs at each of the 2 joints on the legs. The legs are made of 2 different sized U-channel aluminum where the smaller channel fits inside of the bigger one. The legs are hinged with 2 bolts: one hinge to flip the smaller leg from the bigger leg, and one hinge to flip out the big leg from the underside of the PIL. The challenge created with the landing module will be careful drilling in the correct spots so that the folding legs will line up as depicted.

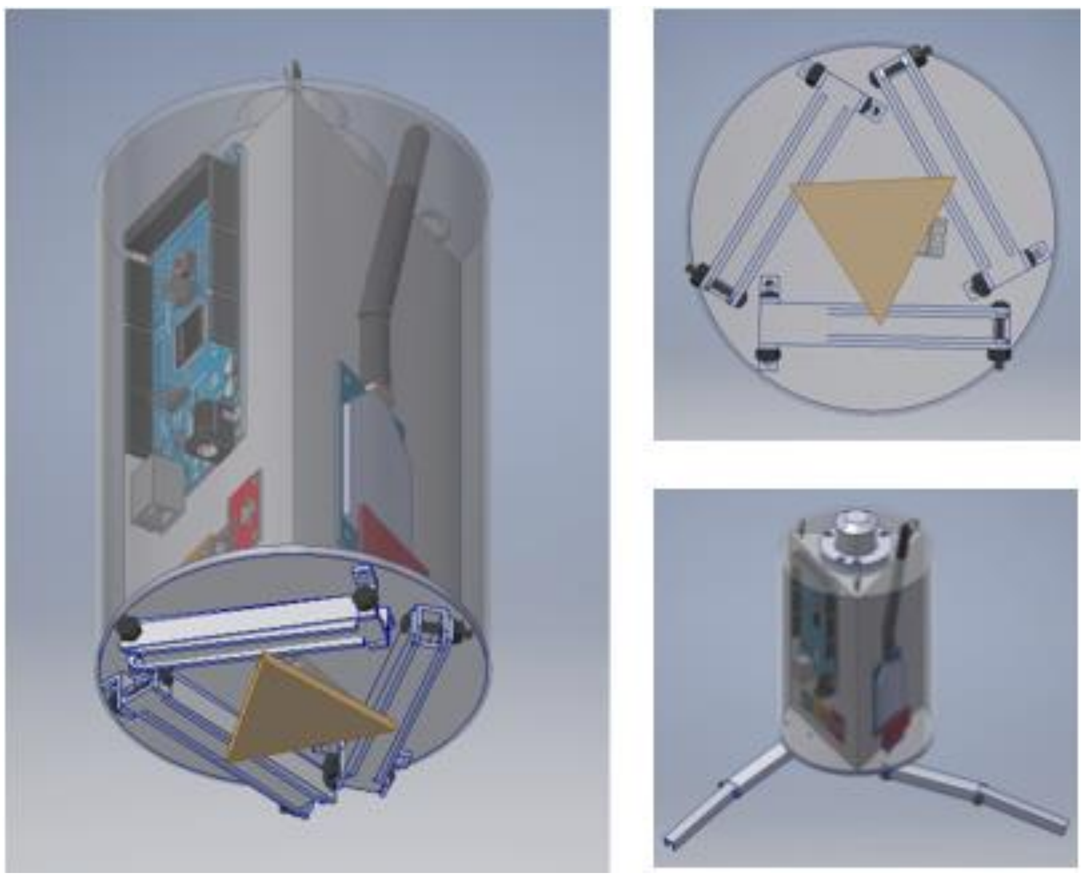


Figure 32: Drawings of the PIL Landing Module

5.1.4 Fairing System

The fairing is another unique aspect of the overall rocket. The fairing will be crafted from fiberglass with polymer/aluminum support rings. The fairing support rings will interlock together, and be fixed together with shear pins. The unique part about the fairing is that it will use an explosive charge in the midsection of the nose cone to break the shear pins and free the fairing from the rocket. The explosive charge will be set off from a standard rocket igniter, which will be wired into a Strato-logger altimeter in the payload bay of the rocket. Once the rocket hits apogee, the Strato-logger will blow the fairing apart, which will release the PIL's parachute. The parachute is stored inside of the fairing above the PIL. This will allow the parachute to automatically deploy once the fairing separates. The challenge that is created with this fairing design will be the fabrication of the fiberglass nose cone.

Figure 33: Drawings of Fairing Design

5.1.5 Electronics System

Table 6: List of sensors being used to measure atmosphere

Parameter	Sensor
Temperature	RHT03 Temp. & Humidity sensor
Relative Humidity	RHT03 Temp. & Humidity sensor
Pressure	BMP180 Barometer
Solar Irradiance	Apogee Instruments SP-215
UV Radiation	ML8511 UV sensor
Images	LinkSprite JPEG Color Camera
Accelerometer	ADXL345
Data Transmission	XTend 900 1W RPSMA radio
GPS	Spark Fun Venus GPS
Micro Controller	Arduino Mega 2650
Ground and PIL Antenna	Digi International A09-HSM-7
Micro SD Card Board	SparkFun microSD Transflash Breakout

5.2 SCIENCE VALUE

5.2.1 Payload Objectives & Success Criteria

5.1.1.2 The payload shall measure atmospheric data both during descent and after landing. For this objective to be successful pressure, temperature, relative humidity, solar irradiance and ultraviolet radiation measurements shall be taken. This data shall be taken at least once every second during decent and at least once every 60 seconds after landing.

5.1.1.3 The payload shall take at least 2 pictures during descent and 3 after landing. For this objective to be successful the sky and ground must be clearly discernable in all pictures.

5.1.1.4 The payload shall remain in orientation both during descent and after landing. For this objective to be successful the line of the horizon as viewed in the pictures taken by the payload shall not deviate more than ±40 degrees from a line parallel to the top and bottom frame of the picture.

5.1.1.5 The payload shall store all collected atmospheric data and pictures. For this objective to be successful 100 percent of all data and pictures taken by the payload shall be stored on the payload.

5.1.1.6 The payload shall transmit all data wirelessly to our ground station. For this objective to be successful 100 percent of all data taken by the payload shall be transmitted to our ground station.

5.1.1.7 A fairing shall be used to house and deploy the payload. For this objective to be successful the fairing shall completely separate to eject the payload while remaining tethered to the rocket.

5.2.2 Experimental logic, approach, and method of investigation

This experiment will be carried out to further the scientific knowledge base of the atmosphere as well as improve the team's ability to communicate with atmospheric probes. The general approach is to build an atmospheric probe that will record and transmit data to a ground station. The data will be investigated through analysis of data with MATLAB. The investigation will compare plots of altitude vs. variables to known atmospheric models. The data will also be investigated visually and/or with additional software to look for abnormalities or points of interest that may occur. The camera data will be investigated visually for points of interest and future reference on the general sequence of events during launch. Any notes on points of interest, abnormalities, or launch sequence will be written in the post launch assessment briefing.

5.2.3 Test and measurement, variables, and controls

To carry out our scientific objectives we will measure data from the following sensors: temperature, relative humidity, pressure, solar irradiance, UV radiation, cameras, accelerometers, and GPS. Data from all sensors except the camera will be gathered at 3 Hz. Camera data will be gathered 3 times during descent and 3 times on the ground.

All sensors except the camera will be used as dependent variables, except for pressure. After converting the pressure to altitude, it will be used as an independent variable for plots.

All sensors have been factory calibrated, providing a control to insure data accuracy. In addition, the pressure sensor on the launch pad before launch will be compared to the known altitude of the launch pad, allowing for an onsite calibration/control of our independent variable.

5.2.4 Relevance of expected data and accuracy/error analysis

This data is expected to match known atmosphere models for all of the variables. Thus, our data will add to the scientific knowledge base and help to reinforce existing atmospheric models.

Data will be analyzed for error by comparing measured variables vs. altitude to expected variables vs. altitude based on known atmospheric models. Plots of error vs. altitude will be created for all measured data. Possible reasons for error will be discussed in a short section along with the plots.

5.2.5 Preliminary Experiment Process Procedures

After collecting the data from all sensors on the PIL, the first step will be to process the pressure sensor and convert the measurements to altitude. This will be offset with the known control altitude at the launch pad gathered before launch. The corrected altitude will be used with our dependent variables to create plots in MATLAB. This data will be compared with expected plots based on known atmospheric models. Plots of error vs. altitude will be created for all variables. The final result will show the measured, expected, and error vs. altitude for all dependent variables.

The camera data will be processed by gathering data from the IMU allowing reorientation of the camera footage to level the horizon. This camera footage will analyzed by team members for scientific merit.

5.3 PLANETARY INVESTIGATION LANDER (PIL) DESIGN AND INTEGRATION

5.3.1 PIL and Rocket Integration

On a larger overview, the PIL needs to integrate into the rocket, to where it is fixed enough to not deploy during launch, but loose enough to deploy when planned. To do this, the team has designed an adapter sleeve, which not only integrates the fairing into the rocket, but the inside of the sleeve will also house an inner retaining ring, as to allow the PIL to set inside of the adapter. This ring prevents the PIL from sliding deeper into the rocket when the rocket is experiencing high G load, but allows the PIL to deploy by sliding from the rocket though the fairing side of the vehicle, once the fairing has separated. Once the fairing deploys, the PIL's parachute will automatically deploy, as it is planted above the PIL, between the fairing sections. As the PIL's parachute deploys, the parachute will deploy, dragging the PIL out of the rocket. As the PIL exits the rocket, the rockets' drogue parachute will be taped to the underside of the PIL, allowing the PIL to help deploy the drogue chute at the same time the PIL is deployed. In the event the PIL doesn't deploy the rockets' drogue parachute, a redundant charge will be set off to ensure the drogue parachutes' deployment.

5.3.2 PIL and landing module

The Landing module will be attached directly to the main structure with small screws extruding through one of the leg mounting holes directly into the tri-structure. This will ensure a sturdy landing module, and decreases the amount of angle brackets and screws needed to hold the landing module to the structure.

5.3.3 PIL Protective Shell and Structure

The Protective shell that covers the rocket will be attached directly to the landing module. Screws extruding through the base plate of the landing module will thread directly into 3 equally spaced threaded nuts, epoxied onto the inside diameter of the protective shell. This will make servicing the PIL much easier as we can remove the Protective shell to service the electronics. The protective shell will also prevent any foreign objects from damaging our sensitive sensors.

5.3.4 PIL and Ground Station

Ground Control will consist of a computer connected to an Arduino, which will be integrated to a radio transceiver. The ground control radio will communicate with the PIL radio, so we can send and receive commands and data.

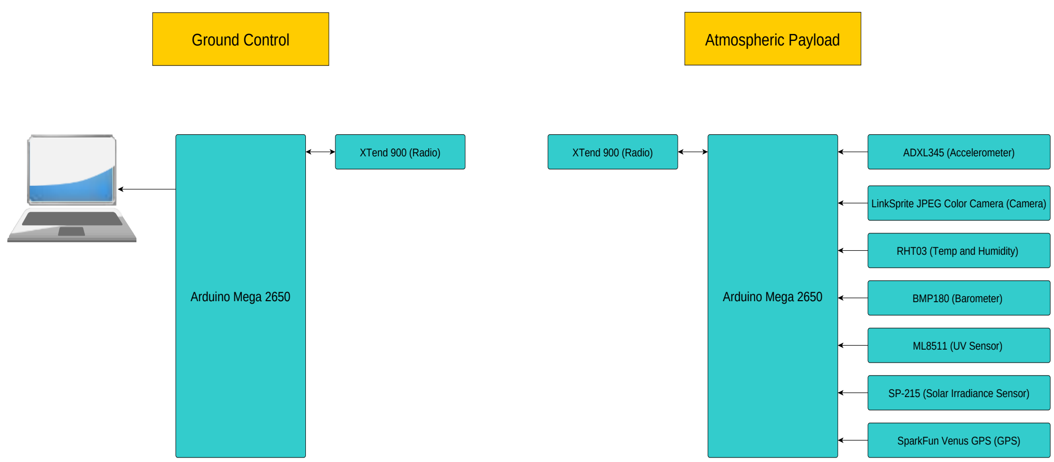


Figure 34: Diagram of Ground Control Payload Commination Hardware

5.4 Planetary Investigation Lander (PIL) Electronics & Description

The electronics for the PIL will provide data and data transmission about the current atmospheric conditions to the Ground Control. Data will be collected by several sensors, and transmitted to ground control in real time via radio communication. An Arduino board will be the microcontroller used to interface the atmospheric sensors and radio. The Arduino program will constantly loop, collecting raw data from the sensors and transforming it into meaningful data (example -

transforming the voltage generated from a pyranometer into solar irradiance using a known equation, relating voltage to solar irradiance). The meaningful data will be put into a JSON string and sent to ground control using the serial stream radio. When a photo is taken, a flag will be sent to the ground informing ground control that part of a JPEG image file is being sent. Part of the JPEG binary will then be sent. And end binary flag will be sent to ground when that part of the JPEG binary is ending, and the ground control will go back to parsing JSON data. We are sending only parts of a JPEG file at a time to continue measuring and sending atmospheric data, without spending too much time transmitting a whole JPEG file. The same data will also be written to a micro SD card on board the PIL as backup, in case of radio failure. The PIL will also scan for incoming radio signals from ground control. These radio signals, if existent, will contain actions for the PIL. These actions will include radio power adjustment and measurement frequency to conserve battery.

5.4.1 PIL Electronics Components

- Arduino Mega 2650 - Microcontroller that interfaces with all sensors and the radio. The Arduino will collect the data from the sensors, create a JSON string from the data, and send the JSON string over serial to the radio. Binary data will be intermittently sent to the radio which corresponds to parts of a jpeg image when a photo is taken.
- XTEND-900 - Radio transceiver that receives and transmits an asynchronous serial stream.
- SparkFun Venus GPS - GPS Module that outputs GPS Coordinates over a serial connection.
- RHT03 - Temperature and Humidity Sensor. Two of these will be used because the response time is 2 seconds for this component. We will alternate the data collection between these two components, to get a one second response time of temperature and humidity. Data is sent over a single wire interface.
- BMP180 - Barometer sensor. Sends barometric pressure over an I2C connection. The barometric pressure can be used to report altitude as well.
- ML8511 - Ultraviolet light sensor. This sensor continuously streams a voltage between 0V and 3.3V that represents the amount of UV light.
- Apogee Instruments SP-215 - Pyranometer. The pyranometer continuously streams a voltage between 0V and 5V that represents solar irradiance.
- ADXL345 - Accelerometer sensor. Sends acceleration data over an I2C connection.
- LS-Y201-2MP - JPEG Color camera that outputs JPEG data over a serial connection.
- SparkFun microSD Transflash - microSD Breakout board to write data to microSD. Backup data storage in case of radio failure.

5.4.2 PIL Electronics Testing

- Arduino Mega 2650 – Microcontroller that interfaces with all sensors and the radio. The Arduino will collect the data from the sensors, create a JSON string from the data, and send the JSON string over serial to the radio. Binary data will be intermittently sent to the radio which corresponds to parts of a jpeg image when a photo is taken.
- XTEND-900 – Radio transceiver that receives and transmits an asynchronous serial stream.
- SparkFun Venus GPS – GPS Module that outputs GPS Coordinates over a serial connection.
- RHT03 – Temperature and Humidity Sensor. Two of these will be used because the response time is 2 seconds for this component. We will alternate the data collection between these two components, to get a one second response time of temperature and humidity. Data is sent over a single wire interface.
- BMP180 – Barometer sensor. Sends barometric pressure over an I2C connection. The barometric pressure can be used to report altitude as well.
- ML8511 – Ultraviolet light sensor. This sensor continuously streams a voltage between 0V and 3.3V that represents the amount of UV light.
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- ADXL345 – Accelerometer sensor. Sends acceleration data over an I2C connection.
- LS-Y201-2MP – JPEG Color camera that outputs JPEG data over a serial connection.
- SparkFun microSD Transflash – microSD Breakout board to write data to microSD. Backup data storage in case of radio failure.

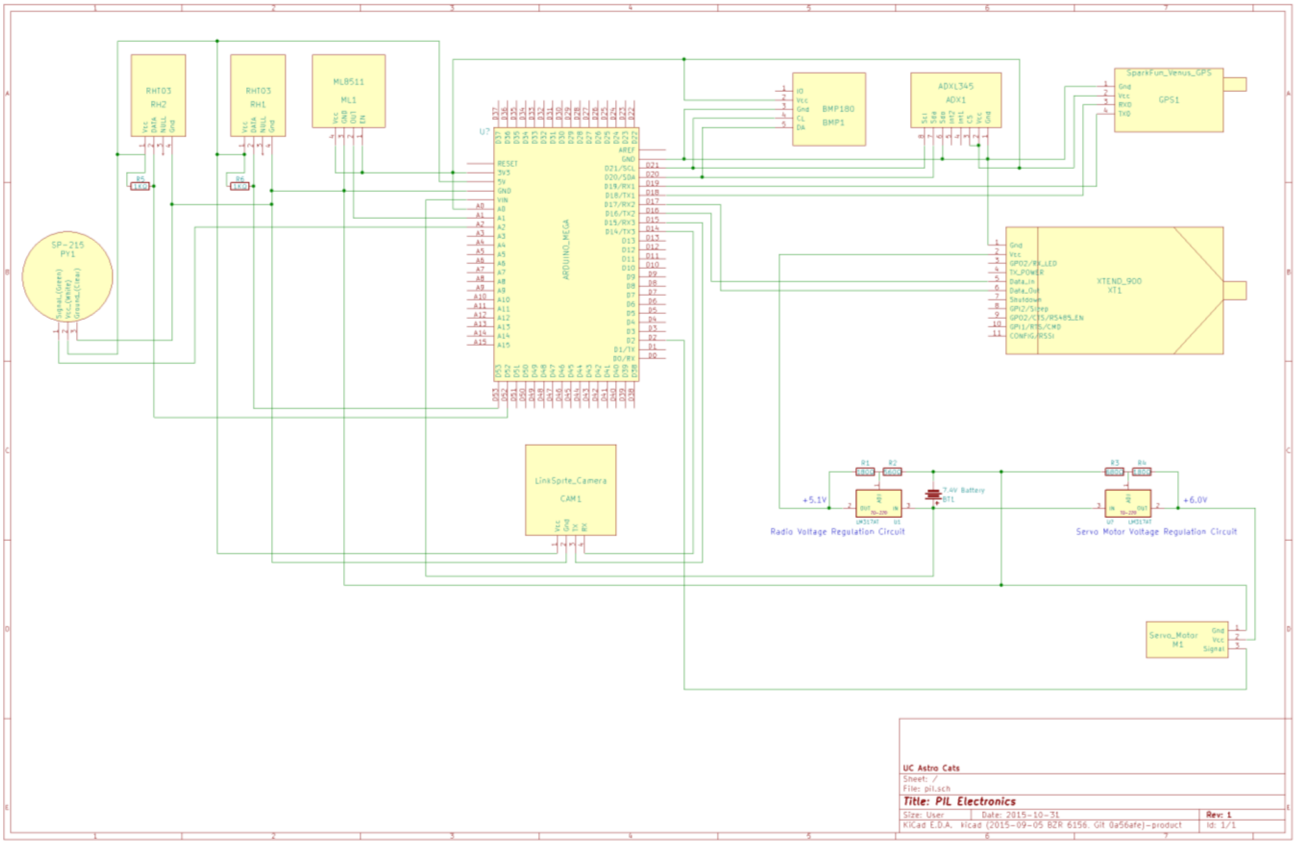


Figure 35: PIL Electrical Schematic

5.2 Ground Support Electronics & Description

The ground control will receive and display data obtained from the PIL and Rocket tracking bay on a PC. Incoming data will be either JSON data or binary data. JSON data will be parsed and the user interface will be updated based on the new values that were received. Binary data that is parts of a JPEG file will be collected and when the end of JPEG file is detected, ground control will put together all parts of the JPEG file, decompress and display the image. The ground control will also be capable of sending commands to the PIL. These commands will include radio power adjustment and measurement frequency to conserve PIL battery. The ground control will consist of a PC, an Arduino board and a radio transceiver. Custom software will be developed that displays the data obtained from the PIL and Rocket Tracking Bay graphically and numerically. The data will be written to disk as it is collected for further analysis.

5.4.3 Ground Control Electronics Components

- Arduino Mega 2650 – Microcontroller that interfaces the radio transceiver with the PC. Sends incoming radio data from the PIL and Tracking Bay to the PC, and sends outgoing commands to the radio, to transmit to the PIL.
- XTEND-900 – Radio transceiver that receives and transmits an asynchronous serial stream.
- PC – A laptop used to interface with the Arduino to display gathered data using custom software. The ground control software will parse the incoming JSON data or binary data, and update the user interface to display the new values received. The intermittently collected binary data will be put together once the end of a JPEG is detected, and the JPEG image will be decompressed and displayed on the ground control user interface.

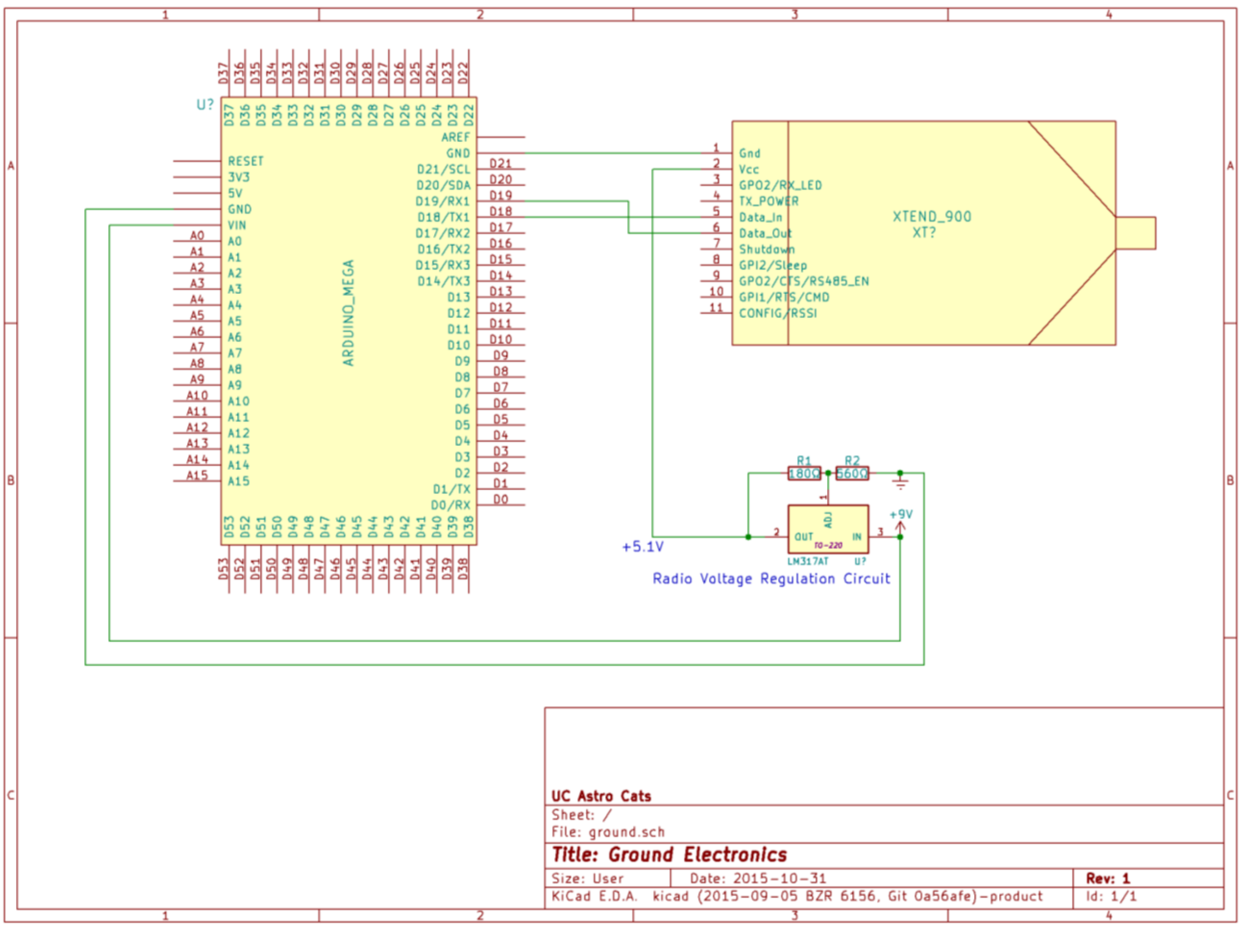


Figure 36: Ground Station Wiring Schematic

5.3 Payload Requirements

Table 7: List of Payload Requirements and Verification Plan

Requirements	Design Features to meet Requirement	Verification
The payload shall be designed to be recoverable and reusable. Reusable is defined as being able to be launched again on the same day without repairs or modifications.	The system is designed to be undamaged after launch with an easily replaceable motor.	This will be verified through testing.
A payload that shall gather data for studying the atmosphere during descent and after landing, including measurements of pressure, temperature, relative humidity, solar irradiance and ultraviolet radiation	The PIL system consists of all sensors necessary to record the atmospheric measurements at altitude and on the ground.	This will be verified through testing.
Measurements shall be made at least once every second during descent, and every 60 seconds after landing. Data collection shall terminate 10 minutes after landing.	The PIL system is designed in a way to collect and transmit data at the required rate and for the required time.	This will be verified through inspection and testing.
The payload shall take at least 2 pictures during descent, and 3 after landing. The payload shall remain in orientation during descent and after landing such that the pictures taken portray the sky towards the top of the frame and the ground towards the bottom of the frame.	The PIL system is design to hang in orientation under parachute at altitude and contains landing legs to remain in orientation on the ground.	This will be verified through testing.
The data from the payload shall be stored onboard and transmitted wirelessly to the Team's ground station at the time of completion of all surface operations.	The PIL system consists of onboard radios to transmit wirelessly to a ground station throughout the flight. Any missed packets of data will be retransmitted before end of operations on the ground.	This will be verified through testing.

A payload fairing design and deployment mechanism.	The rocket contains a fairing and deployment mechanism.	This will be verified through analysis and testing.
The fairings and payload must be tethered to the main body to prevent small objects from getting lost in the field.	The fairing system is tethered to PIL system, offering tracking and safe recovery of the fairing system.	This will be verified through inspection and testing.

5.4 Mass List

Table 8: Component Mass List of Payload

P.I.L.	qty.	weight (g)	total (g)
PIL Housing	1	136	136
Tri-structure	1	117	117
Humidity and Temperature Sensor	2	3	6
Barometer	1	5	5
UV Sensor	1	5	5
Pyranometer	1	90	90
Accelerometer	1	5	5
Camera (x3)	3	30	90
Radio - XTEND 900	1	18	18
Radio Antenna	1	100	100
GPS - SparkFun Venus GPS	1	10	10
GPS Antenna	1	18	18
Micro SD	1	7	7
Arduino	1	37	37
Battery	1	280	280
Parachute (60 in)	1	223	223
Parachute connection hardware	1	100	100
Landing module	1	168	168.0
Landing module servo	1	44	44.0
Power distribution circuit board	1	60	60.0
Total P.I.L. Mass			1519.0

Total P.I.L. Mass	**Kilograms**	1.52
	Lbs.	3.34

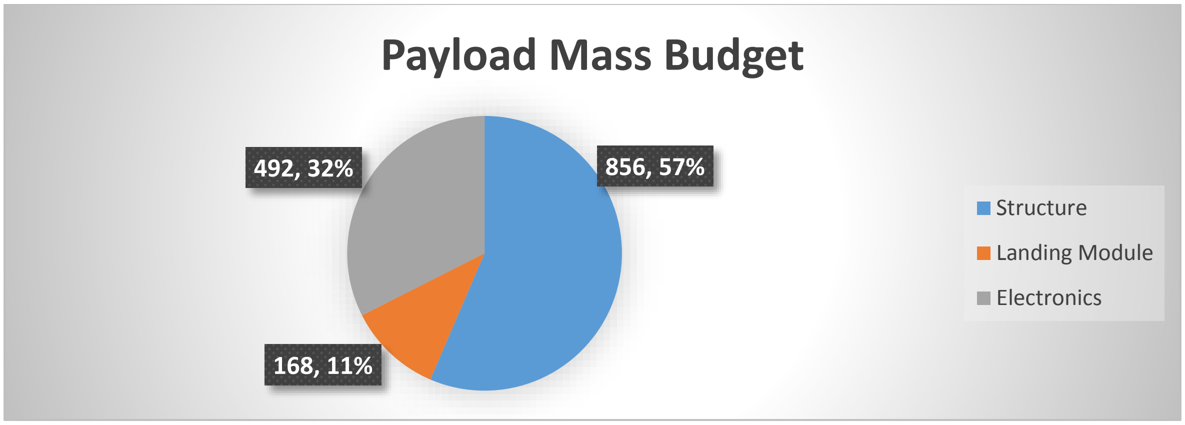


Figure 37: Payload Mass Breakdown

6 Project Plan

6.1 Project Schedule

The following timeline for our project was constructed based on the competition schedule and our Spacecraft senior design class requirements. From the network diagram you can see the completion dates for each work package and the critical path is shown in red. Initially the development of the project hinges on development of the PIL and fairing before switching to rocket subsystem testing and test launches at the end of the project. The Gantt charts show further details of each work package as well as the person responsible for its completion.

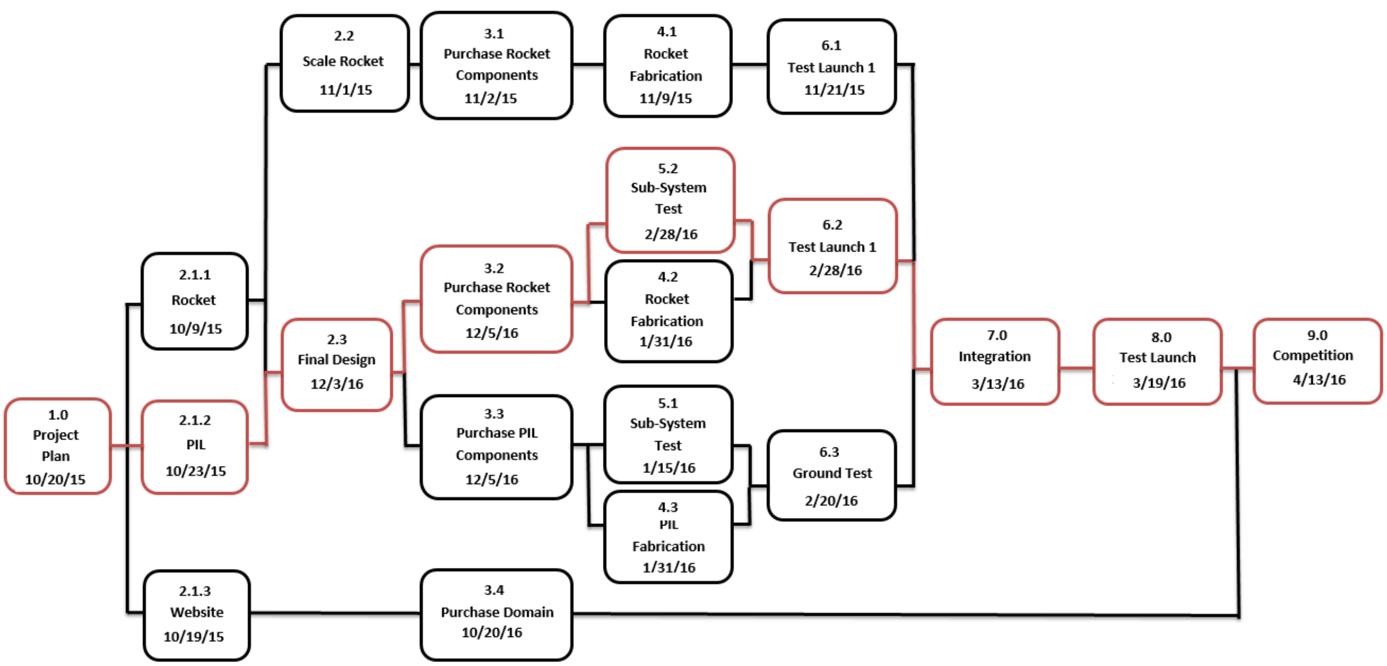
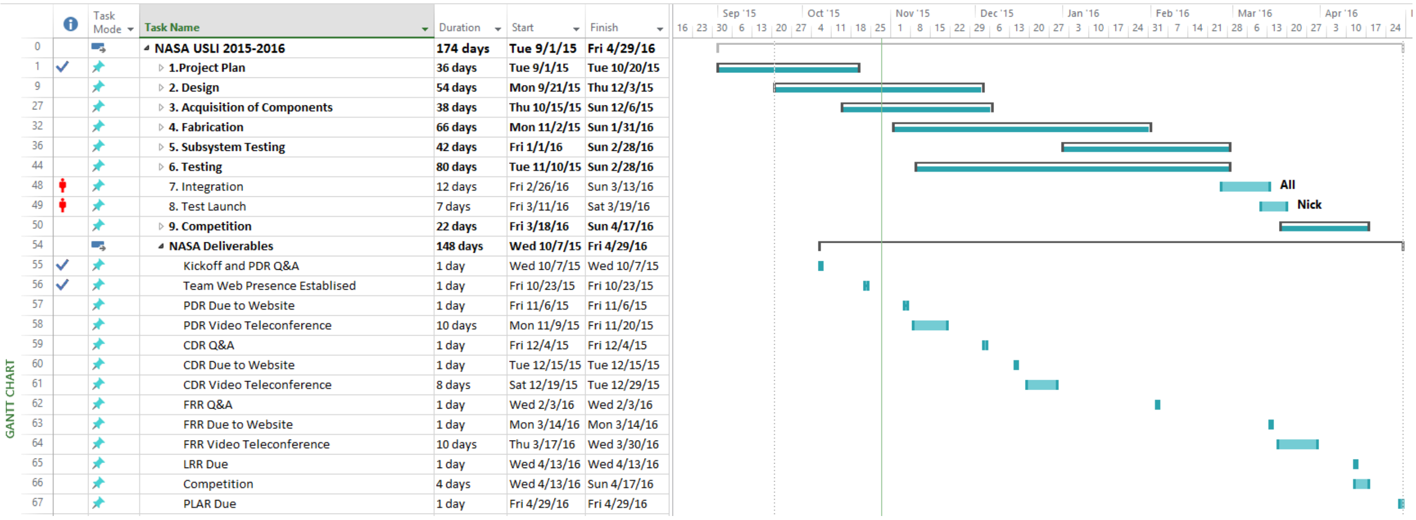
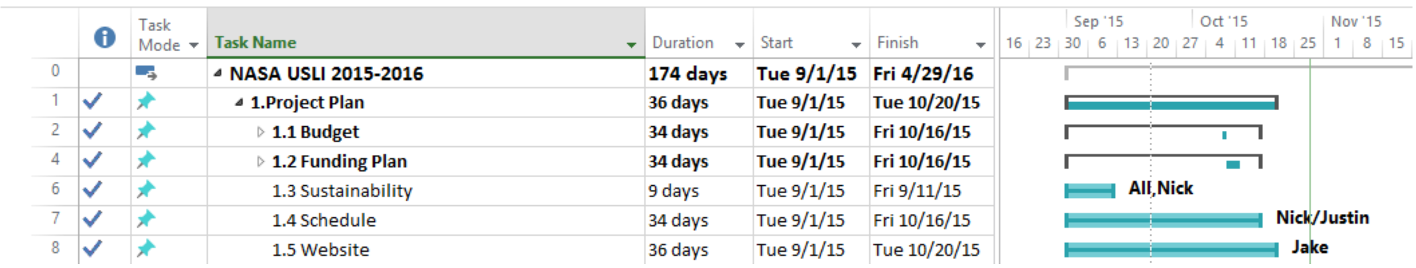


Figure 38: Project Network Diagram



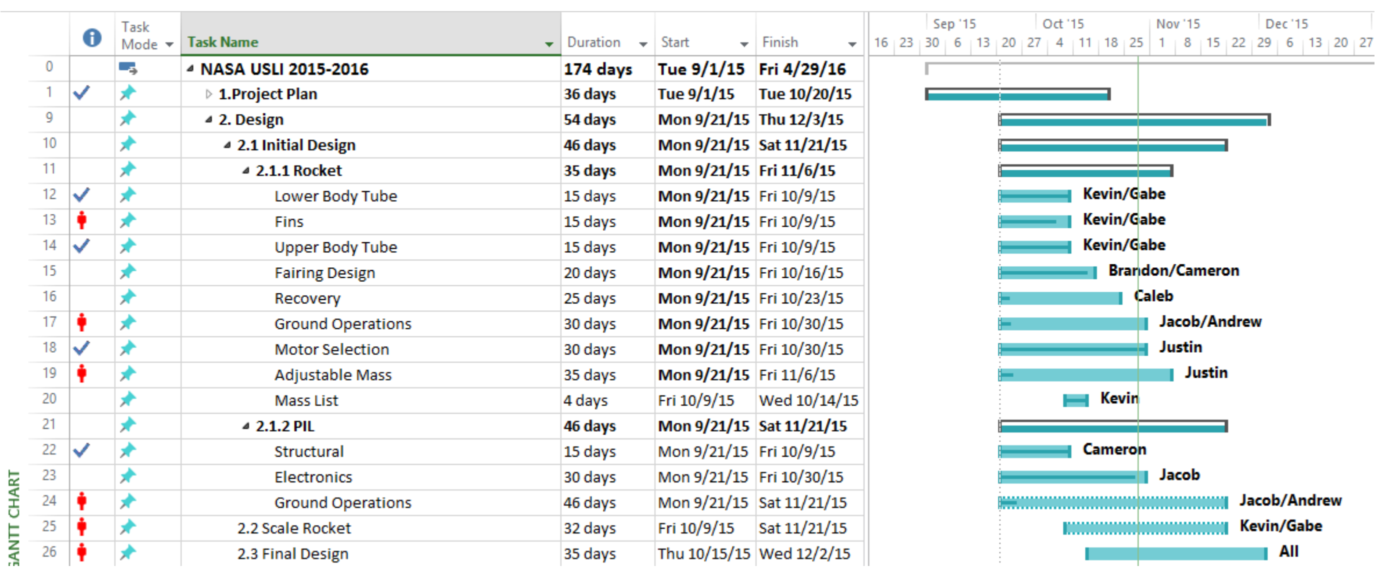
	Task Name	Duration	Start	Finish
0	**NASA USLI 2015-2016**	**174 days**	**Tue 9/1/15**	**Fri 4/29/16**
1	**1.Project Plan**	**36 days**	**Tue 9/1/15**	**Tue 10/20/15**
9	**2. Design**	**54 days**	**Mon 9/21/15**	**Thu 12/3/15**
27	**3. Acquisition of Components**	**38 days**	**Thu 10/15/15**	**Sun 12/6/15**
32	**4. Fabrication**	**66 days**	**Mon 11/2/15**	**Sun 1/31/16**
36	**5. Subsystem Testing**	**42 days**	**Fri 1/1/16**	**Sun 2/28/16**
44	**6. Testing**	**80 days**	**Tue 11/10/15**	**Sun 2/28/16**
48	7. Integration	12 days	Fri 2/26/16	Sun 3/13/16
49	8. Test Launch	7 days	Fri 3/11/16	Sat 3/19/16
50	**9. Competition**	**22 days**	**Fri 3/18/16**	**Sun 4/17/16**
54	**NASA Deliverables**	**148 days**	**Wed 10/7/15**	**Fri 4/29/16**
55	Kickoff and PDR Q&A	1 day	Wed 10/7/15	Wed 10/7/15
56	Team Web Presence Establised	1 day	Fri 10/23/15	Fri 10/23/15
57	PDR Due to Website	1 day	Fri 11/6/15	Fri 11/6/15
58	PDR Video Teleconference	10 days	Mon 11/9/15	Fri 11/20/15
59	CDR Q&A	1 day	Fri 12/4/15	Fri 12/4/15
60	CDR Due to Website	1 day	Tue 12/15/15	Tue 12/15/15
61	CDR Video Teleconference	8 days	Sat 12/19/15	Tue 12/29/15
62	FRR Q&A	1 day	Wed 2/3/16	Wed 2/3/16
63	FRR Due to Website	1 day	Mon 3/14/16	Mon 3/14/16
64	FRR Video Teleconference	10 days	Thu 3/17/16	Wed 3/30/16
65	LRR Due	1 day	Wed 4/13/16	Wed 4/13/16
66	Competition	4 days	Wed 4/13/16	Sun 4/17/16
67	PLAR Due	1 day	Fri 4/29/16	Fri 4/29/16

Figure 39: Top Level View of Project Schedule



	Task Name	Duration	Start	Finish
0	**NASA USLI 2015-2016**	**174 days**	**Tue 9/1/15**	**Fri 4/29/16**
1	**1.Project Plan**	**36 days**	**Tue 9/1/15**	**Tue 10/20/15**
2	**1.1 Budget**	**34 days**	**Tue 9/1/15**	**Fri 10/16/15**
4	**1.2 Funding Plan**	**34 days**	**Tue 9/1/15**	**Fri 10/16/15**
6	1.3 Sustainability	9 days	Tue 9/1/15	Fri 9/11/15
7	1.4 Schedule	34 days	Tue 9/1/15	Fri 10/16/15
8	1.5 Website	36 days	Tue 9/1/15	Tue 10/20/15

Figure 40: Detailed View of Project Plan



	Task Name	Duration	Start	Finish
0	**NASA USLI 2015-2016**	**174 days**	**Tue 9/1/15**	**Fri 4/29/16**
1	**1.Project Plan**	**36 days**	**Tue 9/1/15**	**Tue 10/20/15**
9	**2. Design**	**54 days**	**Mon 9/21/15**	**Thu 12/3/15**
10	**2.1 Initial Design**	**46 days**	**Mon 9/21/15**	**Sat 11/21/15**
11	**2.1.1 Rocket**	**35 days**	**Mon 9/21/15**	**Fri 11/6/15**
12	Lower Body Tube	15 days	**Mon 9/21/15**	Fri 10/9/15
13	Fins	15 days	**Mon 9/21/15**	Fri 10/9/15
14	Upper Body Tube	15 days	**Mon 9/21/15**	Fri 10/9/15
15	Fairing Design	20 days	**Mon 9/21/15**	Fri 10/16/15
16	Recovery	25 days	**Mon 9/21/15**	Fri 10/23/15
17	Ground Operations	30 days	**Mon 9/21/15**	Fri 10/30/15
18	Motor Selection	30 days	**Mon 9/21/15**	Fri 10/30/15
19	Adjustable Mass	35 days	**Mon 9/21/15**	Fri 11/6/15
20	Mass List	4 days	Fri 10/9/15	Wed 10/14/15
21	**2.1.2 PIL**	**46 days**	**Mon 9/21/15**	**Sat 11/21/15**
22	Structural	15 days	Mon 9/21/15	Fri 10/9/15
23	Electronics	30 days	Mon 9/21/15	Fri 10/30/15
24	Ground Operations	46 days	Mon 9/21/15	Sat 11/21/15
25	2.2 Scale Rocket	32 days	Fri 10/9/15	Sat 11/21/15
26	2.3 Final Design	35 days	Thu 10/15/15	Wed 12/2/15

Figure 41: Detailed View of Rocket, PIL, and Final Design

	Info	Task Mode	Task Name	Duration	Start	Finish
0			NASA USLI 2015-2016	174 days	Tue 9/1/15	Fri 4/29/16
1	✓		1.Project Plan	36 days	Tue 9/1/15	Tue 10/20/15
9			2. Design	54 days	Mon 9/21/15	Thu 12/3/15
27			3. Acquisition of Components	38 days	Thu 10/15/15	Sun 12/6/15
28	✓		3.1 Purchase of Scale Rocket Components	2 days	Sun 11/1/15	Mon 11/2/15
29			3.2 Purchase Rocket Components	12 days	Fri 11/20/15	Sat 12/5/15
30			3.3 Purchase PIL Components	11 days	Fri 11/20/15	Fri 12/4/15
31	✓		3.4 Purchase Website Domain	1 day	Thu 10/15/15	Thu 10/15/15
32			4. Fabrication	66 days	Mon 11/2/15	Sun 1/31/16
33			4.1 Scale Rocket	6 days	Mon 11/2/15	Mon 11/9/15
34			4.2 Rocket	42 days	Thu 12/3/15	Fri 1/29/16
35			4.3 PIL	43 days	Thu 12/3/15	Sat 1/30/16
36			5. Subsystem Testing	42 days	Fri 1/1/16	Sun 2/28/16
37			5.1 PIL	11 days	Fri 1/1/16	Fri 1/15/16
38			5.1.1 Measurement accuracy/Repeatibility	6 days	Fri 1/1/16	Fri 1/8/16
39			5.1.2 Radio Testing	10 days	Mon 1/4/16	Fri 1/15/16
40			5.2 Rocket	32 days	Fri 1/15/16	Sun 2/28/16
41			5.2.1 Pop Test	7 days	Fri 1/15/16	Mon 1/25/16
42			5.2.2 Ground OP Verification	23 days	Mon 1/18/16	Wed 2/17/16
43			5.2.3 Subscale Rocket	9 days	Wed 2/17/16	Sun 2/28/16
44			6. Testing	80 days	Tue 11/10/15	Sun 2/28/16
45			6.1 Sub Scale Test Launch	10 days	Tue 11/10/15	Sat 11/21/15
46			6.3 PIL Ground Test	16 days	Mon 2/1/16	Sat 2/20/16
47			6.2 Rocket Test Launch	16 days	Mon 2/8/16	Sun 2/28/16
48			7. Integration	12 days	Fri 2/26/16	Sun 3/13/16
49			8. Test Launch	7 days	Fri 3/11/16	Sat 3/19/16
50			9. Competition	22 days	Fri 3/18/16	Sun 4/17/16
51			9.1 Prep	19 days	Fri 3/18/16	Wed 4/13/16
52			9.2 Travel	1 day	Wed 4/13/16	Wed 4/13/16
53			9.3 Launch	3 days	Thu 4/14/16	Sun 4/17/16

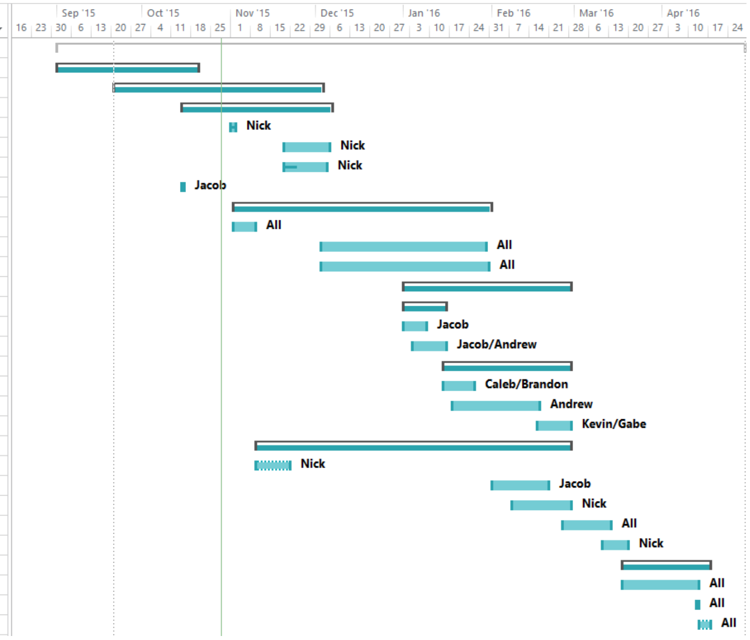


Figure 42: Detail View of Testing, Fabrication, Testing, Integration, and Competition

6.2 Project Risks

The team has found the following risks to be potentially detrimental to the project by possible causing budget overruns and project delays.

The first risk is with our fairing design. Although we currently have a design, and manufacturing plan for our current fairing design we still need to verify our manufacturing method and begin testing and refining our design to ensure it will work as designed. In order to mitigate this risk we are preforming research in how to create fiberglass parts from molds and are going be testing and refining our design between PDR and CDR in hopes of having a final manufactured fairing at the time the CDR is due.

The next risk is with weather delays in our subsystem test and rocket test launches. Given that all test launches will take place in Ohio there is a significant chance that we will have issues with launches being cancelled from December to February due to weather. To mitigate this risk we will make sure to take advantage of launches in November to preform our sub scale rocket launch so we are able to have that done by CDR. We will also be sure to stay on schedule and take full advantage of the days we can launch in the spring so we are able to get all necessary test done. We have also been able to gain contacts at different launch sites which will give us more options on when we can launch this spring if we begin to get crunch for time.

The final potential risk we see is in funding. We realize that it is not guaranteed we will get our funding from OSGC or that it may take longer than mid-February to receive. If this is the case we will first look to fundraise the funds in the same manner as stated in the funding plan. If this is not a possibility we will work with the university officials to determine a method to raise the rest of the required funds.

6.3 PROJECT BUDGET

The following tables detail the team's USLI budget as of our PDR. Since submitting our proposal we have added and removed a few items, as our designs developed, while updated pricing information on others. As a result, our total overall budget has grown slightly. At this point we expect our total expenses to remain at or below our initial proposal total budget of $7,464.39. This is due to some of the items on the list that we already have and do not need to purchase and still having plenty of extra money in our miscellaneous overheads we build into our budget to cover unexpected costs.

Expense Summary	
Travel	$ 3,442.00
Rocket	$ 1,344.38
Payload	$ 2,833.46
Educational	$ 70.00
Total	$ 7,689.84

Availible Misc. Funds	
Travel	$ 175.00
Rocket	$ 101.07
Payload	$ 750.58
Educational	$ (35.00)
Total	$ 991.65

Travel Expenses		
Description	Estimated Price	
Rental Car (2 SUV/ 1 Van for 5 days)	$	1,175.00
Gas (Round Trip Cincinnati to Huntsville +100 miles @ 23MPG & $2.745/Gal)	$	312.00
Hotel (Holiday Inn Express Huntsville 4 rooms 3 nights @107.50/Night)	$	1,720.00
Gas (2 Round Trip Cincinnati to Test Launch Site) 500@ 23MPG & $2.745/Gal)	$	60.00
Food (If additional funds are present at the end of competition)	$	-
Misc. Costs	$	175.00
TOTAL	$	3,442.00

Rocket Expenses				
Part	Quanity	Price	Part Number	Subtotal
Scale Model Kit	1	$ 113.15	PK-56	$ 113.15
54 mm Motor Mount Tube	1	$ 8.09	MMT-2.14	$ 8.09
4 oz Fiberglass Fabric -3 yard	1	$ 27.45	262-B	$ 27.45
6 oz Fiberglass Fabric - 3 yard	1	$ 21.95	259-A	$ 21.95
Chavant Le Beau Touche Clay - 2lb Block	1	$ 11.95	1120-A	$ 11.95
PVA Release Film - 1 Gal	1	$ 24.75	13-B	$ 24.75
System 2060 Epoxy Resin -Hardener	1	$ 21.95	2060-A	$ 21.95
System 2000 Epoxy Resin	1	$ 44.95	2000-A	$ 44.95
5.38" Airframe Tubing 42"	2	$ 38.50	BT-5.38	$ 77.00
Centering Ring 5.38", 54mm	4	$ 7.21	CR-5.38-2.14	$ 28.84
Tube Coupler 5.38"	1	$ 9.08	TC-5.28	$ 9.08
Tube Stiffener 5.38	1	$ 10.85	STC-5.38	$ 10.85
Electronic Bay	2	$ 42.95	EB-5.38	$ 85.90
Bulkhead 5.38"	1	$ 7.98	BA-5.38	$ 7.98
54mm quick change Motor Retainer	1	$ 34.00	RA-54L	$ 34.00
Rail Buttons 1500 Series	1	$ 5.78	RB-1500	$ 5.78
Swivels 400# Test	2	$ 3.50	4/0 Swivel	$ 7.00
Shock Cords	2	$ 13.70		$ 27.40
1/4" Chain Eye Connector (Quicklink)	2	$ 4.13	CEC-2	$ 8.26
Arming Switches	4	$ 9.46	a11112200ux0536	$ 37.84
Droge Parachute	1	$ 18.95	LHPC-36	$ 18.95
Main Chute	1	$ 139.00	Cert 3 Large	$ 139.00
Arming Switches	4	$ 9.46		$ 37.84
Goex Black Powder	1	$ 17.75		$ 17.75
Cessaroni K445 Rocket Engine	3	$ 106.95	71441	$ 320.85
Cessaroni J335 Rocket Engine	1	$ 51.90		$ 51.90
15 min Epoxy 9 oz	2	$ 15.95	EPY-15	$ 31.90
Website Hosting Cost	1	$ 11.99	www.ucrocketry.com	$ 11.99
ABC Fire Extinguishers	1	$ 39.99		$ 39.99
Misc. Overheads	-	-		$ 101.07
Shipping & Handling	-	-		$ 72.12
TOTAL				$1,344.38

Payload Expenses				
Part	Quanity	Price	Part Number	Subtotal
Arduino Mega 2560	2	$ 45.00	2560 R3	$ 90.00
4S 5200 mAh LiPo Battery Pack	2	$ 39.88	912700002-0	$ 79.76
StratoLogger Altimeter	4	$ 58.80		$ 235.20
Energizer Max 9V Batteries, 5pk	2	$ 16.49	552538432	$ 32.98
MG Chemical's Ferric Chloride Etchant	1	$ 36.95	70125797	$ 36.95
Misc. Wiring and Electrical Components	1	$ 20.00		$ 20.00
MG Chemical's Solder	1	$ 16.99	4895-227G	$ 16.99
SP-215 Pyranometer	1	$ 235.00	Apogee SP-215	$ 235.00
LinkSprite JPEG Color	2	$ 54.95	LS-Y201-2MPTTL_M58	$ 109.90
Temperature/Humidity SHT15	2	$ 9.95	RHT03	$ 19.90
Barometer	1	$ 9.95	BMP180 Breakout	$ 9.95
UV Sensor	1	$ 12.95	ML8511 Breakout	$ 12.95
SparkFun GPS	2	$ 49.95	Venus GPS	$ 99.90
GPS Antenna	2	$ 11.95	GPS-00177	$ 23.90
Acceleramotor ADXL345	1	$ 17.95	ADXL345	$ 17.95
Xtend 900 1W RPSMA	3	$ 194.95	XTEND 900	$ 584.85
Radio Antenna	3	$ 20.00	A09-HSM-7	$ 60.00
Micro SD Starage	1	$ 9.95	BOB-00544	$ 9.95
Blank Circuit Board	1	$ 15.00		$ 15.00
Parachute	1	$ 73.95	PAR-60 HD	$ 73.95
Acrylic Frame	1	$ 50.00		$ 50.00
Aluminum 6061 Material for Payload	1	$ 40.00		$ 40.00
Torsion Spring	1	$ 5.01	9271K673	$ 5.01
Small U Shaped Trim	1	$ 8.23	8123A42	$ 8.23
Big U Shaped Trim	1	$ 8.17	8123A44	$ 8.17
4-40 Machine Screw	1	$ 2.32	902728113	$ 2.32
4-40 Lock Nut	1	$ 8.13	90715A005	$ 8.13
1/2" Angle	1	$ 11.73	9178T11	$ 11.73
High Torgue Servo	1	$ 13.95	ROB3947	$ 13.95
Misc. Overhead Costs	-	-		$ 750.58
Shipping & Handling	-	-		$ 150.26
TOTAL				$2,833.46

Education Engagement Expenses				
Part	Quanity	Price	Part Number	Subtotal
Building Materials for Bottle Launcher	1	$ 30.00		$ 30.00
Bicycle Pumps	2	$ 20.00		$ 40.00
TOTAL				$ 70.00

6.4 FUNDING PLAN

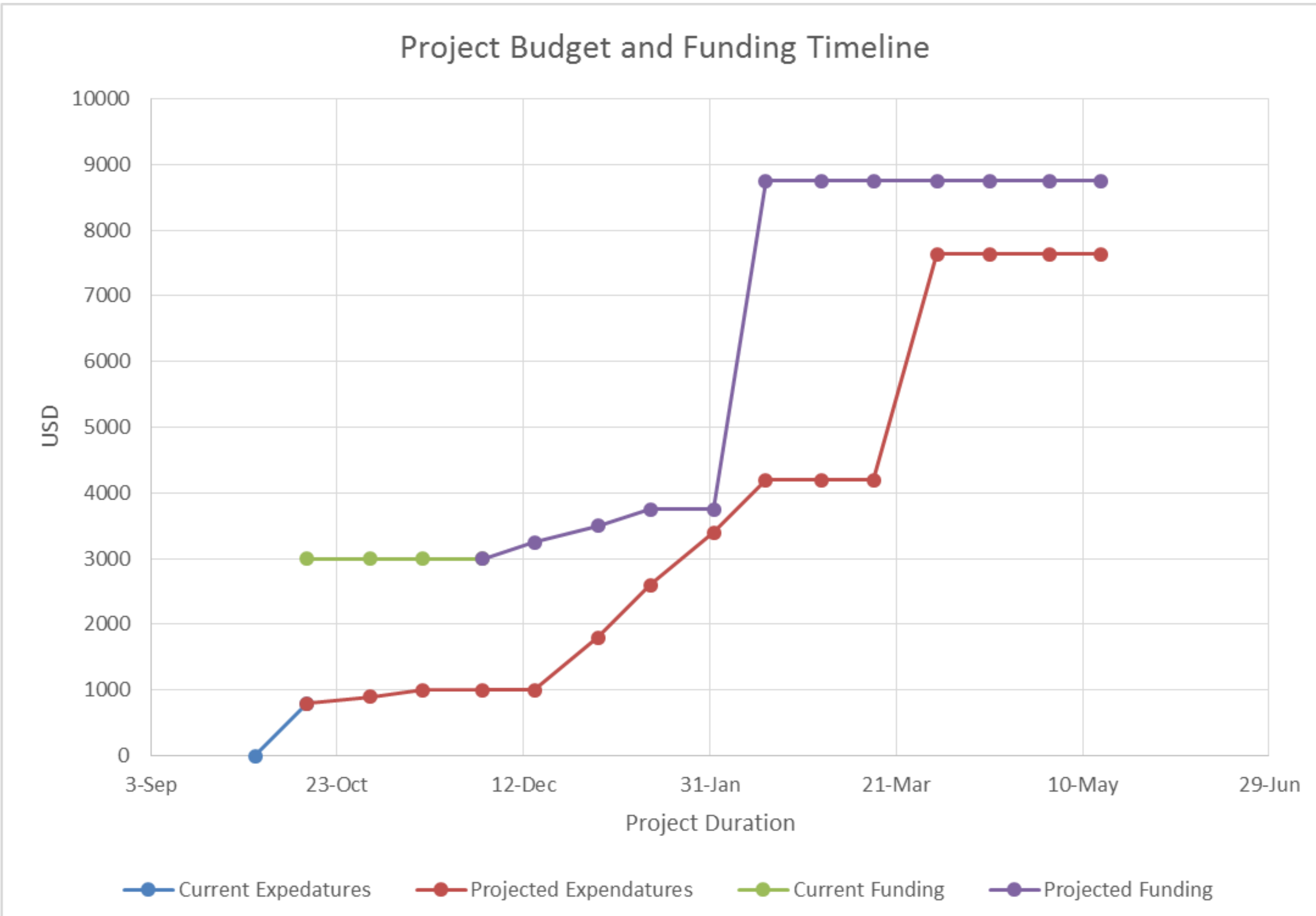
Our senior design team will be getting our funding from various different locations and has a goal of reaching $8500. This money will be enough to cover all expenses for the competition as well as giving us some extra in case we run into any unforeseen complications during the project. As stated in our proposal any additional funds at the end of the project will be given back to the University for next year's team.

The first will be $2333.34 from the University of Cincinnati Students for the Exploration and Development of Space (UC SEDS). This is a student group on campus that gets is granted funds each year from the University's Academic Intercollegiate Competition Committee (AIC). These funds are already secured for the 2015-16 school year and available for the team to use currently. The second source of funding we will be getting $667 from the leftover money from last year's design team. This money is also currently available for use.

The third source of funds is from the Ohio Space Grant Consortium (OSGC). We are in the process of completing our grant application for $5000 and hope to be awarded and have these funds by mid-February.

The plan for the rest of the $500 funds is to fundraise from private donors and businesses. We plan to approach businesses with a project presentation and ask for donations with a tier approach. For $50 or more we will do a thank you on our website, for $100 or more we will do an advertisement on our website. For $250 or more we will do the first two as well as put their company logo on our rocket. Companies could also help us in terms of donations of time on machines or parts and expertise. We plan to start this fundraising campaign following our PDR submission. We choose to wait until after the PDR and the design was further along so we would be able to give our donors accurate information pertaining to our designs and funds needed.

Funding Summary	
Item	Amount
UC SEDS	$ 2,333.00
UC Aero Department	$ 667.00
Outside Sponsers	$ 500.00
OSGC	$ 5,000.00
TOTAL	$ 8,500.00



6.5 EDUCATIONAL ENGAGEMENT

Overview

In order to fulfill our requirement, we had direct interactions with over 200 high school students at Winton Woods High School on November 4, 2015. This consisted of teaching these students rocket physics using water bottle rockets, culminating in the students launching their own rockets. The information taught came from NASA documentation on water bottle rockets. We worked with the teachers at the high school and made sure our lesson related to what the students learned in the classroom.

Lesson details

Each class of around 30 students had 50 minutes of lesson time. We taught between 1 and 3 classes per hour. The lesson was broken into three parts.

Presentation -15 minutes

A short PowerPoint explaining Newton's laws, center of gravity, center of pressure, g forces, fins, thrust, and drag. This was based on the information at http://exploration.grc.nasa.gov/education/rocket/BottleRocket/about.htm. We worked with the teachers at the high school and made sure that the material taught related to the curriculum and was at the level of understanding for the students. This presentation will be available on our website shortly.

Build -20 minutes

This part of the lesson involved groups of students building a water rocket. The students were given one bottle and an array of materials to build fins for their rocket. At the end of this part of the lesson, each rocket was checked for safety by a Student Launch member before the last step.

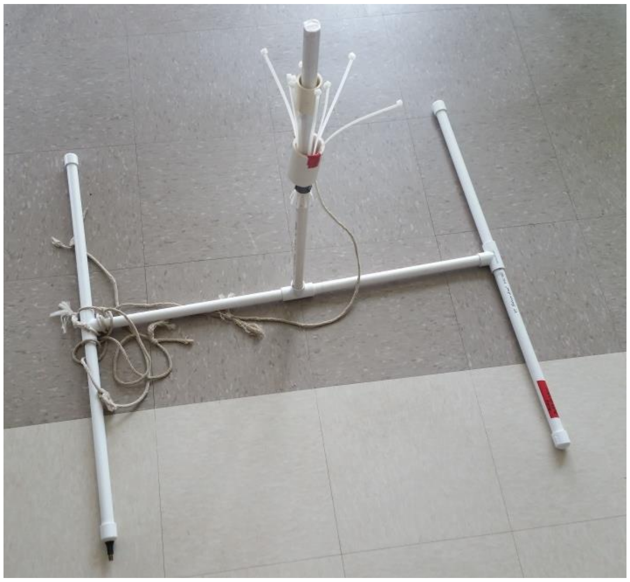
Supplies for each team-

- 2L bottle
- Array of materials to choose from for fins
  - Craft foam
  - Cardboard
  - HDPE plastic
- Electrical tape to attach fins
- #16 Rubber O-Ring for launcher seal

Launch -15 minutes

Each team launched their rocket. An emphasis on safety was used in this step. The weather conditions were favorable to launch, with temperatures around 75 F and little wind. The bottles were pressurized to ~60 psi, well below the failure limit of ~150 psi.

The launcher and air pump was provided by the Student Launch team. Below are pictures of the launcher. The string attached to the launcher allowed students to stand at least 15 feet away during launch.



Evaluation and Documentation

Within one week of the rocket launch, we will send a survey to the faculty of the school asking for feedback on our lesson. Within two weeks, we will complete an education engagement form and send it to the appropriate NASA contacts.

7 Conclusion

In conclusion, the University of Cincinnati Astro Cats are confident that designs detailed in this report will be able to complete our desired mission. Our primary mission consists of deploying a planetary probe too approximately 1 mile above ground level that will then be deployed via a fairing nose cone section. It will then begin to collect valuable atmospheric data such as UV radiation, solar irradiance, temperature, humidity, pressure, and pictures during decent and transmitting them to a nearby ground station where it can be further investigated. We feel confident in our preliminary designs can do this and thus will continue to develop, refine, and expand our current designs, simulations and models throughout the coming months.