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

2850 Campus Way Baldwin 745, Cincinnati OH 45221

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UNIVERSITY OF Cincinnati

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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 assembly. The main flight plan will be to deploy the launch vehicle drogue chute at apogee and then deploy the main and payload at 1500 feet. This plan will be used for winds below 12 miles per hour. For high wind conditions, the drogue will be deployed at apogee and the payload will be deployed at 1000 feet. These plans will be utilized accordingly to ensure that we meet the drift requirements of 2500 feet.

The electronics bay will contain three StratoLogger altimeters connected to ejection charges located on the outside of the top and bottom of the bay. 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 87.14 inches. The outer diameter of the airframe is 5.54 inches. Without the payload or engine loaded, the rocket will weigh approximately 15 lbs. When the rocket is loaded with the payload and engine, it will weigh approximately 23.5 lbs. In this configuration, the center of gravity will be located at 51.72 inches from the tip of the nose cone and the center of pressure will be located at 61.9 inches from the tip. This gives the rocket a margin of 1.85 inches. The launch vehicle will use a Cesaroni - P54-6G Red Lightning (K750) solid rocket motor. The launch rail is 1.5x1.5 by 96".

1.3 PAYLOAD SUMMARY

The main objective of the payload is to record atmospheric measurements of earth's atmosphere from an altitude of 1,500 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 1500 feet, 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 24.9 ft/s.

Milestone Review Flysheet

Institution	University of Cincinnati	Milestone	CDR

Vehicle Properties	
Total Length (in)	87.1
Diameter (in)	5.54
Gross Lift Off Weigh (lb)	23.97
Airframe Material	Kraft Paper w/ Glassine Wrap
Fin Material	G-10 plastic
Drag	0.3 (Cd)

Motor Properties	
Motor Manufacturer	Cesaroni
Motor Designation	K750-RL
Max/Average Thrust (lb)	212.74 / 168.56
Total Impulse (lbf-s)	528.86
Mass Before/After Burn	72.55 oz / 25.96 oz
Liftoff Thrust (lb)	212.74

Stability Analysis	
Center of Pressure (in from nose)	61.92
Center of Gravity (in from nose)	51.72 (before burnout) / 48.60 (after)
Static Stability Margin	1.85 / 2.40
Static Stability Margin (off launch rail)	1.85
Thrust-to-Weight Ratio	7.03
Rail Size and Length (in)	1.5" x 1.5" / 96 in
Rail Exit Velocity	62.07 ft/s

Ascent Analysis		
Maximum Veloxity (ft/s)	621.1	
Maximum Mach Number	0.56	
Maximum Acceleration (ft/s^2)	262.89	
Target Apogee (From Simulations)	5280	
Stable Velocity (ft/s)	44	
Distance to Stable Velocity (ft)	4' 2"	

Recovery System Properties				
Drogue Parachute				
Manufacturer/Model	SkyAngle			
Size	4.4 & 8.6 ft^2			
Altitude at Deployment (ft)	5280			
Velocity at Deployment (ft/s)	0.0249			
Terminal Velocity (ft/s)	103 & 63.2			
Recovery Harness Material	Tubular Kevlar			
Harness Size/Thickness (in)	1/2"			
Recovery Harness Length (ft)	24'			
Harness/Airframe Interfaces	Swivel eye hook / U-bolt			
Kinetic Enerfy of Each Section (Ft-lbs)	Upper	Lower		
	1193 & 564	1259 & 595		

Recovery System Properties				
Main Parachute				
Manufacturer/Model	SkyAngle			
Size	29.5 ft^2 & 14.2 ft^2			
Altitude at Deployment (ft)	1000-1500			
Velocity at Deployment (ft/s)	103 & 63.2			
Terminal Velocity (ft/s)	22.9			
Recovery Harness Material	Tubular Kevlar			
Harness Size/Thickness (in)	1/2"			
Recovery Harness Length (ft)	24'			
Harness/Airframe Interfaces	Swivel eye hook / U-bolt			
Kinetic Enerfy of Each Section (Ft-lbs)	Upper	Lower	PIL	Fairing
	21	71	34	12

Recovery Electonics	
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 Electonics	
Rocket Locators (Make/Model)	Sparkfun Venus 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	CDR

Autonomous Ground Support Equipment (MAV Teams Only)	
Capture Mechanism	Overview
Container Mechanism	Overview
Launch Rail Mechanism	Overview
	Include Description of rail locking mechanism
Igniter Installation Mechanism	Overview

Payload		
Payload 1	Overview	
	The main task of the Payload is to record atmospheric measurements of earth's atmosphere from an altitude of 1,500 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.	
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 1,500 feet, with the 2 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 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. The first test was completed on January 14th, 2016 and was successful. 0.75 grams of Black Powder was used on the subscale fairing design.
Sub-scale Test Flights	Our scale rocket was constructed from the Iris rocket kit from LOC Precision. The outer diameter of the rocket was 3.10" and used a 38mm J335 motor tube. This model was 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 took place on November 21st of 2015. The subscale was loaded with ballast as needed in order to most closely match mass placement and stability margin of the full scale. Due to the loss of our rocket in trees the first sub-scale test was not completely successful and we are going to complete another subscale launch on Jan 30th. 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.

Milestone Review Flysheet

Institution	University of Cincinnati	Milestone	CDR

2 CHANGES TO PROPOSAL

2.1 VEHICLE CHANGES

- U-bolts will be used instead of eye bolts to improve structural integrity of shock cord attachment points
- Bulkheads will be reinforced with G10 fiberglass.
- The length of the upper body tube has increased to
- The fins will be flat 3/16" G10 with rounded edges instead of the fiberglass airfoil with 1/16" G10 core. This is to improve structural integrity and make manufacturing easier.
- Our back-up motor, Cesaroni K750-RL, will be used instead of the K570 motor to ensure the desired altitude is reached.

2.2 PAYLOAD CHANGES

It was found that the landing module initially proposed during PDR would not keep the payload oriented upon landing. To ensure that the payload stays oriented after landing the design was changed. A parachute release mechanism was added to drop the parachute upon landing to help stabilize the payload when it is on the ground. The landing module was removed. The new method of orienting the payload uses torsion spring powered legs that deploy upon landing to lift the payload to the proper orientation. To facilitate this method, the base and top plate shapes were modified to allow the addition of torsion springs and hinges. The outer shell was also cut into individual rectangles making the legs that will lift the payload from the ground. To ensure that the payload structure would survive the shock loads associated with dual deployment a center aluminum structural member was added to the main structure of the payload.

2.3 PROJECT PLAN CHANGES

- Rocket Budget grew by $400 to account for K750 rocket motor and new recovery equipment.
- Payload Budget decreases by $550 scaled back on miscellaneous expenses in budget due to confidence in design.
- Added Second Subscale Launch on Jan 30th to gather necessary flight performance data that was not collected on the first subscale launch.
- Delayed purchasing final components until after CRD review as we wanted to finalize our designs and get feedback before buying the rest of the required components.

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 altimeter will trigger a black powder charge to separate the upper and lower rocket sections to release the drogue 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. The next phase occurs when the rocket reaches either 1500 feet or 1000 feet depending on wind conditions, the second set of altimeters trigger the black powder charge to separate the fairing releasing the payload and deploying 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 1500 ft. or 1000 ft. and deploys the payload
- The drogue parachute deploys at apogee
- The main parachute is deployed at 1500 ft. or 1000 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

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.

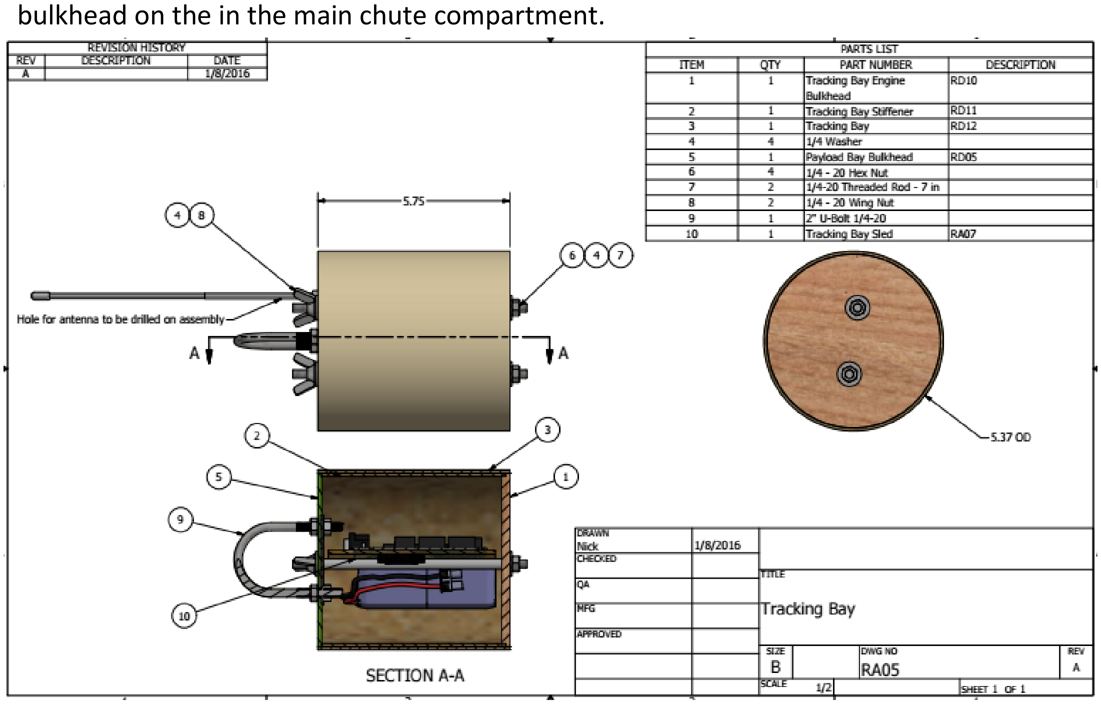


Figure 1: Tracking Bay Drawing

4.2.2 Fin Assembly

The fin assembly will consist of the fins, motor mount tube, and the four centering rings. The fin assembly will be constructed outside the airframe and then slid into place. This will ensure that the team can get the best fin attachment to the motor mount tube. The middle centering ring will have 3 notches laser cut equidistant apart. The notches will go halfway between the outer diameter of the ring and the center hole. Corresponding notches will be cut in the fins to create an interlocking structure. Once the assembly is in place, more epoxy fillets will be created along the outside of the airframe tube.

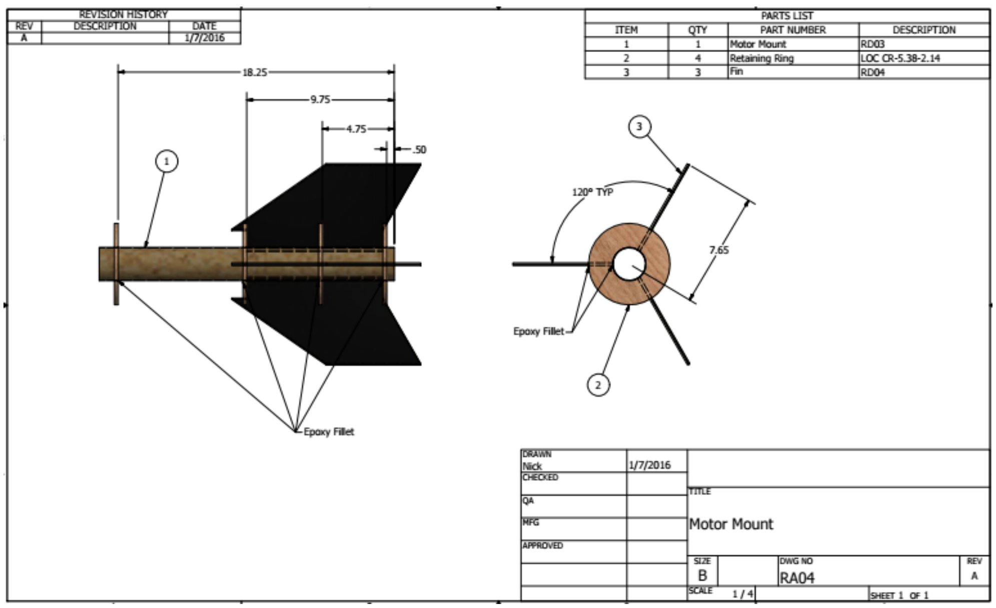


Figure 2: Motor Mount Drawing

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.

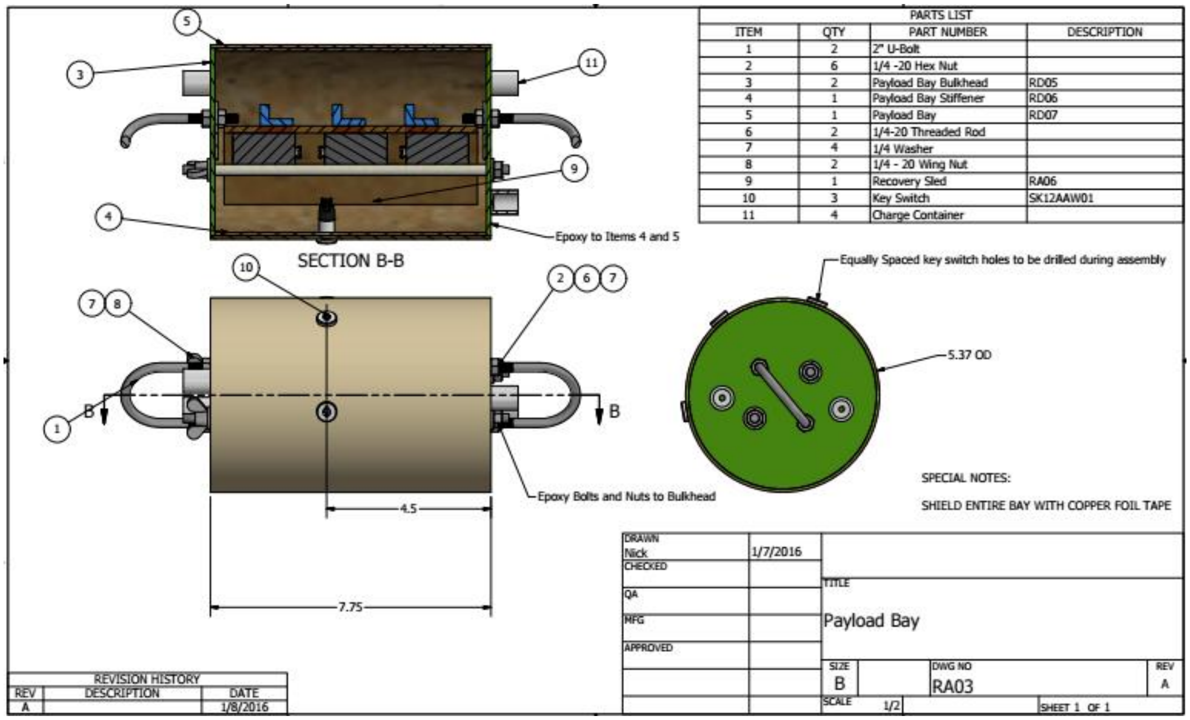


Figure 3: Payload Bay Drawing

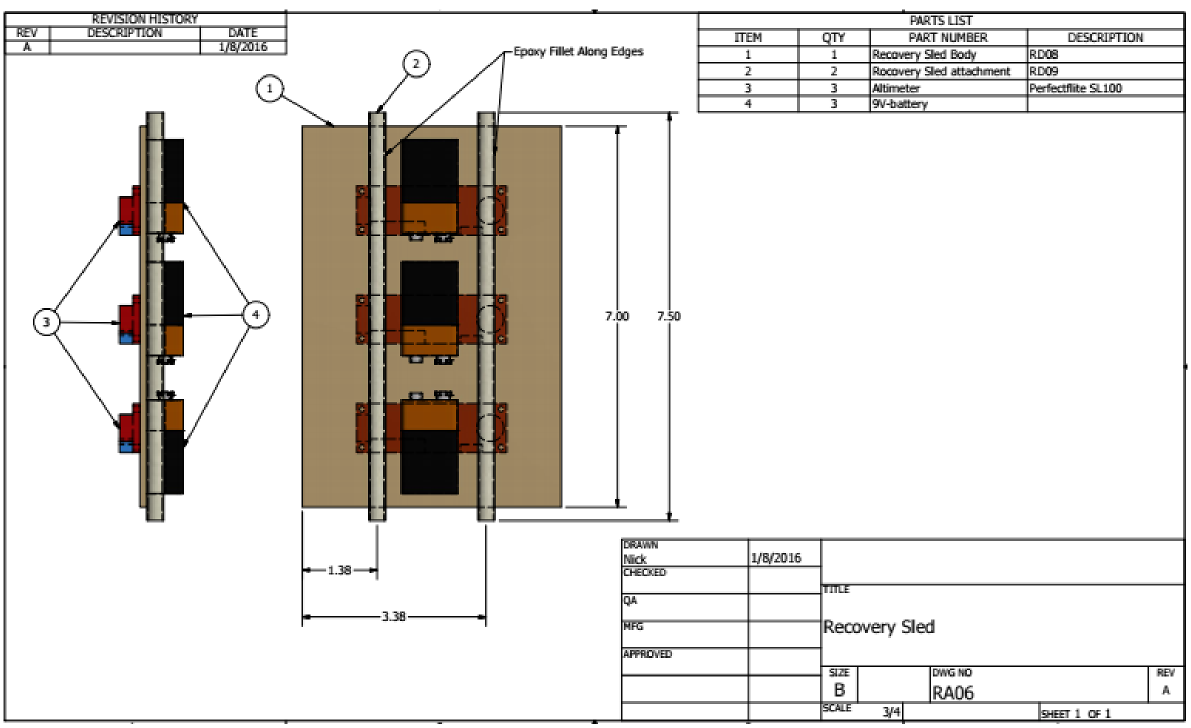


Figure 4: Recovery Sled Drawing

4.2.4 Fairing Design

The fairing will consist of two clamshell pieces, designed to blow apart with a similar powder charge 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. Each piece of the fairing will have a plate that will overlap with the other piece and secured using a shear pin. When joined together, a blast compartment will be created that will house the ejection charge and protect the payload. Four additional shear screws will bolt the base of the fairing to the rocket body. The fairing 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.

4.3 Overview of Scale Rocket

Figure 5 - Figure 10: Sub-Scale Launch Pictures

On November 21, the first subscale launch was conducted. The full scale rocket was reduced by a value of 0.57 to create the subscale. The subscale consisted of standard 3.0" body tube with a LOC precision nose cone. Both the body tube and nosecone were scaled to 0.57. The motor was a Cesaroni J335, based on the scale of the average thrust of the K570 planned to be used for the full scale. The CG and CP locations, along with the stability margin (2.0) were identical to those in the full scale rocket based on a RockSim model. Copper shot was used in the subscale to simulate the weight of the PIL. The only significant variable not scaled directly was the mass. The subscale rocket weighed 7.2 lbs, compared to a scale weight of around 9 lbs. This weight reduction was completed for reasons of launch safety.

During launch, the rocket was expected to reach a height of around 4400 feet. The prelaunch drift analysis also suggested a maximum drift of around 5000 feet (due to high winds on launch day and the lack of room for a multistage parachute on the scale rocket). On launch, the rocket remained stable. At apogee, the rocket released its parachute successfully and was visually tracked to the ground. However, upon travel to the expected landing site, the area was found to be heavily wooded. After 5 hours of searching, the rocket was not found. At a launch 2 weeks later, additional searches were carried out in slightly different areas using new drift analyses, but again, the rocket was not recovered. However, from visual observation and video footage of the launch, some information was able to be recovered. The rocket was found to be stable, structurally sound, and able to release a parachute. For the members of our team without any high powered rocketry experience, the launch also gave them valuable hands-on knowledge of a launch event.

Moving forward, a new subscale rocket will be built with the same parameters, aside from small adjustments made for the new full scale motor (K750) and new full scale size. Wind tunnel tests will be conducted after which the subscale rocket will be flown on the next launch day, January 30. This launch should provide the altitude information necessary to help build the full scale rocket.

3.1 Testing Plan

4.3.1 Pop Testing

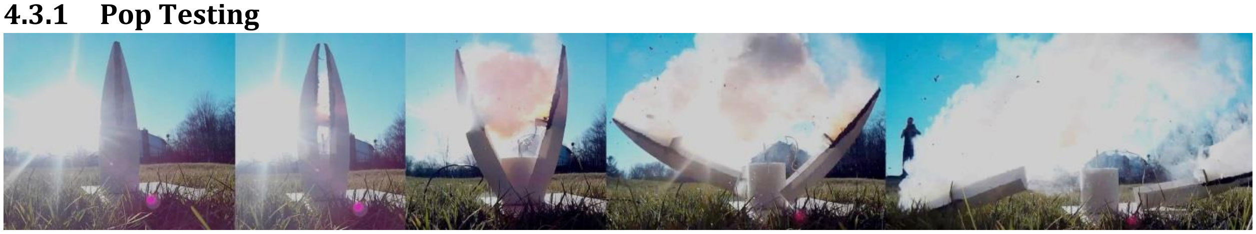


Figure 11: Pop Test Time-lapse

The Astro Cats have conducted a successful pop test on subscale model of the fairing using 0.75 grams of black powder. The subscale fairing was made using an old plastic nosecone. The fairing was sealed using RTV gasket sealer. The test was to see how the sealant would perform under a pop test and get an estimate on how much black powder would be needed to separate the fairing. In addition to this test, the team will conduct multiple ground ejection pop-tests to gauge the amount of black powder to use in our charges. During these test, 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.

4.3.2 Vehicle Testing

In accordance with the requirements for the NASA a subscale model of our rocket was launched to test the reliability of our design. The design was proven to be stable through the test of the subscale model, allowing for full scale testing of the launch vehicle to start. The full scale tests will verify that the full scale launch vehicle is stable and that our fairing will separate as expected.

4.3.3 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.

4.3.4 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.

4.3.5 Tracking Bay Radio Testing

The tracking bay radio communication has been tested by sending data from the ground station equipment to the tracking bay radio. The next step in testing is to test the radios 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

4.4 Recovery and Electronics

4.4.1 Recovery Electronic Summary

The recovery bay will consist of three StratoLogger altimeters for reference see section 4.5.2 Recovery Electronic Diagram. StratoLogger-1 (Strat-1) will deploy the 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 fairing and back-up drogue parachute charge. Each StratoLogger will have its own isolated 9-volt power supply in case of failure and have designated lock-on arming switches.

3.1.1.1 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.

4.4.2 Recovery Electronic Diagram

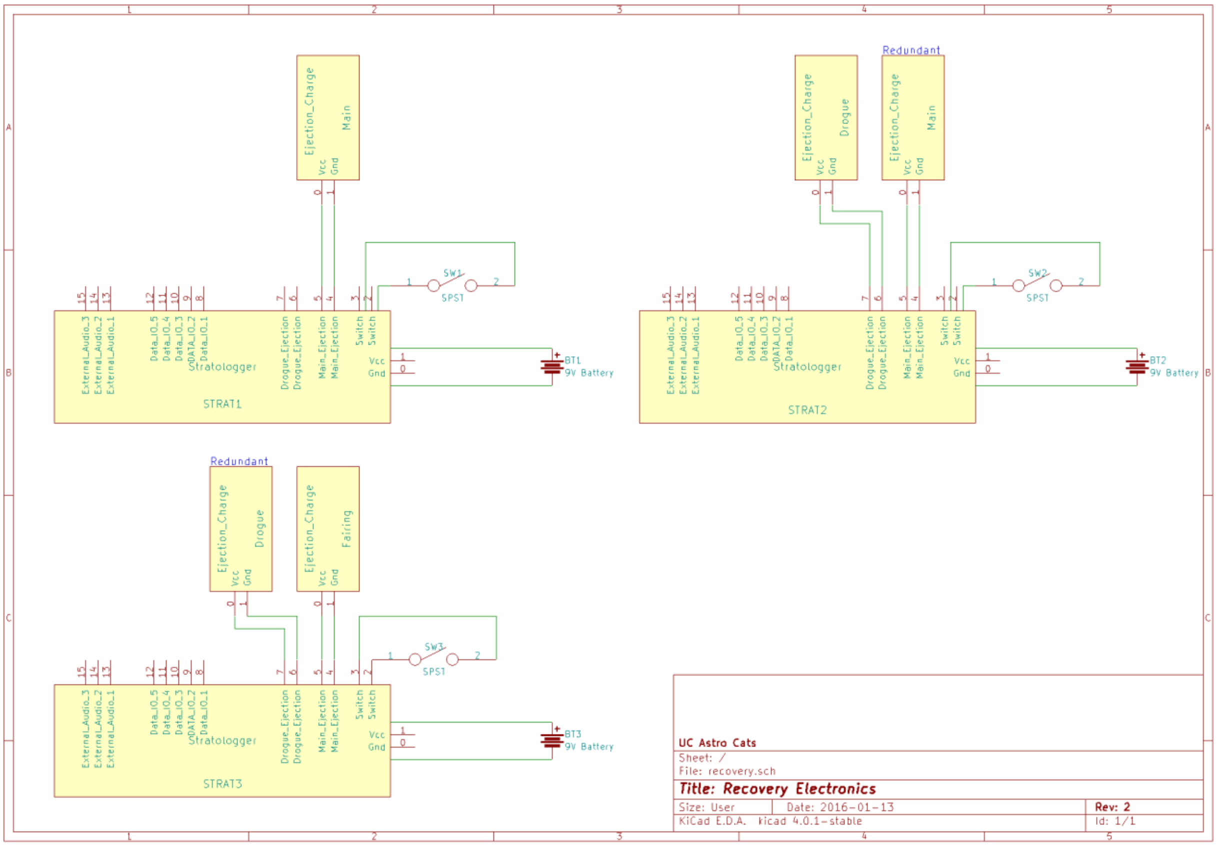


Figure 12: Recovery Electronics Schematic

4.4.3 Ejection Charges

The fairing ejection charge shall be 2 grams of black powder as result of pop-testing. This will be verified through testing the full scale model. The rocket shall use a 1.5-gram ejection charge to separate the upper and lower sections. The rocket recovery system will utilize a 1.5-gram charge and a 2-gram back up charge for 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 more pop-tests are conducted on our final rocket.

4.4.4 Parachute Sizing

Using the mass table, 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:

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

Table 1: Parachute Descent Rates

Deployment	*Parachute*	*Decent Rate (ft/sec)*
Case 1: Drogue	SkyAngle Classic 28"	63.2
Case 2: Drogue	SkyAngle Classic 20"	103
Main	SkyAngle Classic 52"	22.9
PIL	SkyAngle Classic 36"	24.9

Kinetic Energy:

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

Table 2: Kinetic Energy of Sections

Case at specific wind speed	*Section*	*Decent Rate Drogue (ft/sec)*	*Decent Rate Main (ft/sec)*	*K.E. Drogue (lbf)*	*K.E. at Landing (lbf)*
Case 1 (0-12 mph)	Upper Section 1	63.2	22.9	564	21
	Lower Section 1	63.2	22.9	595	71
Case 2 (13-20 mph)	Upper Section 2	103	22.9	1193	21
	Lower Section 2	103	22.9	1259	71
	PIL	N.A.	24.9	N.A.	34
	Faring (2)	N.A.	24.9	N.A.	12

To meet desired descent rates and kinetic energy limits for each section, verified via MATLAB, the parachutes listed in the table above shall be used. The highest kinetic energy experienced by any individual section of the rocket is 71 lbf. which is less than the requirement limit of 75.

4.4.5 Attachment & Deployment Process

Upon reaching apogee, the rocket's upper and lower section will separate releasing the drogue parachute. Due to variability in wild speed a two case scenario will be applied in order to use a parachute with an appropriate decent rate. All parachutes will use ¼" Quicklinks (660lb Test) to attach to U-bolts connected securely to the bulkhead. The Quicklinks allow for easy change out and parachute maintenance. Two cases are examined:

Case 1: 0-12 MPH winds using a Skyangle Classic 28" parachute, Main shall deploy at 1500 feet AGL

Case 2: 13-20 MPH winds using a Skyangle Classic 20" parachute, Main shall deploy at 1000 feet AGL

Each parachute will utilize ½" Tubular Kevlar shock cords, 24 feet in length, each three times the length of the rocket. The Pill will also use ½" Kevlar three times its length. The shock cords will be attached in the same method as tubular nylon outlined in this figure:

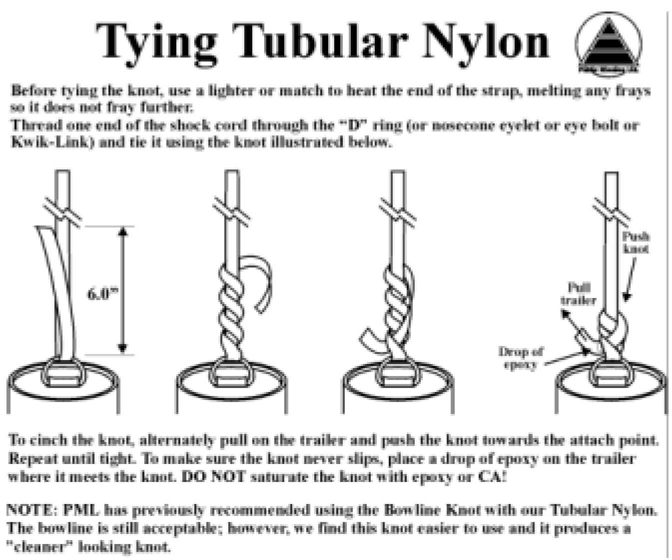


Figure 13: Tying Tubular Nylon

Whether case 1 or 2, the fairing charge will detonate releasing the PIL and the 52" main parachute. The fairing will remain attached to the PIL parachute as the rocket upper and lower body will descend via the main.

4.4.6 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

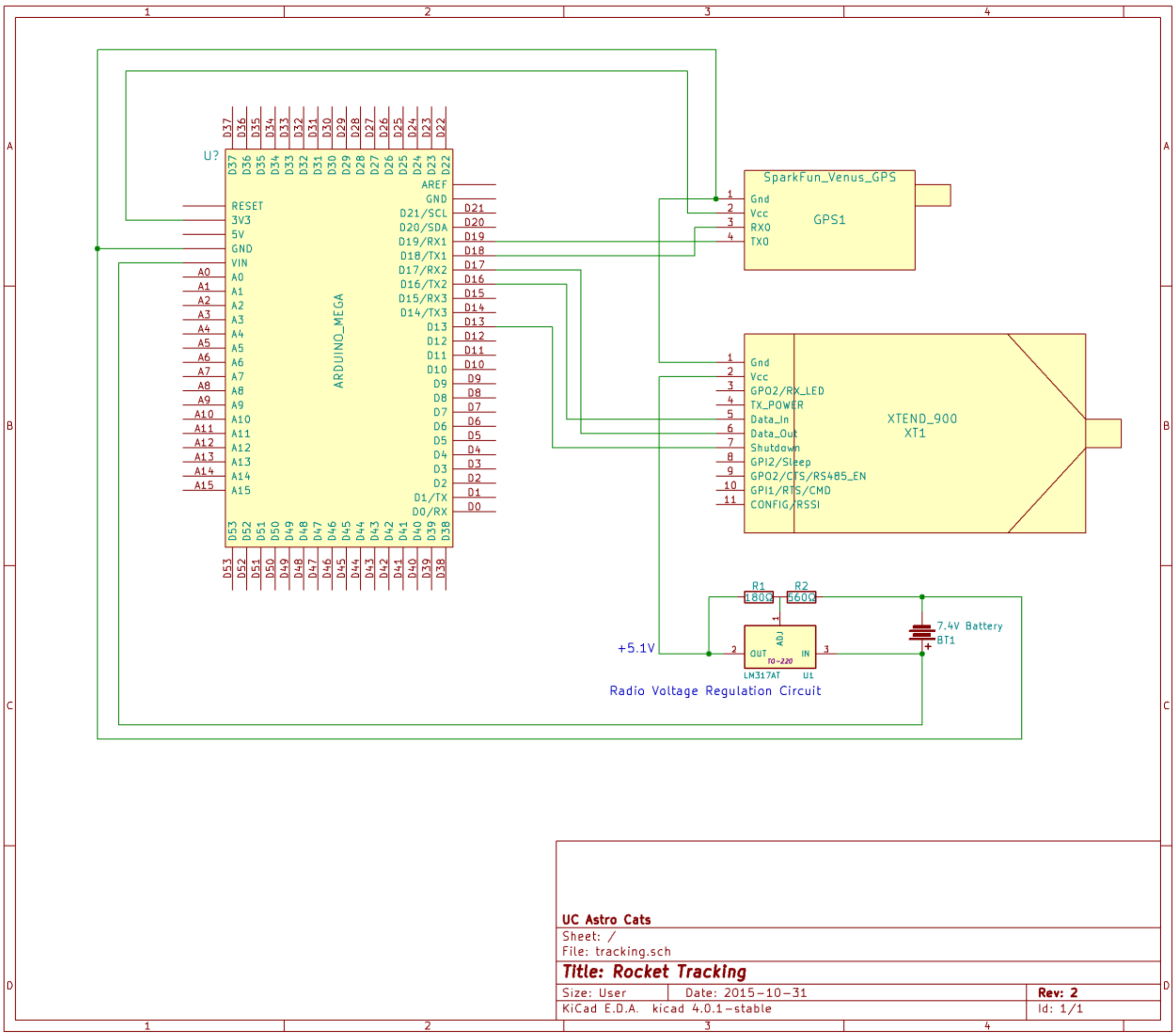


Figure 14: Rocket Tracking Schematic

4.5 Recovery Requirements & Verification

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	The system is designed with two altimeters for the recovery system.	This will be verified through analysis.

chosen as the competition altimeter		
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.

4.6 Vehicle Requirements & Verification

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 will provide adequate thrust.	Will be verified through flight testing.
The rocket must carry one NASA approved altimeter for recording altitude used in competition scoring.	The Rocket will contain a NASA approved altimeter to report altitude.	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 or modifications.	The materials chosen will be capable of withstanding a reasonable amount of impact.	Will be verified through drop tests and flight testing.
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 integration testing.
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 and flight testing.
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 inspection.
Total Impulse may not exceed 5,120 Newton-seconds.	The motor chosen will not exceed the total impulse.	Will be verified through inspection.
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 conducted.	Will be verified through testing.

4.7 Workmanship Statement

Careful attention to detail will always be practiced throughout the project. Members of the team that have high powered rocketry experience will instruct the rest of the team on basic rocket manufacturing techniques. The right tools are to be used at all times for any given job. If the right tool is not available, then the task cannot be completed. Additionally, if the team member performing the job has not had the proper training, then that team member cannot proceed until the proper instructions have been given. This will not only help with quality control but also ensure the safety of all team members involved. All construction will be analyzed and tested to ensure the launch vehicle and payload are structurally stable. Any measurements take will be done multiple times to ensure high precision. Checklists and procedures will be generated before each job to ensure all manufacturing steps are being followed. By maintaining a high level of quality control, our team will focus on creating the best possible launch vehicle and payload we can.

The fiberglass mold that we intend to use to make the fairing has been completed. From this mold, our team will be able to begin manufacturing the actual fairing parts. The launch vehicle parts list has been finalized and will be ordered soon. Since our subscale rocket was not recovered, we will be building another model. This model will be used for in our wind tunnel test and subscale flight test. Additionally, a subscale fairing model was created using an old plastic nosecone so that we could do preliminary pop tests before we do our full scale fairing tests.

4.8 Integrity of Design

Through meticulous research and analysis, the Astro Cats team has selected a launch vehicle design that will be capable of meeting all mission success criteria. Our team is very confident with the design and intend to meet every requirement.

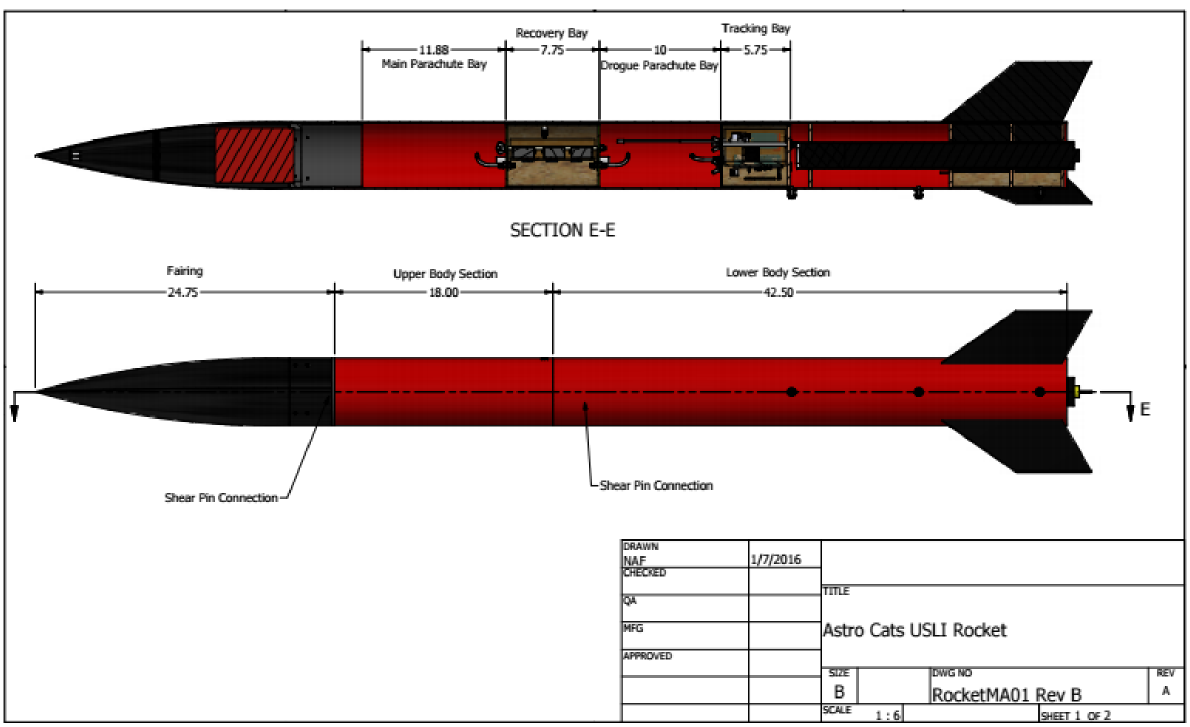


Figure 15: Rocket Assembly Drawing

The materials that we will be using are commonly used within the high-powered rocketry community. The airframe will be made from 5.38" airframe tubing from LOC Precision. This tubing is made of heavy duty cardboard with a Glassine overwrap. This material was chosen because of its strength, relatively low cost and ease of use in manufacturing. The University of Cincinnati Rocket Club mainly uses this material in the construction of their rockets and has proven to be very reliable during flight. Also, epoxy we will use will bond much better to the cardboard than any other material due to the rougher surface. The fairing will be constructed out of fiberglass. This material was chosen because it can easily form to almost any shape and is very ridged when fully cured. Additionally, the thickness of our fairing can be increased or decreased depending on the layers of fabric we use. G-10 fiberglass sheet will be used in the construction of the fins and the bulkheads. This material is incredibly rigid and has high strength properties. Because of these characteristics, we have chosen to use this material for the components that will experience some of the highest loads.

The fin design was chosen based off of a past rocket fin design that had performed well. The sweep was slightly increased to move back the center of pressure and improve the stability margin. Originally, we were going to use shaped airfoils wrapped with fiberglass and a G-10 core but we decided that manufacturing these fins would be too inconsistent and could lead to instability. The same basic shape will be used but the fins will be made from straight 3/16" G-10 fiberglass.

Aeroelastic flutter is a dynamic instability that occurs when the fins of the rocket interact with the surrounding air at high velocities. When the fins are angled or pitched in the oncoming airstream, the lifting force on the fin increases. Due to this, a torsion force is generated at the aerodynamic center of the fin which causes the fin to bend and warp. A positive feedback loop is formed because of the coupling of the lifting and torsional forces. Without a damping system, this instability can lead to failure of the fins.

Fin flutter can occur with any material. The lowest speed attained when the fin sustains a neutrally stable oscillation is known as the flutter speed. The velocity at which this flutter will occur depends on the size, shape and material properties of the fin. According to multiple data sheets, G-10 has a crosswise flexural modulus of about 2,400 ksi. The equation below was used to calculate the velocity that fin flutter will occur with the current fin design. This equation is based off of the NACA TN 4197 technical document and is a simplified equation for use with the most common type of flutter that is torsion-bending flutter and was used in the AeroFinSim software. G is the flexural modulus, AR is the aspect ratio, t is thickness of the fin, c_r is the root chord length, lambda is the taper ratio and P/P_o is the pressure ratio.

$$U_F = a\sqrt{\frac{G}{\frac{39.3\,AR^3}{\left(\frac{t}{c_r}\right)^3 (AR+2)}\left(\frac{\lambda+1}{2}\right)\left(\frac{P}{P_0}\right)}}$$

Table 3: Fin Flutter Calculation

Root Chord, c_R in	Tip Chord, c_T, in	Thickness, t, in	Exposed Semispan, b, in	Panel Aspect Ratio, AR	Taper Ratio, λ	Panel Area, S, in^2	Shear Modulus, G, lb/in^2
10	6.25	0.1875	5	0.6154	0.625	40.625	2400000

From this calculation, we obtained a value fin flutter velocity of around Mach 3.86 assuming a pressure ratio of 1. Our simulated maximum velocity is estimated at close to Mach 0.6. This gives us a factor of safety of about 5.4. Because of the high shear modulus and the relatively small surface area of each fin, our fins will be capable of remaining rigid at very high velocities.

The fin assembly will be constructed outside of the body tube to ensure a solid connection of the fins to the motor mount tube and centering rings. The central centering ring will have notches that will be laser cut equidistant around the ring. This ring will assure the proper alignment of the fins. All attachment points will be very well secured with epoxy and inspected to ensure they are sturdy enough to withstand the rigors of flight. The motor will be held in place by using a standard motor retainer.

4.9 Rocket Mass List

Table 4: Rocket Mass List

Component Mass List			
Lower Section	**qty.**	**weight (g)**	**total (g)**
5.5" Lower Body tube (per inch)	42.5	18.29	777.325
2.25" Motor mount tube (per inch)	22.6	5.68	128.368
centering ring	4	46	184
Stiffy Tube (per inch)	5	21.6	108
Stiffy Tube (per inch)	4	21.6	86.4
Fins	3	303.97	911.91
Rail Buttons	3	14	42
Main Chute	1	238.136	238.136
Main Chute PIL	1	218.291	218.291
Shock Cord (Main)	1	183.27	183.27
Shock Cord PIL	1	163	163
Motor k750	1	2057	2057
Motor Casing	1	211.20	211.2024
Motor Retainer	1	45	45
Total Lower Section Mass			**5353.9024**

Upper Section	qty.	weight (g)	total (g)
5.5" Body Tube (per inch)	18	18.29	329.22
Body tube Coupler	7.75	8.25	63.9375
Nose Cone	1	680.4	680.4
Plastic Piece	1	317.5	317.5
Shock Cord Drogue	1	163	163
Drouge Chute	1	170.097	170.097
Drogue Chute Hardware	3	28.35	85.05
Stiffy Tube (per inch)	7.75	21.6	167.4
Total Upper Section Mass			**1976.6045**
Electronics bay	**qty.**	**weight (g)**	**total (g)**
Stratologger	4	15	60
rod	15.5	4.543	70.4165
U-clamp	2	68.03	136.06
Altimeter Sled	1	45.6	45.6
9volt Battery	4	46	184
Total Electronics Bay Mass			**496.0765**
Tracking Bay	**qty.**	**weight (g)**	**total (g)**
Radio - XTEND 900	1	18	18
Radio Antenna	1	100	100
rod	11	4.55	50.05
U-clamp	1	68.03	68.03
Stiffy tube	5.5	21.6	118.8
GPS - SparkFun Venus GPS	1	10	10
GPS Antenna	1	18	18
Battery	1	280	280
Body tube Coupler	5.5	8.25	45.375
Total Tracking Bay Mass			**708.255**
Total Rocket Weight			**8534.8384**

4.10 MASS SUMMARY

The current estimated mass of the rocket is around 8534.8 grams which is about 18.8 lbs. A breakdown of the masses per section is shown in figure x. All of the components we intend to use were available in the school's rocket lab and were weighed individually. The team is able to report this estimate with a confidence of around 95% accuracy. With the current motor selection, the launch vehicle will have a thrust-to-weight ratio of around 7:1. Up to ten pounds can be added before the thrust-to-weight ratio drops below 5:1 and is unsafe to fly. Approximately 1 pound can be added before target altitude is not met.

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 drogue parachute will be deployed and descend to 1500 feet. A fairing design shall deploy a payload at 1500 feet. 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 1500 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 K750 motor. With a total impulse of 2352.5 N-Sec and a 3.189 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.

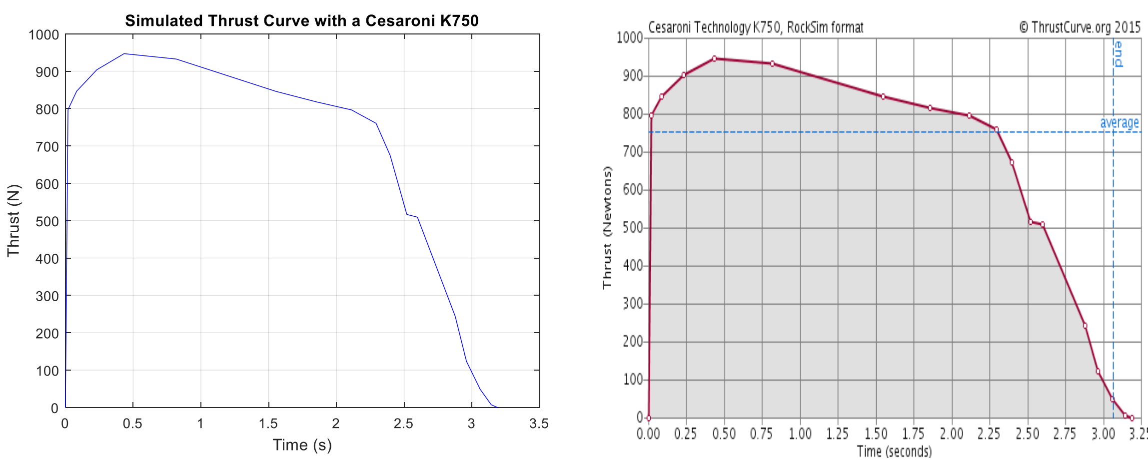


Figure 16: Graph of Actual Thrust Curve and Matlab Code Thrust Curve

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 K750 is able to send our proposed rocket in no-wind to a max altitude of 5,282.19 feet AGL, with 1.33 pound ballast, which is shown in simulation 0. Simulation 1 is the same rocket with light winds (4 MPH) and in Simulation 2 the rocket is subject to medium winds (12 MPH). Simulation 3 is the result of using 0.5 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.

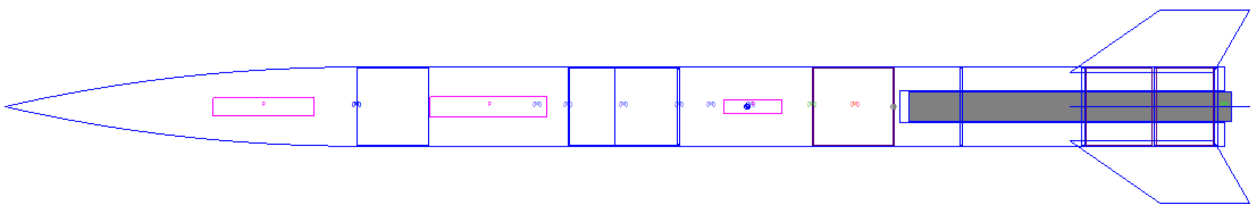


Figure 17: Rocket Diagrams & RockSim 9 Simulation Results

Table 5: Results of Rocksim Simulations

Simulation	Max Altitude Feet	Max Velocity Feet/Sec	Ballast Weight Pounds	Wind Speed MPH
0	5,282.19	621.10	1.33	0
1	5,279.40	621.59	1.31	4
2	5,279.43	628.26	1.05	12
3	5282.19	643.46	0.5	20

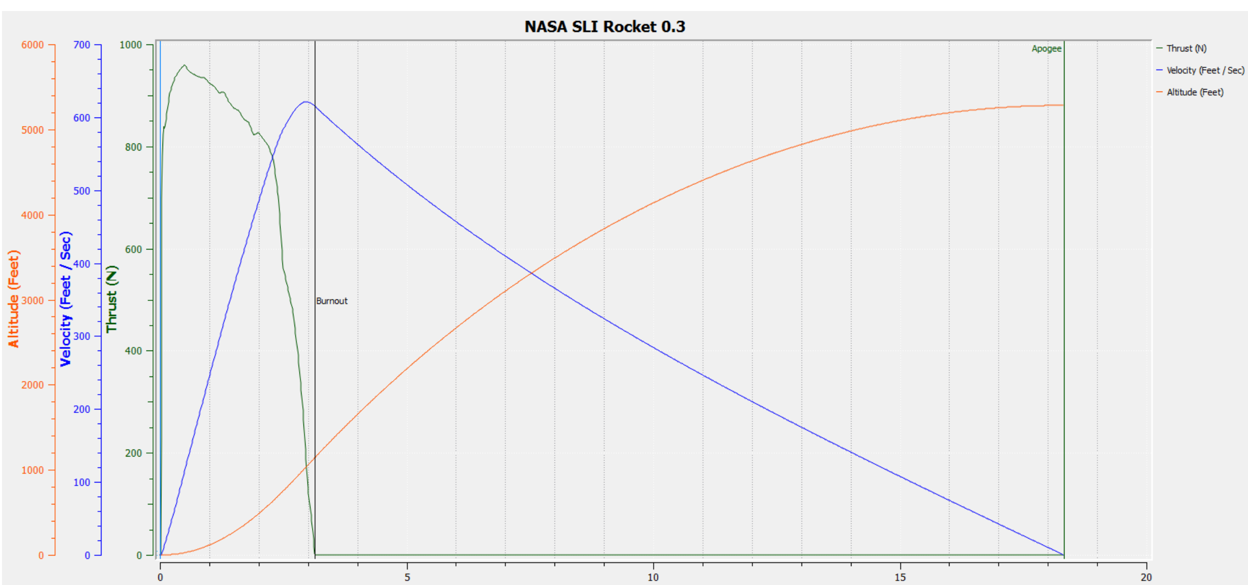


Figure 18: RockSim 9 rocket flight profile with Cesaroni K570

The graph above is the flight profile simulation of the rocket without the ballast, using Rocksim 9. The max altitude with no wind is 5,282.19 feet.

4.11.3 Drift Calculations

One issue that we had to address was that our worst case scenario drift analysis was over the field size requirements. To cut down on our drift we changed our flight procedures. The two cases shown below are for when the wind speed reaches up to 12 MPH, and the second case is the worst case scenario at 20 MPH. For the first case, we will have a drogue parachute deployed at apogee and will descend at 63.2 feet per second. At 1500 feet the main parachute and the fairing will deploy. Both the Payload (PIL) and the rocket will descend 24.9 feet per second and 22.9feet per second, respectively. For cases above 12 MPH, the drogue parachute that deploys at apogee will have a descent rate of 103 feet per second, and the main parachute and fairing will be deployed at 1000 feet. Both will then still fall at the descent rates listed above. This allows us to only have to change out the drogue parachute on launch day, as well as reprogram the altimeter. 12 MPH was chosen based on average wind speed data from the National Weather Service Forecast Office for April for Huntsville Alabama plus 4 MPH to be safe. Graphs for the total drift can be seen below. Total drift with the 12 MPH case comes out to be 2,205.28 feet, and 2,498.52 feet for the 20 MPH scenario.

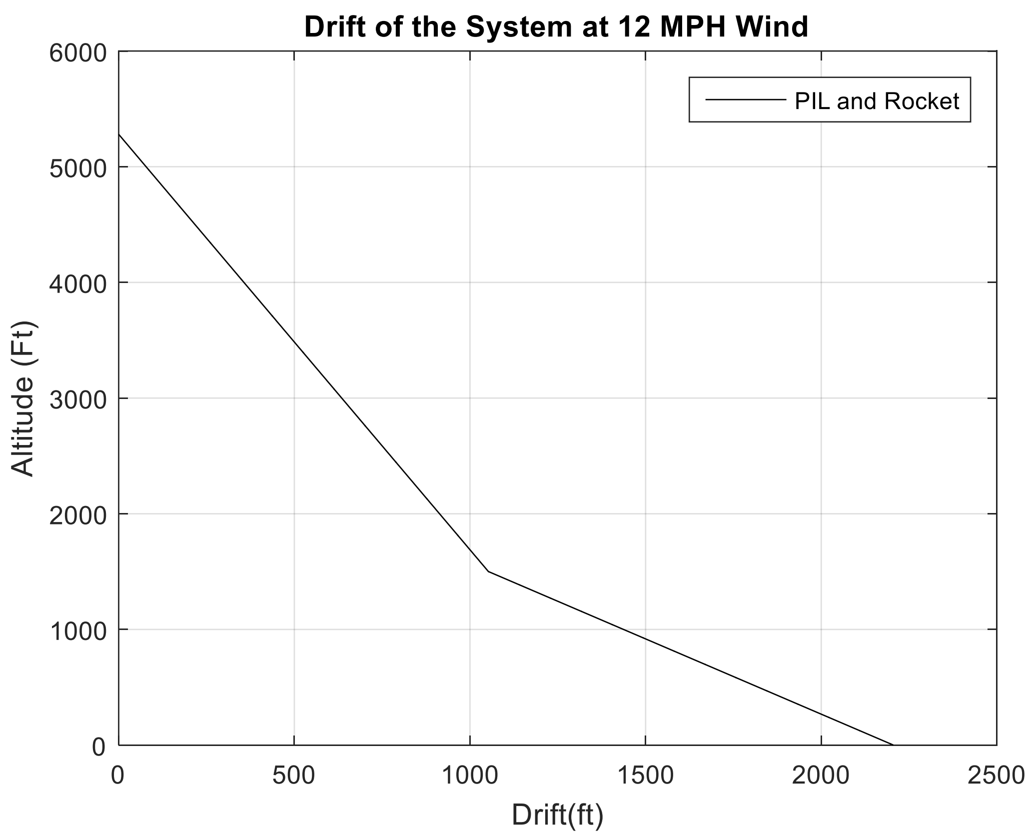


Figure 19: Drift at 12 MPH Wind

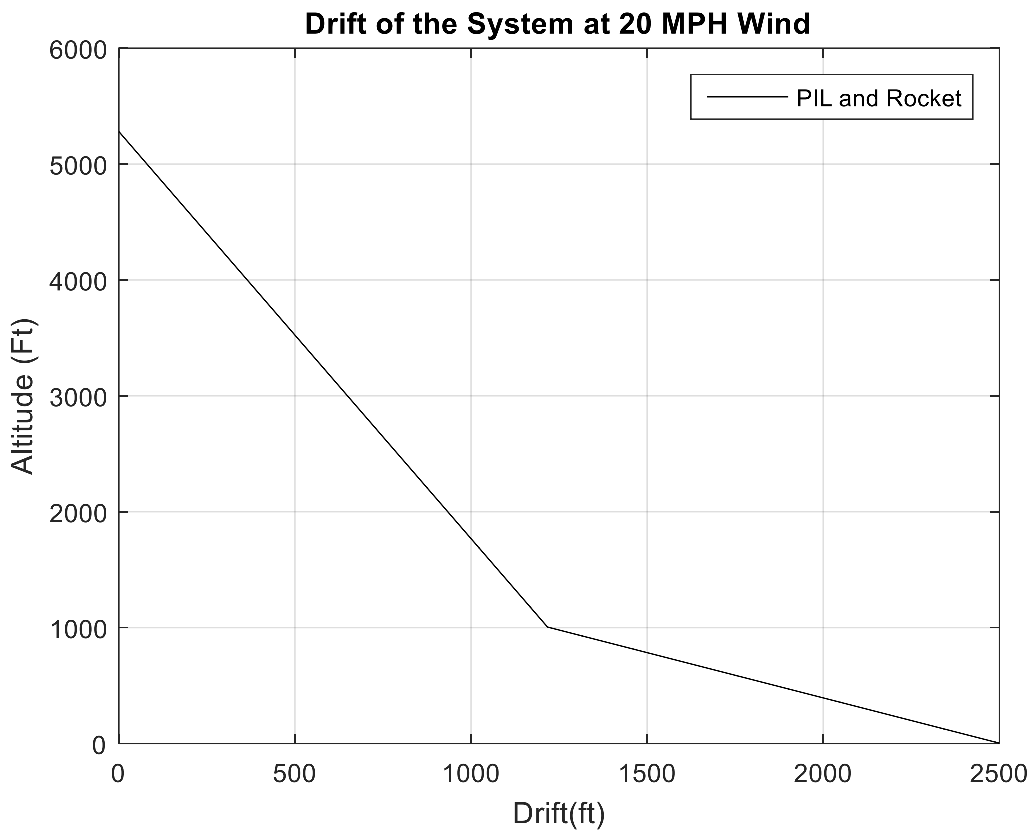


Figure 20: Drift at 20 MPH Wind

Table 6: Huntsville, AL Weather Data

Data from the past 5 years for average wind speeds for April, in Huntsville Alabama can be seen below.

Day	April 2015	April 2014	April 2013	April 2012	April 2011
1	3	6.1	4.6	5.2	4.9
2	10.4	6.6	9	3.5	4.9
3	14.9	11.2	7.4	3.4	12
4	10.6	11.3	9	4.1	16.3
5	7.7	8.1	5.5	5	8.3
6	7.8	6.4	5.2	9.9	8.2
7	6.9	13.1	7	2.1	7.4
8	6	6.2	8.9	4.1	8
9	9.9	5	8.3	3.7	8
10	7.8	7.6	8.6	5.8	7.6
11	6.9	8.1	12.1	9	14
12	7.9	6.8	5.7	3	10.3
13	9.3	11.1	3.2	4	2
14	6.9	8.2	10.1	10.1	5.7
15	5.2	13.6	7.5	11.7	11.2
16	12.5	7.7	8.4	7.5	12.4
17	5.6	9.2	7.9	9.4	3.9
18	4.8	5.9	15.6	7.3	8.3
19	8.7	7.2	9	3.9	13.7
20	7.7	2.3	5.1	5.8	8.8
21	3.6	5	5.9	10.8	3.8
22	5.6	4.5	8.1	11.2	8.8
23	6.5	6.3	8.4	11.2	9.3
24	4.4	7.9	10.1	6.5	8.8
25	9.4	7.5	6.5	8.9	10.8
26	8	5.5	7.4	9.1	12.3
27	8.2	9.2	9.9	3.6	12.7
28	7.5	13.1	7.1	6.1	6.8
29	4.9	5.9	2.3	3.6	4.1
30	6.2	6.6	5.7	5.5	7.6
Average	7.49	7.77	7.65	6.50	8.70

4.11.4 CP, CG, and Static Margin

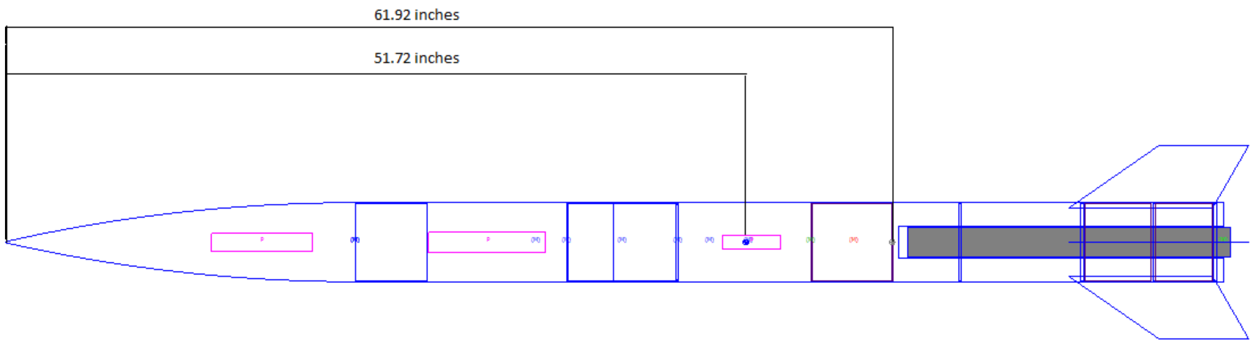


Figure 21: Rocket Static Stability Diagram

Our Center of Gravity was found to be 51.72 inches from the tip of the nose. The center of pressure is located 61.92 inches from the tip. Our margin is 10.20 inches and given our diameter of 5.5 inches we get a static margin of 1.85. Changes to CG and static margin before and after burnout can be seen in the table below.

Table 7: Stability Values for the Rocket

	On Launch Pad	After Burnout
CP (from tip)	61.92 in.	---
CG (from tip)	51.72 in.	48.6 in.
Static Margin	1.85	2.40

4.11.5 Motor Selection, Drag Assessment and Next Steps

Based on our current weight, the Cesaroni K750-RL was selected which has more thrust, approximately 200 N, then our previously test motor the K570. The Cesaroni K750-RL has a total impulse of 2361.966 N-Sec and a 3.14 sec. burn time. Preliminary test show a total altitude of 5,282.19 feet, with no wind, but 1.33 lb. ballast, and a thrust-to-weight ratio of 7:1 and a max velocity of 621 feet/second.

The University of Cincinnati wind tunnel is currently not functioning at the level we need it to for our test. And because we lost our sub-scale model during the test launch we could not get accurate drag data from that either. We plan to continue working on the wind tunnel, and analyzing test launches to get accurate drag data. Once this is complete that data can be entered into our Matlab model to get more accurate altitude predictions.

The next step for drift predictions is also underway. Using data from the National Weather Service, we are creating a model that not only predicts the wind speed, but also the wind direction. This will allow us to create a probability density function of landing zones.

4.12 Launch Concerns and Operation Procedures

Final Assembly Procedure

Recovery Preparations

1. First check the wind speed to determine which drogue parachute to choose. If the wind is between 0 mph – 12 mph then we will select the 8.6 ft^2 parachute. If the wind is 13 mph – 20 mph we will select a 4.4 ft^2 parachute.
2. Once the parachute has been selected, inspect the shock cords and parachutes for any physical damage.
3. Then connect the parachutes to U bolts that are attached to the bulk heads inside the rocket.
4. Before inserting the parachute into the rocket, fold the parachute and wrap the cords around the parachute to ensure that the cords cannot get tangled when it is ejected from the rocket.
5. Finally insert the folded parachute into the rocket and assemble all rockets sections together.

Motor Preparations

1. Before preparing the motor, first check to make sure that there are no open flames within 25 feet of where your motor is located.
2. Remove from portable magazine.
3. Visually inspect the motor for any physical damage from transportation.
4. Then apply a generous amount of lubricant to the outside of the motor, making sure to evenly coat it. Ensure that no lube enters the inside of the motor.
5. After it has been lubricated, insert the motor into the metal casing for it.
6. Place the motor back into the portable magazine until you are ready to go to the launch pad.
7. Once ready, remove the motor from the portable magazine and insert the motor into the rocket. Ensure that you tighten the locking ring so that the motor cannot move once inside the rocket.

Setup on Launcher

1. Take the fully assembled rocket to the launch pad, and then unlock the rail to bring it down to a level that you can put the rocket it on it.
2. Then slide the rail buttons into the slot on the rail and check to make surely that the rocket moves freely without getting stuck.
3. Before putting the rail in the upright position you will need to test each altimeter too separately to ensure that they beep 3 times. This means you need to turn 1 altimeter on, wait it goes through its sequence, once it beeps 3 times shut it off and then test the next altimeter. If they beep 3 times it means that the drogue chute and main chute chargers are properly connected to the altimeter.
4. Once all altimeters work properly, turn them all on and wait till they finish their startup sequence.
5. Then place the rail in the upright position, and lock it into place to ensure that it won't fall down during launch.

Ignitor Installation

1. First make sure that the electrical ignition system is turned off before handling the ignitor.
2. Check to your ignitor for any physical damage before inserting it into the rocket.
3. Then place the ignitor into the motor and secure it in place. Make sure that the ignitor is all the way at the top of the motor.
4. After that attach the ignitor to the electronic ignition system, and ensure that the wires are not touching to prevent a short in the system from occurring.
5. Finally step away from the rocket and get to the minimum safe distance away, before signaling to the RSO that it is ready to launch.

Launch Procedure

Launching the Rocket

1. The RSO will signal to the crowd that it is time to launch and will proceed with a 5 second countdown.
2. Then the RSO will attempt to ignite the motor. If the launch is successful proceed to the "Post-flight Inspection" section. If the launch is not successful proceed to the "Troubleshooting" section.

Troubleshooting

1. If the rocket fails to launch, turn off the electronic ignition system and wait 1 minute before approaching the rocket.
2. First inspect the ignitor to see if any wires could potentially be shorting.
3. If the wires don't seem to be shorting, remove the connection to the ignition system and check the ignition wires for continuity.
4. If everything seems to be working properly but the rocket will not launch, remove the ignitor and replace it with an alternative. Repeat the "Ignitor Installation" steps and move forward with launch the rocket.
5. If all else fails, remove the rocket from the rail (after waiting the 1 minute, and disconnecting the ignition system) and inspect the rocket for a potentially faulty motor.

Post-flight Inspection

1. After the rocket and payload have landed and the area is clear of any other rockets in the air, proceed with retrieving the rocket and payload.
2. Once at the rocket landing site, disarm all altimeters before proceeding to bring the rocket back to a safe location.
3. Once at the safe location, unplug all batteries in the altimeter and in the payload.
4. Then inspect the rocket for any undetonated powder charges. If there are unburnt powder charges, carefully remove them from the rocket before proceeding.
5. If all powder charges have been burnt, then it is safe for you to inspect the rocket body and payload body for any physical damage caused by the flight.
6. Then remove the SD card from the payload and download all the sensitive data onto a computer for further analysis.

4.13 Equipment Checklist to take to Launch

Equipment packing list

1. Lube
2. Safety glasses
3. Work Gloves
4. Masks
5. Sun Screen
6. Equipment
7. Chairs
8. Tables
9. Tent
10. Extension Cord
11. Chargers
12. Drills
13. Hammer
14. Allen wrench
15. Dremel
16. Soldering iron
17. Batteries
18. Drill bits
19. Wrenches
20. Screwdrivers
21. Sand paper
22. Pliers
23. Epoxy
24. Glue
25. Tape
26. Duct tape
27. Masking tape
28. Scotch tape
29. Electrical tape
30. Spare wires
31. Water
32. Towels
33. Cooler
34. Lower Body tube
35. Upper Body tube
36. Fairing
37. Shear pins
38. Fins
39. 4 Parachutes
40. Connection Hardware
41. Shock Cords
42. Tracking Bay
43. GPS
44. Antenna
45. Arduino
46. Radio
47. Radio antenna
48. Black powder
49. Igniters
50. U- bolts and nuts/washers
51. G10 Bulkheads
52. Stiffy tube
53. G10 Bulkheads
54. Stratologger
55. Batteries
56. Switches
57. Altimeters
58. Altimeter sled
59. Batteries
60. Miscellaneous hardware
61. PIL
62. Ground Station
63. Laptop
64. Weather station
65. Table structure
66. Radios

4.14 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. It also is to serve as our procedures

Safety Preparation

- ☐ Had a meaningful PJB and filled out PJB form
- ☐ Ensure that everyone is wearing the proper PPE
- ☐ Have all necessary supplies required for an emergency nearby

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
- ☐ Lubricate the outside of the rocket motor
- ☐ 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 or wadding above or below 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
- ☐ Secure batteries to housing using tape
- ☐ Wait till final assembly steps before connecting altimeters to powder charges

Electronics for Payload

- ☐ Ensure that batteries have been fully charged a day before launch
- ☐ Visually inspect the Payload structure and electronics for any damage.
- ☐ 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

- ☐ Ensure that the altimeters are turned off and are not beeping before proceeding
- ☐ Insert powder charges, wadding, and electronic igniters into their housing.
- ☐ Secure charges with tape, and attach the charges to the altimeters
- ☐ 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

<u>Launch Checklist</u>

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

Post Flight Inspection Procedure

- ☐ Before inspecting the rocket ensure that there are no open flames within 25 ft. of you
- ☐ Once PIL and rocket are in a safe location, disarm all devices and unplug all batteries connected to the altimeters and payload
- ☐ Verify that all powder charges have been detonated, if any of them have not been detonated, remove the ignitor and carefully remove the black powder
- ☐ Inspect the rocket body and rocket fins for physical damage
- ☐ Inspect the payload and fairing for any physical damage
- ☐ Remove the SD card in the payload and take it to the ground station to review the data.

4.15 Hazard Analysis

The University of Cincinnati Astro Cat's safety officer is Aaron Deutsch. His primary objective to ensure the safety of the team and everyone nearby during the design, construction, testing, and launch of a rocket during the competition. Some other responsibilities are to ensure the team has a proper safety/hazard analysis, ensure that all team members are properly trained, and to ensure that the total project is accomplished safely.

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 9 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 8 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 9 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 10 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 11 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. Pre-Job Brief form must be filled out 2.Power Tool Training form must be completed. 3.University of Cincinnati online Machine room training must be completed and filled out. 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. Pre-Job Brief form must be filled out 2.Power Tool Training form must be completed. 3.University of Cincinnati online Machine room training must be completed and filled out. the saw has been turned off while saw 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. Pre-Job Brief form must be filled out 2.Power Tool Training form must be completed. 3.University of Cincinnati online Machine room training must be completed and filled out. the saw has been turned off while saw 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. Pre-Job Brief form must be filled out 2.Hand Tool Training form must be completed. the saw has been turned off while saw is not in use	**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. Accident Avoidance and S.T.A.R Training must be completed and filled out.	**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. Must have Hazard Analysis and Accident Avoidance Training form signed out	**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. Must have Hazard Analysis and Accident Avoidance Training form signed out	**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. Pre-Job Brief form must be filled out 2.Power Tool Training form must be completed. 3.University of Cincinnati online Machine room training must be completed and filled out. the saw has been turned off while saw is not in use	**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. Pre-Job Brief form must be filled out 2.Power Tool Training form must be completed. 3.University of Cincinnati online Machine room training must be completed and filled out. the saw has been turned off while saw is not in use	**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. Accident Avoidance and S.T.A.R Training must be completed and filled out.	**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. Pre-Job Brief must be completed.	**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. Accident Avoidance and S.T.A.R Training must be completed and filled out.	**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. Accident Avoidance and S.T.A.R Training must be completed and filled out.	**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. Accident Avoidance and S.T.A.R Training must be completed and filled out.	**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. Accident Avoidance and S.T.A.R Training must be completed and filled out.	**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. Must have state issued Drivers License 2. Completed the University of Cincinnati drivers training course. 3. Accident Avoidance and S.T.A.R Training must be completed and training log filled out.	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. Must have state issued Drivers License 2. Completed the University of Cincinnati drivers training course. 3. Accident Avoidance and S.T.A.R Training must be completed and training log filled out.	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. Must have state issued Drivers License 2. Completed the University of Cincinnati drivers training course. 3. Accident Avoidance and S.T.A.R Training must be completed and training log filled out.	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. Must have state issued Drivers License 2. Completed the University of Cincinnati drivers training course. 3. Accident Avoidance and S.T.A.R Training must be completed and training log filled out.	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. Must have state issued Drivers License 2. Completed the University of Cincinnati drivers training course. 3. Accident Avoidance and S.T.A.R Training must be completed and training log filled out.	**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. Must have state issued Drivers License 2. Completed the University of Cincinnati drivers training course. 3. Accident Avoidance and S.T.A.R Training must be completed and training log filled out.	**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. Must have state issued Drivers License 2. Completed the University of Cincinnati drivers training course. 3. Accident Avoidance and S.T.A.R Training must be completed and training log filled out.	**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. Hazard Recognition and Mitigation Training must be completed and filled out. 2. High Powered Rocketry Standards and Training must be completed and filled out.	**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. Hazard Recognition and Mitigation Training must be completed and filled out. 2. High Powered Rocketry Standards and Training must be completed and filled out.	**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. Hazard Recognition and Mitigation Training must be completed and filled out. 2. High Powered Rocketry Standards and Training must be completed and filled out.	**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. Hazard Recognition and Accident Avoidance Training must be completed and filled out.	**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. Hazard Recognition and Accident Avoidance Training must be completed and filled out.	**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. No verification documents are required.	**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.Pre-Launch and Launch Checklist "*Launching the Rocket*" section. 2. Prior to launch Fire Extinguisher and Fire Mitigation Training must be completed	**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. Pre-Job Brief form must be filled out	**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. Hazard Recognition and Accident Avoidance Training must be completed and filled out.	**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. Hazard Recognition and Accident Avoidance Training must be completed and filled out.	**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. No verification documents are required.	**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. Hazard Recognition and Accident Avoidance Training must be completed and filled out.	**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. Hazard Recognition and Mitigation Training must be completed and filled out.	**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. Hazard Recognition and Mitigation Training must be completed and filled out.	**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. Hazard Recognition and Mitigation Training must be completed and filled out.	**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. Hazard Recognition and Accident Avoidance Training must be completed and filled out.	**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.Pre-Job Brief document must be filled out. 2. Hazard Recognition and Mitigation Training must be completed and filled out.	**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.Pre-Job Brief document must be filled out. 2. Hazard Recognition and Mitigation Training and Power and Hand Tool Training must be completed and filled out.	**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. Hazard Recognition and Accident Avoidance Training must be completed and filled out.	**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. Must have Hazard Analysis and Accident Avoidance Training form signed out	**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. NASA USLI Student Handbook, page 35, *Minimum Distance Table* , for K motor minimum safe distance is 200 feet. 2. Pre-Launch and Launch Checklist "*Final Launch Preparations, Recovery, and Launching the Rocket* " sections.	**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. NASA USLI Student Handbook, page 35, *Minimum Distance Table* , for K motor minimum safe distance is 200 feet. 2. Pre-Launch and Launch Checklist "*Final Launch Preparations, Recovery, and Launching the Rocket* " sections.	**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. NASA USLI Student Handbook, page 35, *Minimum Distance Table* , for K motor minimum safe distance is 200 feet. 2. Pre-Launch and Launch Checklist "*Ignitor Preparations, Final Launch Preparations, and Launching the Rocket* " sections.	**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 verification documents are required.	**4B**
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. NASA USLI Student Handbook, page 35, *Minimum Distance Table* , for K motor minimum safe distance is 200 feet. 2. Pre-Launch and Launch Checklist "*Final Launch Preparations, Recovery, and Launching the Rocket* " sections.	**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.Hazard Recognition and Mitigation training must be filled out and completed 2. Pre-Launch and Launch Checklist "*Motor Preparations, Safety Preparations, and Final Assembly*" sections.	**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. Pre-Launch and Launch Checklist "*Ignitor Preparations*" section 2. Accident Avoidance and Mitigation Training must be completed.	**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. Every 20 to 30 minutes ensure that you stand up and walk around for a bit. This should mitigate any damage to your body from prolonged sitting.	1. No verification documents are required.	**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. No verification documents are required.	**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. Pre-Launch and Launch Checklist "*Launching the Rocket*" section.	**1E**

4.16 Hazards imposed onto the Environment

Hazards Imposed onto the Environment	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. Pre-Launch and Launch Checklist "*Launching the Rocket*" section.	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. NASA USLI Student Handbook, page 35, *Minimum Distance Table*, for K motor minimum safe distance is 200 feet. 2. Pre-Launch and Launch Checklist "*Final Launch Preparations, Recovery, and Launching the Rocket*" sections. 3. All MSDS sheets and disposal procedures.	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. All MSDS sheets and disposal procedures	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 verification documents 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. No verification documents are required.	**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. No verification documents are required.	**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. All MSDS sheets and safety procedure. 2. Must have Accident Avoidance and S.T.A.R Training completed and filled out. 3. Pre-Launch and Launch Checklist "*Safety Preparations*" section.	**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. All MSDS sheets and safety procedure. 2. Must have Accident Avoidance and S.T.A.R Training completed and filled out. 3. Pre-Launch and Launch Checklist "*Safety Preparations*" section.	**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.Pre-Launch and Launch Checklist "*Launching the Rocket*" section. 2. Prior to launch Fire Extinguisher and Fire Mitigation Training must be completed	**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. Pre-Job Brief form must be filled out. 2. Pre-Launch and Launch Checklist "*Safety Preparations, Motor Preparations, and Final Assembly*" sections. 3. Fire Extinguisher and Fire Mitigation Training must be completed and filled out.	**1E**

4.17 Hazards Imposed by the Environment onto the Rocket

Rocket Environmental Concerns	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Structural damage due to high winds	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. Pre-Launch and Launch Checklist, "*Rocket Airframe*" section.	**4B**
Rocket body drifting outside maximum allowable limits	High wind conditions	Rocket could become lost, and could result in loss of the competition	**2B**	1. Inspect our recovery systems prior to launch. 2. Delay the launch of the rocket if high wind conditions exists.	1. NASA USLI Student Handbook, page 34, NAR High Power Rocket Safety Code, Section 9. 2. Pre-Launch and Launch Checklist "*Launching the Rocket*" section.	**2C**
Epoxy damage due to temperature being too hot	Hot weather	Rocket sections could break apart and cause severe damage to flight characteristics	**1D**	1. Ensure that the epoxy has cured for the manufacturers recommended time. 2. Ensure that the rocket does not stay in hot temperatures for extended amounts of time.	1. Manufacturers MSDS sheets 820 Resin, and 824 Hardener. 2. Manufacturers pre packaged instructions for usage of 820 Resin and 824 Hardener 3. Pre-Launch and Launch Checklist, "*Rocket Airframe*" section.	**1E**
Epoxy damage due to temperature being too low	Cold weather	Rocket sections could break apart and cause severe damage to flight characteristics	**1D**	1. Ensure that the epoxy has cured for the manufacturers recommended time. 2. Ensure that the rocket does not stay in cold temperatures for extended amounts of time.	1. Manufacturers MSDS sheets 820 Resin, and 824 Hardener. 2. Manufacturers pre packaged instructions for usage of 820 Resin and 824 Hardener 3. Pre-Launch and Launch Checklist, "*Rocket Airframe*" section.	**1E**

Wet powder charges	Rain, monsoon, hurricane, or snow storm	Would prevent recovery systems from firing and rocket could come down ballistic	**1C**	1. When working with the powder, ensure that you are in a safe dry location before open up the powder containers. 2. Ensure that wadding and tape has been placed over the powder to prevent any water to touch the powder.	1. Manufacturers MSDS sheet Winchester Ball Propellant. 2. Pre-Launch and Launch Checklist "*Safety Preparations*" and "*Final Assembly*" sections.	**1E**
Fuselage damage from prolonged water exposure	Rain, monsoon, hurricane, or snow storm	Cause rocket to break apart during launch	**1D**	1. Ensure that the rocket is in a dry location during storage, an do no launch the rocket during wet conditions	1. NASA USLI Student Handbook, page 34, NAR High Power Rocket Safety Code, Section 9. 2. Pre-Launch and Launch Checklist "*Rocket Airframe*" section.	**1E**
Rubber RTV not sealing due to temperature	Prolonged exposure to hot or cold weather conditions	Fairing could break apart during flight	**1D**	1. Ensure that the rubber RTV has cured for the manufacturers recommended time. 2. Ensure that the rocket does not stay in cold or hot temperatures for extended amounts of time.	1. Manufacturers MSDS sheets Silastic J-RTV 2. Manufacturers pre packaged instructions for usage of Silastic J-RTV Hardener 3. Pre-Launch and Launch Checklist, "*Rocket Airframe*" section.	**1E**
Low visibility and loss of rocket due to fog	Fog	Would lose the rocket during recovery operations	**1D**	1. If visibility is low, delay the launch of the rocket until the sky has cleared up.	1. NASA USLI Student Handbook, page 34, NAR High Power Rocket Safety Code, Section 9. 2. Pre-Launch and Launch Checklist "*Launching the Rocket*" section.	**1E**

Rocket body damage due to earthquake	Earthquake	Cause rocket to break apart during launch	**1E**	1. During storage of the rocket, ensure that it is in a safe location so that nothing could fall on it, or so that the rocket can not fall a great distance in the event of an earthquake.	1. Pre-Launch and Launch Checklist, "*Rocket Airframe*" section.	**1E**
Rocket body damage from lightning strike	Lightning strike	Would cause the rocket to take severe damage during flight	**1E**	1. Ensure that the rocket isn't launched into clouds or during rainy circumstances.	1. NASA USLI Student Handbook, page 34, NAR High Power Rocket Safety Code, Section 9. 2. Pre-Launch and Launch Checklist "*Launching the Rocket*" section.	**1E**
Rocket body damage from wildlife	Wildlife	Cause rocket to break apart during launch	**1E**	1. Keep the rocket in a secure location to ensure that no wildlife can get near it. 2. Before launch of the rocket, check to make sure that no animals are in the way of the flight path, or that no wildlife is approaching the rocket from the ground.	1. Pre-Launch and Launch Checklist, "*Rocket Airframe*" section. 2. Pre-Launch and Launch Checklist "*Launching the Rocket*" section.	**1E**
Rocket body damage from wildfire	Wildfire	Cause rocket to break apart during launch	**1E**	1. Keep the rocket in a secure location to ensure no fire damage can occur. 2. Before launch of the rocket, check to make sure that no fires are within the vicinity of the rocket.	1. Pre-Launch and Launch Checklist, "*Rocket Airframe*" section. 2. Pre-Launch and Launch Checklist "*Launching the Rocket*" section.	**1E**

4.18 Hazards Imposed by the Environment onto the Payload

Payload Environmental Concerns	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Electrical short circuiting from excess moisture or water in PIL	Rain, snow, sleet, or other wet weather conditions.	Could destroy all vital electronics and recovery system electronics	1C	1. Ensure that the payload is in a dry location during storage, an do no launch the rocket during wet conditions	1. NASA USLI Student Handbook, page 34, NAR High Power Rocket Safety Code, Section 9. 2. Pre-Launch and Launch Checklist "*Electronics for Payload*" section.	1D
Electronics failure due to solar storm	Solar flare or other high energy releases from parts of our universe	Could destroy all vital electronics and recovery system electronics	1E	1. There is nothing that can be done to mitigate this from occurring, but prior to launch inspect all electronics in the payload.	1. Pre-Launch and Launch Checklist, "*Electronics for Payload*" section.	1E
PIL exceeding drift allowances due to high wind	High wind conditions	Loss of PIL due to high drift, or potential disqualifications from the competition	2B	1. Inspect our recovery systems prior to launch. 2. Delay the launch of the rocket if high wind conditions exists.	1. NASA USLI Student Handbook, page 34, NAR High Power Rocket Safety Code, Section 9. 2. Pre-Launch and Launch Checklist "*Launching the Rocket*" section.	2C
PIL damage due to wildlife	Wildlife	Structural damage to the PIL and PIL could break apart during operation	1E	1. Keep the payload in a secure location to ensure that no wildlife can get near it. 2. Before launch of the rocket, check to make sure that no animals are in the way of the flight path, or that no wildlife is approaching the rocket from the ground.	1. Pre-Launch and Launch Checklist, "*Electronics for Payload*" section. 2. Pre-Launch and Launch Checklist "*Launching the Rocket*" section.	1E

PIL damage due to lightning strike	Lightning strike	Total destruction of PIL	**1E**	1. Ensure that the payload isn't launched into clouds or during rainy circumstances.	1. NASA USLI Student Handbook, page 34, NAR High Power Rocket Safety Code, Section 9. 2. Pre-Launch and Launch Checklist "*Launching the Rocket*" section.	**1E**
PIL damage due to earthquake	Earthquake	Potential structure or electronics damage to PIL	**1E**	1. During storage of the payload, ensure that it is in a safe location so that nothing could fall on it, or so that the payload can not fall a great distance in the event of an earthquake.	1. Pre-Launch and Launch Checklist, "*Electronics for Payload*" section.	**1E**
Loss of payload from fog or low visibility conditions	Fog or cloud covering	Loss of PIL due to not being able to recover it after flight	**1C**	1. If visibility is low, delay the launch of the rocket until the sky has cleared up.	1. NASA USLI Student Handbook, page 34, NAR High Power Rocket Safety Code, Section 9. 2. Pre-Launch and Launch Checklist "*Launching the Rocket*" section.	**1E**
Payload damage from wildfire	Wildfire	Potential structure or electronics damage to PIL	**1E**	1. Keep the payload in a secure location to ensure no fire damage can occur. 2. Before launch of the rocket, check to make sure that no fires are within the vicinity of the rocket.	1. Pre-Launch and Launch Checklist, "*Electronics for Payload*" section. 2. Pre-Launch and Launch Checklist "*Launching the Rocket*" section.	**1E**

4.19 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. Pop Test Procedure and Arming Guidelines. 2. Pre-Launch and Launch Checklist "*Recovery Systems*" and "*Final Assembly*" sections.	**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.Pre-Launch and Launch Checklist "*Motor Preparations*" and "*Igniter Preparations*" sections. 2. Manufacturers MSDS sheet ProFire Ignitor.	**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. NASA USLI Student Handbook, page 34, NAR High Power Rocket Safety Code, Section 7. 2. Pre-Launch and Launch Checklist "*Launching the Rocket*" and "*Preparing Rocket on Launch Pad*" sections.	**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. Pre-Launch and Launch Checklist "*Recovery Systems*" section.	**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. Pre-Launch and Launch Checklist "*Recovery Systems*" section.	**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. Pre-Launch and Launch Checklist "*Recovery Systems*" and "*Electronics for Avionics*" sections.	**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. Pre-Launch and Launch Checklist "*Recovery Systems*" and "*Electronics for Avionics*" sections.	**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. NASA USLI Student Handbook, page 34, NAR High Power Rocket Safety Code, Section 7. 2. Pre-Launch and Launch Checklist "*Launching the Rocket*" and "*Preparing Rocket on Launch Pad*" sections.	**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. Pre-Launch and Launch Checklist "*Recovery Systems*" section.	**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. Pre-Launch and Launch Checklist "*Electronics for Avionics*" section.	**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. NASA USLI Student Handbook, page 34, NAR High Power Rocket Safety Code, Section 5. 2. Pre-Launch and Launch Checklist "*Misfire Procedure, Ignitor Preparation, Motor Preparations, Motor Installation, Arming, and Final Launch Preparations*" sections.	**4D**

4.20 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. Pre-Launch and Launch Checklist "*Electronics for Payload*" section.	**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. Pre-Launch and Launch Checklist "*Electronics for Payload*" section.	**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. Pre-Launch and Launch Checklist "*Electronics for Payload*" and "*Final Assembly*" sections.	**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. Pre-Launch and Launch Checklist "*Recovery Systems*" section.	**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. Pre-Launch and Launch Checklist "*Recovery Systems*" section.	**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. Pre-Launch and Launch Checklist "*Electronics for Payload*" section. 2. Radio Communications Procedure and Guidelines.	**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. Pre-Launch and Launch Checklist "*Electronics for Payload*" and "*Final Assembly*" sections.	**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. Pop Test Procedure and Arming Guidelines. 2. Pre-Launch and Launch Checklist "*Electronics for Avionics, Recovery Systems, and Final Assembly*" sections.	**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. Pre-Launch and Launch Checklist "*Electronics for Payload*" section.	**1E**

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, deployment system, 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 deployment system 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.

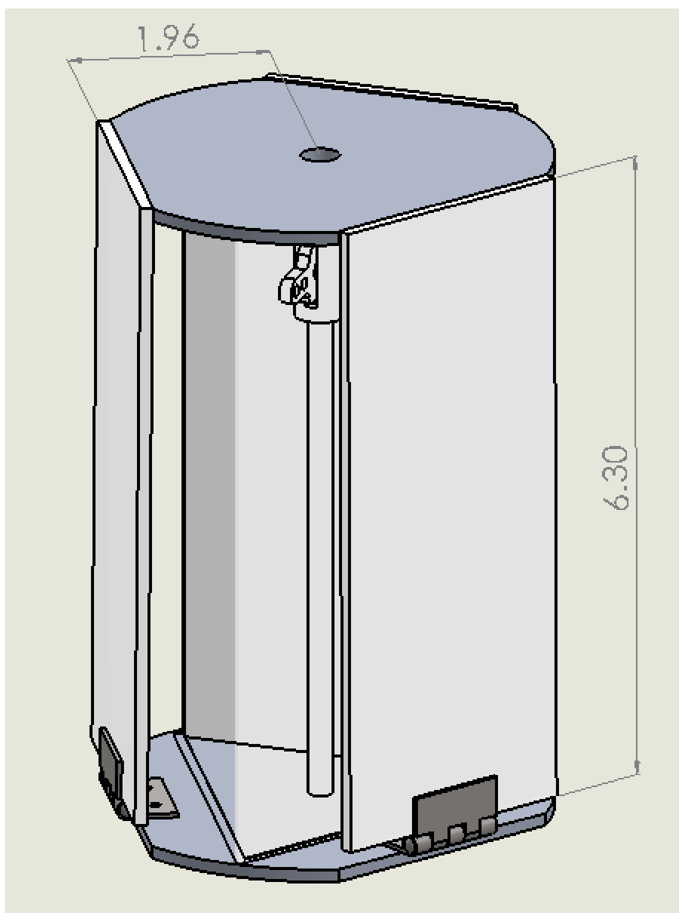
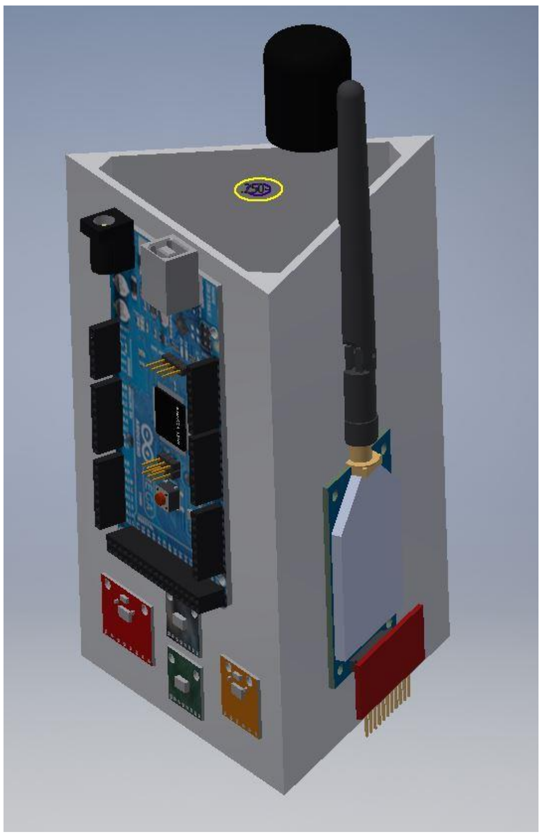


Figure 22: General PIL Dimensions (inches)

5.1.2 PIL Structure

The payload section of this mission took quite a bit of ingenuity. The tri-structure has changed quite drastically from the last iteration. While the main tri-structure is still there, it was decided to rely on an aluminum rod spanning the center of the PIL, rather than tapped polymer to withstand the shock load of canopy deployment. As such, it was decided to weld an aluminum rod to the base plate, with a parachute release mechanism on the other end of the rod. This will allow the tri-structure to rest on the base plate, also held in by bolts, but this aluminum rod will support the main weight of the PIL. A top plate will later be bolted onto the top, with the parachute release mechanism poking through the top plate. This will help center the aluminum rod, as well as provide a nice clean look for the PIL itself



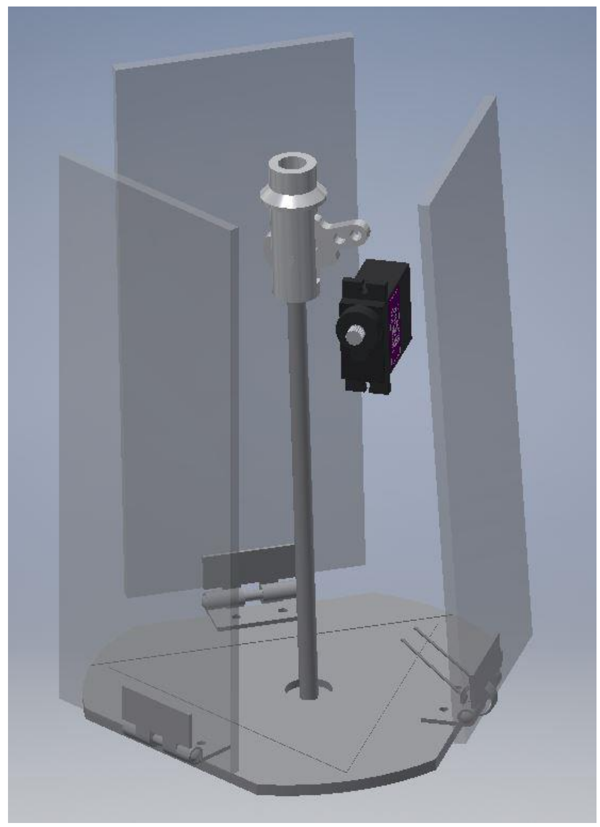


Figure 23: Drawings of the PIL's Structure

5.1.3 Deployment System

Another unique design of the PIL, is that it has an integrated deployment system built into the base. This system is designed to help the PIL deploy upright upon detection of landing. The PIL starts out folded up (left picture) and remains folded until it is out of the rocket, and on the ground. Under canopy, the PIL will remain closed while it is descending. There are plenty of open slots to allow all of the sensors free access to the ambient air, to collect scientific data. Once the PIL lands on the ground, it will tip over onto one of its sides. The parachute release mechanism, controlled by servo, holds the parachute loop as well as one loop for each of the 3 PIL walls. The fishing line wires holding the walls up are tied to the walls and hooked into the parachute release mechanism loop. 28 in-lb tension springs will be utilized in allowing the walls to spring open, mounted near the wall hinge. This torque was chosen based on predicted mass models of the PIL, and will be tested extensively to ensure reliable deployment.

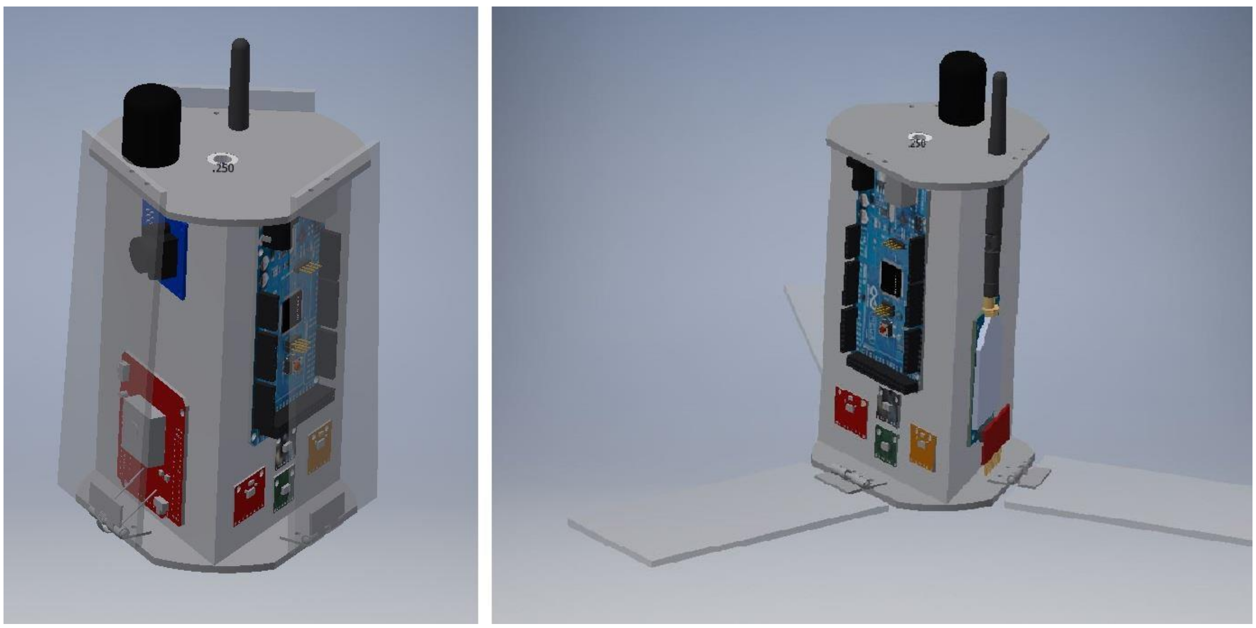


Figure 24: Drawings of the PIL deployment system

5.1.4 Electronics System

Table 12: 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

5.2.1.1 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.

5.2.1.2 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.

5.2.1.3 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.

5.2.1.4 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.

5.2.1.5 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.

5.2.1.6 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, improve the team's ability to communicate with atmospheric probes, and predict payload drift. 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 and data from the ground weather station. 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. A drift analysis will be conducted using the wind speed and direction from the ground station. The actual landing site will be compared with a pre-launch predicted landing site.

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 2 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 and ground weather station data. Plots of difference 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. The data will also be compared with the weather station data. 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.

To process the drift analysis, the predicted landing site will be calculated using MATLAB and the weather station wind speed. The actual landing site will be taken from the GPS coordinates from the PIL.

5.3 PLANETARY INVESTIGATION LANDER (PIL) DESIGN AND INTEGRATION

5.3.1 Structural Analysis

The expected shock load of the payload is shown in the figure below. The force was calculated by ranging the time it takes to decelerate between parachute deployments using descent rates of 103 ft/s and 25 ft/s. The average acceleration was calculated for a range of times and this acceleration was used with the mass of the payload (3.5 lb converted to slugs) to calculate the force. It is estimated that the second stage parachute will not deploy faster than 0.1 seconds making the maximum expected shock load approximately 60 lb force.

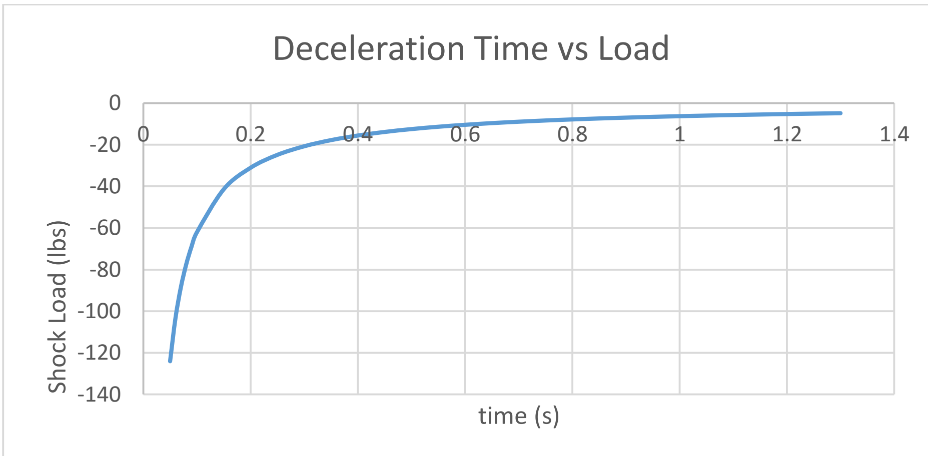


Figure 25: Deceleration Time vs Shock load.

The main structure of the payload consists of an aluminum base plate, aluminum rod and an aluminum release mechanism that attaches to the parachute. These three components are welded together to form the main structure of the payload. A stress, strain, and displacement analysis of this structure was performed using SOLIDWORKS. A static evaluation was done by constraining the outside of the base plate and applying an 80 lb force in the upward direction to the release mechanism. The structure has minimal deformation and withstands the 80 lb static force as shown below.

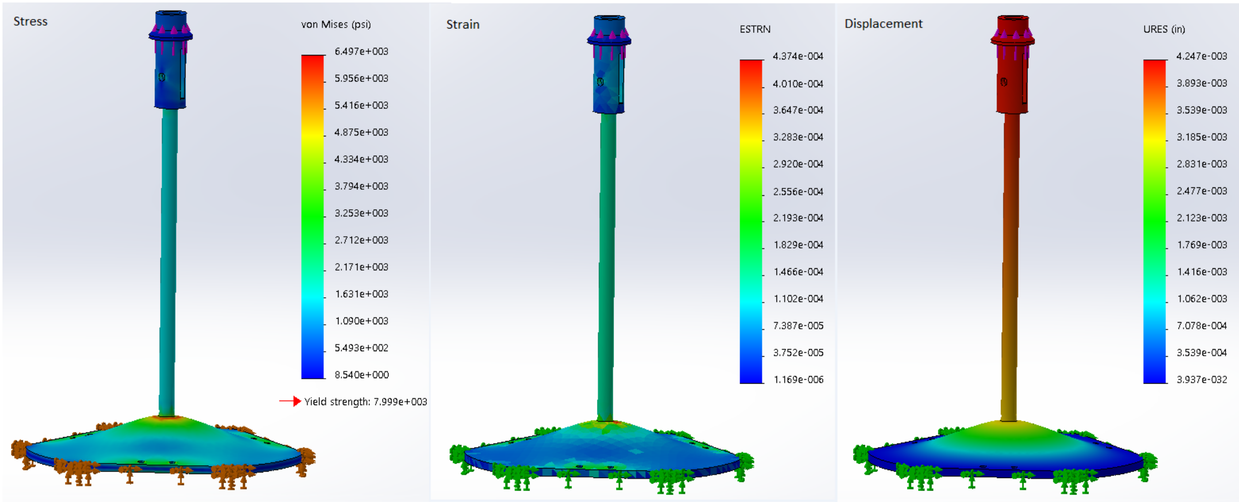


Figure 26: Stress, Strain, Displacement FEA summary

5.3.2 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 it will drag the PIL out of the rocket if the powder charge below doesn't force it out first. As the PIL exits the rocket, the rockets' main parachute will be taped to the underside of the PIL, allowing the PIL to help deploy the main parachute at the same time the PIL is deployed. In the event the PIL doesn't deploy the rockets' main parachute, a redundant charge will be set off to ensure the main parachutes' deployment.

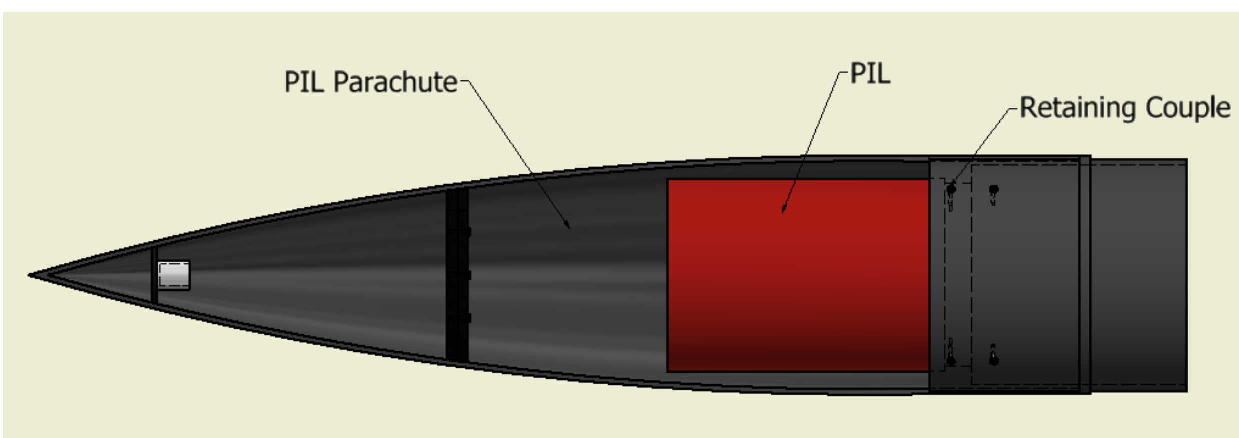


Figure 27: Rocket and PIL integration

5.3.3 PIL and Deployment System

In order for the PIL to completely satisfy all mission requirements, it must deploy into the upright position. This is because the pyranometer must be with-in a 180-degree hemispheric window of the sun to gather any good data. The camera would also benefit from being a few inches higher off the ground, and is therefore placed near the top of the tri-structure. This is to clear any foreign objects obstructing the PIL's view of the ground. The PIL's protective walls double as the deployment legs, and will make it possible for the PIL to stand up after landing.

5.3.4 PIL Protective Shell and Structure

The Protective walls that cover the PIL will be attached directly to the base plate. Screws extruding through the base plate will thread directly into the hinge, which will in-turn be bolted and/or epoxied to the protective walls. This will make servicing the PIL much easier as we can deploy the Protective walls to service the electronics. The protective wall will also prevent any foreign objects from damaging the sensitive equipment.

5.3.5 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.

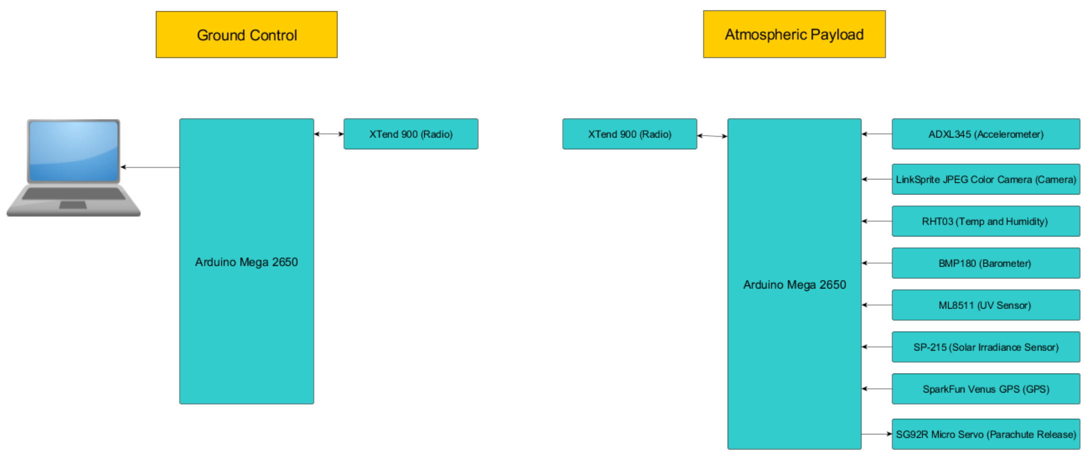


Figure 28: Diagram of Ground Control and Payload Hardware

5.3.6 Testing and Prototyping

A prototype of the payload structure was built to verify that the PIL could orient itself vertically after landing. This prototype consisted of a wooden base plate, all-thread center support, 1 and 28 in-lb torsion springs, and acrylic legs. A 2 lb test weight was attached to the all-thread to bring the total weight of the prototype to 3.5 lbs. The prototype can be seen in the figure below.

Figure 29: Prototype of the Deployment System

The test weight was moved to various positions along the all-thread and the prototype was tested to see if it could orient itself vertically (stand up). It was found that the 28 in-lb torsion spring will have to be used. The 17 in-lb torsion spring could only lift the prototype when the test weight was all the way at the bottom. It was also found that the maximum height of the center of mass of the PIL can be no larger than 4 in measured from the base plate when using the 28 in-lb torsion springs. This testing verified the design of the payload structure. Now that the design has been verified the final production of the payload structure can begin.

5.3.7 PIL Manufacturing

The base plate and top plate will be machined out of 1/8 in thick aluminum 6061 plate stock using CNC mill. The center structural support will be turned out of 3/8 in diameter aluminum 6061 tube stock using a lathe. The outside legs will be cut from 1/8 in thick high impact strength acrylic using a ban saw and an end mill. The inside electronic mounting structure will be cut from 1/8 in abs plastic using a ban saw and an end mill. The base plate, center structural support, and release mechanism (off the shelf product) will be welded together to form the main structure of the payload. All subsequent components will be bolted and or epoxied to this structure. This design has been verified through prototype testing and analysis allowing this manufacturing process to begin.

5.3.8 Future Testing

Now that the payload structure has been verified through a prototype it is possible to move on to fabrication and testing of the final PIL structure. First the main structure of the payload will be fabricated and tested. This will be the base plate, center support, and release mechanism. This portion of the structure will then be tested using a pulley and weights to simulate an 80 lb shock load. Next the rest of the structure will be added; center tri-structure, outer legs, hinges, torsion springs and top plate. The weight of the electronics and battery will be simulated using test weights. This final payload (minus the electronics) will be placed on the ground and the parachute and outer legs will be deployed to verify that the parachute releases and that the PIL orients itself in the vertical position. This final payload (minus the electronics) with test weights will then be placed in the full scale test of the entire rocket.

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. After testing, we discovered only one is needed. Data is able to be captured at a frequency of at least 3HZ. 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.

- Custom PCB – This PCB will hold the SparkFun Venus GPS, RHT03, BMP180, ADXL345 and SparkFun microSD Transflash. This will allow a neat organization of wires, and reduce risk of connection failures.
- SG92R Micro Servo – This servo motor will activate to move the release arm to release the parachute.

5.4.2 PIL Electronics Testing

- Arduino Mega 2650 – Verify the Arduino can communicate with all sensors. This has been purchased and has been successfully tested with several sensors.
- XTEND-900 – Test radio connection between PIL and Ground Control. This has been successfully tested for short range radio communication.
- SparkFun Venus GPS – Test GPS and verify location outputted with current location.
- RHT03 – Test and verify temperature and humidity are within expected range. This has been ordered and has been successfully integrated and tested with the Arduino.
- BMP180 – Test pressure on ground and verify it is within expected range. This has been purchased and has been successfully integrated and tested with the Arduino.
- ML8511 – Test sensor by covering the sensor to prevent any light from entering, then uncover in sunlight. Verify UV intensity increased with sunlight. This has been purchased and has been successfully integrated and tested with the Arduino.
- Apogee Instruments SP-215 – Test sensor by covering the sensor to prevent any light from entering, then uncover in sunlight. Verify solar irradiance increases with sunlight.
- ADXL345 – Test data outputted from accelerometer by standing the sensor upright. Verify acceleration of gravity (z axis) is close to 9.81 M/S^2. Verify x and y axis is close to 0 M/S^2 (no gravity on x and y axis when upright). This has been purchased and has been successfully integrated and tested with the Arduino.
- LS-Y201-2MP – Test photo capture and transmission. Verify JPEG data is fully transmitted and can be displayed on a computer. This has been purchased and has been successfully integrated and tested with the Arduino.
- SparkFun microSD Transflash – Test file creation and writing abilities. This has been purchased and has been successfully integrated and tested with the Arduino.
- Custom PCB – Test trace continuity to verify all connections are made.

5.4.3 Launch Day Checklist

Verify batteries for PIL are charged.

Test radio connection between PIL and Ground, and verify strong signal strength.

Test GPS System and verify reported GPS is within expected area.

Test all sensors using ground control software.

Test MicroSD card. Verify file read and write works on both Arduino and computer.

Test parachute release servo motor.

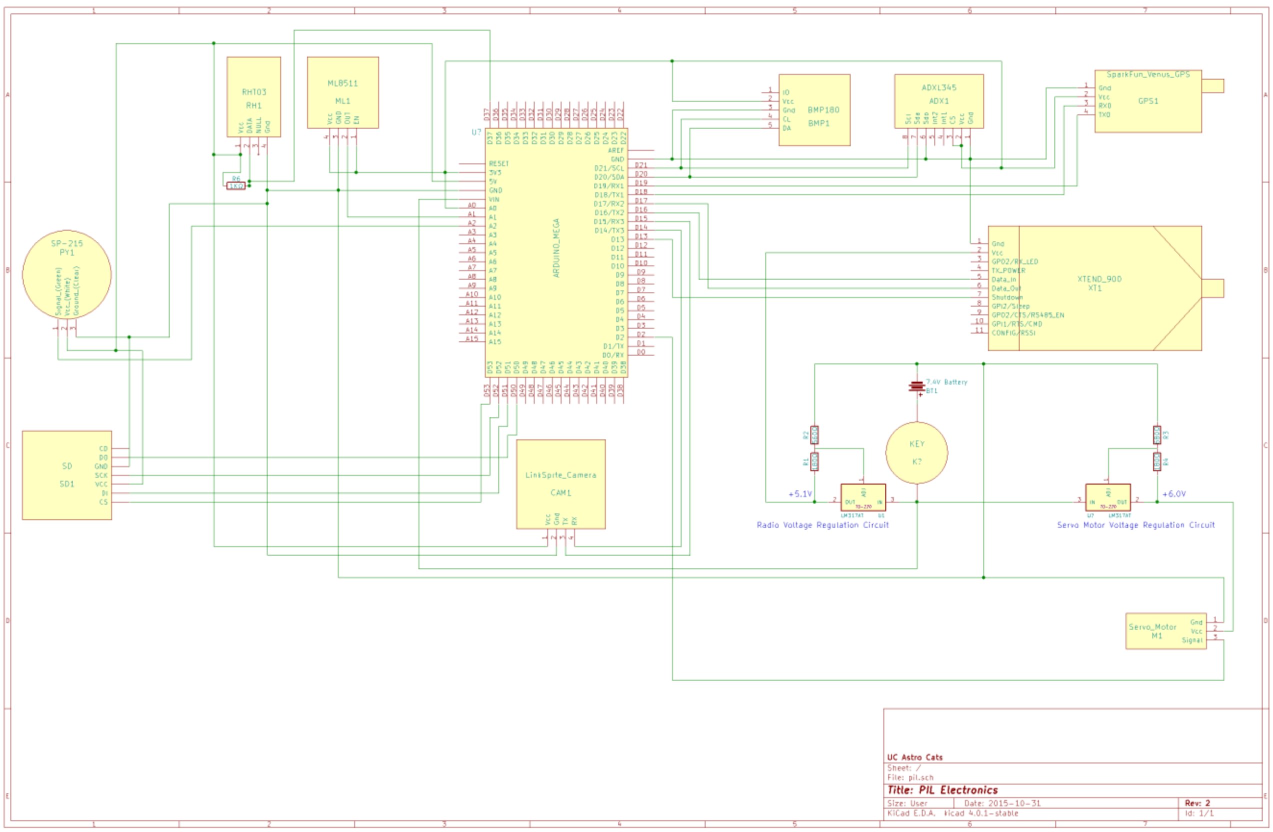


Figure 30: PIL Electrical Schematic

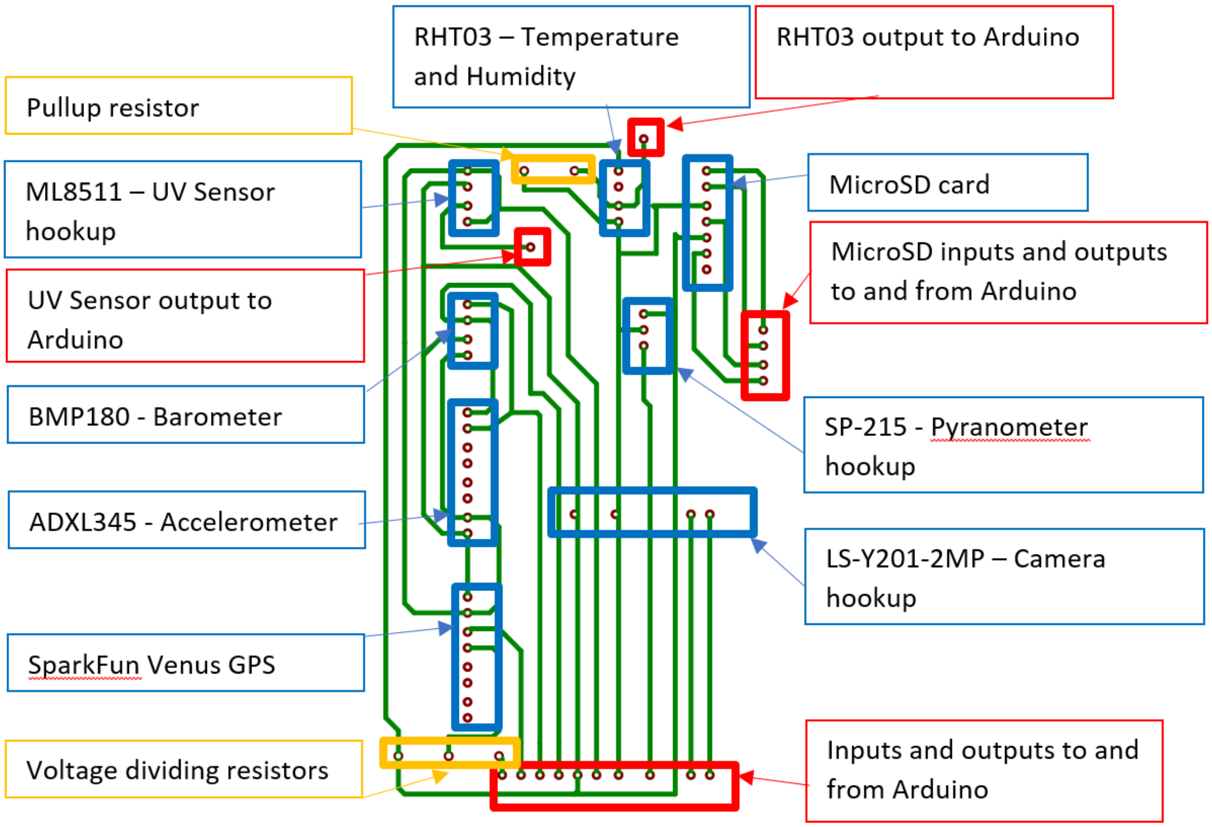


Figure 31: PIL Printed Circuit Board Layout

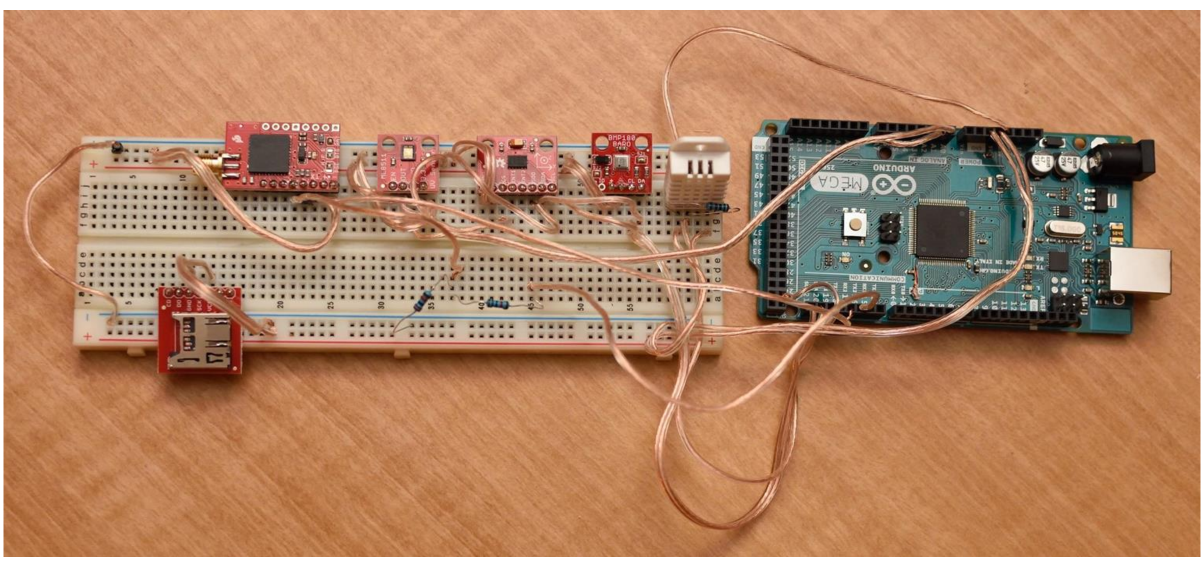


Figure 32: PIL Breadboard Prototype

5.5 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 adjustment 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.

5.5.1 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.

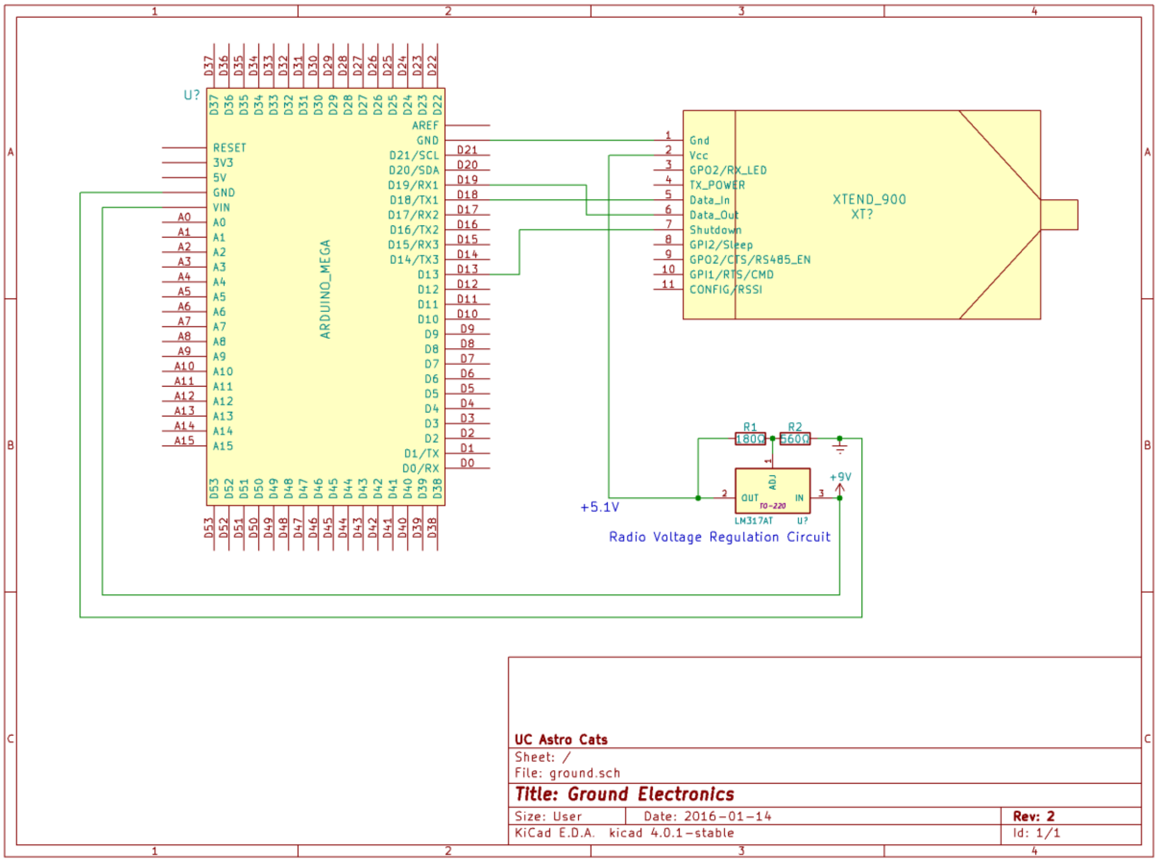


Figure 33: Ground Station Wiring Schematic

5.5.2 Ground Control Software

The ground control software development has been started. The ground control software is being written in C++, using wxWidgets for the GUI library. A serial port reading thread is able to read the data from the Arduino, and a user interface update thread parses the data from the serial port, and updates the display. The following displays development have been started: radio signal strength from PIL and rocket, temperature, humidity, UV intensity, solar irradiance, air pressure and altitude, and pitch and roll display (orientation of PIL relative to the ground).

The ground control software can also record and playback data. This will be our main point of data collection, with the SD card on the PIL as a backup. The data collected will be analyzed after launch, and can be played back with the GUI for visual analysis and testing.

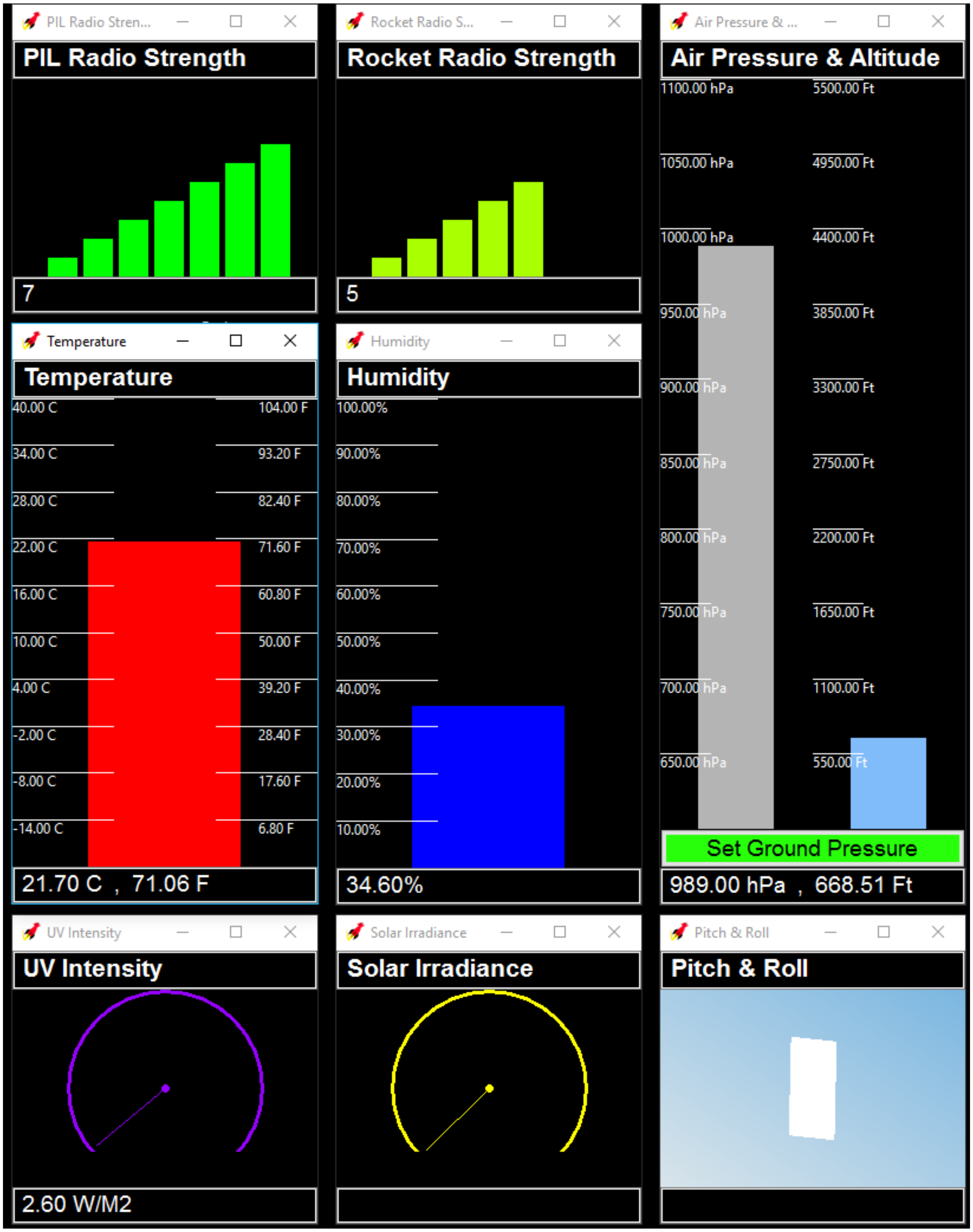


Figure 34: Ground Control Gauges – This displays the latest data captured from the PIL.

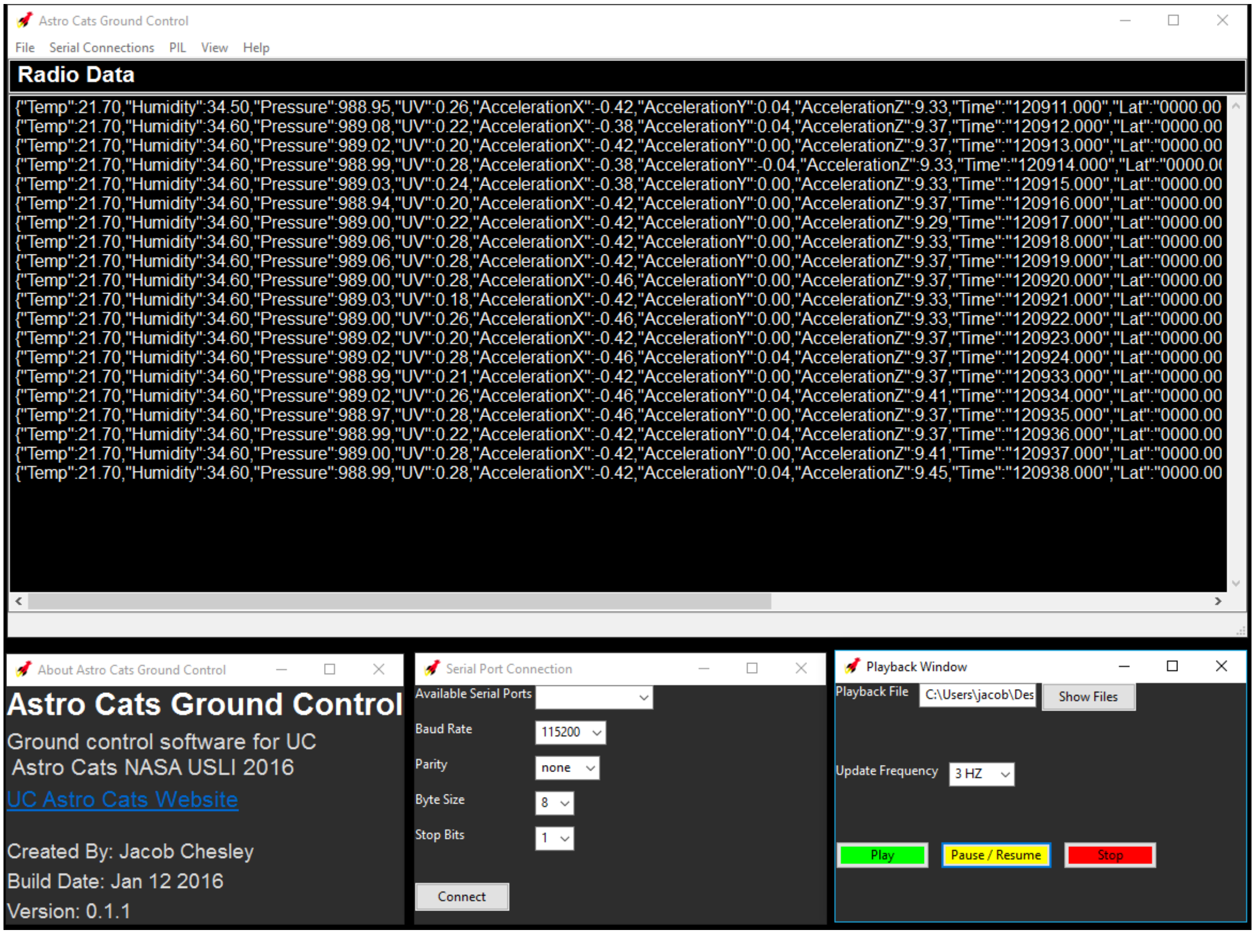


Figure 35: Ground Control Main Window (top), About Window (bottom left), Serial Port Connection Window (bottom middle), Data Playback Window (bottom right).

5.6 Payload Requirements

Table 13: 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.

5.7 Mass List

	component	weight (grams)	category
	Pil Housing	117	structure
	tri-structure	117	structure
	Humidity and Temperature Sensor	3	electronics
	Barometer	5	electronics
	UV Sensor	5	electronics
	Accelerometer	5	electronics
	Camera (x3)	90	electronics
	Radio - XTEND 900	18	electronics
	Radio Antenna	100	electronics
	GPS - SparkFun Venus GPS	10	electronics
	GPS Antenna	18	electronics
	Micro SD	7	electronics
	Arduino	37	electronics
PIL	battery	161	electronics
	parachute (60 in)	223	recovery
	parachute connection hardware	100	recovery
	torsion springs	80	structure
	hinges	30	structure
	hardware	12	structure
	bottom plate	75.7	structure
	top plate	75.7	structure
	center support	4	structure
	epoxy resin	35	structure
	parachute release	5	recovery
	power distribution circuit board	60	electronics
	landing module servo	44	recovery
	c-channels	31.5	structure
	total	1468.9	1505.6 (+2.5%)
			1432.2 (-2.5%)
		3.23158	lbs

Figure 36: Component Mass List of Payload

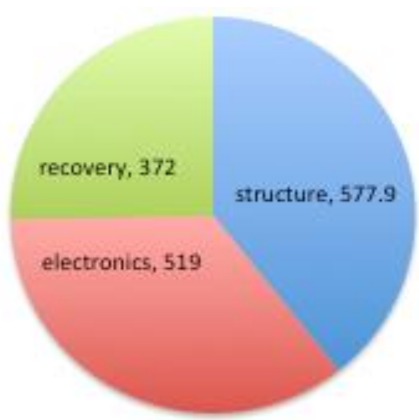


Figure 37: Payload Mass Breakdown

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. Currently the project is on schedule. We have completed the design phase of the project and are now ready to finish purchasing the rest of the components and complete the fabrication of our designs. We plan to complete the fabrication process by Mid-February and will be completing the required testing as we finish each component. Following that we will begin integrating the components together and complete the final test launches and preparing for the competition. The Gantt charts show further details of each work package discussed above.

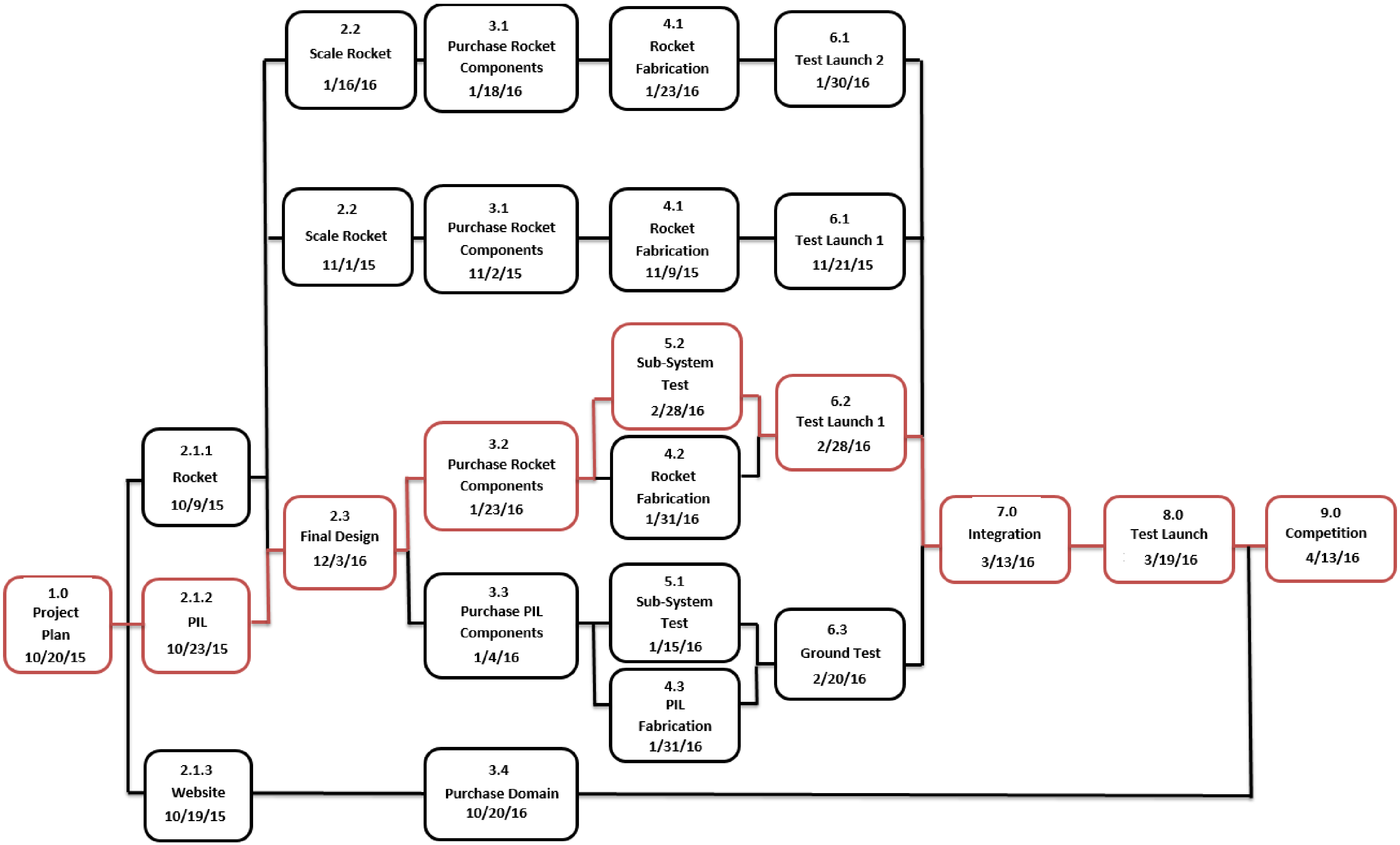
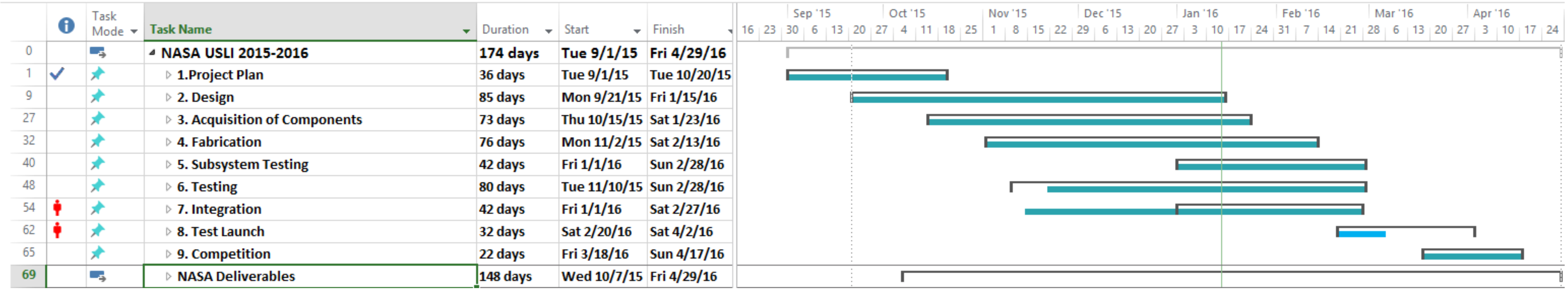
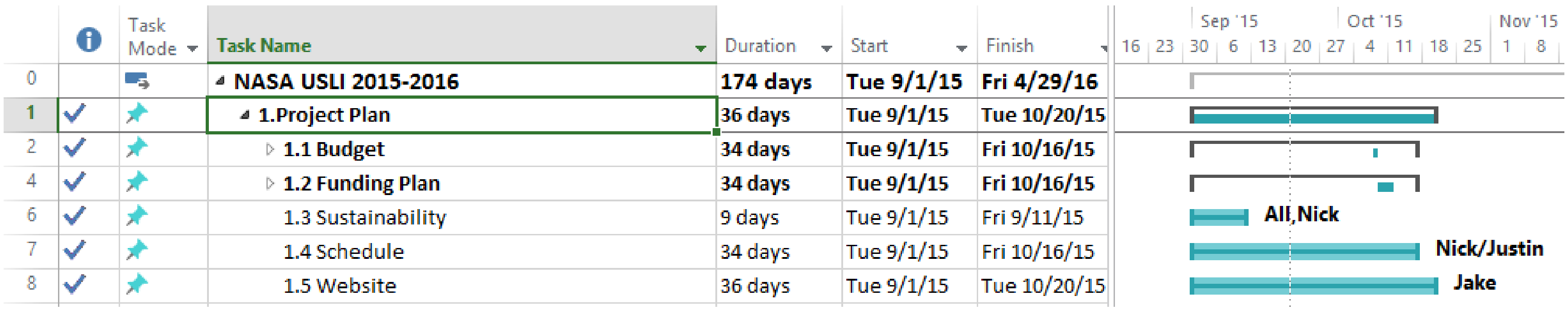


Figure 38: Project Network Diagram



ID	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	85 days	Mon 9/21/15	Fri 1/15/16
27	3. Acquisition of Components	73 days	Thu 10/15/15	Sat 1/23/16
32	4. Fabrication	76 days	Mon 11/2/15	Sat 2/13/16
40	5. Subsystem Testing	42 days	Fri 1/1/16	Sun 2/28/16
48	6. Testing	80 days	Tue 11/10/15	Sun 2/28/16
54	7. Integration	42 days	Fri 1/1/16	Sat 2/27/16
62	8. Test Launch	32 days	Sat 2/20/16	Sat 4/2/16
65	9. Competition	22 days	Fri 3/18/16	Sun 4/17/16
69	NASA Deliverables	148 days	Wed 10/7/15	Fri 4/29/16

Figure 39: Top Level View of Project Schedule



ID	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

ID	Task Name	Duration	Start	Finish
9	2. Design	85 days	Mon 9/21/15	Fri 1/15/16
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
21	2.1.2 PIL	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	41 days	Sat 11/21/15	Fri 1/15/16

Figure 41: Detailed View of Design Schedule

27	3. Acquisition of Components	73 days	Thu 10/15/15	Sat 1/23/16
28	3.1 Purchase of Scale Rocket Components	2 days	Sun 11/1/15	Mon 11/2/15
29	3.2 Purchase Rocket Components	47 days	Fri 11/20/15	Sat 1/23/16
30	3.3 Purchase PIL Components	32 days	Fri 11/20/15	Mon 1/4/16
31	3.4 Purchase Website Domain	1 day	Thu 10/15/15	Thu 10/15/15

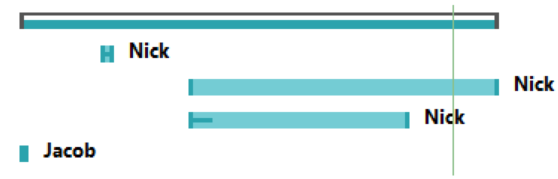


Figure 42: Detail View of Acquisition Schedule

32	4. Fabrication	76 days	Mon 11/2/15	Sat 2/13/16
33	4.1 Scale Rocket	6 days	Mon 11/2/15	Mon 11/9/15
34	4.2 Rocket	48 days	Sat 11/14/15	Tue 1/19/16
35	4.2.1 Fairing Mold	18 days	Sat 11/14/15	Tue 12/8/15
36	4.2.2 Fairing	12 days	Sat 1/23/16	Sat 2/6/16
37	4.3 PIL	53 days	Thu 12/3/15	Sat 2/13/16
38	4.3.1 Electronics	42 days	Sun 12/6/15	Sat 1/30/16
39	Ground Station	7 days	Sat 1/30/16	Sat 2/6/16

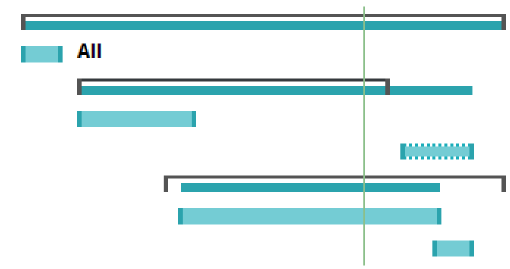


Figure 43: Detail View of Fabrication Schedule

41	5.1 PIL	11 days	Fri 1/1/16	Fri 1/15/16
42	5.1.1 Measurement accuracy/Repeatibility	6 days	Fri 1/1/16	Fri 1/8/16
43	5.1.2 Radio Testing	10 days	Mon 1/4/16	Fri 1/15/16
44	5.2 Rocket	32 days	Fri 1/15/16	Sun 2/28/16
45	5.2.1 Pop Test	7 days	Thu 1/14/16	Fri 1/22/16
46	5.2.2 Ground OP Verification	23 days	Mon 1/18/16	Wed 2/17/16
47	5.2.3 Subscale Rocket	17 days	Sat 1/30/16	Sat 2/20/16

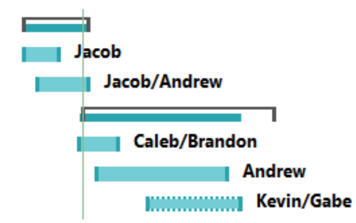


Figure 44: Detail View of Component Testing Schedule

48	6. Testing	80 days	Tue 11/10/15	Sun 2/28/16
49	6.1 Sub Scale Test Launch 1	1 day	Sat 11/21/15	Sat 11/21/15
50	6.1 Wind Tunnel Test	4 days	Wed 1/27/16	Sun 1/31/16
51	6.1 Sub Scale Rocket Test Launch 2	1 day	Sat 1/30/16	Sat 1/30/16
52	6.3 PIL Ground Test	16 days	Mon 2/1/16	Sat 2/20/16
53	6.2 Rocket Test Launch	16 days	Mon 2/8/16	Sun 2/28/16

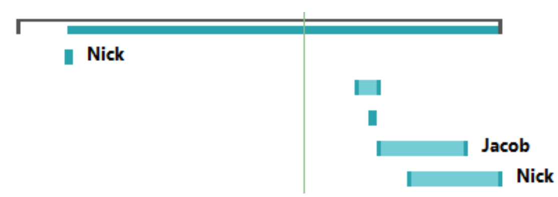


Figure 45: Detail View of Testing Schedule

	Task Name	Duration	Start	Finish
54	**7. Integration**	**42 days**	**Fri 1/1/16**	**Sat 2/27/16**
55	**7.1 Rocket**	**37 days**	**Fri 1/1/16**	**Sat 2/20/16**
56	7.1.1 Electronics	7 days	Sun 1/24/16	Sun 1/31/16
57	7.1.2 Fairing	17 days	Sat 1/30/16	Sat 2/20/16
58	**7.2 PIL**	**77 days**	**Sat 11/14/15**	**Sat 2/27/16**
59	7.2.1 Electronics	62 days	Sat 11/14/15	Sat 2/6/16
60	7.2.2 Fairing	12 days	Sat 1/30/16	Sat 2/13/16
61	7.2.3 Rocket	7 days	Sat 2/20/16	Sat 2/27/16

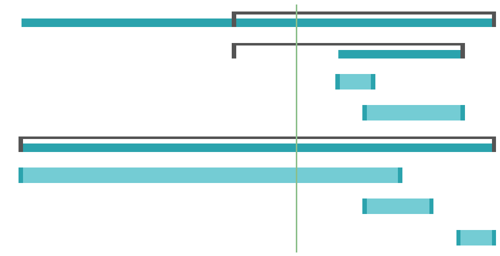


Figure 46: Detail View of Integration Schedule

6.2 PROJECT RISKS

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

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.

6.3 PROJECT BUDGET

The following tables detail the team's USLI budget as of our PDR. Since submitting our PDR 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 from $7,464.39 to $7,551.27. We expect our final expenses to stay at or less that this amount throughout the rest of our project. We believe our rocket budget to be finalized and do not expect it to rise much from its current point. The payload budget we expect to also remain similar to what is listed but can possible grow as we begin to manufacture the final design. To account for this we have $150 in miscellaneous expenses still in reserve to account for any unaccounted for expenditures that may arise during the fabrication phase of the project.

Expense Summary	
Travel	$ 3,442.00
Rocket	$ 1,750.62
Payload	$ 2,288.65
Educational	$ 70.00
Total	$ 7,551.27

Figure 47: Summary of Project Expenses

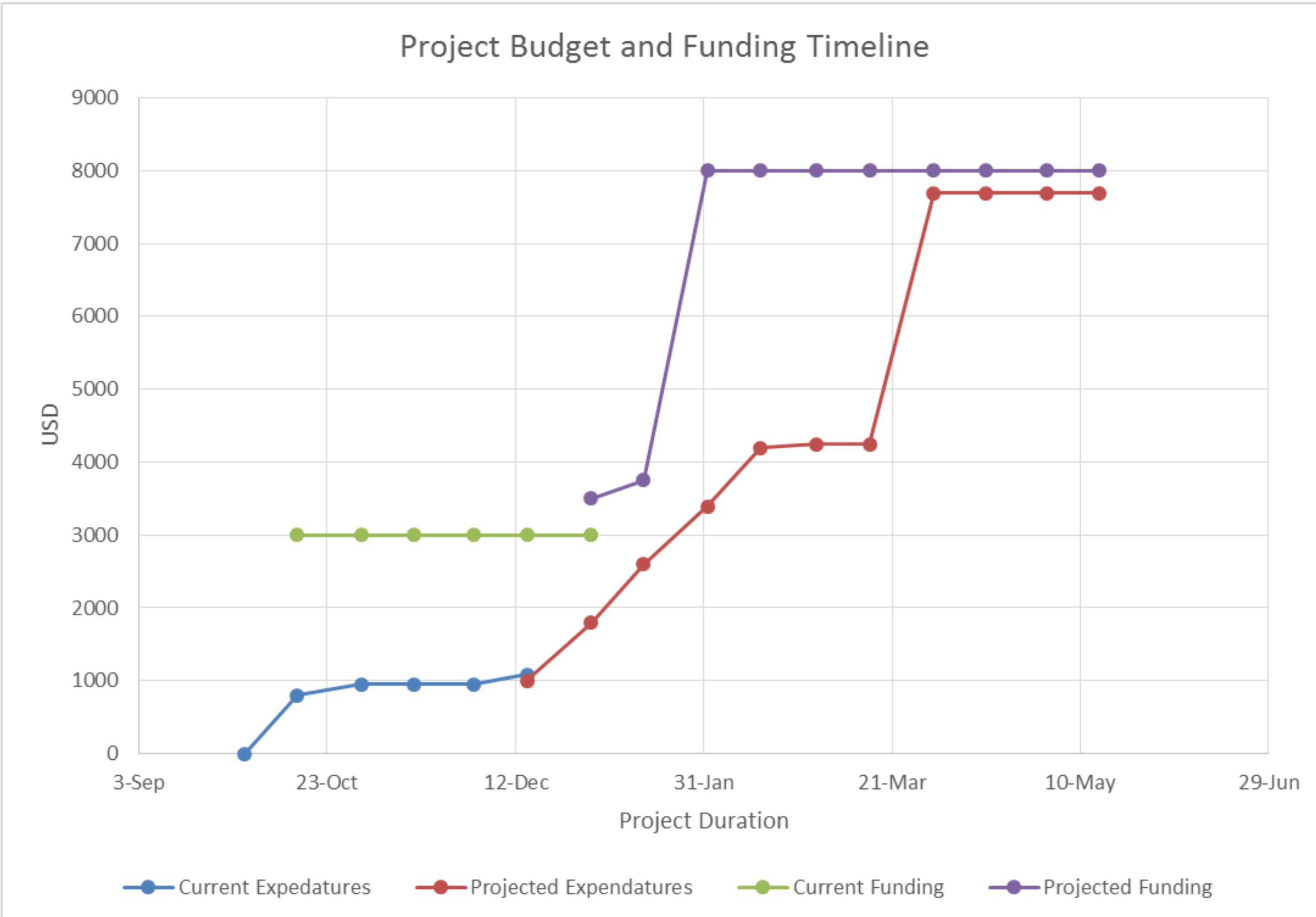


Figure 48: Project Expense and Funding Timeline

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

Figure 49: Table of Current Travel Expenses

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

Figure 50: Table of Current Educational Engagement Expenses

Rocket Expenses				
Part	Quanity	Price	Part Number	Subtotal
Scale Model Kit	2	$ 113.15	PK-56	$ 226.30
4 oz Fiberglass Fabric -3 yard	2	$ 27.45	262-B	$ 54.90
6 oz Fiberglass Fabric - 6 yard	1	$ 32.95	259-B	$ 32.95
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	2	$ 21.95	2060-A	$ 43.90
System 2000 Epoxy Resin	2	$ 44.95	2000-A	$ 89.90
China Bristle Brush - 1 1/2"	1	$ 1.05	31-A	$ 1.05
China Bristle Brush - 2"	1	$ 1.35	32-A	$ 1.35
China Bristle Brush - 3	1	$ 1.55	33-A	$ 1.55
Quart Mixing Set	1	$ 8.55	588-A	$ 8.55
1/4" Acrylic Sheet 12"x12"	1	$ 17.50	8650K31	$ 17.50
54 mm Motor Mount Tube	1	$ 8.09	MMT-2.14	$ 8.09
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	2	$ 10.85	STC-5.38	$ 21.70
Electronic Bay	2	$ 42.95	EB-5.38	$ 85.90
3M Copper Shielding Tape	2	$ 14.61	1125	$ 29.22
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
Kevlar Shock Cords	20	$ 4.34		$ 86.80
1/4" Chain Eye Connector (Quicklink)	2	$ 4.13	CEC-2	$ 8.26
Arming Switches	4	$ 9.46	a11112200ux0536	$ 37.84
Droge Parachute Case 1	1	$ 22.00	AMX Pro-X 20"	$ 22.00
Droge Parachute Case 2	1	$ 18.95	SkyAngle Classic II	$ 18.95
Parachute Slip Ring	2	$ 13.22	Slider 3	$ 26.44
Main Chute	1	$ 82.00	AMX Pro-X 82"	$ 82.00
Fire Blanket	2	$ 10.49	29314	$ 20.98
Goex Black Powder	1	$ 17.75	GX4F	$ 17.75
Cessaroni K750 Rocket Engine	3	152.95	71466	$ 458.85
Cessaroni J335 Rocket Engine	1	$ 51.90	71356	$ 51.90
Pro 54 6G Motor Casing	1	105.93	71035	$ 105.93
15 min Epoxy 9 oz	2	$ 15.95	EPY-15	$ 31.90
Website Hosting Cost	1	$ 11.99	www.ucrocketry.com	$ 11.99
Misc. Overheads	-	-		$ 50.00
Shipping & Handling	-	-		$ 94.14
TOTAL				$1,750.62

Figure 51: Table of Current Rocket Expenses

Payload Expenses				
Part	Quanity	Price	Part Number	Subtotal
Arduino Mega 2560	3	$ 45.00	2560 R3	$ 135.00
4S 5200 mAh LiPo Battery Pack	2	$ 39.88	912700002-0	$ 79.76
StratoLogger Altimeter	3	$ 58.80	SL100	$ 176.40
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	$ 50.00	AMX Pro-X 36"	$ 50.00
Aluminum 6061 Plate Stock 12x12x0.125	1	$ 28.56	89015K18	$ 28.56
Acrylic/PVC Plate Stock 12x12x0.1250	1	$ 17.17	8650K12	$ 17.17
Torsion Spring 17 in-lbs	3	$ 1.78	9271K591	$ 5.34
Torsion Spring 28 in-lbs	3	$ 2.19	9271K592	$ 6.57
Steel Hinges	3	$ 1.62	16175A12	$ 4.86
Threaded Rod 1/4-20	1	$ 9.80	98935A205	$ 9.80
50 lb Nylon Cable	1	$ 15.35	9442T4	$ 15.35
Towline Release	2	$ 10.00	TOP-05013	$ 20.00
Easy to Machine ABS (PIL Body)	1	$ 14.07	8586K361	$ 14.07
Impact Resistant PolyCabonate Tube	1	$ 23.17	8585K78	$ 23.17
Clear Cast Acrylic Sheet	1	$ 23.21	8560K259	$ 23.21
PVC Ground Station Antenna Structure	1	$ 50.00		$ 50.00
MG90a Servo Motor	2	$ 2.62		$ 5.24
Ground Weather Station	1	$ 109.00	WS2080	$ 109.00
Misc. Overhead Costs	-	-		$ 100.00
Shipping & Handling	-	-		$ 108.98
TOTAL				$2,288.65

Figure 51: Table of Current Payload Expenses

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). The team has reached out to the University of Cincinnati's OSGC contact Professor Kelly Cohen and has begun the process of securing funds to be available by the end of January.

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 have currently reached out to local companies. We have been able to secure time on machines at both Federal Equipment Company and ThyssenKrupp Bilstein and are pending donations from TKF Conveyor and Barnes Aerospace.

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.

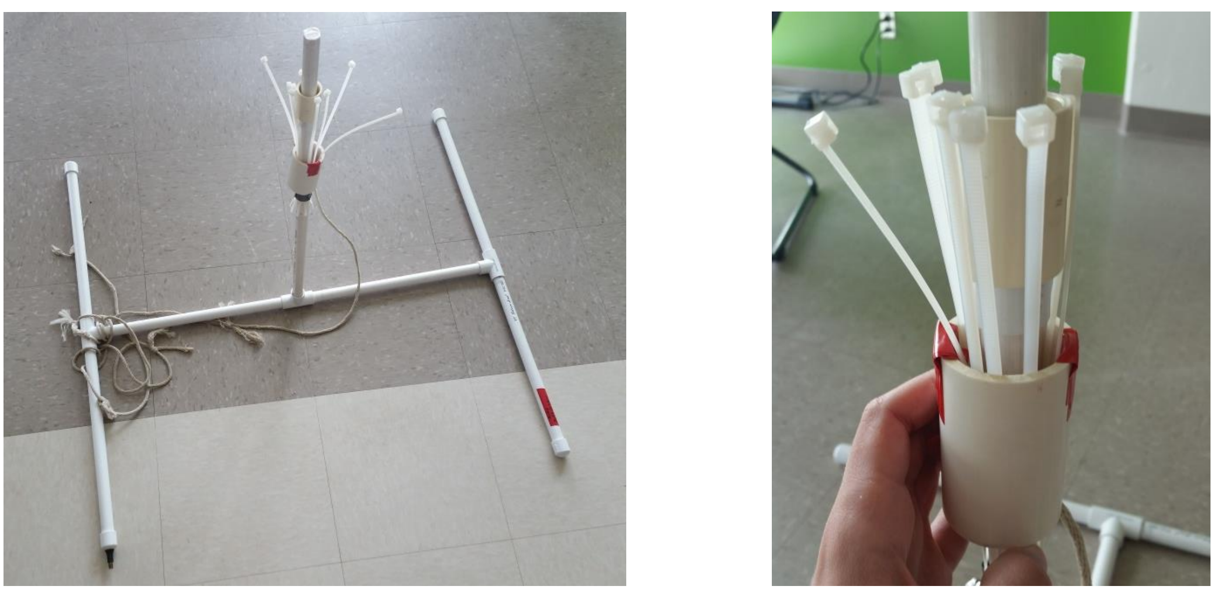


Figure 53: Stand for Educational Engagement

Evaluation and Documentation

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

Additional Steps

Going forward, we plan to hold a design contest for the body of our rocket. This will engage UC students and raise awareness of our team throughout campus. This contest will be held during February.

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 carrying a planetary probe to approximately 1 mile above ground level that will then be deployed via a fairing nose cone section at around 1500 feet. 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 refined designs, and believe we are very close to a successful design that will be ready for launch in the coming months.

8 FIGURE APPENDIX