Preliminary Design Reveiw
NASA University Student Launch, 2018

Target Detection

by

The University of Cincinnati - Galacticats Senior Design Team
2850 Campus Way Baldwin 745,
Cincinnati OH 45221

November 3, 2017

Contents

1 General Information

1.1 Team Contact Information

Faculty Advisor
Mark Fellows

B.S. and M.S. in Aerospace Engineering; Masters of Business Administration
Adjunct Professor, Aerospace Engineering & Engineering Mechanics
606L Old Chem Building
P.O. Box 210070, Cincinnati, OH 45221-0070
Phone: (937) 469-1934
Fax: (513) 556-5038
Email: mark.fellows@ucmail.uc.edu

Purchasing and Test Advisor
Curtis Fox

Masters in Aerospace Engineering
Sr. Research Associate and Adjunct Professor @ ERC 466
2901 Woodside Drive, Cincinnati, OH 45221
Tel: (513)556-3602
Fax: (513)556-5038

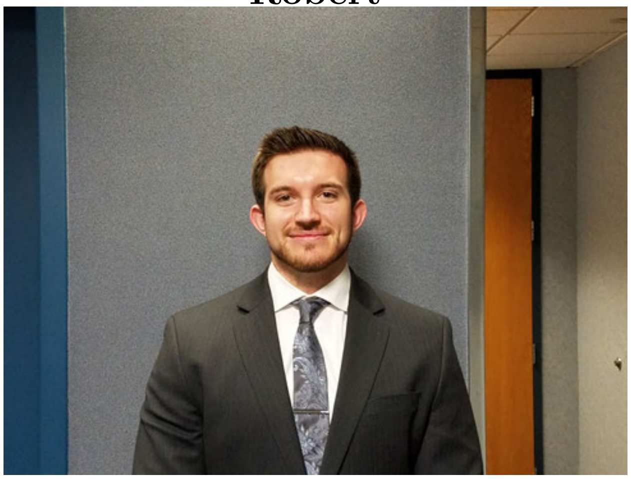
Team Mentor
Timothy Arnett

NAR Level 2, Graduate Student, Aerospace Engineering, University of Cincinnati
Email: arnetttj@mail.uc.edu

Student Team Leader
Justin

Undergraduate Student, Aerospace Engineering, University of Cincinnati
Email: young2jt@mail.uc.edu

Safety Officer
Robert



Undergraduate Student, Aerospace Engineering, University of Cincinnati
Email: lynnrr@mail.uc.edu

1.2 NAR/TRA Contact Information

David E. Cook - West Virginia and Southern Ohio Association of Rocketry (WVSOAR) 564
Email: dacook58@aol.com
Gary Dickinson - Tripoli Mid Ohio Section 31
Email: gdickinson@woh.rr.com
Lee Berry - Team Ohio Rocketry, NAR Section 703
Phone: (937)667-5297
Email: klnjberry@hotmail.com

1.3 Educational Outreach Contacts

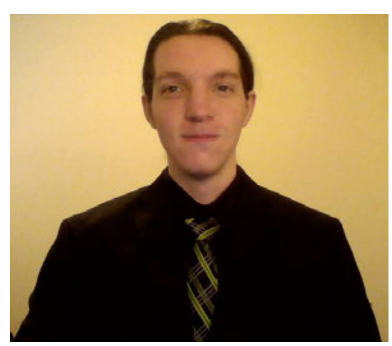
Andy Schroeder - Oak Hills High School
Email: schroeder_a@ohlsd.org

1.4 Meet the Team

Patrick

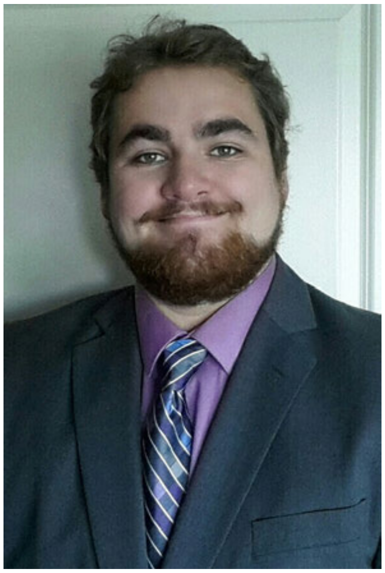
Patrick is currently an undergraduate student at the University of Cincinnati for Aerospace Engineering.He serves as Chief Editor of official documents and provides support for both the rocket and payload teams.After graduation, he hopes to work as an Astronautical Engineer working on satellite systems. He has completed 2 internship semesters at Ally PLM, working within CAD software programs, helping engineers from multiple backgrounds on their engineering projects. He has also spent 2 semesters as an intern at TECT Power, working on the forging of turbine blades. Patrick likes to play tennis and racquetball with friends and play interesting board games.

Jacob



Jacob is a fifth year Aerospace Engineering undergraduate student, and serves as the Galacticats Rocket Design Lead, drawing on his previous model rocketry and aircraft design experience. He has completed two internships: the first with the Air Force Research Laboratory, working on the design and development of small unmanned aerial systems, and the second with QuEST Global, designing thermal analysis and CFD post-processing automation tools. Jacob enjoys building and playing guitars, aeromodelling, amateur astronomy, and programming. He aspires to work in control systems engineering, for astronautical applications, after graduation.

Mason



Mason
is currently an undergraduate student at the University of Cincinnati for Aerospace Engineering. He hopes to work as an Astronautical Engineer working with advanced spacecraft propulsion systems. He has had 3 internships working with Rhinestahl Corporation working with Solidworks modeling software, quality assurance, and assisting engineers with problem solutions. He also spent 2 semesters in Germany as a laboratory assistant at Forschungszentrum Jülich. There he conducted experiments studying water condensation in the boundary layer of a flow, and analysed the data. Mason enjoys knitting, playing sports, and bicycling.

Dane

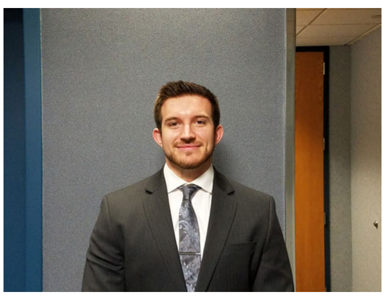
Dane is currently a senior Computer Science major at the University of Cincinnati and he plans to pursue a Masters of Engineering in Computer Science after graduation this May. He is interested in embedded, mobile, and large-scale application development as well as parallel computing and data science. He has worked as an R&D intern at the Air Force Research Laboratory in Dayton, Ohio as well as a full-stack developer for several startups in the Cincinnati area. Dane enjoys programming and 3D design/printing, and currently spends a majority of his time developing a social robotics network web application for his CS senior design project. Dane will be responsible for developing a parallel image-processing program for use in the payload's target detection system.

Austin

Austin is in his final year at the University of Cincinnati studying Information Systems with a minor in Entrepreneurship. After graduation he is looking forward to starting a career as a technology analyst is the aerospace industry. Previously he interned with CGI federal working as business analysts. There he had the opportunity to work with Kanban team managing incident tickets, updating databases and coordinating discussions with knowledge experts and stakeholders to help identify root causes and evaluate solutions. Austin is working with the payload team developing the onboard computer systems. In his free time he likes to read, code, and play video games such as Kerbal Space Program.

Krysta

Krysta is currently an undergraduate student at the University of Cincinnati for Aerospace Engineering working on her bachelors degree. She plans to pursue a career in the aerospace manufacturing industry as a project manager. She has completed four co-op rotations at Barnes Aerospace, one in quality and three in manufacturing. She has experience in managing manufacturing projects, 3D design work, internal and external quality procedures and supplier and vendor communications. During this time she has gained communication, leadership, design and measurement experience and skills. Krysta will serve on the Galacticats team as part of the rocket team.



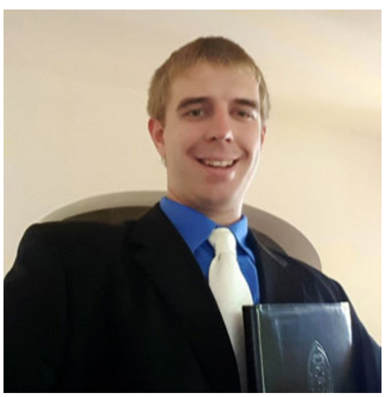
Robert

Robert is currently is an undergraduate student at the University of Cincinnati where he is working on a bachelors in aerospace engineer and a minor in astrophysics. He plans to pursue a career as a structural engineer specializing in spacecraft composite structures. He has completed two co-op rotations with EDAC Composites (Now Meggitt) in Erlanger, Kentucky. During which he was tasked with collaborating with project engineers on their projects, learned the basic of composite layup, as well as basic CAD Design skills through CNC tooling fixture design. He has also completed another two co-op rotation with QuEST Global in East Hartford, Connecticut. There, he was tasked with creating and interpreting stress models, calculating lifing through NDS and fracture mechanics, and assessing structural implications of repair plans for engine components for the F-22, C-17, and F-35 aircraft. Through his time in the field and the classroom, Robert has gained skills in ANSYS FEA, ANSYS Workbench FEA, Abaqus FEA, Solidworks CAD, Siemens NX 9 CAD, Autodesk Inventor CAD, and MATLAB. Outside of class Robert enjoys backpacking, kayaking, and exploring the world around him.

Liberty

Liberty is currently an undergraduate and graduate student at the University of Cincinnati for Aerospace Engineering. She will commission in the United States Air Force as a 2nd Lieutenant in May of 2019 when she completes her degrees. She hopes to serve as an Astronautical Engineer working on Space and Missiles systems. She has completed 2 internships at NASA Goddard Space Flight Center, the first working on star scanner attitude determination and the last in the Observational Astrophysics Laboratory. She has joined Dr. Shaaban Abdallah's team in Cincinnati to work on a disposable microjet engine project for her graduate studies. Liberty loves to travel the world to learn languages, about different cultures, and to cook like the locals. She spent a semester in Varanasi, India for Project Global Officer, and returns frequently to a Buddhist monastery in Nepal where she teaches English. Liberty will serve the Galacticats as the Webmaster and on the Payload team.

Darren



Darren is the Payload and Embedded Systems Team Lead. He is a fifth-year Aerospace Engineering student at the University of Cincinnati, and is also pursuing a minor in computer science. His first three co-op semesters were spent at Barnes Aerospace as a Process Engineer for jet engine manufacturing, working on document control, Solidworks modeling, and non-conforming parts rework. His last two co-op semesters were spent at L3 Cincinnati Electronics as a Design Verification Engineer, creating LabVIEW programs for Space Transceiver testing, TestStand programs for IR camera test automation, and Excel VBA and Matlab programs for data manipulation/processing. After graduation he will be returning to L3 to continue in a career as a Design Verification Engineer. His other interests include drumming and ultimate frisbee.

Tyler

Tyler is the team treasurer, and a member of the payload design team. He is a fifth-year aerospace engineering student at the University of Cincinnati, and will graduate with his Bachelor's Degree in May, 2018. He has experience working at Meyer Tool, Inc. as a project engineer, primarily planning machining processes, quoting machining work-scopes, and analyzing process efficiency. He also has an interest in programming and simulation, having learned MATLAB/Simulink, Java, and HTML at various points during his education. He intends to seek out the final frontier in his professional career.

Justin

Justin is the project lead, and is a 5th year aerospace engineering student at the University of Cincinnati. His co-op experience consists of 4 semesters at TECT Power in Utica, NY, where he developed a passion for working with others in group environments. Justin picked up experience in NX9, VBA Excel programming, and systems engineering methods during his time in the quality, design, and robotics divisions of TECT Power. Outside of work and school Justin enjoys spending time with friends, playing board games, card games, video games, and hiking. Justin hopes to be able to continue working in large groups and work with other engineers to solve various aerospace problems, preferably in the astronautics section of aerospace engineering.

2 List of Acronyms

ABS - Acrylonitrile Butadiene Styrene
AEEM - UC Department of Aerospace Engineering and Engineering Mechanics
AIC - Academic Intercollegiate Competition
API - Application Programming Interface
CDR - Critical Design Review
CEAS - College of Engineering and Applied Science
CPU - Central Processing Unit
CSI - Camera Serial Interface
DDR - Double Data Rate
eMMC - embedded Multi Media Controller
FAA - Federal Aviation Administration
FMEA - Failure Modes and Effects Analysis
FOV - Field of View
FPS - Frames per Second
ft - Feet
ft/s - Feet per Second
GPIO - General Purpose Input/Output
GPS - Global Positioning System
GPU - Graphics Processing Unit
GUI - Graphical User Interface
HDMI - High Definition Multimedia Interface
HIPS - High Impact Polystyrene
IMU - Inertial Measurement Unit
in - Inches
I/O - Input/Output
JST - Japan Solderless Terminal
Lbs - Pounds
LED - Light Emitting Diode
MAX - Maximum
MPH - Miles per Hour
N/A - Not Available
NAR - National Association of Rocketry
OSGC - Ohio Space Grant Consortium
Oz - Ounces
PDR - Preliminary Design Review
PETG - Polyethylene Terephthalate Glycol-modified
PJB - Pre-Job Briefing
PLA - Polylactic Acid
PPE - Personal Protective Equipment
Qty - Quantity
RAM - Random Access Memory
R/C - Remote Control
ROS - Robot Operating System

RPi - Raspberry Pi
RPSMA - Reverse Polarity SubMiniature version A
SD - Secure Digital
SEDS - Students for the Exploration and Development of Space
SICHOP - Student Innovative Creative Hands-On Project
SoC - System on a Chip
UC - University of Cincinnati
USB - Universal Serial Bus
USLI - University Student Launch Initiative
V - Version

3 Team and Design Overviews

3.1 Team Summary

Team Name: Galacticats
Mailing Address: 2850 Campus Way Baldwin 745, Cincinnati, OH 45221
Team Mentor: Tim Arnett, NAR 94008 L2

3.2 Launch Vehicle Summary

Target detection being the chosen scientific payload, the mission of the launch vehicle is twofold: to reach an altitude of 5,280 feet AGL and safely deploy said payload. Successful deployment of the payload hinges upon the development of a robust launching platform. The current launch vehicle design, to be further outlined below, is comprised of two segments. The payload and its recovery subsystem will be housed in the top section, along with the rocket's drogue parachute. The bottom section will house the rocket's main parachute, telemetry subsystem, and any required ballast. At apogee, the payload and nose cone will be ejected, at which point the rocket will deploy its drogue chute, and later its main chute, to slow descent rate accordingly. Designed to be fully reusable, construction methodology that ensures minimal post-flight preparation will be utilized.

3.3 Payload Summary

The mission of this payload is target detection. The payload will include a camera, computer, and power system, as well as sensors for measuring and transmitting flight data. The payload will sit below the nose cone to be easily deployable when the rocket separates at apogee. It will be assisted with a drogue chute and shock cord, as well as a structured casing to house all electronics. It will contain a Pixy camera sensor to identify the targets, an Inertial Measurement Unit to track orientation, a GPS unit for position tracking, and a radio for data transmission. Coding competencies needed for a successful system are Python and MATLAB, which multiple members of the team have experience with.

4 Changes Made Since the Proposal

4.1 Launch Vehicle

To both afford easier access during construction and account for new developments in regards to payload design, the launch vehicle design has been scaled up to an airframe diameter of 7.67 inches. In addition the rocket design team was considering a staged main parachute recovery system, where the main parachute would be partially unfurled at apogee, and fully unfurled at a lower altitude. However, this idea has been discarded in favor of the more traditional drogue and main chute combination, to meet landing energy requirements. The altimeters have been relocated to within the coupler, for ease of access, and to add distance between such and the telemetry electronics. As well, the bulkhead between the rocket's drogue parachute housing and the payload bay has been removed to simplify the launch vehicles ejection system.

4.2 Payload

To accommodate a UC Computer Science project, the flight computer selection was changed to the NVIDIA Jetson TK1 because it has a GPU. This will enhance the real-time target identification capabilities of the payload.

4.3 Project Plan

The changes to the project plan mainly include budgeting and schedule adjustments. The project estimated expenses increased from $12,650 to $16,325 due to implemented budgeting and safety changes. This also prompted a change in allocation of resources, which will be further highlighted in section 8. Schedule adjustments include a change of launch dates due to a launch field cancelling a launch date, and more detailed deadlines as they will occur further into the competition. The deadlines now detail all deliverables until the FRR milestone on March 5th. These changes can be found in the gantt charts in Appendix D of the document.

5 Launch Vehicle Criteria: Selection, Design, and Rationale

5.1 Design Requiremnts and Driving Factors

For the NASA USLI competition, the University of Cincinnati Galacticats aims to design, construct, and successfully fly a high powered launch vehicle for deployment of a target detection payload. Evaluation of launch vehicle success is dependant upon several criteria, these being:

- The launch vehicle shall reach an apogee of 5,280 feet AGL.
- The launch vehicle shall deploy a target detection payload.

- The launch vehicle shall deploy recovery devices in order to achieve a landing energy of no more than 75 ft. lbf.

- The launch vehicle shall be constructed in a manner such that it is reusable, requiring no repairs or modifications for multiple flights in a given day.

The above stated mission criteria form the basic requirements that will govern the design of the launch vehicle throughout the project. Though there are many design requirements listed in the NASA USLI Handbook that are expected of developed launch vehicles, there are a few key driving factors which greatly influence the course of the design. Through the preliminary research, testing, and simulation that the team has conducted thus far, these driving factors are: payload dimensions and mass, rocket motor selection, recovery device selection, and airframe material selection. Changes to each of these parameters (trade studies of which are presented below) can greatly affect the performance and viability of the overall design.
Increases or decreases in payload mass effect the achievable altitude of the launch vehicle, as well as the position of the launch vehicle's center of gravity, which in turn affects the stability margin. Achieving the altitude requirement relies heavily on choosing the appropriate rocket motor, which can be made difficult due to the somewhat limited supply available. In addition, though there exists a wide variety of motors across the power spectrum, having to drop or increase one step can have a significant impact on apogee altitudes as well as the rocket's center of gravity, and thus the stability margin. Ensuring that landing energy is below the required threshold, that the drift distances are kept to a minimum, and that meeting the recovery requirement hinges on selecting appropriate recovery devices. The diameters, materials, drag coefficients, and reliability of both the drogue and main parachutes all must be accounted for. Finally, airframe material selection is key. Reusability centers on robust design, though keeping the mass incurred to a minimum is important considering possible total system mass gains (from payload design changes and through construction).

5.2 Current Design Overview

Several designs, as outlined further below in table 1, have been considered for the launch vehicle. The current favored launch vehicle design has an external body diameter of 7.67 inches, to accommodate developing changes in regards to payload design, as well as ease of construction. While building rockets to use for HPR Level 1 and Level 2 certifications, the team experienced some challenges in working with smaller airframe diameters. Being that the payload dimensions are likely to increase as a result of recent developments, the decision was made to move to a larger airframe size. The overall length of the launch vehicle is currently 124.37 inches, and the mass sits at 30.78 pounds (including the motor and payload). The launch vehicle is comprised of two sections, section 1 housing the payload and launch vehicle drogue parachute, section 2 containing the rocket's main parachute and telemetry systems. The favored motor is currently a Cesaroni L995, chosen due to its ability to lift the launch vehicle nearest to the required altitude. The decision was made early on to strongly consider Cesaroni motors if at all possible, due to their ease of use and reliability. See figure 2 for a cross-sectional view of the current launch vehicle design, and note that the following sections will more deeply investigate the trade studies performed thus far.

5.3 Launch Vehicle Parameters

5.3.1 Design Summary

Table 1 below has the parameters of the favored designs during different phases of the project. v1.1 was the original design but the airframe was later enlarged to allow for more flexibility for the payload design, as well as to allow more ease of access during construction of the launch vehicle. There were four iterations of version 2 of the rocket that tested different fin shapes, detailed in table 7. The fin design of v2.3.1 was chosen for its simple construction and overall aerodynamic properties. v2.3.1 was then revised to v2.3.2 due to expected difficulties assembling and reinforcing the telemetry bay as well as the unavailability of a long enough airframe tube for construction. A scale comparison of these three rocket designs is detailed in figure 1. The favored launch vehicle design (v2.3.2) is detailed in figure 2. The launch vehicle will have 5 separate bays and the nose cone. During launch the nose cone will be secured to the payload/drogue parachute bay using thin nylon shear pins and will be ejected with the payload during flight. The altimeter bay will be constructed out of an airframe tube coupler and be secured inside the payload/drogue parachute bay from 52" up vertically using 3 removable bolts and inside the main parachute bay from 57" down vertically using thin nylon shear pins. The telemetry bay will be secured in the main parachute bay and motor bay from 87" up and 92" down respectively, using 3 removable bolts for each connection.

Version	Motor	Length (in)	Outer Diameter (in)	Launch Mass (lbs.)	Descent Mass (lbs.)	Stability Margin at Launch
v1.1	Cesaroni K635	86.25	5.54	13.83	10.26	2.49
v2.3.1	Cesaroni L995	124.37	7.67	31.72	20.11	2.44
v2.3.2	Cesaroni L995	124.37	7.67	30.73	19.11	2.34

Table 1: Details of the favored designs as trade studies were completed.

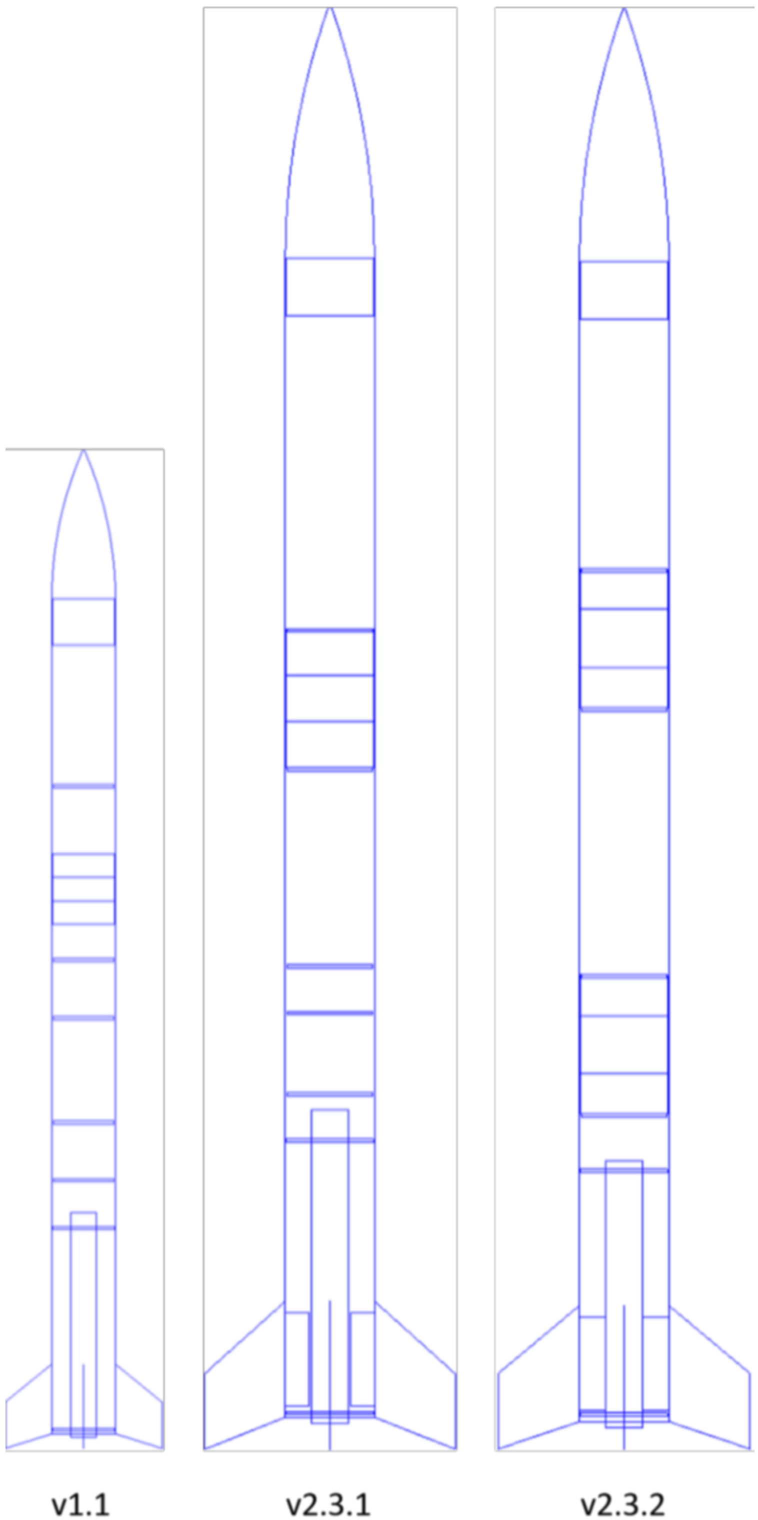


Figure 1: Scale comparison of the three main rocket design iterations.

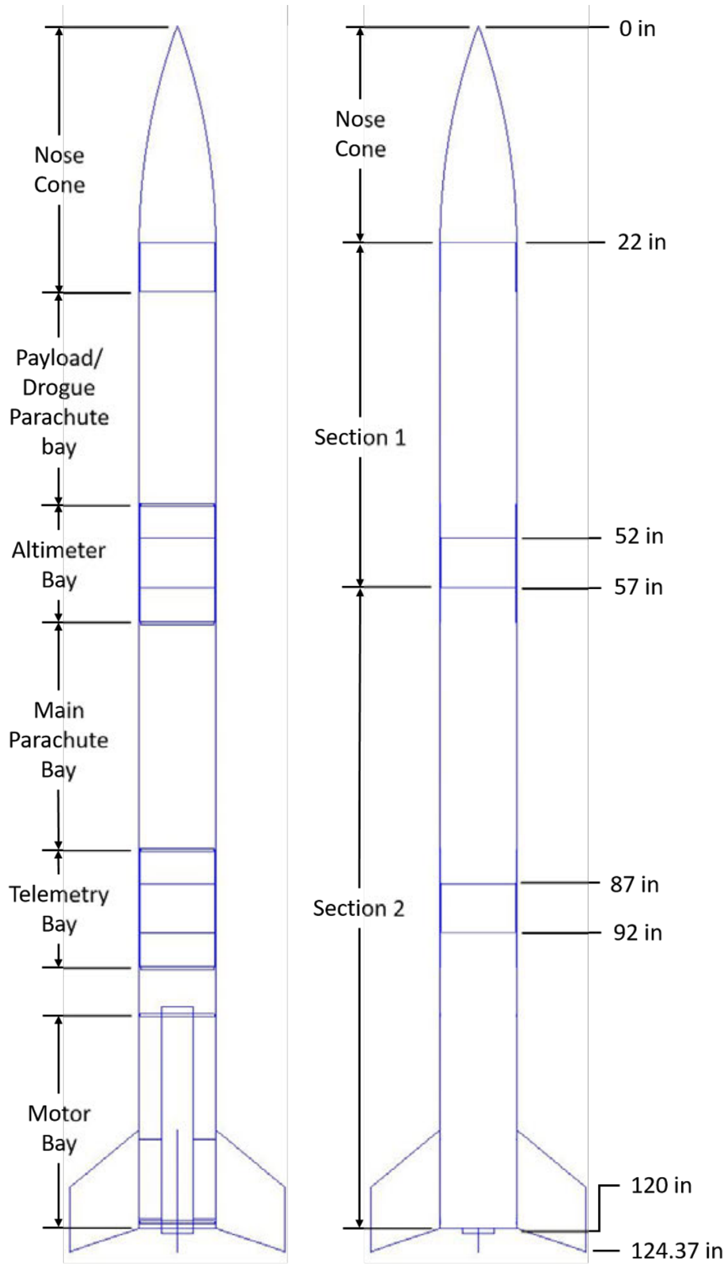


Figure 2: Side and cross sectional view of the launch vehicle in launch ready configuration.

5.3.2 Flight Events

The current design of the rocket requires two separation events. There will be two sets of ejection charges located on the top bulkheads of each electronics bay as shown in figure 3. The first set of ejection charges will detonate at apogee and at a slightly lower altitude (figure 4), deploying the payload and drogue parachute of the launch vehicle. The placement of these charges on the bulkhead of the altimeter bay will allow for easier ejection of the payload and drogue parachute. Alternatively, if the charge were to be placed on the underside of the nose cone and the payload was ejected from between the payload and altimeter bays, there would be a greater risk of the payload becoming entangled in the shock cord connecting the two bays. The second set of ejection charges will detonate at two consecutive altitudes of 700 ft and 500 ft. These detonations, shown in figure 5, will separate the altimeter bay and payload/drogue parachute bay from the main parachute bay, also deploying the main parachute. It is important to note that the payload will be capturing images during the descent phase of the mission and that there is a possibility that the launch vehicle will obstruct the view of the camera. In order to alleviate this concern, the payload is separated from the rocket body before the latter releases its main parachute, allowing the two sections to gain distance from one another.

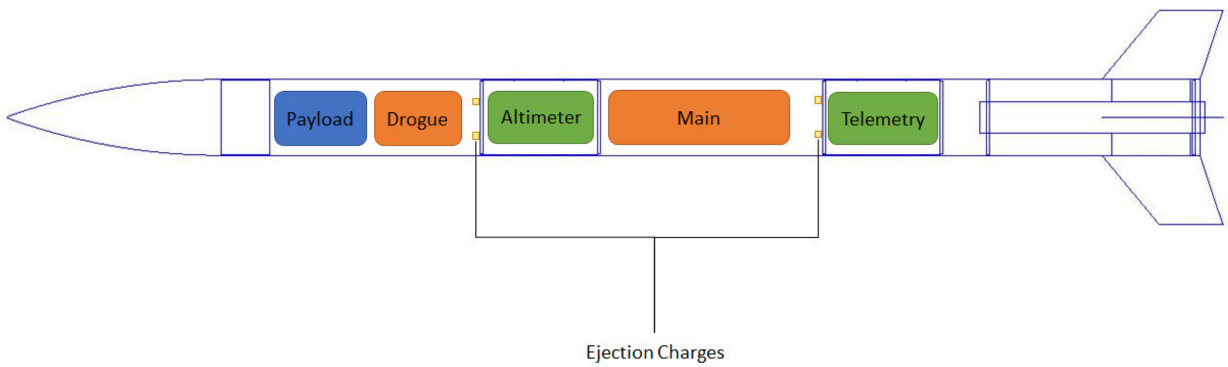


Figure 3: Location of ejection charges and bay configurations. Note: Objects in rocket are not to scale.

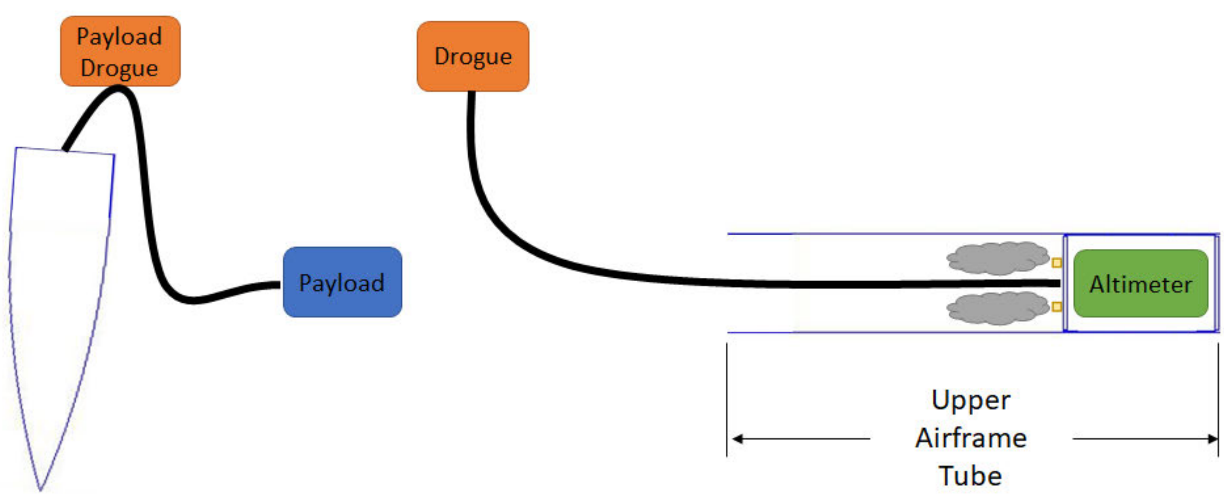


Figure 4: Ignition of the payload/drogue parachute ejection charges at apogee and deployment of the drogue parachute and payload. Note: Objects in rocket are not to scale.

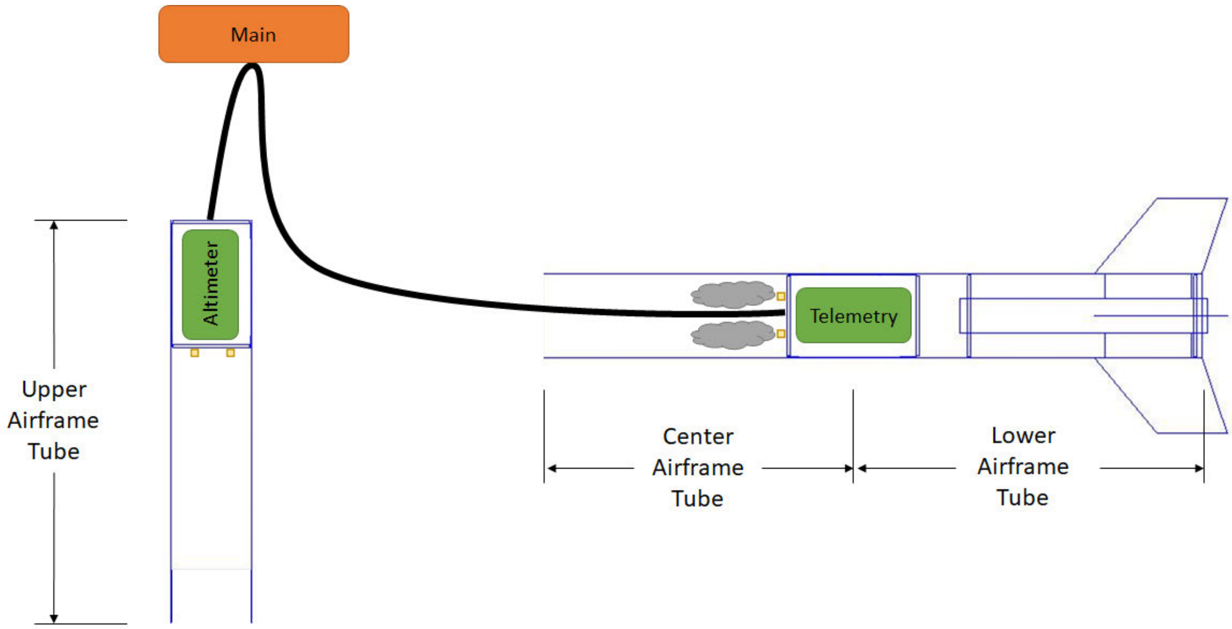


Figure 5: Ignition of the main parachute ejection charges at 700 ft and 500 ft and deployment of the main parachute. Note: Objects in rocket are not to scale.

5.4 Airframe

The current size of the airframe is 124.37" in length with a 7.67" external diameter. The diameter is large enough to allow for adjustments in payload sizing based on the options that are currently being explored. The choice for airframe material is currently a carbon fiber wrapped, brown kraft tube, chosen for its light weight and durability. The airframe of the rocket will consist of three 30" airframe tubes with two 5" couplers. Airframe tubes of different materials were evaluated concerning cost, strength rating, weight and dimensions. Data gathered for use in assessing airframe material is presented in table 2.

Research on the relative strength of materials provided enough information to determine the strength rating of the airframes relative to one another. Table 2 contains the data that was retrieved during this trade study, which provided an idea of the most effective options. The strength ratings provided in table 2 are admittedly subjective, such being arrived at solely through discussions with experienced rocketeers. More technical information will be requested from suppliers of top candidates or collected from test articles.

5.5 Recovery Subsystem

5.5.1 Overview

The recovery subsystem consists of a drogue parachute, main parachute, shock cords, black powder charges, altimeter bay, and telemetry bay. The altimeter bay will contain a redundant altimeter system, responsible for detonating black powder ejection charges which deploy the payload and launch vehicle parachutes. The telemetry bay will contain

Full Tube Material	Manufacturers	Dimensions	Price ($)	Strength Rating	Weight (lb)
Pre-glassed phenolic tube	- Public Missiles	ID: 7.512" L: 48"	628.97	Very High	6.05
Phenolic tube with carbon fiber wrapping	- Public Missiles (phenolic) - Jamestown Distributors (carbon) - Aeropoxy (resin)	ID: 7.512" L: 48"	351.06	High	13.52
Phenolic tube with fiberglass wrapping	- Public Missiles (phenolic) - Jamestown Distributors (carbon) - Aeropoxy (resin)	ID: 7.512" L: 48"	291.62	High	13.94
Phenolic tube	- Public Missiles	ID: 7.512" L: 48"	178.97	Low	3.435
Fiberglass Wound tube	- Proline Composites	ID: 7.500" OD: 7.740" L: 48"	1027.48	Very high	11.18
Brown Kraft paper tube with carbon fiber wrapping	- Loc Precision (brown) - Jamestown Distributors (carbon) - Aeropoxy (resin)	ID: 7.515" OD: 7.675" L: 30"	295.19	High	13.14
Brown Kraft paper tube with fiberglass wrapping	- Loc Precision (brown) - Jamestown Distributors (carbon) - Aeropoxy (resin)	ID: 7.515" OD: 7.675" L: 30"	235.75	High	13.53
Brown Kraft paper tube	- Loc Precision	ID: 7.515" OD: 7.675" L: 30"	123.1	Low	3.78

Table 2: Comparison of airframe materials based on price, strength and weight.

the positioning system consisting of a GPS and a radio transceiver for communicating with the ground station.

5.5.2 Parachute

The driving constraint of parachute choice is that the launch vehicle must have a landing energy of no more than 75 ft-lbf, as specified in the USLI Handbook. Using a rearranged form of equation (1) below, the maximum speed that the launch vehicle can land at was estimated to be 15.89 ft/s with a current estimated descending mass of 19.11 lbs. In order to achieve this landing energy a trade study was conducted of various parachute sizes and manufacturers. Only options from two manufacturers have been considered thus far, as most manufacturers do not provide drag data. The team plans to contact additional manufacturers in an effort to gather data on more parachute options. Based on the results of this study, detailed in table 3, the ideal parachute size is 96". It should be noted that the equations used to simulate these landing energies do not account for a horizontal velocity vector acting on the rocket body. An additional trade study was done to compare the effects of using the main parachute furled with a Jolly Logic altimeter instead of a drogue parachute. The furled parachute makes the deployment system simpler, however it also results in less drag. It was decided that due to the weight of the larger launch vehicle, the greater drag created by the drogue parachute would be better for reducing velocity. Two additional trade studies have been planned to determine the optimal altitude at which to deploy the launch vehicle's main parachute and optimal drogue parachute size. These trade studies will help to ensure that the descent vehicle is slowed to a sufficient velocity before ejection of the main parachute. The current deployment altitude is set at 700 ft due to such being a standard altitude used in model rocketry flights.

$$Ke = \frac{1}{2}mv^2 \tag{1}$$

$$V = \sqrt{\frac{2mg}{Cd\rho S}} \tag{2}$$

5.5.3 Rocket Body Electronics Shielding

The purpose of shielding in the rocket electronics is to prevent electromagnetic interference (EMI) in the altimeters and igniters. This helps ensure that there will not be a misfire before the rocket reaches the target altitudes. A very simple way to shield the altimeter is to cover the inside of the container bay in a conductive material. A trade study was conducted to compare the different materials used in EMI shielding. The three options investigated were copper tape, aluminum tape, and shielding paint. Because copper is more conductive than aluminum it is often considered to be a more effective shielding material. Shielding paint often is just as effective as copper tape because it usually utilizes copper as the shielding material. Due to how easy it is to apply in more confined spaces, shielding paint is the material selected for altimeter bay.

Approximate Parachute Diameter (in.)	Mass of descent vehicle (lbs.)	FruityChutes Drag Coefficients	FruityChutes Descent Energy (ft-lbf)	SkyAngle Drag Coefficients	SkyAngle Descent Energy (ft-lbf)
60-66	19.11	2.2	111	1.87	122
72-78		2.2	77	1.46	108
84-90		2.2	56	1.89	66
96-102		2.2	43	1.16	73

Table 3: Contains values of descent velocity and energy from the parachute manufacturer website verified by hand calculations. Note that this only contains vertical descent velocities.

5.5.4 Rocket Body Tracking Electronics

The telemetry system provides the location of the rocket segments by sending GPS coordinates from the launch vehicle tracking electronics to a ground station. For the telemetry electronics of this rocket, the system selected as the favored design was a custom configuration using an arduino with a radio transmitter and GPS.
Ardupilot is an option to explore if the control functionality is switched off. Ardupilot is an off the shelf system that would have the ability to process all of the applicable information needed. Looking into off the shelf developed tracking electronics can save time and is more guaranteed to function properly.

Figure 6: Launch vehicle tracking subsystem diagram

5.5.5 Rocket Body Altimiter Electronics

The altimeter electronics consists of a set of redundant Perfectflite StratologgerCF altimeters wired into two sets of ejection charges for the main parachute and payload/drogue parachute. This system will work by detonating the primary drogue/payload charge at apogee and the secondary at a slightly lower altitude. At 700 ft the primary main parachute ejection charge will detonate followed by the secondary at 500 ft. These redundancies help to ensure that the parachutes will deploy and the payload will be ejected.

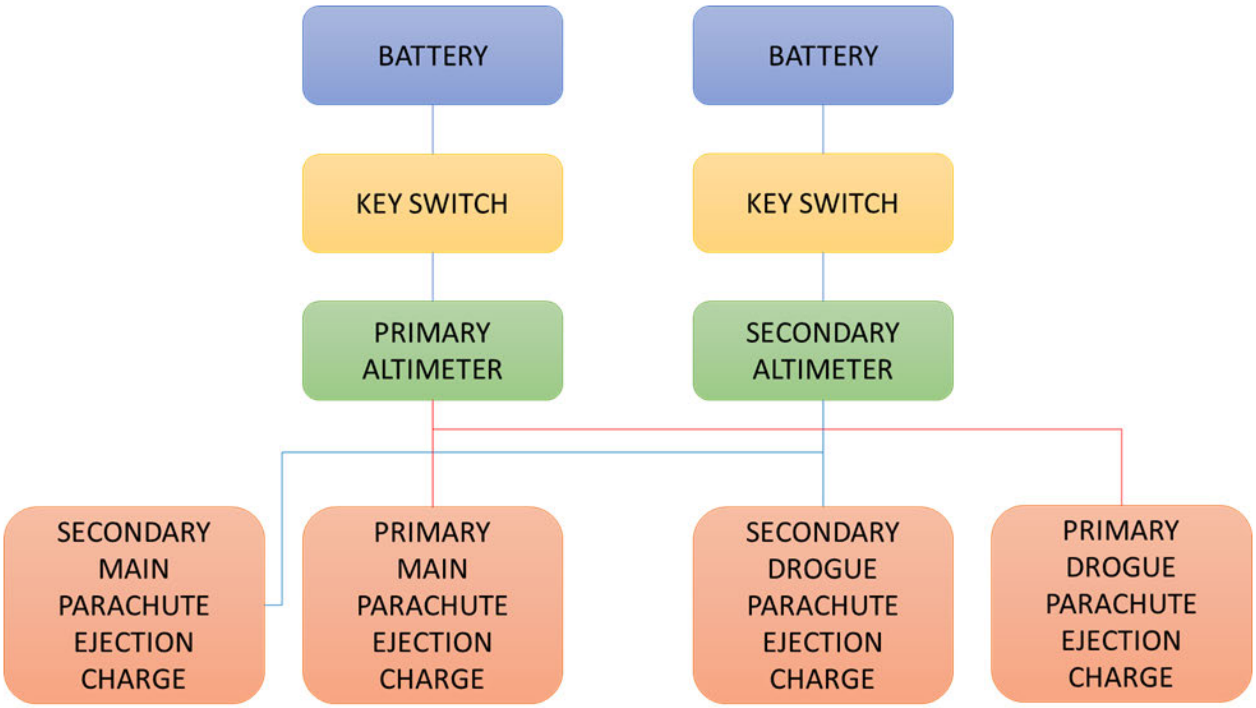


Figure 7: Diagram of payload electronics

5.6 Motor Subsystem

The motor subsystem will consist of the motor mount tube, centering rings, motor casing, and motor. The motor mount tube holds the motor in place during launch while the centering rings ensure that it remains parallel to the longitudinal axis of the vehicle. The motor mount tube also supplies a surface to attach the fins to. Several trade studies were conducted in order to determine the best motor for this rocket design.

The first consideration was which motor supplier to use. Based on conducted research of the last several UC USLI teams' launch issues, a common problem was error during construction of motors. Cesaroni Technology manufactures extremely simple to assemble motors. Given the low maintenance nature and ease of use, Cesaroni Technology will be the primary motor manufacturer of choice. The final consideration was which motor was the most appropriate for the current leading rocket design. More simulations were conducted in Rocksim 9 to determine which of the Cesaroni motors achieved an altitude close to the mission target. Based on these simulations, detailed in table 4, the optimal motor for the current rocket design was between the Cesaroni L995 and L851 which performed very similarly.

Size (mm)	Model	Max. Altitude (ft)	Max Vel. (ft/s)	Rail Exit Vel. (ft/s)
75	Cesaroni L1050	6063	742	74
75	Cesaroni L3200	5313	786	130
75	Cesaroni L851	5823	692	63
75	Cesaroni L995	5813	705	78

Table 4: Contains the simulation results of the four different motors. Simulations completed assuming 0 mph wind conditions as well as a 12ft launch rail.

In order to validate these two motor options and to decide which one was the best for the current design, another trade study was conducted comparing the performances of these two engines under increased payload mass. The payload mass was increased incrementally up to an additional 30% of its estimated current weight. Based on the results detailed in table 5, the L995 was determined to be the best choice for the current favored design. This is primarily because the maximum velocity achieved is higher for the L995 than the L851. A higher thrust and maximum velocity will do better to ensure that the minimum rail exit velocity is achieved during launch if more mass is added to the rocket.

5.7 Fin Design and Construction

The current favored fin design choice is a normal tapered sweep. Data gathered from Rocksim helped to validate this choice by providing data on all four fin design options detailed in table 7. Normal tapered swept fins offer a good balance of all of the considerations listed in the simulation results, as well as being the most simple design to manufacture. Forward tapered swept fins push the center of pressure forward causing higher instabilities. Another issue with a forward sweep is fluttering during launch, which can damage the rocket if the fins begin to oscillate at a natural frequency of the design. During incompressible flows elliptical fins provide the lowest coefficients of drag, but the rocket is actually going to be exceeding the velocity where elliptical fins would be effective. Ringtail fins are the most stable option for a rocket however they create an large amount of drag during flight. This is supported in table 7 by the drastic decrease in maximum altitude achieved when using this fin design.

The fins on the rocket will be non-removable. This was determined as the best course of action to prevent the added weight of the hardware that removable wings impose. The fins will be attached using the through wall method, which from NAR safety standards is considered the most effective way to mount the fins securely. From this there will be epoxy added to support the mounts.

An individual component comparison trade study, led to finding the most effective fin material based on the options and comparison data. Table 6 is a visual comparing price, strength and weight of all the materials considered. The fins are designed to be strong and

Motor (Cesaroni)	Percentage of Payload Mass	Additional Mass (lbs.)	Altitude (ft)	Max Velocity (ft/s)
L851	0%	0	5823	692
	10%	0.499	5736	681
	20%	1.000	5650	670
	30%	1.499	5563	650
L995	0%	0	5813	705
	10%	0.499	5730	694
	20%	1.000	5648	683
	30%	1.499	5566	673

Table 5: Rocksim 9 simulations results while increasing the payload mass by 10%, 20%, 30% of it's current estimated mass of 5 lbs. Simulations conducted assuming 0 mph wind conditions.

durable, so the material choice of the current design is G10 fiberglass. Fiberglass plating (G10) is cost effective, strong, but not light-weight. The G10 plate durability will be extremely important to the reusability of this rocket because the rocket fins are the most susceptible to damage during landing.

Fin Material	Dimensions	QTY	Price	Total Price	Strength Rating	Weight (oz)
StyroFoam	11" by 14" by 0.1875" (4 sheets)	1	9.44	9.44	Low	2.2
Cardboard	8.5" by 11" by 0.0625"	1	19.94	19.94	Low	0.8
Balsa	8" by 36" by 0.125"	4	5.15	20.6	Low	0.40
Plywood	12" by 24" by 0.125"	2	10.64	21.28	Medium	6.7
Carbon Fiber Plate	12" by 12" by 0.125"	2	55.5	111	High	10
Fiberglass Plate (G10)	12" by 24" by 0.125"	2	34.05	68.1	Very High	41.44
Built up fins: Plywood skeleton, foam inside, thin fiberglass skin	12" by 24" by 0.125" .005" by 12" by 12" 11" by 14" by 0.1875" (4 sheets)	2	52.72	52.72	High	8.92
Carbon Fiber Cloth	50" by 12"	1	39.78	39.78	High	5.8
Fiberglass cloth	50" by 108"	1	29.95	29.95	High	4
Epoxy Kit	Quart	1	52.75	52.75	N/A	144

Table 6: Comparison of fin materials.

Version	V2.1	V2.2	V2.3.1	V2.4
Motor	Cesaroni L995	Cesaroni L995	Cesaroni L995	Cesaroni L995
Outside Diameter (in)	7.67	7.67	7.67	7.67
Total Length (in)	122.5	122.5	122.5	122.5
Fin Shape	Forward Tapered Sweep	Elliptical	Normal Tapered Sweep	Ring Tail
Max Altitude (ft)	5826	5774	5609	2704
Landing Drift Distance (ft)	193	118	234	633
Max Drift Distance (ft)	670	696	669	633

Table 7: Contains drift distances and max altitudes for different fin shapes under constant 8 mph wind conditions

5.8 Launch Vehicle Flight Simulations

5.8.1 Performance Expectations

The performance of the rocket will be close to the values from the average of 10 Rocksim 9 simulations stated in table 8. These values represent the expected performance of the rocket under 8-14 mph wind conditions. The landing energy and velocity are taken from table 3 because Rocksim does not account for the loss of the payload and nose cone mass of the descent vehicle. As a result the Rocksim descending velocity of the vehicle is much greater than what it will actually be during flight.

Average Max Altitude (ft)	Average Landing Velocity (ft/s)	Average Landing Energy (ft-lbf)	Average Landing Drift Distance (ft)	Average Max Drift Distance (ft)	Average Rail Exit Velocity (ft/s)
5714	14	58	177	1014	78

Table 8: Contains the average figures of merit for rocket version 2.3.2

5.8.2 Simulations

While Rocksim 9 is a very useful tool for approximating the attributes of a rocket during launch, it has several inaccuracies that must be taken into consideration when being used. One of the greatest discrepancies is that the coefficient of drag is underestimated in the program which results in a higher maximum altitude. This effect can be seen below in table 9. It is acceptable to include the altitude data from two different motors in this study because the altitude overestimations in the simulations should scale proportionally to the difference of the coefficient of drag. As stated above in Section 5.8.1, Rocksim also does not account for the ejection of mass during the flight. This results in a higher descent velocity and landing energy that must be corrected. In addition, the program does not account for the drag of the drogue and main parachutes during the final segment of the descent phase. This also results in more inaccuracy in landing velocity and drift distance.
In addition to RockSim, the team intends to conduct further testing in a custom MATLAB simulation, which will account for the discrepancies listed above as well as the horizontal wind velocity component mentioned in earlier sections. The emphasis of these simulations will be to both compare results against those derived from RockSim, and perform "worst case" testing.

Motor (Cesaroni)	Tested Maximum Altitude (ft)	Simulated Maximum Altitude (ft)	Error (%)	Average Errors (%)
H120	1200	1717	43	32
	1332	1727	30	
	1287	1708	33	
J270	3477	4568	31	
	3754	4561	21	

Table 9: Calculates the percent error of the field tested and the Rocksim 9 maximum altitudes for the Loc Precision PK-51 Fantom 438-EXL rocket using two motor types.

6 Payload Criteria: Selection, Design, and Rationale

6.1 Payload Objectives

The objective of this payload is to successfully deploy as an independent subsystem, identify three separate colored tarps on the ground located near the launch site, detect the colors, and track them during descent. A stipulation is it must complete this mission during flight time, not during post-processing or on the ground station. Mission success will be determined when flight data is transmitted to the ground station, and reports that the targets have been identified and tracked. After recovery of the payload, the video feed showing the tracked tarps will be ready for viewing. Additionally, the payload assembly will house all flight electronics and feature a protective casing so it is reusable.

6.2 Payload Design

6.2.1 Launch Vehicle Interface

Figure 8 below shows how the payload and recovery system will be placed inside the rocket. The drogue will be closest to the nose cone so that it will deploy upon exiting the rocket and not get tangled with the payload or main parachute. The payload will be placed upside down (camera facing up) inside the rocket so that gases from the ejection charges will not damage the camera or cloud the lens. A protective structure will be added to the bottom of the housing to shield the camera lens from impacts with the drogue chute or nose cone during launch and ejection, as well as ground impact during landing. Figure 9 below shows an example of one possible protective structure.

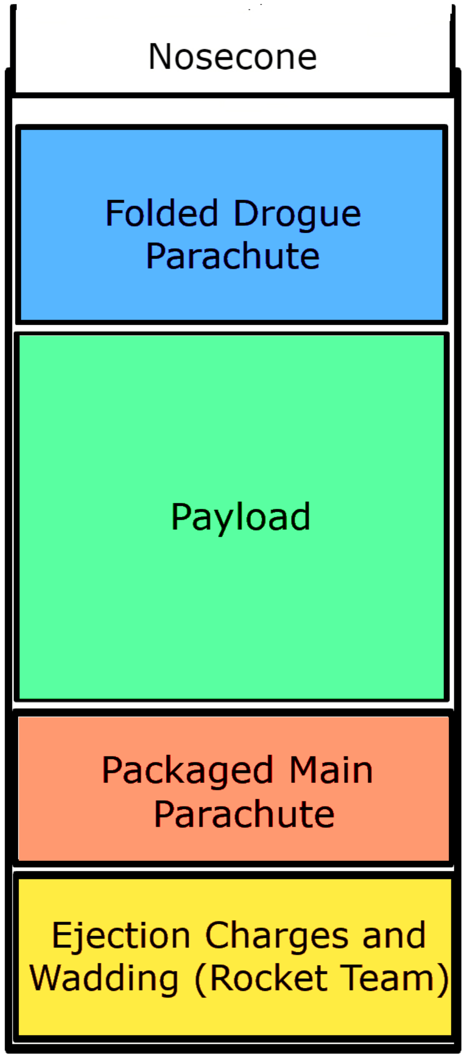


Figure 8: Diagrams the payload and recovery system

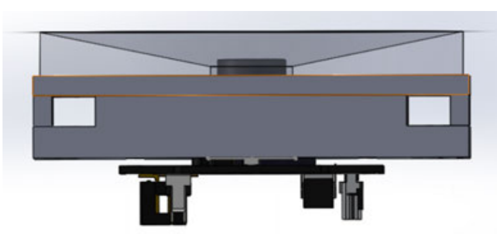


Figure 9: Diagram of the housing to enclose the payload

6.2.2 Structure and Housing

The structure and housing of the payload must be strong enough to withstand the environment of launch and of deployment, however it also must be small and light to be able to be integrated into the rocket easily. For the design we have had a few concept ideas, however we felt that the design should be more driven by the needs of the hardware and not just aesthetic desires of the designer. With this in mind, we are planning to focus more on the hardware of the payload and allow the design of the housing to complement the needs of the hardware. Figures 10 - 16 below show a few different design concepts that we have so far.

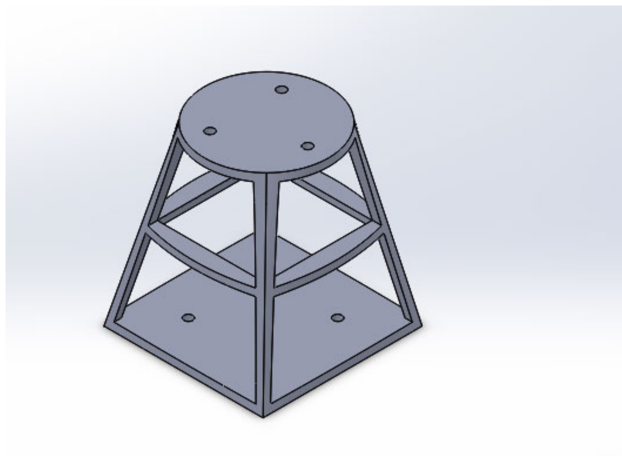


Figure 10: Isomectric view of payload housing

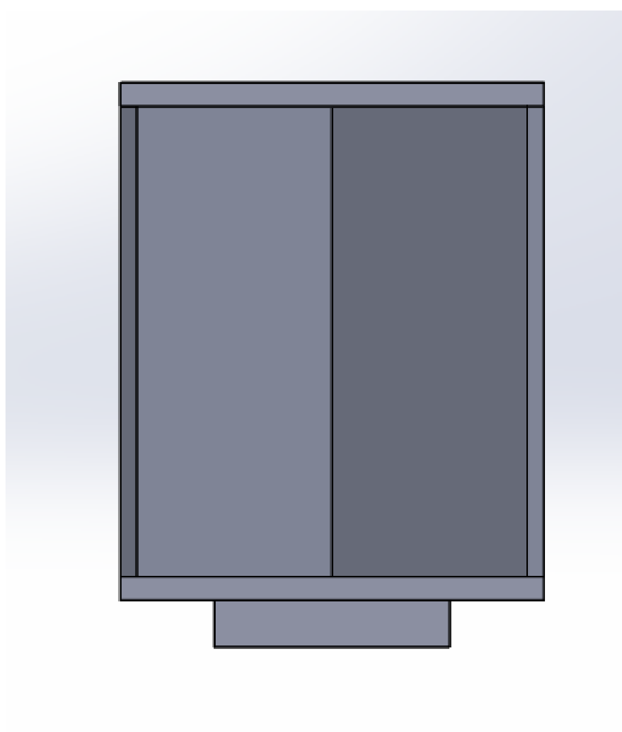


Figure 11: Enclosed payload design

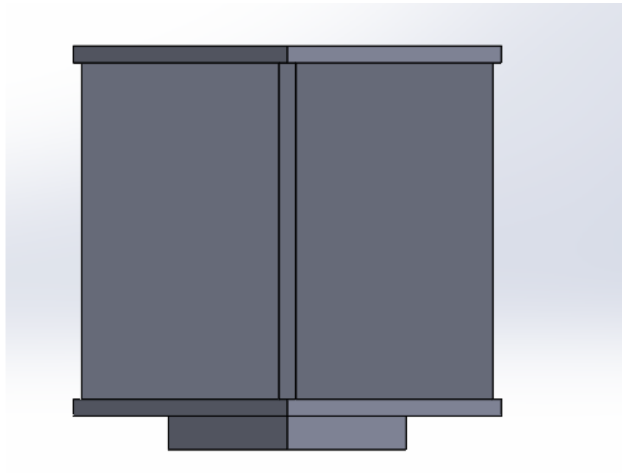


Figure 12: Enclosed payload design

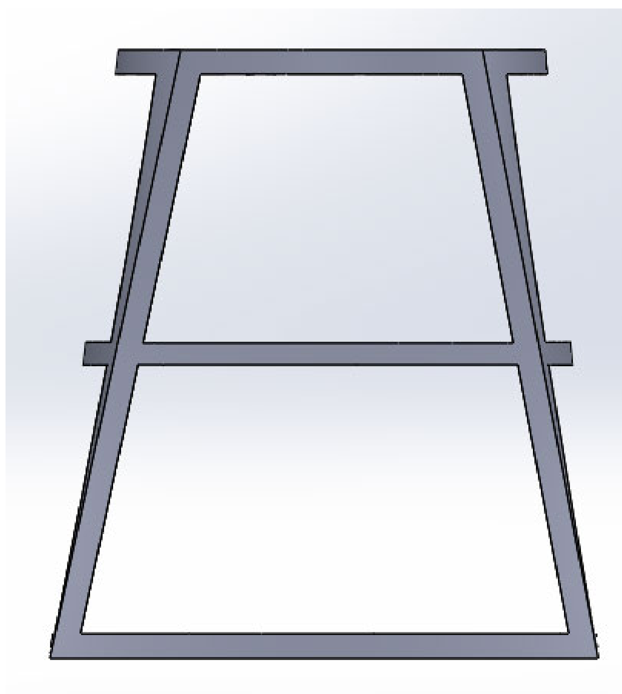


Figure 13: Cross section of payload

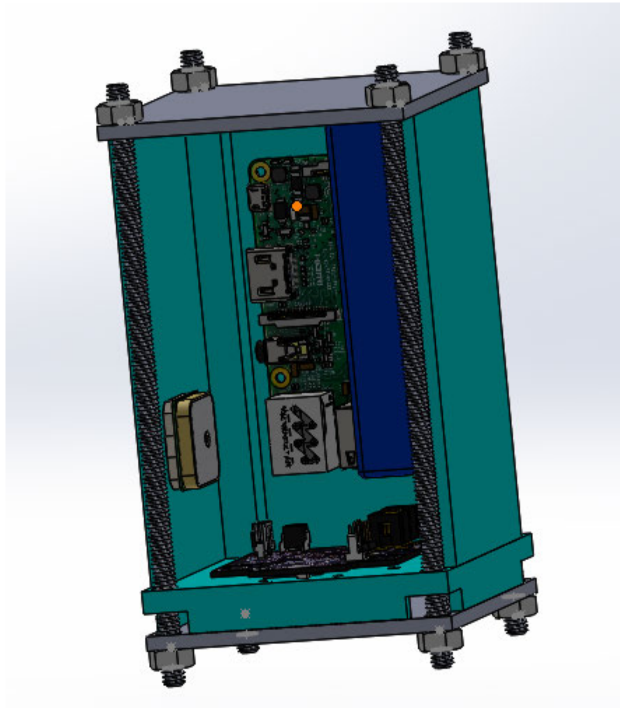


Figure 14: Housing design for the payload

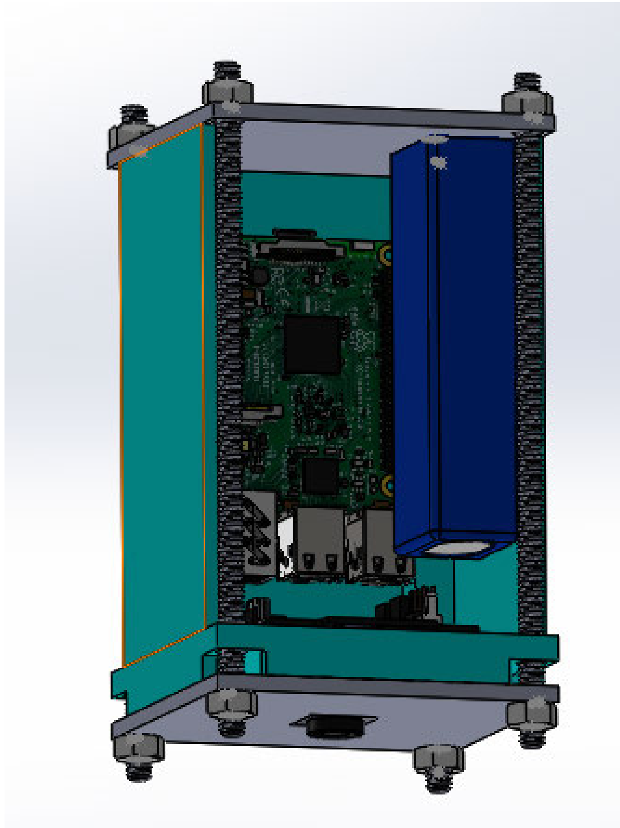


Figure 15: Housing design for the payload

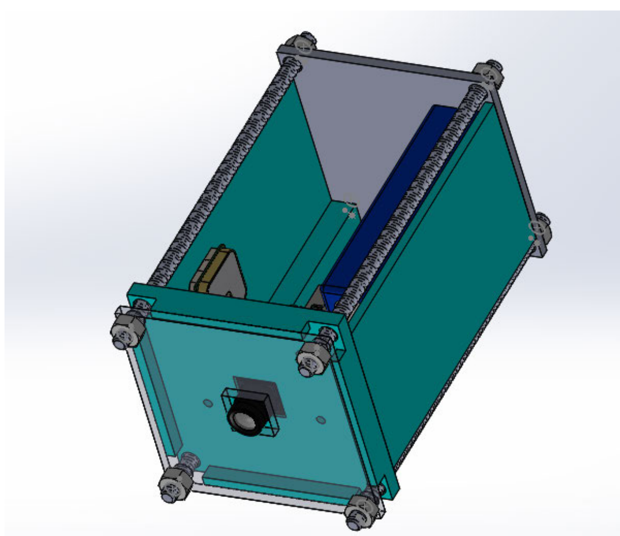


Figure 16: Housing design for the payload

Material selection of the structure will take place after the design is finalized. Currently we are leaning towards an aluminum structure. For the outside casing, we will be using polycarbonate plates that are screwed onto the front faces around the outside of the payload to allow easy access to the electronics on the inside, but still provide protection in case of an impact. Some of the inner pieces that will hold the electronics will be 3D printed.

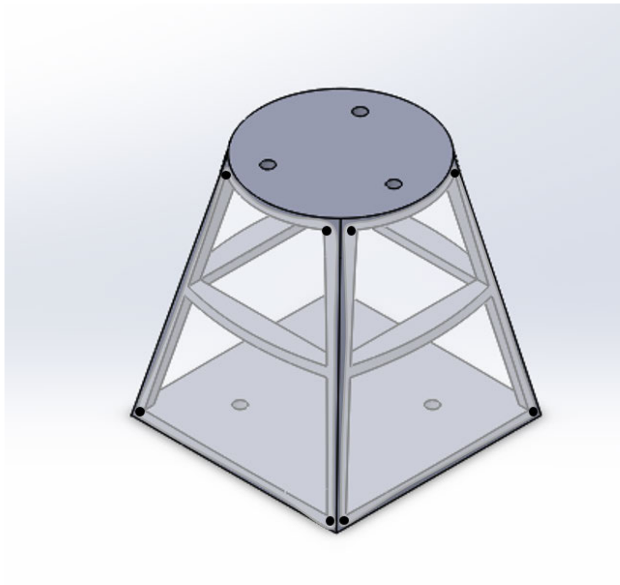


Figure 17: Polycarbonate panel for payload

6.2.3 3D Printing

3D printing will most likely be used in the creation of much of the payload housing. Because of this, it is very important to research what type of material should be used. The team has access to a 3D printer with high printing temperatures and a heated print bed, so those considerations were not needed. The other main areas of importance were density, strength, heat resistance, and impact resistance. Density was considered because the weight of the payload needs to be minimized. Strength and impact resistance were considered because the housing has to withstand the forces of launch, ejection and landing without breaking. Heat resistance was considered because running electronics and a battery in a confined space for a long period of time may generate a build-up of heat, and the housing has to withstand these above average temperatures. Cost was also a minor factor, though the materials all ended up being similar in price. Below is a chart comparing the four materials considered.

	Density	Strength	Impact Resistant?	Heat Resistant?	Cost
ABS	0.9 g/cm^3	Above Average	Average Resistance	Yes	$25-$30 per kg
PLA	1.25 g/cm^3	Average	No	No	$25-$30 per kg
HIPS	1.05 g/cm^3	High Strength	Highly Resistant	Yes	$25-$30 per kg
PETG	1.27 g/cm^3	High Strength	Highly Resistant	Yes	$30-$40 per kg

Table 10: Comparison of various plastics

The current material of choice is HIPS. PLA was immediately discarded because it fails multiple criteria. ABS was also discarded because its strength and impact resistance are good, but not as good as the other materials available. Between HIPS and PETG, both meet the main requirements, but HIPS is slightly stronger and more impact resistant. It is also lighter and cheaper, so it was chosen as the 3D printing material.
Although 3D printed material can be strong, we will be adding an internal structure that will bear most of the outside forces on the payload during launch, ejection and landing. The 3D printed sections will be used to hold the electronics in place. Below is an example of what a section to hold the Pixy camera in place might look like.

6.3 Payload Electronics

6.3.1 Camera System

Criteria	Pixy (CMUcam5)	Raspberry Pi
Price	$75	$25
Weight	27 grams	3 grams
FOV	75x47 degrees	62x48 degrees
FPS	50	47
Weather Capabilities	Very Good	Done by ISP
Compatibility	Arduino or Raspberry Pi	Raspberry Pi
Language	C++ or Python	C++ or Python

Table 11: Comparison of Pixy and Raspberry Pi

The camera used for this payload should have a wide Field of View (FOV), not be affected by non-ideal weather conditions, be lightweight, and compatible with the options we're considering for our flight computer. The Raspberry Pi camera costs less and integrates really well with Raspberry Pi boards, but has a smaller FOV and picks up color by its RGB value, which could fail in adverse weather conditions. Pixy has a larger FOV, is still compatible with our flight computer options, but is heavier and more costly. Additionally, Pixy image detection is done by saturation rather than traditionally picking up RGB values, so weather does not affect its performance.This is ultimately the deciding factor to utilize the Pixy to ensure we accomplish our mission.

Pixy will connect to the flight computer by USB, which will store tracking data and the video feed for post-processing. Once samples come in from NASA, Pixy will be taught to identify those colors and testing the tracking system using a variety of altitudes and movement with the camera.

6.3.2 Flight Computer

Two viable options have been considered for use as the rocket's main flight computer. Both the Raspberry Pi 3 Model B (RPi) and the NVIDIA Jetson TK1 have benefits and drawbacks when it comes to embedded computing. While the RPi was designed to promote Computer Science education, the Jetson was designed to incorporate the architecture and performance of a NVIDIA GPU in smaller, developer-friendly form factor. Although the RPi has become the go-to for education and embedded development because of its simplified I/O connectivity and general performance, the Jetson may be better suited for our purposes. Four important distinctions between these single-board computers that must be taken into consideration are their individual performance characteristics, memory, size, and power requirements.

While the RPi's updated quad-core CPU is suitable for basic development, the Jetson's higher performance CPU and NVIDIA GPU will allow for improved image-processing and target-detection capabilities while also managing the rocket's subsystems. Another benefit of using the Jetson is that it implements integrated eMMC memory. Besides improving the computer's performance, integrated eMMC storage will be less susceptible to the extreme forces experienced during the rocket's lift-off compared to the RPi's required external micro-SD storage.

The hardware's size will also play an important role in the computer's usability and overall performance during the rocket's flight. Although the Jetson's area is more than 3x that of the RPi (16,129 mm2 vs 4,902 mm2 respectively), it is still within the size requirements of the rocket's payload. The main drawback of using the Jetson instead of the RPi is its power requirements. Because of its hardware and performance capabilities, the Jetson will require a lithium polymer battery which is more powerful and slightly larger than the battery required for the RPi.

A hardware specification and benefit analysis comparison between the Raspberry Pi 3 Model B and NVIDIA Jetson TK1 can be found below:

Specification	Raspberry Pi 3 Model B	NVIDIA Jetson TK1
Size	86 mm × 57 mm x 17 mm (3.4 in × 2.3 in x 0.7 in)	127 mm x 127 mm x ~26mm (5 in x 5 in x ~1 in)
SoC	BCM2837	Tegra K1
CPU	Quad Cortex A53 @ 1.2 Ghz	Quad Cortex A15 @ 2.32 Ghz
GPU	400 Mhz VideoCore IV	NVIDIA Kepler GK20a
RAM	1GB DDR2	2GB DDR3L
Storage	micro-SD	16GB eMMC and SD/MMC support
USB	4 x USB 2.0	1 x USB 3.0 and 1 x micro-USB 2.0
Wireless	802.11n and Bluetooth 4.0	N/A (need external WiFi adapter)
Video Output	HDMI	HDMI
Camera ports	CSI port for RPi camera	2 x CSI-2 MIPI (4 lane and 1 lane)
GPIO	40 Pin	7 Pin (not including camera ports)
Power requirement	2.5A @ 5V	44A @ 11.1V (2200mAh 20C 3S Lipo)
Power consumption	Idle: 260 mA (1.4W) Stress: 730 mA (3.7W)	Idle: 140 mA (1.6W) Stress: 420 mA (4.7W)
Price	$35	$200

Table 12: Comparison of Raspberry Pi and NVIDIA Jetson

	Raspberry Pi 3 Model B	NVIDIA Jetson TK1
Pros	- Small form factor - Lower power consumption - Integrated wireless adapters - High GPIO	- Higher performance CPU - NVIDIA GPU - Superior RAM - Integrated eMMC storage
Cons	- Lower performance CPU - Integrated GPU - Limited RAM - External storage	- Large form factor - Single full-size USB port - Requires external wireless adapter - Limited GPIO - High power consumption

Table 13: Comparison of Raspberry Pi and NVIDIA Jetson

6.3.3 Imaging and Targeting Detection

The most popular library for practical computer vision and image processing is the OpenCV (Open-Source Computer Vision) library. The library supports development using C++, Java, and Python for use on several platforms including Linux, Windows, Android, and iOS. OpenCV is broken down into over three dozen modules which support the development of applications that incorporate image processing, object detection, video analysis, machine learning, etc. An important part of the OpenCV library is a selection of modules written using NVIDIA's CUDA programming language. These modules are specifically designed to run on NVIDIA GPUs including the one found on the Jetson TK1. Developing our target detection program using OpenCV's CUDA modules in conjunction with the Jetson will produce the highest performance image processing possible given our payload's size requirements.

For the purposes of this project, the target detection program will be written using a combination of Python with OpenCV and PyCUDA, a CUDA parallel computation API for use with Python. Our program will be developed to identify viable targets by shape and then differentiate by color before saving evidence of target detection to the computer's primary storage for post-flight analysis.

According to many popular blogs about drone usage for target detection and scientific papers on making embedded standalone tracking systems, Python is more commonly used for target detection and tracking missions on Raspberry Pi boards and Arduino. There are even open source code packages available for download that we are able to use and modify to accomplish our mission. Additionally, more people on our team are becoming familiar with Python than C++. For these reasons it is recommended that Python is our primary language of use.

The RGB values provided by NASA are as follows:

Yellow - 255, 210, 30

Blue - 14, 64, 114

Pink - 226, 86, 95
This target detection and tracking system will feature a redundant system, due to the fact the Pixy identifies color by saturation value Due to Pixy's machine learning capabilities, when samples of the tarps are received from NASA, our system will be able to identify and track those colors in any environment. If deemed necessary, the robust flight computer working with Pixy as just a camera will be able to check RGB values as well in case of system failure. This high performance system removes the dependence on a clear sky during launch day.

6.3.4 Battery

There are a lot of different options available for powering the flight computer and other electronics. The most import criteria are current, discharge rate, voltage and weight. Due to the fact that the flight computer will most likely be the Jetson TK1, the battery we will currently be choosing for it is the Turnigy Lipo Pack. It is the only battery that meets the Voltage requirements of the TK1. Although the Turnigy uses a XT60 connector, which the TK1 does not contain, a cheap and light adapter can easily be used between the two. Because of this special connector, a second battery may be chosen to power the other electronics. Additional research will need to be completed into the various components to see if they draw power from the flight computer or run off of separate power supplies.

Criteria	Lithium Ion Battery Pack	Lithium Ion Battery Pack	USB Battery Pack for Raspberry Pi	USB Battery Pack for Raspberry Pi	Turnigy 2200mAh 3S 20C Lipo Pack
Voltage	3.7	3.7V	5V	2x5V	11.1V
Current	4400mAh	3x2200mAh 6600mA	4000mAh	10000mAh	2200mAh
Discharge rate	Under 1A	1.3A	1A	2A	20C
Weight	95g	155g	126g	289g	208 g
Connector	JST2pin	JST 2pin	USB	USB x 2	XT60
Price	$19.95	$29.50	$24.95	$39.95	$9.99

Table 14: Comparison of various battery packs

There are a lot of options to power the onboard computer, when comparing recommended draw rate, voltage and weight are the most important factors.

6.3.5 GPS Tracking

Our payload will include an onboard GPS for tracking. The data will help us to analyze the flight and descent of the payload after launch. The tracking data will also be sent to our ground computer in real time so that we can find our payload after it lands.
The Adafruit Ultimate GPS Breakout was the chosen GPS module. It will communicate with the flight computer via a Python package for Linux called ROS. This package allows us to create simple Publisher and Subscriber nodes which will easily access and store the data. This GPS was chosen because it has a 20mA current draw, can track 22 satellites on 66 channels, updates at 10Hz, and allows for an external LED to be hooked up to it for status updates. The LED compatibility will be especially helpful during integration and testing.

6.3.6 Commuication

Criteria	XBee Pro 900 RPSMA	XBee Pro 900 XSC RPSMA
Range	6 miles	15 miles
Power consumption	210mA @ 3.3v	256mA@ 3.3v
Frequency	900MHz	900MHz
Data Rate	156kbps	9.6kbps
Power	50mW	100mW
Price	$41.75	$43.00

Table 15: Comparison of the XBee Pro 900 and 900 XSC radio transmitters

When looking at potential options for a radio transmitter, the main factors we took into consideration were range, power consumption, data transfer rate and frequency.
Our launch vehicle is going to deliver our payload to a target altitude of 5280 ft. and the recovery area is 5000 ft. in diameter. Assuming the ground station is located at the edge of the recovery area, the furthest distance the launch payload can be from the ground station while being in the recovery area is 7271.75 ft or 1.4 miles. There is a possibility that the launch vehicle may go over the target altitude and beyond the target area. The rocket body will most likely also reduce the range of the transmitter before payload ejection occurs. Even with these considerations, the range of the Xbee Pro RPSMA should give us a large enough margin.
Another important factor when comparing the two models is power consumption. By reducing power consumption of components on the onboard computer we can decrease the size of our battery and reduce weight of the payload. The Xbee Pro 900 uses 22% less power than the Xbee Pro 900 XSC. The Xbee Pro has the advantage in power consumption, and also gains an advantage in data transfer rate.

After comparing the two radio transmitters, the Xbee Pro 900 RPSMA fits our constraints better than the Xbee Pro 900 XSC RPSMA and is our current choice. The Xbee Pro does not connect directly to the flight computer. Instead, it will be soldered to a second circuit board with a built-in USB or micro-USB port. This adapter circuit is specifically designed and manufactured for the Xbee Pro by the same company.

6.4 Weight Breakdown

Figure 18 has all current estimated weights. These may change as the design process continues. As our payload changes shape and size, the amount of 3D printed material we are using, and the weight of our metal structure will both change. The miscellaneous parts section is also likely to change, as the current number is a very rough estimate. This section includes items such as cords and wires, small screws to fasten electronics, and a USB dongle for the Jetson.

Part	Weight
NVIDIA Jetson TK1	5.04 oz.
Pixy Camera	0.95 oz.
Turnigy Battery	7.34 oz.
Ultimate GPS	0.30 oz.

Part	Weight
XBee Pro	3.53 oz.
3D Printed Sections	8.82 oz.
Metal Structure	14.11 oz.
Miscellaneous Parts	16 oz.

Total Estimated Weight	56.09 oz. / 3.5 lbs.

Figure 18: Weight by part of the payload

6.5 Ground Station

The primary purpose of the ground station shall be three-fold: 1) Provide confirmation that the payload has successfully identified the tarps, 2) Provide landing coordinates, and 3) Displaying the flight computer's current battery level. Additionally, the team is looking into transmitting flight data such as IMU data, apogee altitude, ejection altitude, and the times which these events occur during the flight to the ground station. In its current concept, the ground station GUI shall be used to display information only - not to transmit commands to the flight computer. In order to perform these tasks, the payload shall transmit signals to the ground station program to update a GUI containing all the information the team has determined pertinent. Preliminary debate of the language with which to code the ground station had narrowed the choices down to MATLAB, C++ and Python.

	MATLAB	C++	Python
Pros	- Team significantly experienced with MATLAB - Lots of pre-coded functions built into MATLAB - Generally easy GUI set-up	- Highly Customizable - Powerful and fast coding language - Likely easy interface for data transmission	- Plenty of third party packages due to open source model - Same coding language between flight computer and ground station - Likely easy interface for data transmission
Cons	- Real-time updates of GUI may be cumbersome - Resource intensive on ground computer	- Team completely unfamiliar with language - Coding from the ground up - GUI creation labor intensive	- Need to understand packages selected in coding - Not all team members familiar with Python

Table 16: Comparison of coding languages

C++ has the benefit of being incredibly powerful and requiring little processing time once compiled. However, it will require a significant time investment to have a smoothly working C++ program. To accomplish coding a ground station using C++, the team would have to code every function that required for the station to operate. This shows one of the benefits of using MATLAB to create our ground station: the built in GUI creation tool will make it easier to lay out the relevant information for display in an easily readable fashion. Creating such a GUI in C++ presents a significant challenge to code. Viewing the information in a simple command prompt output window is possible, but not ideal out in the field. The other major benefit to using MATLAB for the team's ground station is familiarity with the software and language. Members of the Galacticats have been using MATLAB in their studies for the last 3-4 years. Experience with C++ from the team as a whole is quite sparse. Naturally, in order to create a ground station with C++, a member or two of the payload team would be required to dedicate the time and energy to learning C++ on the fly to complete the station. The consensus thus is that dedicating a team member to learning C++ is an unwise use of the team's resources, and the language has been ruled out of final consideration for the ground station.
Using Python to code the ground station has the benefit of using the same leading candidate language for the flight computer and the ground station, preventing issues that would stem from switching back and forth between languages. With careful selection of third party Python packages, it would be possible to generate a GUI to present the relevant information almost as easily as MATLAB's GUI creation tool. The primary benefit to running Python would be running a fast, stable program. As Python is open-source, it has the community following to likely to generate packages we may need. It is uncertain how difficult the dynamic updates will be to code in MATLAB. Due to Python only running the necessary packages for the code to run, it is likely that Python would be superior to MATLAB in resource usage on the ground station computer. This would be due to MATLAB requiring the full program available to run. However, MATLAB still wins out on team member familiarity, as all team members have created a MATLAB GUI. As a

result of the team's familiarity with MATLAB, most of the pre-coded functions likely to be used in the ground station are already well understood. To use a similar Python package, the team would be required to analyze the package's code to understand it well enough to use effectively.

As a result, MATLAB is the leading candidate for the language used to code the team's ground station. Since Python is a highly competitive second option, further development and investigation will lead to a chosen language by CDR.

6.6 Stabilization and Control

Stabilization is a very important aspect to think about for not only the rocket itself but the payload as well. After the payload has been ejected from the rocket and the parachute has deployed, it will begin taking images of the ground below for target detection. This is one of the most crucial phases for the payload because this is when the image processing will begin. With this in mind, it is important that the camera be kept as stable as possible to ensure that the camera is pointing at the ground, in the direction of the targets, as much as possible.

Through research and information supplied from previous teams it was found that vibrations as well as pendulum motion have been known to occur and become problematic with the stability of a payload. To mitigate this issue several different passive stabilization methods have been researched and compiled into table 17 below.

Passive Stabilization method	Pros	Cons
Swivel Bearing	• Prevents parachute suspension line from twisting up which would transfer to the payload • Low cost • Easy to implement • Helps reduce decent speed	• Bearing may jam up over time • May not reduce motion enough
Increasing Shock Cord Length	• Helps to reduce pitch motion • Low cost • Simple to implement	• May get tangled on deployment
Multiple Main Parachutes	• Helps to reduce roll motion • Help reduce decent speed more	• More complicated • More likely to tangle • More expensive • May cause instability of one of the chutes fails to deploy
Spring Mass Damping System	• Helps to reduce vibration in payload • Fairly inexpensive	• Some what more complicated • Would need to know range of vibration frequency before uses
Single Axis Gyroscope	• Helps to reduce roll and pitch motion • Very precise	• Heavy • Large • Would need initial energy to get started • Expensive • May cause unwanted vibrations
Bob Weight	• Simple • Inexpensive • Easy to implement • Helps reduce vibration	• May not reduce motion enough • May cause the payload to become to heavy • May cause deployment issues due to weight

Table 17: A comparison of stabilization methods

Through observation of the table, three different passive stabilization methods stand out. Those methods would be installation of a swivel bearing somewhere on the shock cord above the payload that attaches the main parachute, increasing the length of the shock cord, and installing a bob weight somewhere on the payload. These passive stabilization methods stood out from the rest because they were overall more cost effective, simple, and not too heavy. All of these methods would help to reduce the vibration and pendulum motion that are expected. Selection of one or more of these methods for the final design will take place once a prototype of the payload has been created and these stabilization methods have been properly tested in a realistic setting. Implementation of additional stabilization techniques such as heat shrinking wire connection and the addition of shock absorbent materials will be utilized to ensure optimal mitigation of vibrations and pendulum motion.
In order to ensure the greatest chance of success, we also researched active controls. Currently, the payload team is reliant on the rocket team to release the payload within an area where it will be able to view the targets while it falls. An unsuccessful rocket launch could set the payload up for failure. Failures would include floating into a tree or structure or being released at a point too far away from the targets for the camera to detect them.

One possible solution to this potential problem is to add an active control system to the payload. Even if released away from the targets, it could fly itself into a position where the targets could still be viewed. The active control system that was most researched was a Ram Air Parachute system.

There are a few substantial advantages to using a ram air chute system over a traditional parachute. The first, and perhaps most important, is that the descent path of the payload can be controlled. If the rocket launch goes poorly and the ejection location is not ideal, the payload can still be maneuvered into a position where it can view the targets. The payload would also be able to avoid leaving the launch field, reducing the risks of the payload landing in a tree or floating to some other area where it could not be recovered. Along with a controlled descent path, the descent speed could also be controlled. Instead of free falling with a drogue until the main parachute opens at a lower altitude, the payload could descent slowly throughout the entire fall. This would improve the video quality, reduce the forces on the payload when the main parachute is deployed, and ensure that the payload would land at a slow speed. Though not an advantage, research showed that R/C skydivers already exist, and one of these systems could be taken and modified to fit our needs. After reading through several rocketry forums, it was found that the use of a ram air chute system has been used by enthusiasts before for recovery of entire rockets. Although these systems are uncommon and we would most likely be building from the ground up, enough enthusiasts have attempted it that we should be able to find others more knowledgeable to help us if we encounter major problems.

Though there are some good advantages, there are many cons to this system. One disadvantage is that a ram air chute could potentially end up being more expensive than a traditional parachute.Although some parafoil kites exist that are similar in price to a traditional parachute, the limited specs available make it unclear whether or not it could handle the needs of the payload. This would require buying and testing one of these units. Ram air chutes are also much more complicated to pack than a traditional system, and so the risk of tangling during ejection would be much greater. In order to effectively use this system, we would either need to use two or more motors, or design another type of system that would only use one motor. This added system would increase the weight of the payload, and additional study would be needed to decide if it would be worth the added weight. There is a chance that this system could also take battery and processing power away from the flight computer. In an autonomous system, the processor would need to take GPS and IMU data from the payload sensors, determine the location and orientation of the payload with respect to the targets, determine what needs to be done to move the payload closer to the targets, and then send those commands to the control system. Additional research would also need to be done into this system to determine the full effect of this system on the processing power of the onboard computer. The final disadvantage is that there are three main ways to control the system, and all of them would require a lot of additional time and effort. The payload could be controlled from the ground using an expensive long range controller, but this would involve an additional flight computer that could communicate with the controller, as well as a pilot with enough practice to successfully control the payload. The second method of control would involve controlling the motors using commands sent from the ground station. This would involve adding additional code to the ground station, interface between the main flight computer and the

	Traditional Parachute System	Ram Air Parachute System
Cost	$100-200	$75-150 using parafoil kite, $250-400 using ram air chute
Prep Time	Approximately 1 hour	Approximately 1 hour
Chute Weight	250 grams	(requires more research)
Design Time	2-3 hours	minimum 10 hours, maximum 30
Testing Time	2 hours	15 hours

Table 18: A comparison of parachute systems

	Traditional Parachute System	Ram Air Parachute System
Pros	-cheaper -easy setup -smaller chance of cords tangling -no programming or design work	-descent speed can be controlled -descent path can be controlled -greater chance of target detection success -could modify R/C skydiver or similar system -help of enthusiasts who have used these systems in the past
Cons	-descent speed cannot be controlled -descent path cannot be controlled -payload less stable until main deploys -susceptible to high winds	-most likely more expensive -more complicated setup -relies on airflow over chutes -potentially very difficult to implement -chance of cords tangling during ejection

Table 19: A Pro - Con comparison of parachute systems

motors, and again a pilot with enough practice on the system to successfully steer the payload. The third method would involve making the payload autonomously flown by the flight computer using GPS coordinates. This would involve a lot of additional code for the flight computer, and would also take away some of its power from the image processing. Testing an autonomous system would also present challenges and take additional time. After extensive research, it was decided that initial payload designs will not include a ram air chute system. Several of the disadvantages are very concerning, and additional time and money would be needed to continue research into the topic, build a prototype system, and test it to a level that would satisfy concerns. Due to the interest but lack of knowledge in this area, additional investigation may be done, but it will not be included in the design at this time.

6.7 Recovery Systems

There will be two main phases to the payload descent. The first will be after ejection of the payload from the rocket. At ejection, the drogue will deploy to stabilize the fall. The main will be folded and held together by a Jolly Logic unit. The Jolly Logic unit includes a pin that will stay in place until the rocket is placed on the pad to ensure that the unit does not fire prematurely while the rocket is still on the ground. The second phase will occur when the payload reaches the main deployment altitude. At this point, the Jolly Logic altimeter will trigger release, and the main parachute will deploy. This altitude will be determined later using analysis of our system's capabilities and creating a target detection envelope that our payload has to hit. The two figures below show the two different phases. The lengths of the various shock cord sections and the sizes of the drogue and main parachutes will be determined after the payload design is finalized. During the entire descent, a GPS inside the payload will be collecting location data and transmitting it through the flight computer to the ground station. This data will be used in determining the payload's final resting place and will aid in a successful recovery.

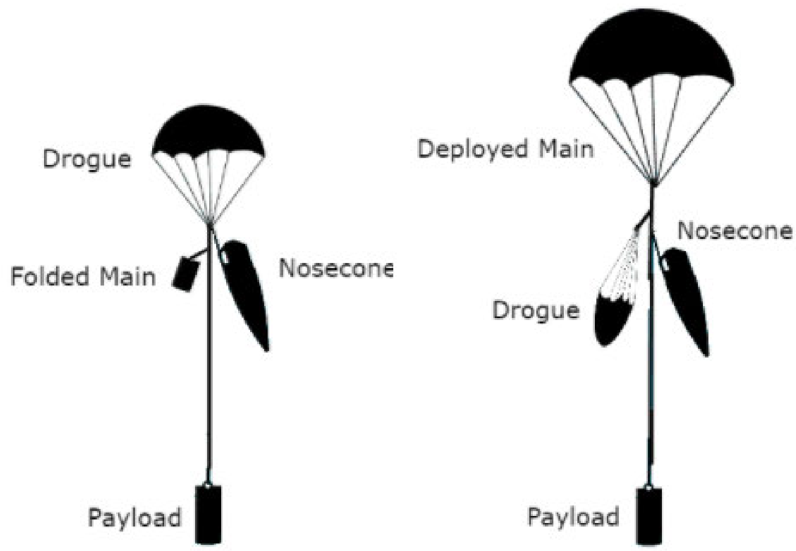


Figure 19: Diagrams of two recovery systems

7 Safety

7.1 Federal Aviation Administration Model Rocketry Laws

The Safety Officer will ensure that the team abides to and follows all FAA rules pertaining to high-powered rocketry. The FAA Model Rocketry Law Title 14, Chapter 1, Subchapter F, Subpart C, Section 101.29, states: (a) Class 2 - High-Power Rockets. When a Class 2 - High-Power Rocket requires a certificate of waiver or authorization, the person planning the operation must provide the information below on each type of rocket to the FAA at least 45 days before the proposed operation. The FAA may request additional information if necessary to ensure the proposed operations can be safely conducted. The information shall include for each type of Class 2 rocket expected to be flown:

- Estimated number of rockets
- Type of propulsion (liquid or solid), fuel(s) and oxidizer(s)
- Description of the launcher(s) planned to be used, including any airborne platform(s)
- Description of recovery system

- Highest altitude, above ground level, expected to be reached, Launch site latitude, longitude, and elevation
- Any additional safety procedures that will be followed

7.2 National Association of Rocketry Rules and Procedures

The team has read and understood all rules and procedures written out by the National Association of Rocketry. The minimum-distance table for high-powered rockets, created by NAR, can be found in the Appendix B. NAR members or teams must follow these rules:

- Certification. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing. Materials. I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.
- Motors. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.
- Ignition System. I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.
- Misfires. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.
- Launch Safety. I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.
- Launcher. I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use

a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.

- Size. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.
- Flight Safety. I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.
- Launch Site. I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).
- Launcher Location. My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.
- Recovery System. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.
- Recovery Safety. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

7.3 Safety Compliance

The University of Cincinnati Galacticats are committed to ensure the safety of each of its members and others throughout the duration of this project. The Safety Officer will be enforcing all safety protocols to ensure that the team is properly trained in safe operations for all aspects of the project. This also includes all laws and regulations set forth by all governing entities, to ensure that our team is eligible to compete in the NASA Student Launch Competition.

Team Safety Compliance

By agreeing to this document, you have read and fully comply with the rules and regulations that this document sets forth.

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

Signature Section: Please sign and date onto the lines below

7.4 Launch Procedures

Prior to testing and launching any rocket or its components, multiple safety procedures must be carried out before the team Safety Officer gives permission to proceed. On the day of a test, an effective PJB must occur, in which all team members must sign off on in order to proceed. After the PJB, the Safety Officer will require completion of a Pre-Launch, Launch, and Post-Launch checklist. These checklists are designed to ensure all required safety steps have been completed and all laws are followed. The Safety Officer will oversee proper handling of hazardous material, and ensure that all federal and state regulations have been met. Each checklist is detailed in the following bulleted list:

- A pre-launch checklist will include but is not limited to: safety preparation, rocket airframe, recovery systems, electronics bay operations, payload electronics, motor preparation and installation.
- A Launch checklist will include but is not limited to: safety preparation, launch pad preparation, arming the rocket, igniter installation, go for launch, and misfire procedures.
- A post-launch checklist will include, but is not limited to: recovery and clean up.

7.5 Hazards, Failure Modes and Effective Analysis

The Safety Officer along with collaboration from members of each of the teams sub teams, have compiled and organized a list of hazards and failure modes that could potentially affect the preliminary design phase of this project. All team members who were involved in the collaboration worked on ways to help mitigate and reduce the likelihood of these hazards and failures occurring. The hazards and failure modes that were discussed were given numerical and color codes based on hazards or failure modes level of impact. The definitions for Likelihood, Severity, and Risk assignment are shown in Appendix A figures 21, 22, and 23 - respectively. The Risk Assessment Matrix, shown in Figure 24, brings all of these elements together for a transparent assessment of hazards and failure modes. Preliminary risk assessments and mitigations have been completed for hazards and failure modes that could occur for this particular phase of the project. The risk values currently applied are based on the event severity before any mitigations are applied. Post-mitigation severity values will be assigned throughout the time period between the preliminary design review and critical design review. The goal is to reduce the probability and or severity of each hazard or failure mode from the red or yellow severity value into the green severity value through design changes and or mitigation techniques. Risk levels can also be lowered through extensive testing of relevant components to ensure that the initial risk is no longer an issue.

All hazards and failure modes have gone through the same processes to identify risk and establish preliminary mitigations. The team has broken down the current design process into five categories consisting tables describing the hazards and failure mode. All data regarding the risk assessment of these categories can be found in Appendix A. A brief description of each category can be found below:

- Project Hazards Assessment: the hazards outlined are risks that may occur during project subgroup operations.
- Personnel Hazards Assessment: the hazards outlined are risks that may occur to personnel throughout the lifetime of the project.

- Environmental Hazard Assessment: the hazards outlined are risks that may occur to the environment or building.
- Rocket Risk Assessment: the hazards outlined are risks that may occur to rocket related components and structures.
- Payload Risk Assessment: the hazards outlined are risks that may occur to payload related components and structures.
- Launch Operations Risk Assessment: the hazards outlined are risks that may occur before, during, or after a rocket launch.

8 Project Plan

The NASA requirements verification palns and team requirements verification plans can be found in Appendix B.

8.1 Budgeting and Timeline

In order to assure successful completion of the project in the allotted amount of time, the team treasurer has established a funding goal of $22,000. Funding for the team has been split into 4 primary sources: the University of Cincinnati (UC) Academic Intercollegiate Competition (AIC) program, the Ohio Space Grant Consortium (OSGC) Student Innovative Creative Hands-On Project (SICHOP) grant, departments within the University of Cincinnati, and corporate sponsors. Figure 20 demonstrates the planned and actual revenues and expenses over the lifetime of the project.

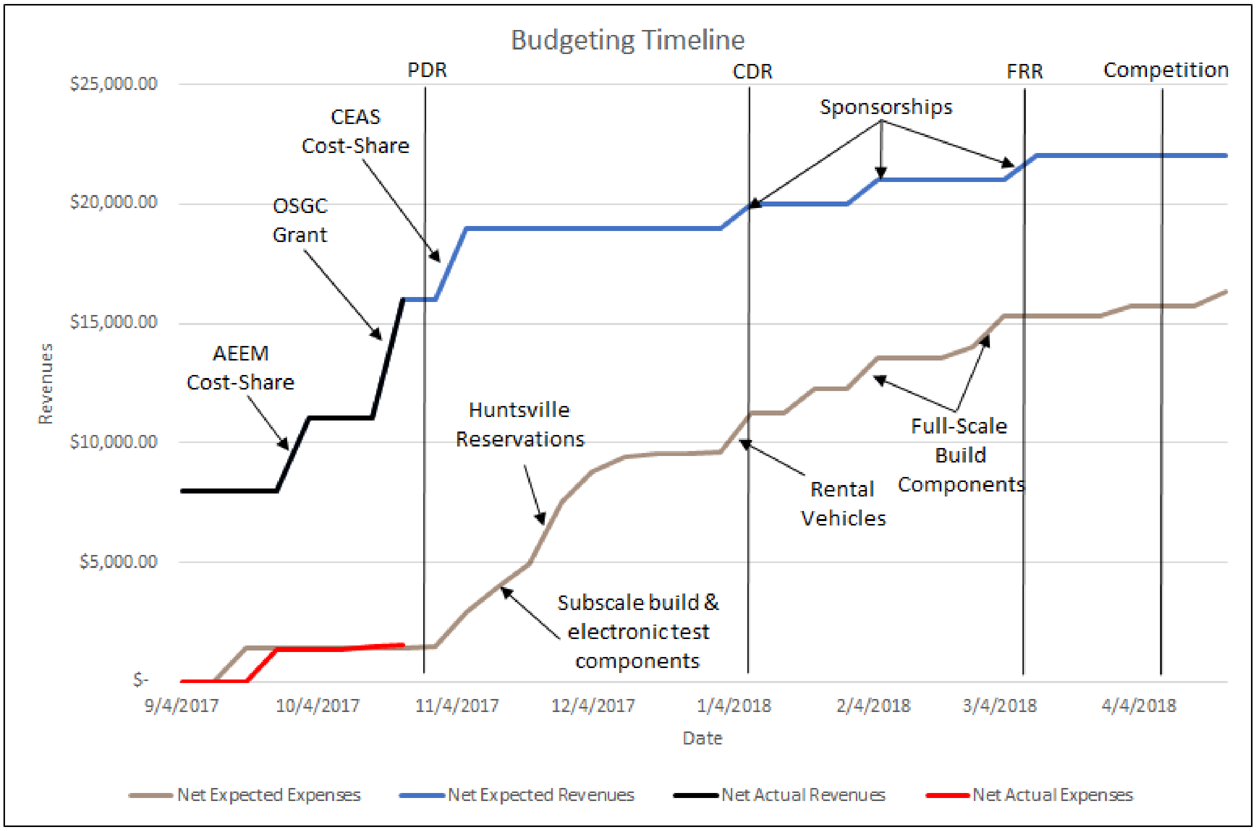


Figure 20: Estimated budget timeline over the entire project

Funding from the UC AIC program had already been procured at the onset of the project. The amount of which was $8,000. This funding is granted through the student organization UC Students of the Exploration and Development of Space (SEDS), thanks to early registration and a presentation from last year's Baerocats senior design team. To ensure continuity of this funding for next year's senior design team, the Galacticats will be required to undergo the same process of re-registering the club and presenting to the AIC board for a funding request.
As of October 30rd, the OSGC SICHOP grant application had been approved, and the funding has been made available to the Galacticats. This source represents $5,000 of our project's funding. Team obligations related to receiving this grant include submitting a project status update by the end of 2017, as well as a submittal of final project report within one year of the grant award.
Two departments within the University of Cincinnati have been contacted regarding funding our project: The Department of Aerospace Engineering and Engineering Mechanics (AEEM), and the Department of Undergraduate Affairs. As of October 23rd, $3,000 has been procured from AEEM, and a total of $3,000 has been requested from the Department of Undergraduate Affairs. The latter request is still pending, with a projected procurement date of November 8th.
Corporate Sponsorship of our team will fill in at least the remaining $3,000 of the team budget, as well as any funding differential between what was requested from the

Department of Undergraduate affairs and what is actually procured. This represents a change from the proposal in that at the time of project proposal, funding from the College of Engineering and Applied Science (CEAS) Department of Undergraduate Affairs was anticipated to be "In-Kind" in the form of faculty mentor's time, lab and machine use, etc. and has since been clarified to be monetary. Additional sponsorship revenue that brings project funding beyond the $22,000 goal shall be used for improvements to UC's Rocket lab equipment, as well as leaving any leftover funding to the next senior design team in a bank account in the UC SEDS club name. Note that corporate sponsorship money on expected revenues line in figure 20 are preliminary projections, included for completion. It is not expected that actual procurement dates and amounts will match these projections.

- Tier 1: $250 supporter
  - Small corporate logo displayed on the team website
  - Social Media Shoutout
- Tier 2: $500 supporter
  - Corporate Logo on team banners at events
  - Large Corporate Logo displayed on team website
  - Social Media Shoutout
- Tier 3: $1000 supporter
  - Corporate Logo on the launch rocket
  - All tier 2 benefits

As corporate needs may vary, these tiers shall be used as guidelines when presenting the sponsorship opportunity. Any in-kind sponsors of the Galacticats will be awarded a tier depending on the impact of their contribution, not necessarily dependant on the monetary value of their contribution.

8.2 Budget Allocation

Detailed tables of the Galacticats' projected and actual expenditures as of October 23rd will be found in Appendix C. A general overview of Procured Funding, Expenses to Date, and Projected funding and expenses is shown in tables 20 - 23. Of notable change between proposal and PDR is the establishment of a reimbursement fund. This fund, totaling $1,000, shall be held in reserve in order to reimburse team members for any personal money spent on materials and transit related to the project. It shall be disbursed as each team member determines fit. However, this money will be pulled from UC AIC funding, and University regulations stipulate only one reimbursement per member per semester may occur. This does not, however, affect the overall budget as described in the Proposal as the overall budget amount was set significantly higher than projected expenses to account for realizations, such as the necessity of a reimbursement fund, that would only occur once the project was underway. Additionally, a $220 PPE budget has been established at the request of our team's Safety Officer.

AIC Funding:	$8,000.00
Aerospace Department Funding:	$3,000.00
OSGC Grant:	$5.000.00
Total Revenues:	$16,000.00

Table 20: Procurred Revenues

CEAS Dept. of Undergraduate Affairs:	$3,000.00
Corporate Sponsorships:	$3,000.00
Total Revenues:	$6,000.00

Table 21: Projected Revenues

NAR Certification Materials:	$1,356.93
Electronics:	$104.10
PPE:	$28.98
Shop Supplies:	$23.15
Total:	$1,520.16

Table 22: Incurred Expenses by Type

Travel:	$5,250
Rocket Build:	$3,250
Electronics:	$1,300
Reimbursements:	$1,000
Payload Build:	$800
Outreach:	$250
Shop Supplies:	$225
PPE:	$220
Miscellaneous:	$3,075
Total:	$15,370

Table 23: Expected Expenses by Type

9 Appendix A: Safety Hazard Tables

9.1 Risk Assessment Matrices

Figure 21: Event Likelihood Table

Description	Value	Criteria
Probable	1	76% - 100% chance of occurrence
Infrequent	2	51% - 75% chance of occurrence
Remote	3	26% - 50% chance of occurrence
Improbable	4	0% - 25% chance of occurrence

Figure 22: Event Severity Table

Description	Value	Criteria
Catastrophic	A	Could result in death, complete mission failure, monetary loss of $2k or more.
Critical	B	Could result in severe injuries, particle mission failure, monetary loss of $500 or more but less then $2k.
Marginal	C	Could result in minor injury, minor mission complications, monetary loss of $1 or more but less then $500

Figure 23: Risk Definition Table

Description	Criteria
High	Highly undesirable, requires additional engineering controls and safety measures before the rocket will be launch
Moderate	Undesirable, may or may not require additional engineering controls and safety measures before the rocket will launch
Low	Acceptable risk, minimal alterations may need to be made before launch but overall acceptable.

Figure 24: Risk Assessment Matrix

Likelihood	Severity		
	Catastrophic (A)	Critical (B)	Marginal (C)
Probable (1)	High 1A	High 1B	Moderate 1C
Infrequent (2)	High 2A	Moderate 2B	Moderate 2C
Remote (3)	Moderate 3A	Moderate 3B	Low 3C
Improbable (4)	Moderate 4A	Low 4B	Low 4C

9.2 Project Hazards

Figure 25: Project Hazard 1

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Missing due dates for documentation	Mismanagement of time and resources	Deduction of points during SLI competition	3C	Low
Mitigation		Ensure that all team members are aware of upcoming dates and times that important documents are due and set up system to ensure that documents are submitted before due date to ensure that they are on time.		

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Missing allocation of Funds	Mismanagement of funds	Inability to make purchases for things needed for the project	3B	Moderate
Mitigation		Ensure that the Treasure has everything in hand and ensure that funds are being spent properly		

Figure 26: Project Hazard 2

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Lack of presence on website or social media accounts	Lack of activity with website and keeping social media current	Loss of interest in community and deduction of points during SLI competition	3C	Low
Mitigation		Ensure that the Media Team lead is keeping website and social media up to date and ensure that they have all things necessary to perform their job optimally		

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Team's safety becomes compromised	Team member was not fallowing proper safety procedures and or isolated incident	Injury could set back timetable for project	3A	Moderate
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB and ensure that they have been properly prepared to avoid them.		

9.3 Personal Hazards

Figure 27: Personal Hazard 1

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Missuses of power tools	Improperly trained or unaware of danger (not thinking)	May result in injury or damage to the project	3A	Moderate
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB and ensure that they have been properly trained before they are allowed to use equipment and have access to PPE		

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Exposure to hazardous chemicals	Improperly trained or unaware of danger (not thinking)	May result in injury	3B	Moderate
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB and ensure that the proper ventilation is being utilized and PPE and MSDS are available.		

Figure 28: Personal Hazard 2

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Missuses of sharp tool	Improperly trained or unaware of danger (not thinking)	May result in injury or damage to the project	3A	Moderate
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB and ensure that they have been properly trained before they are allowed to use equipment and have access to PPE		

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Exposure to hot tool (soldering iron)	Improperly trained or unaware of danger (not thinking)	May result in injury or damage to the project	3B	Moderate
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB and ensure that they have been properly trained before they are allowed to use equipment and have access to PPE		

Figure 29: Personal Hazard 3

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Exposure to small airborne particulates	Improperly trained or unaware of danger (not thinking)	May result in injury	3B	Moderate
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB and ensure that they have been properly trained before they are allowed to use equipment and have access to PPE		

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Exposure to dangerous fumes	Inadequate ventilation of lab	May result in injury	3B	Moderate
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB and ensure that the proper ventilation is being utilized and PPE and MSDS are available.		

Figure 30: Personal Hazard 4

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Vehicular accident	Misjudgment and or lack of situational awareness	May result in serious injury or even death	2A	High
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB. All team members that will be driving are required to complete a defensive driving training before being allowed to drive.		

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Rocket failure on launch pad	Minimum safe distance from launch pad not adhered to	May result in serious injury or even death	2A	High
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB and ensure that all members are at the safe distance from the launch pad and ensure that all team members are adhering to the rules of the RSO		

9.4 Environmental Hazards

Figure 31: Personal Hazard 1

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Missuses of power tools	Improperly trained or unaware of danger (not thinking)	May result in injury or damage to the project	3A	Moderate
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB and ensure that they have been properly trained before they are allowed to use equipment and have access to PPE		

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Exposure to hazardous chemicals	Improperly trained or unaware of danger (not thinking)	May result in injury	3B	Moderate
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB and ensure that the proper ventilation is being utilized and PPE and MSDS are available.		

Figure 32: Personal Hazard 2

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Missuses of sharp tool	Improperly trained or unaware of danger (not thinking)	May result in injury or damage to the project	3A	Moderate
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB and ensure that they have been properly trained before they are allowed to use equipment and have access to PPE		

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Exposure to hot tool (soldering iron)	Improperly trained or unaware of danger (not thinking)	May result in injury or damage to the project	3B	Moderate
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB and ensure that they have been properly trained before they are allowed to use equipment and have access to PPE		

Figure 33: Personal Hazard 3

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Exposure to small airborne particulates	Improperly trained or unaware of danger (not thinking)	May result in injury	3B	Moderate
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB and ensure that they have been properly trained before they are allowed to use equipment and have access to PPE		

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Exposure to dangerous fumes	Inadequate ventilation of lab	May result in injury	3B	Moderate
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB and ensure that the proper ventilation is being utilized and PPE and MSDS are available.		

Figure 34: Personal Hazard 4

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Vehicular accident	Misjudgment and or lack of situational awareness	May result in serious injury or even death	2A	High
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB. All team members that will be driving are required to complete a defensive driving training before being allowed to drive.		

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Rocket failure on launch pad	Minimum safe distance from launch pad not adhered to	May result in serious injury or even death	2A	High
Mitigation		The Safety officer will ensure that all team members have been properly informed of possible dangers during the PJB and ensure that all members are at the safe distance from the launch pad and ensure that all team members are adhering to the rules of the RSO		

9.5 Rocket Hazards

Figure 35: Rocket Hazard 1

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Structural failure during launch	Improperly constructed and or tested	My lead to full loss of rocket	3A	Moderate
Mitigation		Rocket Design lead will ensure that all structural rocket components are properly constructed and tested prior to launch. Lead will consult with adult advisor if uncurtains.		

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Shock cord failure	Faulty component and or installation	May lead to serious damage to rocket or even loss	3A	Moderate
Mitigation		Rocket team lead will ensure that shock cord is properly installed and will test that it is prior to the structural completion of the rocket		

Figure 36: Rocket Hazard 2

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Rail button failure	Improper installation	May prevent rocket from launch properly or launch it off target	4A	Moderate
Mitigation		The Rocket team lead will be sure to double check all work performed by the rocket team and ensure that the quality is where it should be. Adult advisor will also double check construction prior to launch		

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Parachute entanglement	Parachute not deploying and or packed correctly	May prevent the parachute from deploying at all and lead to serious damage or loss of rocket	2A	High
Mitigation		Rocket Team will perform tests to ensure that the method used to pack the parachute will not cause it to entangle and implement hardware to help ensure that it doesn't tangle		

Figure 37: Rocket Hazard 3

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Parachute Tear	Faulty parachute and or damaged while packed into rocket	May cause the parachute to completely fail which may lead to serious damage or loss of rocket	3A	Moderate
Mitigation		The Rocket team will inspect the parachute before installation in rocket to ensure quality and ensure that parachute is properly installed to ensure no damage while in flight		

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Unstable Flight	Aerodynamics and or structural issues with fins	May cause rocket to become out of control or miss target	3A	Moderate
Mitigation		The Rocket team will need to ensure that the fins are constructed properly and installed into the rocket properly. Adult advisor will help ensure quality.		

Figure 38: Rocket Hazard 4

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Altimeter Failure	Faulty electronics and or improper installation	May cause late and or early payload and or chute deployment	3A	Moderate
Mitigation		Rocket team will ensure that altimeter is tested prior to the launch to ensure that it is functioning properly and is wired correctly		

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Hard landing	Parachute failure or complications	May cause serious damage or loss of rocket	3A	Moderate
Mitigation		Rocket team will check quality of parachute prior to launch and will ensure that parachute is proper dimensions for the rocket being used. Hand calculations and testing will be done to ensure this		

9.6 Payload Hazards

Figure 39: Payload Hazard 1

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Battery failure	Faulty battery and or low power output	May cause failure of rocket electronics for tracking and ejections charge detonations	3A	Moderate
Mitigation		Rocket team will double check all batteries will multimeter prior to launch and ensure that they have the proper current and voltage for uses prior to launch.		

Figure 40: Payload Hazard 2

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Loss of communication with payload	Electronics failure	Ground team will not be able to track rocket after launch	3B	Moderate
Mitigation		Electronics will be tested to ensure that they will survive launch conditions and back up systems will be employed to reduce likelihood further.		

Figure 41: Payload Hazard 3

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Failure of payload to separate from rocket	Electronics failure and or ejection charge failure	Payload will remain in rocket and may cause the rocket to land harder then anticipated which may lead to damage to the payload and or the rocket	3B	Moderate
Mitigation		Ejection charges will be tested prior to launch to ensure that the electronics are setup properly and to ensure that ejection charges and strong enough to separate the rocket.		

Figure 42: Payload Hazard 4

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Camera failure	Electronics failure and or improperly installed	Payload will be unable to detect target and unable to complete SLI competition objectives	3A	Moderate
Mitigation		Payload camera will be tested thoroughly tested to ensure that it has been properly installed and integrated with its electronics and that the electronics will operate under deployment conditions		
Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Structural failure of payload	Improper construction of payload and or material failure	May cause failure of payload and be unable to complete SLI competition objectives	3A	Moderate
Mitigation		Payload team will test the structural components of the payload to ensure that it is robust enough to survive launch and deployment conditions.		

Figure 43: Payload Hazard 5

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Tumbling of payload after deployment	Improper stability	May cause payload to be unable to detect target and will be unable to fulfill SLI competition objectives	3B	Moderate
Mitigation		Stabilization systems will be utilized during prototype testing once stability has been proven to be an issue.		
Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Short circuit in payload electronics	Improper electronic installation and or circuit failure	May cause failure of Payload	3A	Moderate
Mitigation		Electronic installation and soldering will be tested and inspected to ensure that the possibility of a short circuit is as small as possible		

Figure 44: Payload Hazard 6

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Coding Error in Payload	Human Error	May lead to payload losing communication with ground station and or being unable to complete SLI mission objectives	2A	High
Mitigation		Payload code will be rigorously tested to ensure that robustness of the code and to find any hole in the code that may lead to failure		
Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Micro computer failure in payload	Improper installation and or faulty micro computer	May cause failure of payload	3A	Moderate
Mitigation		Payload micro computer will be tested to ensure that it is operating properly prior to test and a redundancy computer may be added to payload to reduce risk further.		

9.7 Launch Hazards

Figure 45: Launch Hazard 1

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Pre-Launch	Missing steps established in Pre-Launch Checklist	May causes failure of the Rocket, Payload, and or electronics	2A	High
Mitigation		Ensure that all team members are aware of the steps in the prelaunch check list and ensure that at least one member on each team is present during the launch		

Figure 46: Launch Hazard 2

Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Launch	Missing steps established in Pre-Launch Checklist	May causes failure of the Rocket, Payload, and or electronics	2A	High
Mitigation		Ensure that all team members are aware of the steps in the prelaunch check list and ensure that at least one member on each team is present during the launch		
Failure Mode	Cause	Effect	Likelihood	Severity & Risk Value
Post-Launch	Missing steps established in Pre-Launch Checklist	May causes failure of the Rocket, Payload, and or electronics	2A	High
Mitigation		Ensure that all team members are aware of the steps in the prelaunch check list and ensure that at least one member on each team is present during the launch		

10 Appendix B: Testing Compliance Tables

10.1 NASA Requirements

Requirement	Description	Verification Type	Verification Plan
1.1	Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor).	Demonstration	Through the various milestones of the project, the students will show through their knowledge and demonstration of work done that they have done all the required work without major assistance from a mentor.
1.2	The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations.	Demonstration	Project plans, budgets, and other requirements stated will be covered and updated from milestone to milestone and shown to NASA
1.3	Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during these activities.	Demonstration	Foreign Nationals will be identified to NASA during the various milestones throughout the year.
1.4	The team must identify all team members attending launch week activities by the Critical Design Review (CDR). Team members will include:	Demonstration	A list of team members attending the launch day activities will be shown in the CDR milestone in January
1.4.1	Students actively engaged in the project throughout the entire year	Inspection	Inspection by the team mentor will verify that all students on the team are actively engaged in the project throughout the entire year.
1.4.2	One mentor (see requirement 1.14).	Inspection	It shall be verified by inspection that the team only has one team mentor.
1.4.3	No more than two adult educators.	Inspection	Inspecton of team organization will verify that no more than two educators will guide the team throughout the duration of the project.
1.5	The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the Educational Engagement Activity Report, by FRR. An educational engagement activity report will be completed and submitted within two weeks after completion of an event. A sample of the educational engagement activity report can be found on page 31 of the handbook. To satisfy this requirement, all events must occur between project acceptance and the FRR due date.	Demonstration	Using the Engagement Activity Report, the team will show throughout the project all of the educational engagement activities performed to provide outreach to 200 or more students.
1.6	The team will develop and host a Web site for project documentation.	Demonstration	A link to the team's website will be sent to NASA alongside the PDR documents
1.7	Teams will post, and make available for download, the required deliverables to the team Web site by the due dates specified in the project timeline.	Demonstration	The website will have a designated section for NASA milestone documents
1.8	All deliverables must be in PDF format.	Demonstration	All documents (including presentations) will be exported in the PDF file format
1.9	In every report, teams will provide a table of contents including major sections and their respective sub-sections.	Demonstration	All documents will include a table of contents at the beginning of the document
1.10	In every report, the team will include the page number at the bottom of the page.	Demonstration	The team will ensure all documents include page numbers for each page
1.11	The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a broadband Internet connection. Cellular phones can be used for speakerphone capability only as a last resort.	Demonstration	The team will provide all hardware on their end to participate in video teleconferences and group calls
1.12	All teams will be required to use the launch pads provided by Student Launch's launch service provider. No custom pads will be permitted on the launch field. Launch services will have 8 ft. 1010 rails, and 8 and 12 ft. 1515 rails available for use.	Demonstration	The team will design the rocket such that it can be used with the given launch rails.
1.13	Teams must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194)	Demonstration	The team will comply with all standards designated in the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standard
1.14	Each team must identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to launch week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attends launch week in April.	Demonstration	The team mentor will be identified in all milestone reports to NASA

2.1	The vehicle will deliver the payload to an apogee altitude of 5,280 feet above ground level (AGL).	Testing	The team shall verify, though test launches and simulation data, that the rocket reaches an altitude of 5,280 feet above ground level.
2.2	The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner. Teams will receive the maximum number of altitude points (5,280) if the official scoring altimeter reads a value of exactly 5280 feet AGL. The team will lose one point for every foot above or below the required altitude	Inspection	One of the rocket's onboard altimeters shall be identified, before each launch of the rocket, as the scoring altimeter for a given test or competition launch.
2.3	Each altimeter will be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	Inspection	It shall be identified that each altimeter on the rocket is activated by a dedicated arming switch, from the exterior of the rocket's airframe, through inspection of design shematics and a physical model.
2.4	Each altimeter will have a dedicated power supply	Inspection	It shall be identified that each altimeter has a dedicated power supply through inspection of design schematics and a physical model.
2.5	Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	Inspection	It shall be identified, through inspection of the physical rocket model, that all arming switches may be locked for flights of the rocket.
2.6	The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	Demonstration	The team shall demonstrate through test launches that the rocket is both recoverable and reusable.
2.7	The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	Inspection	Verifiable through inspection of both design schematics and physical models, the rocket will have no more than four independant sections.
2.8	The launch vehicle will be limited to a single stage.	Inspection	Through inspection of the team's rocket design schematics and physical models, it shall be verified that the rocket is single-staged.
2.9	The launch vehicle will be capable of being prepared for flight at the launch site within 3 hours of the time the Federal Aviation Administration flight waiver opens.	Demonstration	The team shall demonstrate, through testing of launch preparation procedures, that the rocket may be readied for launch within 3 hours of the time the FAA flight waiver opens.
2.10	The launch vehicle will be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board components.	Testing	Through testing of the electronic systems of the rocket, it shall be verified that said systems may operate for a minimum of 1 hour and remain capable of launch operations.
2.11	. The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated Range Services Provider.	Testing	The team shall verify that the rocket is capable of being launched by standard 12-volt direct current firing systems through test launches of the rocket.
2.12	The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).	Demonstration	It shall be demonstrated through test launches that no external circuitry is required to initate launch operations.
2.13	The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	Inspection	It shall be identified through inspection of design documentation and constructed models that only approved comercially available solid rocket motors are used for flight operations.
2.13.1	Final motor choices must be made by the Critical Design Review (CDR).	Inspection	It shall be identified through design documentation that a final motor choice is made prior to the Critical Design Review.
2.13.2	Any motor changes after CDR must be approved by the NASA Range Safety Officer (RSO), and will only be approved if the change is for the sole purpose of increasing the safety margin	Analysis	Analysis of the safety margin will inform the team of any necessary changes in motor choice, and these will be discussed with the NASA RSO if required.
2.14	Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria:	Inspection	Any pressure vessels included in the launch vehicle desing will be verified through analysis of desing dicumentation to meet the requirements specified below.
2.14.1	. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.	Testing	Any pressure vessels will be verified through testing to meet the minimum safety factors for Burst and Ultimate vs Max Expected Operating Pressure.
2.14.2	Each pressure vessel will include a pressure relief valve that sees the full pressure of the valve that is capable of withstanding the maximum pressure and flow rate of the tank.	Testing	Any pressure vessels incorporated in the launch vehicle design will through testing be verified to have a relief valve that sees full pressure and is capable of withstanding the maximum pressure and flow rate of the tank.
2.14.3	Full pedigree of the tank will be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.	Inspection	Design documentation shall verify the pedigree of any pressure vessels incorporated in the launch vehicle design.
2.15	The total impulse provided by a College and/or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).	Analysis	Analysis of chosen motor specifications for the launch vehicle shall verify that the total impulse does not exceed 5,120 Newton-seconds.
2.16	The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	Testing	Both test launches and computer simulations of the launch vehicle shall verify that the static stability margin is at a minimum of 2.0 at the point of rail exit.

2.17	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit	Testing	Both test launches and computer simulations of the launch vehicle shall verify that the velocity at rail exit is no less than 52 fps.
2.18	All teams will successfully launch and recover a subscale model of their rocket prior to CDR. Subscales are not required to be high power rockets.	Testing	The team shall design and test launch a scale model of the inteded competition launch vehicle prior to CDR.
2.18.1	The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale will not be used as the subscale model.	Analysis	Through analysis of design specifications for the subscale model, it shall be verfied that the subscale model retains performance capabilities analogous to the full-scle model.
2.18.2	The subscale model will carry an altimeter capable of reporting the model's apogee altitude.	Analysis	Analysis of the design documentation for the subscale model shall verify that an altimeter is incorporated in subscale flight operations.
2.19	All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day. The purpose of the full-scale demonstration flight is to demonstrate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at a lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full-scale demonstration flight:	Testing	The team shall test launch and recovery the launch vehcle prior to FR, which will then be taken to and flown on launch day.
2.19.1	The vehicle and recovery system will have functioned as designed.	Demonstration	The team shall demonstrate through test launches and competition launch that the vehicle and recovery systems of the rocket function as designed.
2.19.2	The payload does not have to be flown during the full-scale test flight. The following requirements still apply:	Demonstration	The team shall demonstrate the capability of the launch vehicle to carry a payload through either incorporation of a mas simulator or payload model on each flight.
2.19.2.1	If the payload is not flown, mass simulators will be used to simulate the payload mass.	Testing	For each test flight which does not incorporate a payload model, a mass simulator will be used to ensure that the rocket is capable of flight operations as expected.
2.19.2.1.1	The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.	Inspection	Inspection of launch vehicles before each launch shall verify that mass simulators are located in the same approximate location as where the mision payload will be located.
2.19.3	If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale demonstration flight	Demonstration	In the event that the payload design requires protuberances of the launch vehicle airframe, it shall be demonstrated that external elements of said design will be demonstrated to function as expected during full scale demnostration flights.
2.19.4	The full-scale motor does not have to be flown during the full-scale test flight. However, it is recommended that the full-scale motor be used to demonstrate full flight readiness and altitude verification. If the full-scale motor is not flown during the full-scale flight, it is desired that the motor simulates, as closely as possible, the predicted maximum velocity and maximum acceleration of the launch day flight	Demonstration	It shall be demonstrated that any motor used for full-scale test flights that is not the designated full-scale design motor of choice will enable flight operations to meet those expected from use of the designated full-scale motor.
2.19.5	The vehicle must be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the launch day flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.	Testing	The full-scale test flight of the launch vehicle design intended to be used for FRR and at the competition shall have the intended ballast desired during competition flight.
2.19.6	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).	Inspection	The team will commmunicate any desired modifications of the launch vehicle post demonstraition flight, and submit said modifications for inspection, to the NASA RSO for approval.
2.19.7	Full scale flights must be completed by the start of FRRs (March 6th, 2018). If the Student Launch office determines that a re-flight is necessary, then an extension to March 28th, 2018 will be granted. This extension is only valid for re-flights; not first-time flights.	Demonstration	The team shall demonstrate that the full-scale design is viable through a test fight before FRR, and if any re-flights are deemed necessary by NASA, the team will conduct such before the extension date.
2.20	Any structural protuberance on the rocket will be located aft of the burnout center of gravity.	Inspection	Inspection of the launch vehicle will verify that no protuberances of a stuctural nature will be located before the burnout center of gravity.
2.21	Vehicle Prohibitions	Inspection	Any vehicle prohibitions shall by inspection be verified to be non-existant in the design of the launch vehicle.
2.21.1	The launch vehicle will not utilize forward canards.	Inspection	The launch vehicle shall by inspection be verified to not use forward canards.
2.21.2	The launch vehicle will not utilize forward firing motors.	Inspection	The launch vehicle shall by inspection be verified to not use forward firing motors.
2.21.3	The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	Inspection	The launch vehicle shall by inspection be verified to not use spark emitting motors.
2.21.4	The launch vehicle will not utilize hybrid motors.	Inspection	The launch vehicle shall by inspection be verified to not use a hybrid motor.

2.21.5	The launch vehicle will not utilize a cluster of motors.	Inspection	The launch vehicle shall by inspection be verified to not use a cluster of motors.
2.21.6	The launch vehicle will not utilize friction fitting for motors.	Inspection	The launch vehicle shall by inspection be verified to not utilize friction fitting for motors.
2.21.7	The launch vehicle will not exceed Mach 1 at any point during flight	Testing	Through velocity data collected during test flights and computer simulations the launch vehicle shall be verified to not exceed Mach 1 at any time during flight.
2.21.8	Vehicle ballast will not exceed 10% of the total weight of the rocket.	Inspection	Inspection of the launch vehicle design shall verify that no more than 10% of the vehicle's total weight will be added as ballast during flight.
3.1	The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the RSO.	Demonstration	It shall be demonstrated that recovery devices are staged and adequately slow descent rates of the lanch vehicle to meet landing energy requirements.
3.2	Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full-scale launches.	Testing	The team shall test ejection systems prior to at least the first full-scale and subscale test launches.
3.3	At landing, each independent sections of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.	Testing	It shall be verified through computer simulation and data retrieved from full-scale launches that landing energies do not exceed the specified limit of 75 ft-lbf.
3.4	The recovery system electrical circuits will be completely independent of any payload electrical circuits	Inspection	Inspection of electrical system schematics of both the payload and luanch vehicle shall verify that these are independant of one another.
3.5	All recovery electronics will be powered by commercially available batteries.	Inspection	Inspection of the batteries used for recovery system electronics shall verify that they are commercially available.
3.6	The recovery system will contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	Inspection	Inspection of the recovery system design of the launch vehicle shall verify that redundant altimeters are present.
3.7	Motor ejection is not a permissible form of primary or secondary deployment.	Demonstration	The rocket design does not include motor ejection
3.8	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Inspection	Shear pins will be located on launch vehicle
3.9	Recovery area will be limited to a 2500 ft. radius from the launch pads.	Demostration	Data will be collected from test launches and simulations to show this requirement will be met
3.10	An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver	Testing	Will be tested during launches prior to competition launch
3.10.1	Any rocket section, or payload component, which lands untethered to the launch vehicle, will also carry an active electronic tracking device.	Demonstration	A properly secured electronic tracker can be shown in each section needed
3.10.2	The electronic tracking device will be fully functional during the official flight on launch day.	Testing	Electronic testing during flights before competition flight
3.11	The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	Testing	Sheilding of all recovey system components can be tested in a realistic setting
3.11.1	The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	Inspection	Inspection of the vehicle compartments can verify seperation
3.11.2	The recovery system electronics will be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.	Testing	Sheilding of all recovey system components can be tested in a realistic setting
3.11.3	The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	Testing	Sheilding of all recovey system components can be tested in a realistic setting
3.11.4	The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	Testing	Sheilding of all recovey system components can be tested in a realistic setting
4.1	Each team will choose one design experiment option from the following list.		
4.2	Additional experiments (limit of 1) are allowed, and may be flown, but they will not contribute to scoring.	Demonstration	The team shall allow no more than one additional experiment on the final launch vehicle

4.3	If the team chooses to fly additional experiments, they will provide the appropriate documentation in all design reports, so experiments may be reviewed for flight safety.	Demonstration	Any additional experiments will be discussed in design reports if an additional experiment is determined
4.4	Target Detection		
4.4.1	Teams will design an onboard camera system capable of identifying and differentiating between 3 randomly placed targets.	Testing	Testing shall be done to determine that a custom designed camera system can identify and differentiate between 3 randomly placed targets
4.4.1.1	Each target will be represented by a different colored ground tarp located on the field.	Testing	Testing shall be done to assure that the camera system can differentiate between 3 different colors on the ground
4.4.1.2	Target samples and RGB values will be provided to teams upon acceptance and prior to PDR.	Demonstration	The team shall state the recieved RBG values in documentation starting from the PDR to the competition date
4.4.1.3	All targets will be approximately 40'X40' in size.	Demonstration	NASA shall assure the targets are approximately 40'x40' in size
4.4.1.4	The three targets will be adjacent to each other, and that group will be within 600 ft. of the launch pads.	Demonstration	NASA shall assure that the targets are adjacent to each other and within 600 feet of the launch pads
4.4.2	Data from the camera system will be analyzed in real time by a custom designed on-board software package that shall identify, and differentiate between the three targets.	Testing	The team shall load a program onto the flight computer to analyze the data from the camera system and identify the tarps and verify that the program performs solely on the flight computer
4.4.3	Teams will not be required to land on any of the targets	Demonstration	Design of the payload shall not include programming to make the payload land on the colored tarps
5.1	Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations	Demonstration	The Safety Officer will create launch and safety checklist with input from the other teams to ensure relivants. These documents will be uploaded to the team web site and will be implemented in the LRR and FRR reports
5.2	Each team must identify a student safety officer who will be responsible for all items in section 5.3.	Demonstration	The team will select a person to be the Safety Officer and that individual will be responsible for all safety related maters for the team
5.3.1	Monitor team activities with an emphasis on Safety during: Design of vehicle and payload Construction of vehicle and payload Assembly of vehicle and payload Ground testing of vehicle and payload Sub-scale launch test(s) Full-scale launch test(s) Launch day Recovery activities Educational Engagement Activitie	Inspection	the Safety officer will document his work during the different phases of the project through Pre-Job Briefings.
5.3.2	Implement procedures developed by the team for construction, assembly, launch, and recovery activities	Inspection	The Safety Officer will working with memebers from each of the teams to create procedures for each of the different phases of the project
5.3.3	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data	Demonstration	The Safety Officer will work with members from each team to ensure that the hazard analysis sheets and MSDS are kept up to date as the project progresses
5.3.4	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	Demonstration	The Safety Officer will work with members from each team to ensure that the hazard analysis sheets to ensure that they are formated correctly and the procedures are useful
5.4	During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch Initiative does not give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	Demonstration	The Safety Officer will work with the Rocket team to ensure that the launch vehicle and its payload will be permitted to launch by comunicating with the local NAR launcher
5.5	Teams will abide by all rules set forth by the FAA.	Demonstration	The Safety Offcier will ensure that all activities that the team are involved in fallow all FAA, government, and local laws and regulations

10.2 Team Requirements

Requirement	Description	Verification Type	Verification Plan
1.1	The team shall meet at least two times a week in order to discuss current progress on tasks and plan out future actions	Demonstration	The team shall meet at their scheduled time (Tuesdays and Thursdays from 6-7:20PM)
1.1.1	The team lead shall direct meetings to ensure the team stays on task	Demonstration	The team lead will begin and direct meetings to ensure everyone provides updates and can discuss the team's overall progress
1.1.2	The team shall meet with the faculty advisor once a week to discuss project progress	Demonstration	The team will meet with the faculty advisor on Tuesdays at 6:45 PM to discuss progress on the project
1.2	The team lead and documents manager shall have joint responsibility for ensuring all deliverables get completed and sent to NASA on time	Demonstration	The team lead and documents manager will meet privately at least once per week to discuss progress on upcoming milestones
1.3	Each subsection team shall assign a leader to take responsibilty for the actions of the subteam	Demonstration	Each of the subsection team leads will be chosen and idnetified in the team project hierarchy
1.4	The team shall have access to a designated workspace to perform rocket construction	Demonstration	The team will receive keys to the University of Cininnati's rocketry lab to utilize 24/7
1.5	The team shall submit all NASA deliverables the team mentor at an 80% draft point one week before each NASA deliverable deadline	Demonstration	The team mentor will receive an email containing an 80% draft of each milestone a week before it's due in PDF form.
2.1	Rocket team members shall complete level 2 model rocketry certification	Demonstration	The rocket team shall build and launch kit rockets and complete the NAR level 2 certification requirements.
2.2	The rocket shall have a maximum landing energy of 70 ft lbs	Testing	The rocket team shall test this through simulations and launching of the rocket design
2.3	The rocket shall be launch ready on the launch pad for a minimum of 1.5 hours	Testing	The rocket team shall test the duration that the batteries can remain active before flight operations would be prohibited.
2.4	The rocket shall shall house the payload module safely until it is deployed	Testing	The rocket team shall confirm that the rocket can safely deliver the payload to apogee with tests using a dummy payload

2.5	The rocket body shall be able to withstand launch forces	Testing	The rocket team will test matierial strength in sub-scale launches and ground tests
2.6	The rocket shall have parachute packaging that shall be placed and packed to minimize chance of tangling	Testing	The parachute packing will be tested in sub-scale launches and ground tests
2.7	Rocket designs will be simulated before all launches	Analysis	All rocket designs shall be simulated and recorded in rocksim before launch
2.8	All versions of the rocket will be logged during design	Demonstration	All versions of the rocket will be logged using version numbers such as v1.2.3
3.1	The payload shall be able to remain active on the launch pad for a minimum of 1.5 hours	Testing	The payload team shall test the duration of the batteries while the electronics are idling and running at full capacity.
3.1.1	The batteries shall provide enough power to last through the maximum idle time and the entirety of the mission	Testing	The payload team shall test the battery usage during ground tests
3.2	The payload team shall use a ground station to monitor the payload status from before launch until landing	Testing and Demonstration	The payload team shall develop and test a ground station on a laptop computer.
3.3	The payload casing shall be able to safely house the payload electronics until mission is complete	Testing	The payload casing will be tested in sub-scale launches and ground tests
3.4	The payload shall have stable enough conditions during decent to take clear images	Testing	Payload stablility will be tested in test launches and drop tests tests
3.5	The payload shall have parachute packaging that shall be placed and packed to minimize chance of tangling	Testing	The parachute packing will be tested in sub-scale launches and ground tests
3.6	The payload shall be able to survive all mission impulses	Testing	Payload survivability will be tested in sub-scale launches
3.7	The payload and ejection cartridges shall be orientated as to not obscure the camera with ejection gasses	Testing and Demonstration	Payload and ejection cartidge orientation shall be tested in sub-scale launches
3.8	The payload shall be able to fit within the rocket	Demonstration	The payload shall fit within the designated section for the payload

4.0	The budget shall not be exceeded	Analysis	The budget shall be analyzed regularly to assure projected/actual costs do not exceed projected/actual revenues
4.1	Each team shall recieve allocation based on need	Analysis	Cost-benefit analyses shall be performed during the design phase to assure each team has a cost effective design that satisfies all NASA derived and team derived requirements
4.2	The team lead and treasurer shall coordinate on the travel plans and budget	Inspection	The team document keepers shall ensure that communication between the team lead and treasurer to finalize the competition itinerary occurs in a timely fashion
4.3	Each team member shall seek out sponsors for the project	Inspection	The team treasurer shall ensure that all team members are persuing possible sponsor leads
5.0	Pre-Job Briefings will be performed before all group activities	Inspection	Safety Officer will ensure that all team members complete there PJB before activities started
5.1	All Team members will be required to complete safety trainings if they plan to be involved in construction of any type	Inspection	Safety Officer will provide training material to all of the team members and they will be required to show proof of there completion of the trainings before they are allowed to be involved in any construction
5.2	All members that work in the lab must check in and out	Inspection	A checking sheet will be placed in the Rocket lab and all team members that work in the lab will be required to check in when that enter and check out when they are finished

11 Appendix C: Finances

11.1 Incurred Transaction Tables

Build Expenses:	$104.10
Operational Expenses	$1,460.85
Total Expenses:	$1,564.95

Table 24: Overall Incurred Expenses

AIC Funding:	$8,000.00
Aerospace Department Funding:	$3,000.00
OSGC Grant:	$5.000.00
Total Revenues:	$16,000.00

Table 25: Procurred Revenues

Electronics Expenses:	$104.10
Total Expenses	$104.10

Table 26: Incurred Build Expenses

Item	Quantity	Piece Price	Total
Pixy CMUcam5:	1	$69.00	$69.00
Raspberry Pi 3 M:B:	1	$35.10	$35.10
		Total Cost:	$104.10

Table 27: Incurred Electronics Expenses

Item	Quantity	Piece Price	Total
Certification Expenses	See Table 29		$1,356.59
Miscellaneous Expenses	See Table 30		$52.13
		Total Expenses:	$1,408.72

Table 28: Incurred General Operational Expenses

Item	Quantity	Piece Price	Total
Loc Fantom 438 Rocket Kit	4	$139.95	$559.80
Cesaroni H120A Engine	5	$31.95	$159.75
Ejection Cannister Caps (2-Pack)	6	$3.15	$18.90
Cesaroni 38mm 2-Grain Case	3	$34.10	$102.30
Cesaroni 38mm 5-Grain Case	3	$53.46	$168.68
Cesroni J270A Engine	4	$56.00	$224.00
Shipping Charges	1	$131.46	$131.46
		Total Expenses:	$1,356.59

Table 29: Incurred Certification Expenses

Item	Quantity	Piece Price	Total
PPE & Other Safety Equipment	See Table 31		$28.98
Shop Supplies	See Table 32		$23.15
		Total Expenses:	$52.13

Table 30: Incurred Miscellaneous Expenses

Item	Quantity	Piece Price	Total
12-Pack Safety Glasses	1	$14.99	$14.99
12-Pack Resperators	1	$13.99	$13.99
		Total Expenses:	$28.98

Table 31: Incurred PPE Expenses

Item	Quantity	Piece Price	Total
Shear Pins (20 Pack)	5	$3.10	$15.50
Shipping	1	$7.65	$7.65
		Total Expenses:	$23.15

Table 32: Incurred Shop Supply Expenses

11.2 Projected Expense/Revenue Tables

Build Expenses:	$5,550.00
Operational Expenses	$9,800.00
Total Expenses:	$15,150.00

Table 33: Overall Projected Expenses

CEAS Dept. of Undergraduate Affairs:	$3,000.00
Corporate Sponsorships:	$3,000.00
Total Revenues:	$6,000.00

Table 34: Projected Revenues

Item	Quantity	Piece Price	Total
5.38 in Loc Precision Airframe Tube:	5	$38.50	$192.50
5.38 in Loc Precision Tube Coupler:	4	$9.08	$36.32
5.38 in Loc Precision Short Nose Cose:	2	$54.95	$109.90
5.38 in Loc Precision Bulkhead Assemblies:	10	$7.98	$79.80
Cesaroni Technology K670RR:	5	$115.50	$577.50
Fruity Chutes 15” Elliptical Parachute:	2	$50.00	$100.00
Fruity Chutes Iris 60” Ultra Light Parachute:	2	$275.00	$550.00
AMW 54-1750 Motor w/ Carrier:	1	$140.00	$140.00
G10 Fiberglass Sheet 1/8” x 1 ft$\hat{2}$:	2	$27.00	$54.00
General Telemetry Components:	1	$250.00	$250.00
General Subscale Components:	1	$500.00	$500.00
		Factor of Safety:	1.2
		Total Cost:	$3,108.02
		Rounded Total:	$3,250.00

Table 35: Projected Rocket Build Expenses

Item	Quantity	Piece Price	Total
Pixy CMUcam5:	1	$69.00	$69.00
Pan/Tilt Kit:	1	$29.95	$59.90
NVIDIA Jetson TK1:	1	$199.99	$199.99
IMU 10 DOF:	2	$37.34	$74.68
Adafruit Uli GPS:	2	$44.95	$89.90
Odroid-XU4:	2	$59.00	$118.00
oCam:	2	$96.00	$192.00
Biscuit:	2	$29.00	$58.00
myAHRS+:	2	$75.00	$150.00
USB GPS Module:	2	$20.00	$40.00
Battery:	5	$5.00	$25.00
		Factor of Safety:	1.2
		Total Cost:	$1,261.76
		Rounded Total:	$1300.00

Table 36: Projected Electronics Expenses

Item	Quantity	Piece Price	Total
18"x18"x1/8" 6061 Aluminum Sheet	1	$57.12	$57.12
3/16" dia. x 6' len. 6061 Aluminum Rod	4	$16.38	$65.52
Shouldered Steel Eyebolt	8	$3.81	$30.48
Extreme-Strength Steel Hex Nut, 25 pk.	1	$11.42	$11.42
Mil. Spec. Black Hook, 1"x30'	2	$14.10	$28.20
TBD Payload Supplies	1	$350.00	$350.00
ABS 3D Printing Material	1	$100.00	$100.00
		Factor of Safety:	1.2
		Total Cost:	$771.29
		Rounded Total:	$800.00

Table 37: Projected Payload Build Expenses

Item	Quantity	Piece Price	Total
Outreach Expenses	See Table 39		$250.00
Huntsville Trip Expenses	See Table 40		$5,250.00
Miscellaneous Expenses	See Table 41		$4,300.00
		Total Budget:	$9,800.00

Table 38: Projected General Operational Expenses

Item	Quantity	Piece Price	Total
Educational Supplies	1	$150.00	$150.00
Transit Gasoline	2.5 Gallons	$2.75/gal	$6.68
		Factor of Safety:	1.2
		Total Cost:	$188.25
		Rounded Total:	$250.00

Table 39: Projected Outreach Expenses

Item	Quantity	Piece Price	Total
Hotel Rooms	5 Rooms, 4 Nights	$100.00/room/night + fees	$2156.95
Rental Cargo Van:	1 Van	$550/week	$550.00
Rental Transit Van:	2 Vehicles	$425/week	$850.00
Cargo Van Gasoline:	45 Gallons	$2.75/gal	$123.75
Transit Van Gasoline:	35 Gallons	$2.75/gal	$192.50
Backup Materials:	1	$400.00	$400.00
		Factor of Safety:	1.2
		Total Cost:	$5,127.84
		Rounded Total:	$5,250.00

Table 40: Projected Huntsville Trip Expenses

Item	Quantity	Piece Price	Total
Gasoline to (4) Test Launches, Rio Grande, OH	56.4 Gallons	$2.75/gal	$155.10
Polo Shirts:	20	$30.00	$600.00
Website Subscription:	7 Months	$14/Mo.	$98.00
PPE/Other Safety Equipment:	1	$220.00	$220.00
Other Marketing Expenses:	1	$250.00	$150.00
Overhead:	1	$550.00	$550.00
Reimbursments:	1	$1,000.00	$1,000.00
Shipping Costs:	1	$500.00	$500.00
Shop Supplies:	1	$225.00	$225.00
		Factor of Safety:	1.2
		Total Cost:	$4,197.72
		Rounded Total:	$4,300.00

Table 41: Projected Miscellaneous Expenses

12 Appendix D: Gantt Charts

Figure 47: Payload Team Gantt Chart

Task Name	Duration	Start	Finish
Payload Design	**119 days**	**Wed 9/20/17**	**Mon 3/5/18**
Top Level Design Decisions and Trade Studies	29 days	Wed 9/20/17	Sat 10/28/17
Verify and Order Parts Needed	4 days	Wed 10/25/17	Sat 10/28/17
Payload Fabrication and Coding	29 days	Sat 10/28/17	Wed 12/6/17
Payload Succesful Ground Tests	4 days	Wed 12/6/17	Sat 12/9/17
Build Payload Casing	29 days	Sat 12/9/17	Wed 1/17/18
Payload Optimization and Tweaking	14 days	Wed 1/17/18	Sat 2/3/18
Payload Incorporated in Second Full-Scale Launch	0 days	Sat 2/3/18	Sat 2/3/18
Redesign and Optimize based on Test Launch Results	22 days	Sat 2/3/18	Mon 3/5/18
Payload Embedded Systems Design	**119 days**	**Wed 9/20/17**	**Mon 3/5/18**
Top Level Design Decisions and Trade Studies	29 days	Wed 9/20/17	Sat 10/28/17
Verify and Order Parts Needed	4 days	Wed 10/25/17	Sat 10/28/17
Payload Embedded Systems Fabrication and Coding	**72 days**	**Sat 10/28/17**	**Sat 2/3/18**
Design	27 days	Sat 10/28/17	Sat 12/2/17
Test	27 days	Sat 12/2/17	Mon 1/8/18
Redesign, Test, etc.	21 days	Mon 1/8/18	Sat 2/3/18
Payload Embedded Systems Incorporated Into Rocket	22 days	Sat 2/3/18	Mon 3/5/18
Ground Station Design	**119 days**	**Wed 9/20/17**	**Mon 3/5/18**
Top Level Design Decisions and Trade Studies	29 days	Wed 9/20/17	Sat 10/28/17
Verify and Order Parts Needed	4 days	Wed 10/25/17	Sat 10/28/17
Ground Station Coding and Setup	27 days	Sat 10/28/17	Sat 12/2/17
Ground Station Test With First Full-Scale Launch	0 days	Sat 12/2/17	Sat 12/2/17
Ground Station Redesign and Retests	67 days	Sat 12/2/17	Mon 3/5/18

Figure 48: Rocket Team Gantt Chart

Task Name	Duration	Start	Finish
NAR Certification Rockets Build	**29 days**	**Wed 9/20/17**	**Sat 10/28/17**
Verify and Order Parts Needed	1 day	Wed 9/20/17	Wed 9/20/17
Choose Certification Rocket Design	1 day	Wed 9/20/17	Wed 9/20/17
Certification Rocket Fabrication	14 days	Wed 9/27/17	Sat 10/14/17
Certification Launch	0 days	Sat 10/28/17	Sat 10/28/17
Sub-Scale Rocket Design	**39 days**	**Wed 9/20/17**	**Sat 11/11/17**
Decide on Launch Vehicle Design and Sub-Scaling	14 days	Wed 9/20/17	Sat 10/7/17
Verify and Order Parts Needed	2 days	Fri 10/6/17	Sat 10/7/17
Sub-Scale Rocket Fabrication	22 days	Fri 10/13/17	Sat 11/11/17
Sub-Scale Rocket Launch	0 days	Sat 11/11/17	Sat 11/11/17
Full-Scale Rocket Design	**27 days**	**Sat 10/28/17**	**Sat 12/2/17**
Review Design From Sub-Scale and Make Changes	4 days	Sat 10/28/17	Wed 11/1/17
Order Parts For Full Scale Design	3 days	Mon 10/30/17	Wed 11/1/17
PDR Document Due	0 days	Fri 11/3/17	Fri 11/3/17
Full Scale Rocket Fabrication	24 days	Wed 11/1/17	Sat 12/2/17
Full Scale Rocket First Test Launch	0 days	Sat 12/2/17	Sat 12/2/17
Full-Scale Rocket Redesign and Revision	**67 days**	**Sat 12/2/17**	**Mon 3/5/18**
Review Design From First Full-Scale Launch and Make Design Changes	31 days	Sat 12/2/17	Fri 1/12/18
CDR Document Due	0 days	Fri 1/12/18	Fri 1/12/18
Order Parts For Revised Full-Scale Design	7 days	Sat 1/13/18	Sat 1/20/18
Build and Ground Test Second Full Scale Rocket Design	12 days	Sat 1/20/18	Sat 2/3/18
Second Full-Scale Design Launch	0 days	Sat 2/3/18	Sat 2/3/18
Review Design From Second Full-Scale Launch and Make Design Changes	12 days	Sat 2/3/18	Sat 2/17/18
Order Parts For Revised Full-Scale Design	4 days	Sat 2/17/18	Wed 2/21/18
Build and Ground Test Third Full-Scale Rocket Design	6 days	Wed 2/21/18	Wed 2/28/18
Third Full-Scale Design Launch	0 days	Sat 3/3/18	Sat 3/3/18
[illegible]	[illegible]	[illegible]	[illegible]

Figure 49: Finance Team Gantt Chart

Task Name	Duration	Start	Finish
Finance Team Deliverables	**138 days**	**Wed 9/20/17**	**Fri 3/30/18**
Know Support Package From UC Aerospace Department	6 days	Sun 9/10/17	Fri 9/15/17
Purchase Rocket Certification Kits	4 days	Fri 9/15/17	Wed 9/20/17
Meet With Prior Year's Treasurer For Info	5 days	Mon 9/25/17	Fri 9/29/17
Write OSGC Grant Application	8 days	Wed 9/20/17	Fri 9/29/17
Purchase Subscale Components	7 days	Fri 9/29/17	Sat 10/7/17
Plan For Corporate Fundraising	61 days	Mon 10/9/17	Sun 12/31/17
Order Payload Parts	4 days	Wed 10/11/17	Sat 10/14/17
Purchase Full Scale Build Components	13 days	Mon 10/16/17	Wed 11/1/17
Hotel Room Book Deadline For Huntsville	1 day	Fri 12/1/17	Fri 12/1/17
Rental Car Book Deadline For Huntsville	1 day	Fri 1/12/18	Fri 1/12/18
Purchase Full and Extra Components For Competition Build	31 days	Sun 1/28/18	Fri 3/9/18
Presentation of Funding Request For Next Year's Design Team	6 days	Sun 3/25/18	Fri 3/30/18

Figure 50: Gantt Chart for NASA deliverables

Task Name	Duration	Start	Finish
NASA Deliverables	**158 days**	**Wed 9/20/17**	**Fri 4/27/18**
Proposal to Compete	14 days	Fri 9/1/17	Wed 9/20/17
Awarded Proposals Announced	0 days	Fri 10/6/17	Fri 10/6/17
PDR Q&A Session	0 days	Thu 10/12/17	Thu 10/12/17
Establish Web Presence	46 days	Fri 9/1/17	Fri 11/3/17
PDR Posted to Website and Submitted	0 days	Fri 11/3/17	Fri 11/3/17
PDR Video Teleconferences	14 days	Mon 11/6/17	Thu 11/23/17
CDR Q&A Session	0 days	Wed 12/6/17	Wed 12/6/17
CDR Posted to Website and Submitted	0 days	Fri 1/12/18	Fri 1/12/18
CDR Video Teleconferences	12 days	Tue 1/16/18	Wed 1/31/18
FRR Q&A	0 days	Wed 2/7/18	Wed 2/7/18
FRR Posted to Website and Submitted	0 days	Mon 3/5/18	Mon 3/5/18
FRR Video Teleconferences	13 days	Tue 3/6/18	Thu 3/22/18
Huntsville Launch Week	4 days	Wed 4/4/18	Sun 4/8/18
PLAR Posted to Website	0 days	Fri 4/27/18	Fri 4/27/18

Figure 51: Safety Team Gantt Chart

Task Name	Duration	Start	Finish
Safety Team Deliverables	**158 days**	**Wed 9/20/17**	**Fri 4/27/18**
Awareness of Laws and Regulations	34 days	Wed 9/13/17	Sat 10/28/17
Safety and Hazard Documentation	34 days	Wed 9/13/17	Sat 10/28/17
Safety Planning	163 days	Wed 9/13/17	Fri 4/27/18
Equipment Safety Training	18 days	Wed 9/13/17	Fri 10/6/17
Risk Analysis	149 days	Wed 9/13/17	Sun 4/8/18
Manage Known Hazards	163 days	Wed 9/13/17	Fri 4/27/18