Tacho Lycos
2019 NASA Student Launch
Proposal

High-Powered Rocketry Club at NC State University
911 Oval Drive
Raleigh, NC 27695

September 19, 2018

Common Abbreviations & Nomenclature

AGL	=	above ground level
APCP	=	ammonium perchlorate composite propellant
ARRD	=	advanced retention and release device
AV	=	avionics
BP	=	black powder
CDR	=	Critical Design Review
CG	=	center of gravity
CP	=	center of pressure
EIT	=	electronics and information technology
FAA	=	Federal Aviation Administration
FMECA	=	failure mode, effects, and criticality analysis
FN	=	foreign national
FRR	=	Flight Readiness Review
HEO	=	Human Exploration and Operations
HPR	=	High Power Rocketry
HPRC	=	High-Powered Rocketry Club
L3CC	=	Level 3 Certification Committee (NAR)
LCO	=	Launch Control Officer
LRR	=	Launch Readiness Review
MAE	=	Mechanical & Aerospace Engineering Department
MSDS	=	Material Safety Data Sheet
MSFC	=	Marshall Space Flight Center
NAR	=	National Association of Rocketry
NCSU	=	North Carolina State University
NFPA	=	National Fire Protection Association
PDR	=	Preliminary Design Review
PLAR	=	Post-Launch Assessment Review
PPE	=	personal protective equipment
RFP	=	Request for Proposal
RSO	=	Range Safety Officer
SL	=	Student Launch
SLS	=	Space Launch System
SME	=	subject matter expert
SOW	=	statement of work
STEM	=	Science, Technology, Engineering, and Mathematics
TAP	=	Technical Advisory Panel (TRA)
TRA	=	Tripoli Rocketry Association
UAV	=	Unmanned Aerial Vehicle

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1. General Information

1.1 Team Advisors and Mentors

i. **Name: Dr. Charles (Chuck) Hall**
ii. Email: chall@ncsu.edu
iii. TRA Certification: 14134

iv. Biography: Dr. Hall directs the Flight Research Group in the Mechanical and Aerospace Engineering Department at North Carolina State University. Dr. Hall is the current advisor for the High-Powered Rocketry Club. He is also the professor in charge of the aerospace senior design project. Dr. Hall has level 3 certification with Tripoli Rocketry Association (TRA).

i. **Name: Alan Whitmore**
ii. Email: acwhit@nc.rr.com
iii. Phone: (919) 929-5552
iv. TRA Certification: 05945

v. Biography: Alan became involved in High Power Rocketry in 1997 and has since earned his Level 3 certification for both TRA and NAR. Since 2002, Alan has served as the prefect of the Eastern North Carolina branch of TRA. In 2006, he was accepted onto the TRA Technical Advisory Panel (TAP) to advise the TRA board of directors on technical aspects of propellants, construction material, and recovery techniques. Alan is also a current member of the NAR Level 3 Certification Committee (L3CC), allowing him to supervise individual members during the process of designing, manufacturing, and flying rockets used for Level 3 certification for both NAR and TRA. Alan was recently selected as the Chairman of the Tripoli Motor Testing Committee, which is responsible for testing and certifying all new commercially manufactured hobby rocket motors manufactured in the United States.

i. **Name: James (Jim) Livingston**
ii. Email: livingston@ec.rr.com
iii. Phone: (910) 612-5858
iv. TRA Certification: 02204

v. Biography: Jim joined the TRA in 1993 and achieved his Level 3 certification in 1997. As of 1998, Jim has served as a member of the TRA TAP and has supervised over twenty Tripoli members in their own Level 3 certifications. He has also been involved in Tripoli research since 1997 and manufactures all the motors he uses (sizes I through N).

1.2 High Powered Rocketry Club

Established in 2009, the High-Powered Rocketry Club (HPRC), team name "Tacho Lycos," is an interdisciplinary student organization within the Department of Mechanical and Aerospace Engineering (MAE) at NC State University. The Club gives undergraduate students the opportunity to gain real-world design and construction experience through participation in the annual Student Launch (SL) competition sponsored by the NASA Marshall Space Flight Center (MSFC) in Huntsville, Alabama. Team mentors communicate regularly with club officers to supervise research, design, construction, testing, and launch of high-powered rockets. While all members of the club participate in these activities, they are led by a group of Aerospace Engineering seniors who have chosen to participate in the SL competition to satisfy the requirement for a senior capstone project before graduation. These seniors receive a final grade that corresponds to the final competition score.

1.3 Safety Officer

i. **Name: Shiv Oza**
ii. Email: sjoza@ncsu.edu
iii. Responsibilities: Shiv will act as the NC State University Safety Officer for the 2018-19 NASA Student Launch competition. Shiv is responsible for the safe operation of all equipment in the lab including, but not limited to: power tools, drill presses, hand tools, batteries, and chemicals. He will be present for all aspects of construction to ensure the safety of team members as well as accompanying guests, and to train new members on the proper and safe usage of all equipment. The Safety Officer is required to be present for any testing or vehicle launches. He is also responsible for maintaining a clean working environment in the lab that meets or exceeds safety regulations instituted by the MAE department which includes the maintenance of a flame cabinet and proper stocking of a first aid kit.

1.4 Student Team Leader

i. **Name: Harvey Hoopes IV**
ii. Email: hwhoopes@ncsu.edu
iii. Phone: (910) 389-3757
iv. Responsibilities: Harvey will act as the NC State University Student Team Leader for the 2018-19 NASA Student Launch competition. Harvey is also serving as HPRC president and Team Lead for the Senior Design team which consists of other aerospace engineering seniors: Jacob, Josh, Michelle, Nathan, Nolan.

1.4.1 Senior Design Team

i. Name: Jacob
ii. Subteam: Payload Structures
iii. Biography: Jacob Daye is a 4th year student pursuing an Aerospace Engineering degree as well as two minors in physics and Tenor Saxophone performance. He is a University Scholar and member of the NC State Men's Choir, Jazz Ensemble II, and Jazz Combo II. When he is not on campus, he is travelling, backpacking, and spending time with friends and family.

i. Name: Josh
ii. Subteam: Payload Integration
iii. Biography: Joshua Daniels is a senior pursuing a bachelor's degree in Aerospace Engineering with a minor in Aerospace Studies. He is an Air Force ROTC Cadet planning on commissioning as a Second Lieutenant in Space Operations upon graduation. He is an active participant in the ROTC honor guard where he has led the presentation of the flags in front of thousands of people. He is also a member of the Tau Beta Pi Engineering Honor Society and recently completed an internship at NASA Langley.

i. Name: Michelle
ii. Subteam: Structures
iii. Biography: Michelle is a 5th year senior in Aerospace Engineering. She is also Vice President of Sigma Gamma Tau, the Aerospace Engineering Honor Society and is active in AIAA. When not on campus, she enjoys reading, running, and spending time with friends and family.

i. Name: Nathan
ii. Subteam: Avionics & Recovery
iii. Biography: Nathan is a senior pursuing a bachelor's degree in Aerospace Engineering. In his time with the High-Powered Rocketry Club, Nathan has previously served as the Vice President of Integration and the Electronics and Programming Lead.

i. Name: Nolan
ii. Subteam: Payload Communications
iii. Biography: Nolan is a senior completing a B.S. in Aerospace engineering. He is a member of AIAA, serves as a Study Abroad Ambassador, and works at Carmichael Gymnasium. In his free time, he enjoys travelling, scuba diving, and spending time with family.

1.5 Club Officers

For the 2018-19 school year, the team leadership consists of two major parties: Senior Design and Club Officers. While the two parties interact with each other regularly, they are both responsible for different aspects of the team's operation for the SL competition. The Club Officers and their respective responsibilities are listed below:

i. Position: President
ii. Name: Harvey
iii. Years in Club: 2
iv. Prior Experience: None
v. Biography & Responsibilities: Harvey is a 5th year senior studying Aerospace Engineering. As president, he is expected to preside the weekly club meetings, attend at least half of all outreach events, and represent the club at all NC State Student Organization events. In his spare time, Harvey is pursuing a private pilot's license in gliders.

i. **Position: Vice President**
ii. Name: Ashlee
iii. Years in Club: 4
iv. Prior Experience: Assistant Treasurer 2016-17, VP of Operations 2017-18
v. Biography & Responsibilities: Ashlee is a 3rd year Civil Engineering student. As the Vice President of Operations, she is expected to attend outreach events, aid fellow officers in their duties, and manage all general club activities. In her spare time, Ashlee enjoys reading, sketching/designing, and traveling.

i. **Position: Treasurer**
ii. Name: Ashby
iii. Years in Club: 3
iv. Prior Experience: Treasurer 2017-18
v. Biography & Responsibilities: Ashby is a junior studying Aerospace Engineering. In addition to High-Powered Rocketry Club, Ashby is an active member of NC State's section of the Society of Women Engineers and the University Honors Program. As treasurer, Ashby is expected to effectively manage the club funds and plan for future investments. In her free time, Ashby enjoys reading and running.

i. **Position: Safety Officer**
ii. Name: Shiv
iii. Years in Club: 1
iv. Prior Experience: None
v. Biography & Responsibilities: Shiv is a second-year junior-year student majoring in Aerospace Engineering and minoring in Industrial Engineering. As Safety Officer, his responsibilities include but are not limited guaranteeing human and mission safety by upholding the regulations and guidelines put farther in Section 3 and the FMECA Tables. In his free time, Shiv also does research with the North Carolina State University Engineering Mechanics and Space Systems Lab, and enjoys playing Kerbal Space Program, reading space science fiction novels, and spending time with friends.

i. **Position: Coordination Officer**
ii. Name: John
iii. Years in Club: 5
iv. Prior Experience: Outreach Coordinator
v. Biography & Responsibilities: John is a 5th year student majoring in Aerospace Engineering with a minor in Music Performance. As Coordination Officer, he is expected to manage all lines of communication within the club and plan all events including outreach. In his free time, John greatly enjoys playing and performing music with one of the groups that he is a member of on campus.

i. **Position: Web Administrator**
ii. Name: Gabe

iii. Years in Club: 2
iv. Prior Experience: Web Administrator 2017-18
v. Biography & Responsibilities: Gabe is a sophomore student majoring in Aerospace Engineering and minoring in Mathematics, as well as being part of the University Scholars program. As Website Administrator, he is expected to maintain and update the club website, integrate social media, upload reports, and establish a strong web presence. In his free time, Gabe enjoys playing video games and guitar.

i. Position: Social Media Officer
ii. Name: Joseph
iii. Years in Club: 4
iv. Prior Experience: Social Media Officer 2015-18
v. Biography & Responsibilities: Joseph is a 3rd year student studying Environmental Science with a focus on sustainable architecture. As the Social Media Officer, he is responsible for curating and posting content on the team social media pages. He is also an executive member of the Climate Reality Project Campus Corps working to bring renewable energy solutions to NC State campus. In his free time, Joseph enjoys drawing and creative writing.

i. Position: Outreach Coordinator
ii. Name: Daniel
iii. Years in Club: 1
iv. Prior Experience: None
v. Biography & Responsibilities: Daniel is a third-year student majoring in Aerospace Engineering and minoring in Mathematics. He is a University Scholar and an active member of AIAA. As Outreach Officer, he is responsible for coordinating educational events with the surrounding community to facilitate growth and interest in STEM fields. In his free time, Daniel enjoys hiking, running, and spending time with friends.

1.6 Weekly Club Briefings

The Senior Design team and all members of the club meet on campus once per week during the school year to discuss:

- Weekly updates
- Upcoming outreach events
- Ongoing experiments
- Career opportunities
- Topics of special interest

The club strives to provide an atmosphere that fosters learning and facilitates the flow of knowledge from veteran members to newcomers. Beyond the weekly meetings, the rocketry lab space is open for members to work on reports, rocket construction, and/or classwork, as well as for general fraternization amongst members. The Senior Design team also conducts regular meetings amongst the subteams to discuss document and project progress, as well as to resolve any outstanding issues.

1.7 Local TRA/NAR Chapter Information

Alan Whitmore, whose qualifications are described in Section 1.1**Error! Reference source not found.**, is the current prefect of Tripoli East NC (TRA Prefecture 65) and is responsible for the purchase and storage of all motors used for vehicle launches during the competition. These motors are only purchased after his approval and are stored according to his safety requirements. At launches, the motors are assembled and installed under his supervision. Dr. Chuck Hall and Jim Livingston are both Level 3 certified with the TRA, and are equally capable of supervising the storage, assembly, and installation of rocket motors.

2. Facilities and Equipment

2.1 Description

The HPRC meets primarily in the MAE Student Fabrication Lab (“Rocketry Lab”), Room 2003, Engineering Building III. The Senior Design team also has access to the Space Senior Design Lab, Room 1224, Engineering Building III. These workspaces are equipped with handheld power tools, small drill presses, and a 3D printer.

Though the labs are equipped with their own basic tools, the club also has access to a precision machine shop in Engineering Building III. The machine shop supervisor is very helpful with design and parts requests, and usually delivers the product of a machine shop request within a week. Additionally, the club has access to the structures lab in Engineering Building III which allows for materials testing using the Instron tensile and compression loading machine. If needed, the club can request access to the MAE laser cutter operated by graduate students in Flight Research, which located in the Wind Tunnel High Bay adjacent to Engineering Building III.

2.2 Hours of Accessibility

Monday – Friday: 6am – 12am for undergraduate student access

12am – 6am for graduate or professor assisted entry

Saturday – Sunday: All day for graduate or professor assisted entry

2.3 Necessary Personnel

The club safety officer, identified in Section 1.3, must be present in the Rocketry Lab for any construction or testing. Dr. James Kribs, MAE Lab Director, must approve any testing conducted using the mechanical engineering lab equipment. Dr. Shreyas Narsipur or Dr. Hall must approve any testing conducted in the subsonic or supersonic wind tunnels located at NC State.

2.4 Available Equipment

Equipment relevant to the construction of rockets that are available in the Rocketry Lab:

- Craftsman 1.6” Variable Speed Scroll Saw
- Craftsman 12” Bench Drill Press with Laser
- Task Force 4” Belt & 6” Disc Sander
- 120 Volt 60 Hz Band Saw
- 16 Gallon 6.5 HP Shop Vac
- Dremel 400 XPR Rotary Tools
- Ryobi HG600 Heat Gun
- DeWalt 18V Hand Drill
- Drill Bit Case from 3/64” – ½”
- Ryobi Forstner 7-piece Drill Bit Set 1" - 2"

- Task Force Ratchet/Socket Kit
- Digital Micrometer
- SeeMeCNC Rostok Max V2 3D Printer
- SoftWorks 5lb Food Scale
- AWS 1 kg Digital Scale
- Wilton Bench Vice
- Vacuum hoses for wet layups

2.5 Supplies Required

Materials required to design and build a rocket and payload include, but are not limited to, the following items:

- Safety equipment (fire extinguisher, first aid kit, gloves, goggles, masks, etc.)
- Equipment listed in Section 2.4
- Fiberglass tubes
- Motor retainer
- Nose cone
- Birch plywood sheets
- Epoxy
- Fiberglass sheets
- Black powder
- Altimeters
- Wires
- E-matches
- 3D printer and plastic rolls
- Handheld tools
- Screws
- U-bolts
- Shock cord
- Main parachute
- Drogue parachute
- Processors
- Batteries
- Software (Microsoft Office, SolidWorks, OpenRocket, MATLAB, Abaqus, ANSYS)
- UAV Frame
- UAV Propellers
- UAV electronics and controllers
- Stepper Motor
- Threaded Rod
- Aluminum Honeycomb Grid Core
- Hinges

3. Safety

3.1 Federal Regulations

The team will comply with all United States federal regulations with regards to the use of the National Airspace System (FAR 14 CFR, Subchapter F, Part 101, Subpart C) and fire prevention guidelines (NFPA 1127) for the safe and legal operation of high-powered rockets. Additionally, this year, the team will comply with all federal regulations regarding UAS (FAR 14 CFR, Part 107).

3.1.1 Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C

The team will comply with regulations set forth by the FAA to not operate a high-power rocket:

a) At any altitude where clouds or obscuring phenomena of more than five-tenths coverage prevails;
b) At any altitude where the horizontal visibility is less than five miles;
c) Into any cloud;
d) Between sunset and sunrise without prior authorization from the FAA;
e) Within 9.26 kilometers (5 nautical miles) of any airport boundary without prior authorization from the FAA;
f) In controlled airspace without prior authorization from the FAA;
g) Unless you observe the greater of the following separation distances from any person or property that is not associated with the operations:
    1) Not less than one-quarter the maximum expected altitude;
    2) 457 meters (1,500 ft.);
h) Unless a person at least eighteen years old is present, is charged with ensuring the safety of the operation, and has final approval authority for initiating high-power rocket flight; and
i) Unless reasonable precautions are provided to report and control a fire caused by rocket activities.

3.1.2 NFPA 1127 Code for High Power Rocketry

The team will comply to guidelines set forth by the NFPA to allow for the safe operation of high-powered rockets and to reduce the risk of injury, death, or destruction of property.

3.1.3 Federal Aviation Regulations 14 CFR, Part 107

The UAV and its operation will follow Section 107 of FAA regulations as follows:

a) UAV operators must avoid manned aircraft.
b) UAV operators will never operate in a reckless or careless manner.
c) UAV must stay within unaided sight at all times, i.e. without binoculars.
d) A UAV can only fly in daylight (30 minutes before official sunrise and 30 minutes after sunset local time) or in twilight with appropriate anti-collision lighting.
e) Minimum weather visibility is three miles from control station.

f) Maximum permitted altitude is 400 feet above the ground or 400 feet over a structure.
g) UAV speed is not to exceed 100 mph or 87 knots.
h) You cannot fly a small UAV over anyone not directly participating in the operation, not under a covered structure, or inside a covered stationary vehicle.
i) No operations are allowed from a moving vehicle unless you are flying over a sparsely populated area.
j) You can carry an external load if it is securely attached and does not adversely affect the flight characteristics or controllability of the UAV.
k) You also may transport property for compensation or hire within state boundaries provided the UAV, including its attached systems, payload and cargo, weighs less than 55 pounds total and other flight rules are obeyed.
l) You can request a waiver of most restrictions if you can show your operation will provide a level of safety at least equivalent to the restriction from which you want the waiver.
m) Anyone flying under Part 107 must register each UAV they intend to operate. If your UAV weighs less than 55 lbs, you can use the automated registration system.
n) To operate the controls of a small UAV under part 107, you need a remote pilot certificate with a small UAS rating or be under the direct supervision of a person who holds such a certificate.
o) You must be at least 16 years old to qualify for a remote pilot certificate, and you can obtain one of two ways.
    1. You may pass an initial aeronautical knowledge test at an FAA-approved knowledge testing center.
    2. If you already have a part 61 pilot certificate, you must have completed a flight review in the previous 24 months and you must take a small UAS online training course provided by the FAA.
p) You are responsible for ensuring a UAV is safe before flying, but the FAA does not require small UAVs to comply with current agency airworthiness standards or obtain aircraft certifications.
q) You must make your UAV available to the FAA for inspection or testing on request, and you must provide any associated records required to be kept under the rule.
r) You must report any operation that results in serious injury, loss of consciousness, or property damage of at least $500.00 to the FAA within 10 days.
s) FAA can issue waivers to certain requirements of Part 107 if an operator demonstrates they can fly safely under the waiver without endangering other aircraft or people and property on the ground or in the air.
t) Operations in Class G airspace are allowed without air traffic control permissions.

3.2 NAR/TRA Personnel Procedures

The safety plan established for use by members of HPRC is a culmination of safety guidelines regarding high power rocketry, handling of hazardous materials, and handling of explosives, rocket motors, and other energetic devices. Members are required to review and apply the safety guidelines presented below at the start of each new school year.

3.2.1 NAR High Power Rocket Safety Code

Table 3--1 contains all components of the NAR High Power Rocket Safety Code (effective August 2012) as well as how the team will show compliance to each item.

Table 3--1 NAR High Power Rocketry Safety Code and Compliance Action

NAR Safety Code Items	Compliance Action
1. *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.	The team mentors (listed in Section 1.1) are all NAR Level 3 certified and will review technical aspects of the vehicle and provide supervision when handling rocket motors.
2. *Materials*. I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or ductile metal when necessary, for the construction of my rocket.	The rocket design uses only Fiberglass composite body tubes, fiberglass, wood, and plastic.
3. *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.	The current rocket design utilizes a commercially-available AeroTech L1150R-P motor. The Safety Officer and mentors enforce a no smoking policy within 50 ft of rocket motors.
4. *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.	The team will only fly at launch sites operated by NAR/TRA to ensure that proper ignition systems are installed and working as expected.
5. *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.	The team will rely on instructions from the NAR/TRA RSO at the launch site after a misfire occurs. Once the igniter is installed, only essential personnel may approach the rocket.

NAR Safety Code Items	Compliance Action
6. *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.	The team will rely on the NAR/TRA RSO at the launch site to perform a 5-second countdown prior to launch. Team members are also instructed to always stop working when a launch occurs to increase bystander awareness. Team members are encouraged to communicate with each other during the launch and to point at the rocket during its descent phase to increase bystander awareness. After the rocket is constructed and motor inserted, the CG location will be measured and marked on the rocket using a sticker to confirm that the rocket has a stability margin greater than 2.0 calibers before launch. The team does not intend to perform simultaneous launches.
7. *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.	The team will only use launch rails with blast deflectors provided at the NAR/TRA launch sites that have been approved for use by the RSO. In compliance with competition requirements, rockets will be launched at an angle 85° from horizontal, pointed into the wind. Team members are instructed to stand at least as far back as the Minimum Distance table during launches and are encouraged to stand farther back for increased safety. The team does not intend to launch any rocket with titanium sponge in the propellant.
8. *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.	The total impulse of the AeroTech L1150R-P motor selected for launch is 3,560 N-sec which is less than the competition maximum of 5,120 N-sec. The full-scale rocket is currently projected to weigh 38.6 lb at launch.

NAR Safety Code Items	Compliance Action
9. *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.	The team will only launch at NAR/TRA approved launch sites with an RSO present to confirm that an FAA-approved TFR is in place over the launch site. Prior to any launch, the sky will be confirmed clear by the RSO and bystanders. If wind speeds exceed 20 mph or if the cloud level is too low, the launch will be scrubbed immediately. The team will use only the motor included in the design for launches to ensure that no part of the vehicle exceeds its expected apogee altitude.
10. *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).	The team will only launch at NAR/TRA approved launch sites. The team plans to launch its subscale and full-scale rockets at the Bayboro, NC launch site which meets the minimum range requirements described. The final, competition launch will occur at another NAR/TRA approved launch site near Huntsville, AL.
11. *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.	Team members are instructed to stand at least as far back as the Minimum Distance table during launches and are encouraged to stand farther back for increased safety. Traffic at the launch site will be controlled to increase bystander safety.
12. *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.	Both subscale and full-scale rockets will use a dual deploy recovery system with a drogue deployment at apogee and main deployment at approximately 500 ft AGL. Nomex cloth will be used to protect the drogue and a deployment bag will be used to protect the main parachute during flight and separation.

NAR Safety Code Items	Compliance Action
13. *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.	Team members will work with the RSO to ensure that bystanders are all located upwind of the launch site. Team members are instructed to never make contact with a rocket during its descent.

3.2.2 Hazardous Material Operations and Handling

HPRC works closely with the Department of Environmental Health and Public Safety (EHPS) at NC State to ensure that all hazardous materials are transported, stored, accessed, and used in accordance with their safety guidelines and supervision if applicable. The Rocketry Lab contains a certified flame cabinet for chemical storage that is vented and located outside of the path to the nearest exit from the Rocketry Lab.

The classifications of hazardous materials as defined by EHPS are defined as follows:

Class 1 – Explosives

Division 1.1	Explosives with a mass explosion hazard
Division 1.2	Explosives with a projection hazard
Division 1.3	Explosives with predominately a fire hazard
Division 1.4	Explosives with no significant blast hazard
Division 1.5	Very sensitive explosives; blasting agents
Division 1.6	Extremely insensitive detonating devices

Class 2 – Gases

Division 2.1	Flammable Gases
Division 2.2	Non-flammable, non-toxic compressed gases
Division 2.3	Gases toxic by inhalation

Class 3 – Flammable Liquids (and Combustible Liquids)

Flammable	liquid with a flash point of 140°F or less
Combustible	liquid with a flash point between 140°F and 200°F that does not meet any other hazard class definition.

Class 4 – Flammable Solids; Spontaneously Combustible Materials; Dangerous when Wet Materials

Division 4.1	Flammable solids - wetted class 1 explosives, self-reactive materials or readily combustible solids
Division 4.2	Spontaneously combustible materials -pyrophoric or self-heating materials
Division 4.3	Dangerous when wet materials - gives off flammable or toxic gas or become spontaneously combustible on contact with water

Class 5 -- Oxidizers and Organic Peroxides

Division 5.1 Oxidizers - by yielding oxygen, causes or enhances the combustion of other materials

Division 5.2 Organic peroxides - organic compounds with the bivalent R-O-O-R structure where at least one R is a carbon chain, except for materials that meet class 1 (Explosive) definition or are *"forbidden"* on the HMT.

Class 6 -- Toxic Materials and Infectious Substances

Division 6.1 Poisonous materials - a liquid with an LD50 oral not more than 500 mg/Kg, or a solid with an LD50 oral not more than 200 mg/Kg, or a compound with a LD50 dermal not more than 1000 mg/Kg, or a dust/mist with a LC50 or not more than 10 mg/L

Division 6.2 Infectious substances – Go to Guide to Shipping Biological Materials and Biological Materials Online Certification for more information.

Class 7 -- Radioactive Materials

Radioactives are any material with a specific activity greater than 0.002 microcuries per gram (mCi/g). The specific activity of a nuclide means the activity of the nuclide per unit mass of that nuclide.

Class 8 -- Corrosive Materials

(Intentionally left blank)

Class 9 -- Miscellaneous Dangerous Goods

Materials that present a hazard during transport but do not meet other hazard class definitions. Examples are dry ice and lithium batteries.

3.2.3 Purchase, Storage, Transport, and Use of Rocket Motors and Energetic Devices

Commercially-produced rocket motors will be purchased from reputable vendors or distributors under the supervision of a team mentor. Motors will be transported and stored by a team mentor in accordance with manufacturer and on-campus Environmental, Health, and Public Safety (EHPS) guidelines. The motor will never be stored in the rocket, and motor insertion is the final step of rocket construction at the launch site which will be conducted under the close supervision of the RSO and a team mentor.

All black powder will remain in the sealable container provided by the manufacturer for both transport and storage. When not needed, black powder is stored either with a team mentor or in the Rocketry Lab flame cabinet. When ejection charges are necessary for either testing or launch, the proper amount of black powder needed will be determined using Equation 1, below:

$$CD^2L = m_{BP} \tag{1}$$

where C is a pressure-dependent constant, D is the compartment diameter, L is the compartment length, and m_{BP} is the mass of black powder necessary (in grams). Any person handling exposed black powder must do so under the supervision of a team mentor or the Safety Officer and must wear safety glasses, gloves, and a mask in accordance with the established safety plan. Any surface where black powder is poured, measured, or spilled must be cleaned before and after handling.

3.3 Safety Plan

The following safety plan, in conjunction with the NAR and TRA regulations, is designed specifically to keep the members of HPRC and the public out of danger while also minimizing the risk of damaging materials. Clear instructions will be made available at all events with the intent of ensuring that all members follow and comprehend proper safety procedures.

3.3.1 Application of Caution Statements

HPRC will be utilizing a system of warning labels that rely on text, images, and colors to indicate the appropriate level of danger, as shown in below:

This label denotes negligible risk when risk is present. The level of danger is consistent with that which would cause minimal damage to material or user. The maximum injury sustained from this category should only require very basic First-Aid. The complexity involved with any tasks is consistent with proficiency achieved with on-site instructions from a trained member.

This label denotes a moderate level of risk. The level of danger is consistent with that which could cause moderate damage to user or material. The maximum injury sustained from this category should only require advanced First-Aid. The complexity involved is consistent with requiring prior experience or a previous instructional lesson. The area under the label may contain a short description to further inform on the condition for which a warning is necessary.

This label denotes a catastrophic level of risk. The level of danger is consistent with that which could cause major damage to user or material. The maximum level of injury sustained from this category should require hospital care or may cause death. The complexity of this category requires considerable experience. Items or locations denoted in this way are only open to HPRC officers (Section **Error! Reference source not found.**), Senior Design (Section 1.4.1), and mentors (Section 1.1). The area under the label may contain a short description to further inform on the condition for which a warning is necessary.

3.3.2 Team Hazard Recognition, Accident Avoidance, and Pre-Launch Briefings

To increase hazardous awareness and recognition, and to mitigate or avoid any launch accidents, the team will follow the published TRA Pre-Flight Checklist outline:

a. General
   i. Is this member known to the TAP reviewer?
   ii. Does this member have the appropriate Certification Level or will this be a Certification Flight?
   iii. Does the proposed launch site and date have the appropriate recovery area and launch set-up for this flight?
   iv. Does the Prefect require TAP Review?

b. Rocket Review
   i. General
      1. Are there attachments to the Pre-Flight Data Capture?
      2. Drawings: airframe; structures; payloads, etc.
      3. Schematics: avionics, ignition systems, payloads, etc.
      4. Performance calculations: Center of Pressure; Center of Gravity, motor type, altitude, velocity, etc.

   ii. Airframe
      1. Is the design generally suitable for the application?
      2. Is the airframe material suitable for this rocket?
      3. Is the fin material/attachment sound?
      4. Is the motor mount sound?
      5. Is the nosecone suitable?
      6. What are the most probable airframe faults and corrective actions?
      7. What are the safety implications of an airframe failure?
      8. Are there any design change recommendations?

   iii. Recovery System
      1. Is the recovery system attachment secure/suitable?
      2. Does the recovery system have sufficient capacity for a safe descent?
      3. What is the deployment system?
      4. What are the most probable deployment system faults and corrective actions?
      5. What are the safety implications of a recovery system failure?
      6. Are there any design change recommendations?

   iv. Avionics Description
      1. Commercial or unique design?
      2. What are the functions of the avionics components?
      3. Are the avionics appropriate to the application?
      4. Do the avionics have flight safety implications?
      5. Can the avionics and inhibits be accessible from outside the vehicle?

6. Are there arming indicators?
7. Are any of the systems redundant?
8. What are the most probable avionics system faults and corrective actions?
9. What are the safety implications of an avionics system failure?
10. Are there any design change recommendations?

v. Motor
1. Is the motor suitable for the rocket?
2. Is the motor Tripoli Certified?
3. Is the motor ignition suitable?
4. What are the most probable motor faults and corrective actions?
5. What are the safety implications of a motor failure?
6. Are there any design change recommendations?

vi. Launcher
1. Is the launcher suitable for the rocket?
2. Is the launch lug, or rail guide suitable for the rocket?
3. What will the launch angle be?
4. Are there any special launch control requirements?
5. What are the most probable faults with the launcher?
6. What are the safety implications of a launcher failure?
7. Are there any design change recommendations?

vii. Performance
1. How were the performance calculations done?
2. Were the calculations done manually?
3. Are the algorithms used correct?
4. Were the calculations accomplished correctly?
5. Was a computer used?
6. What is the source of the software?
7. Is the software suitable for this rocket?
8. Are there printouts?
9. Should the calculations be independently run?
10. What are the safety implications of poor performance data?
11. Are there any changes or recommendations?

viii. Operations
1. Is there a pre-flight checklist?
2. Which operations does it cover?
3. Are each the operations sufficiently documented?
4. Are hazardous operations flagged?
5. What are the safety implications of poor checklists?
6. Are there any changes or recommendations?

3.4 Team Member Safety Compliance

All team members must understand and abide by the guidelines and rules set forth by the NAR/TRA RSO before launching any high-powered rocket. The team understands that the RSO has final authority on determining whether a rocket launch may or may not continue.

3.4.1 Range Safety Inspection

The RSO must perform a safety inspection on the range and rocket before any launch:

Launch Systems

The RSO shall familiarize themselves with the types of launch pads available ensuring that they do not approve any flight for which there is not a sufficient pad.

The RSO shall make a cursory examination of the Range area to ensure that the pads available have been placed appropriately according to the Safety Code.

The RSO should become familiar with the launch control systems and ensure that sufficient safety interlocks are in place to prevent accidental ignitions.

Emergency

The RSO shall confirm that adequate safety equipment is on site including a portable fire extinguisher, first aid kit, and cellular communications.

The RSO shall have available to them contact numbers for local fire departments, police, emergency medical, and power authority personnel.

Flight Operations

The RSO is to perform a Flight Safety Review (FSR) of all rockets intended for launch. Upon completion of the FSR the RSO will make a flight readiness decision. If the flight is approved this should be indicated by the RSO initialing the flight card. If minor modifications will bring the rocket to flight ready status the flyer should be informed of the required modifications and asked to return only after taking appropriate corrective actions. If a situation arises that the RSO is unfamiliar with and/or feels uncomfortable making a judgment call on, it is their obligation the find one or more experienced Tripoli members on the field to consult with. As always, the final decision rests with the Certificate of Waiver Holder.

Flight Safety Review – Safety First

At all times prior to a safe firing position on the rod, rail, tower, or other suitable ground support facility, the igniter shall not be inside the motor, and all ejection charge related electronics must be off!

Flyer

By asking to see a current membership card: verify that the individual flying the rocket is a current member in good standing of Tripoli Rocketry Association or the National Association or Rocketry; verify the certification level of the individual and that they are flying within their certification level or attempting a new certification level; observe that the individual does not appear impaired by the use of drugs or alcohol.

Under no circumstances should someone who has participated in the consumption of alcoholic beverages be allowed to enter the range or launch a rocket.

Flight Card

Verify that an applicable flight card exists, is filled out in a legible manner, and indicates all pertinent flight data including but not limited to flyer name and TRA number, physical vehicle parameters, motor configuration, and recovery systems. Special attention should be given to flights that are indicated as Heads-up or Certification. In the case of a Level 3 certification attempt, verify the presence of associated TAP member.

History

Ask the flyer if they have flown this particular rocket and motor combination. If they have, ask for the results of that flight. If not, ask if they have flown a similar rocket/motor combination and the outcome.

Use the results of this line of questioning to determine into how much detail the remainder of the FSR will go.

IMPORTANT: By no means does a response of "I've flown it just like this perfectly before" exempt the flyer from the remainder of the FSR.

Propulsion

Verify that the motor used is a currently certified motor or that it is on the consumer list.

Verify that the total installed power does not exceed the limitations of the field.

Verify, as best possible, that the vehicle is capable of withstanding the forward thrust that will be produced by the motor.

Verify that the initial thrust of the motor chosen will provide at least a 5:1 thrust-to-weight ratio. This can be done by one of three ways:

1. The flyer can provide documentation that shows the initial thrust produced by the motor. This can then be compared to the GLOW (Gross Lift Off Weight) of the rocket as presented.
2. The peak thrust of the motor can be assumed to be at least equal to the average thrust as indicated in the motor designation. In this case, the average Newtons produced by the motor should be converted to pounds and compared to the GLOW of the rocket as presented.
3. A printout from a flight prediction software package can be presented. In this case the prediction output should indicate the thrust-to-weight of > 5, the initial acceleration of > 5 g's, or the velocity of the rocket at the end of the rod/rail/tower > 45 f/s. The motor installed and the weight of the rocket must also be indicated and shall be verified to match the presented rocket. Verify that a suitable means of aft retention is used to keep the motor in place during the flight and recovery.

Construction

Check the structural integrity of the vehicle including the body tubes, nose cone, and fins to ensure that they are adequate to withstand the forces anticipated during the flight and recovery.

Verify the fit of the nose cone. Whenever possible hang the rocket by the nose cone. The vehicle should stay in place. With agitation however, the nose should come free or begin to come free. Exception: When shear pins are being employed ask the flyer to explain how they determined the number, size, and type of shear pins to use and what special provisions have been taken in regards to calculation of ejection charges.

Compare the fin material, stiffness, size and attachment method to the projected flight velocity and acceleration to avoid the potential for excessive fin flutter and any structural failures. If a questionable situation arises, consider assigning the flyer to a pad that is further away than the minimum setback.

Verify that a suitable launch guidance system is employed. Take into consideration the overall dimensions of the vehicle, the total weight of the vehicle, the predicted acceleration, and the current wind conditions. In the case of launch lugs or rail guides, ensure that mounting of the lug or button is sufficient to withstand the loads.

In the case of a two-stage vehicle, check the strength of the inter-stage connection. Verify that is will not buckle under the acceleration loads, and that it will separate as intended.

Stability

Verify that the rocket is of a stable design.

1. If it has flown in the current configuration with a similar motor and was stable it will likely remain stable.
2. If the design employs unusually small fins be extra careful with the stability verification.
3. Providing the C_p (center of pressure) calculation by Barrowman or other suitable calculation method should be compared to the C_g (center of gravity) as found on the flight ready vehicle. If stability calculations indicate a Cg, its accuracy should always be verified.
4. If no calculations are available or it is an untested design, use past experiences and call upon the expertise of others at the launch in coming to consensus about stability. If the stability is uncertain on an unusual design, ask for proof of stability. Any marginally stable rockets should be treated with extra concern and additional launch safety precautions should be taken.

Recovery

Verify that the parachutes selected for recovery are rated for the weight of the vehicle and the expected conditions at deployment. Confirm that the parachutes intended for the final descent phase to the ground will not allow a decent rate of >30f/s.

Verify that there is an adequate system in place to contain all of the separable parts of the rocket and parachutes at the forces anticipated during deployment. This includes adequate length of retaining cord, strength of retaining cord, and hard points for recovery system attachment.

Ensure that adequate protection is in place to prevent the hot ejection gases from causing burn damage to retaining cords, parachutes, and other vital components.
If electronics are being used to activate the recovery system, verify that an externally controllable method is being used to turn electronics on and that a known good battery is in use.

3.4.2 Range Safety Officer Clearance Policy

The RSO has the final authority to ensure that a range is safe for launch:

Range Operations

The RSO/LSO is responsible for determining the status of range operations. Before any launch begins, or in the event of a breech, the following criteria must be assessed. If not met, it is up to the RSO/LSO to halt any further launches until a safe condition is returned.

Site

The RSO shall make a cursory examination of the Range area to ensure that adequate barriers, markings, and safety measures exist to prevent unauthorized person from entering the range and alert authorized person as to any hazardous situations.

The RSO shall make themselves aware of the largest motor that can be supported by the site area given the table in the High-Power Rocketry Safety Code.

The RSO has the authority to open and close the range to any and all personnel.

Airspace

Where applicable (i.e. when entering controlled airspace):

The RSO must have knowledge that a current Certificate of Waiver issued by the U.S. Department of Transportation is in force and applies to the sections of the Federal Aviation Regulations that will be bypassed.

The RSO should have knowledge of the Special Provisions of the Certificate of Waiver and that they are being adhered to.

The RSO must have knowledge that a Notice to Airman has been issued for the date and times of the launch.

The RSO must not allow launches when aircraft are within a three-mile radius of the projected flight path.

Weather

The RSO must have clear and convincing evidence that the following constraints are not violated.

1. Do not launch if ground level winds exceed 20 mph.

2. Do not launch if the planned flight path will carry the vehicle through any clouds.
3. Do not launch if any type of lightning is detected within 10 miles of the launch site.

Time Interval Determination Method:

1. Visual confirmation of lightning flash
2. Count number of seconds until you hear thunder
3. Divide the result by five (5)
4. Result is in miles

GOOD SENSE RULE: Even when constraints are not violated, if any other hazardous weather conditions exist, the RSO may hold at any time based on the instability of the weather.

3.4.3 Links to Material Safety Data Sheets (MSDS)

GOEX Black Powder
Klean-Strip Acetone
West System 105 Epoxy Resin
West System 206 Slow Hardener
Fiberglass Fabric
Batteries
Cotton Flock
Baby Wipes
Igniters
Liquid Nails
Glass Microspheres
WD-40

3.4.4 Demonstrated Team Compliance

The safety guidelines, regulations, and plans listed in Section 3.4 were presented to all HPRC members who then signed the following forms to indicate compliance.

By signing below, I agreed that I have read, understand, and will follow all parts of the Safety Plan shown above.

1. Print Name: Ashley Scruggs
   Signature & Date: 9/16/18
2. Print Name: Harvey Hooper IV
   Signature & Date: 9/16/18
3. Print Name: Nathan Cox
   Signature & Date: 2018-09-16
4. Print Name: Annette Gray
   Signature & Date: 9/16/18
5. Print Name: Erik Benson
   Signature & Date: 9/18/18
6. Print Name: Shiv Jitendra Oza
   Signature & Date: Sept. 18, 2018
7. Print Name: Daniel Bonifaz
   Signature & Date: Sept 18, 2018
8. Print Name: Amit Bhande
   Signature & Date: 9/18/18
9. Print Name: Nolan Hopkins
   Signature & Date: 9-18-18
10. Print Name: Gabriel Buss
    Signature & Date: 9/18/18
11. Print Name: Christopher Buck (Advisor)
    Signature & Date: 9/18/18
12. Print Name: Charles Hall 18/Sep/18 (Advisor)
    Signature & Date: 18 Sept 18
13. Print Name: Alex Thomas
    Signature & Date: 9/18/18
14. Print Name: Katherine Wolf
    Signature & Date: 9/18/18
15. Print Name: Evan Patterson
    Signature & Date: 9/18/18
16. Print Name: Walter G. Buckley
    Signature & Date: 9/18/18
17. Print Name: Mercedes McCarthy
    Signature & Date: 09/18/18
18. Print Name: Jacob Doyle
    Signature & Date:
19. Print Name: David Torres
    Signature & Date: 9/18/18

20. Print Name: Michelle Nursey
Signature & Date: 9/18/18
21. Print Name: Casson Conder
Signature & Date: 9/18/18
22. Print Name: Ashlee Bracewell
Signature & Date: 9/18/18
23. Print Name: Robert Kemp
Signature & Date: 9/18/18
24. Print Name: Evan Waldron
Signature & Date: 9/18/18
25. Print Name: Sarah Schroeder
Signature & Date: 9-18-18
26. Print Name: Nate Faulkner
Signature & Date: 9/18/18
27. Print Name: David Schuler
Signature & Date: 9/18/18
28. Print Name: Timothy Dzwill
Signature & Date: 9/18/18
29. Print Name: Michael Barton
Signature & Date: 9/18/18
30. Print Name: Andrew Langford
Signature & Date: 9/18/18
31. Print Name: Frances McBride
Signature & Date: 9/18/18
32. Print Name: Eugene Zboichyk
Signature & Date: 9/18/18
33. Print Name: Alec Brewer
Signature & Date: 9/18/18
34. Print Name: Joseph Taylor
Signature & Date: 9/18/18
35. Print Name:
Signature & Date:
36. Print Name:
Signature & Date:
37. Print Name:
Signature & Date:
38. Print Name:
Signature & Date:
39. Print Name:
Signature & Date:

3.5 Risk Assessment and Mitigation

The team will define risks according to the level of caution needed per the signage listed in Section 3.3.1. The team will utilize failure mode, effects, and criticality analysis (FMECA) tables to identify and assign risks to different subsystems. These risks will be analyzed to understand the effects of any failures and how these risks can be mitigated or eliminated. See APPENDIX A for FMECA tables.

4. Technical Design

4.1 Launch Vehicle and Experimental Payload Requirements

Per the 2019 NASA SL competition handbook, the team must successfully design, construct, and launch a recoverable and reusable high-powered rocket ("launch vehicle") of original design. Additionally, the launch vehicle must contain an experimental payload to complete one of the challenge options. The team has chosen to include a deployable UAV as the experimental payload onboard the full-scale rocket. A deployable UAV presents several unique challenges that blend different engineering regimes, including, but not limited to, mechatronics, computer science, and mechanical and aerospace engineering. The challenge has also inspired the team to reach out to students in other relevant disciplines for help with UAV design, increasing interest in the club and the NASA SL competition itself.

4.1.1 Launch Vehicle Requirements

To complete the challenge requirements, the full-scale launch vehicle must:

a. The vehicle will deliver the payload to an apogee altitude between 4,000 and 5,500 feet.
b. The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the Altitude Award winner.
c. Each altimeter will be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.
d. Each altimeter will have a dedicated power supply.
e. Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).
f. 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.
g. The launch vehicle will have a maximum of four 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.
h. Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length.
i. Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.
j. The launch vehicle will be limited to a single stage.
k. The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.
l. The launch vehicle will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components.
m. The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.
n. The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).
o. 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).

p. Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria:
    a. The minimum factor of safety (Burst of Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.
    b. Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.
    c. 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 on the tank, by whom, and when.
q. The total impulse provided by the launch vehicle will not exceed 5,120 Newton-seconds (L-class).
r. The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit (defined at the point where the forward rail button loses contact with the rail).
s. The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.
t. Have a successful launch and recovery of a subscale model of the rocket prior to CDR.
    a. 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.
    b. The subscale model will carry an altimeter capable of recording the model's apogee altitude.
    c. The subscale rocket must be a newly constructed rocket, designed and built specifically for this year's project.
u. Have a successful launch and recovery of the full-scale rocket prior to FRR in its final flight configuration using the same rocket that will be flown on launch day and meet the following criteria:
    a. The vehicle and recovery system will function as designed.
    b. The full-scale rocket must be a newly constructed rocket, designed and built specifically for this year's project.
    c. The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. Mass simulators must still be used if the payload is not flown and the mass simulators must be in the same approximate location on the rocket as the missing payload mass.
    d. If the payload changes the external surfaces of the rocket or manages the total energy of the vehicle, those systems will be active during the full-scale Vehicle Demonstration Flight.
    e. The launch day motor should be used for the Vehicle Demonstration Flight. The RSO may approve use of an alternative motor if the home launch field cannot support the full impulse of the launch day motor or in other extenuating circumstances.
    f. 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.
    g. The launch vehicle or any of its components will not be modified after completing the full-scale demonstration flight without concurrence of the NASA RSO.

h. Proof of a successful flight shall be supplied in the FRR report.
i. Vehicle Demonstration flights must be completed by the FRR submission deadline. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. The extension is only valid for re-flights, not first-time flights. Teams completing a required re-flight must submit an FRR Addendum by the FRR Addendum deadline.

v. Have a successful launch and recovery of the full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown must be the same rocket to be flown on launch day and must meet the following criteria:
a. The payload must be fully retained throughout the entirety of the flight, all retention mechanisms must function as designed, and the retention mechanism must not sustain damage requiring repair.
b. The payload flown must be the final, active version.
c. The above criteria can be met during the original Vehicle Demonstration Flight and the FRR Addendum will not be required.
d. Payload Demonstration Flights must be completed by the FRR Addendum deadline. No extensions are granted.

w. An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA-required Vehicle Demonstration Re-flight after the submission of the FRR Report.
a. Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR addendum by the deadline will not be permitted to fly the vehicle at launch week.
b. Teams who successfully complete a Vehicle Demonstration Flight but fail to qualify the payload by satisfactorily completing the Payload Demonstration Flight requirement will not be permitted to fly the payload at launch week.
c. Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload at launch week. Permission will not be granted if the RSO or the Review Panel have any safety concerns.

x. Any structural protuberance on the rocket will be located aft of the burnout center of gravity.

y. The team’s name and launch day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.

z. Vehicle Prohibitions
a. The launch vehicle will not utilize forward canards. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket’s stability.
b. The launch vehicle will not utilize forward firing motors.
c. The launch vehicle will not utilize motors that expel titanium sponges.
d. The launch vehicle will not utilize hybrid motors.
e. The launch vehicle will not utilize a cluster of motors.
f. The launch vehicle will not utilize friction fitting for motors.
g. The launch vehicle will not exceed Mach 1 at any point during flight.
h. Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad.

i. Transmissions from onboard transmitters will not exceed 250 mW of power.
j. Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of light-weight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.

4.1.2 Recovery System Requirements

To complete the challenge requirements, the requirements for the launch vehicle and experimental payload recovery systems are as follows:

a. 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.
    a. The main parachute shall be deployed no lower than 500 feet.
    b. The apogee event may contain a delay of no more than 2 seconds.
b. Ground ejection tests for both the drogue and main parachutes must be performed successfully. This must be done prior to the initial subscale and full-scale launches.
c. At landing, each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.
d. The recovery system electrical circuits will be completely independent of any payload electrical circuits.
e. All recovery electronics will be powered by commercially available batteries.
f. The recovery system will contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.
g. Motor ejection is not a permissible form of primary or secondary deployment.
h. Removeable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.
i. Recovery area will be limited to a 2,500 ft. radius from the launch pads.
j. Descent time will be limited to 90 seconds (apogee to touch down).
k. 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.
    a. Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic tracking device.
    b. The electronic tracking device(s) will be fully functional during the official flight on launch day.
l. The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).
    a. 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.
    b. The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.
    c. 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.

d. The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.

4.1.3 Deployable UAV Requirements

To complete the challenge requirements, the deployable UAV must satisfy the following criteria:

a. The UAV must deploy from the internal structure of the launch vehicle.
b. The UAV shall be powered off until the rocket has safely landed on the ground.
c. The UAV will be retained within the vehicle utilizing a fail-safe active retention system, which can withstand atypical flight forces.
d. At landing, and under the supervision of the Remote Deployment Officer, it will remotely deploy from the rocket.
e. After deployment and from a position on the ground, the UAV will take off and fly to a NASA specified location, called the Future Excursion Area (FEA). Both autonomous and piloted flight are permissible, but all reorientation or unpacking maneuvers must be autonomous.
f. Once the UAV has reached the FEA, it will place or drop a simulated navigational beacon on the target area. The simulated navigational beacon will be designed and built by each team and will be a minimum of 1 in w x 1 in h x 1 in D. The school name must be located on the external surface of the beacon.
g. The UAV's batteries must be sufficiently protected from impact with the ground and must be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other UAV parts.
h. The UAV and its operation will follow all FAA regulations as detailed in Section 3, Subsection 1.13.1.

4.2 Launch Vehicle Specifications

Per the 2019 NASA SL competition rules, the team must successfully design, construct, and launch a recoverable and reusable high-powered rocket of original design. Additionally, the launch vehicle will contain the deployable UAV system as its payload.

4.2.1 Launch Vehicle Dimensions

The launch vehicle was designed using OpenRocket, an open source rocket design software widely used by hobby rocketeers. The body diameter of the launch vehicle will be 5.5 inches throughout. This dimension is based on an estimated 4.5 inches diameter payload space required to safely house a UAV. The design utilizes a 4:1 ogive nosecone and the total length of the rocket is 95 inches. The rocket will be comprised of three separable sections: the fin can, avionics bay, and nose cone. Shown in Figure 4-1 below, these sections will be secured at launch using nylon shear pins through couplers.

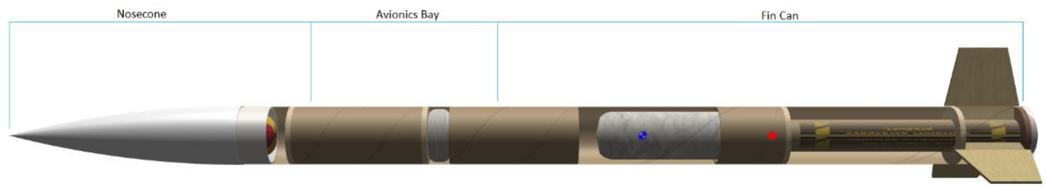

Figure 4--1 OpenRocket 3D Schematic for Rocket

The current design places the center of gravity and center of pressure of the launch vehicle at 59.607 and 71.828 inches from the nosecone tip, respectively. This configuration gives the launch vehicle a static stability margin of 2.21 caliber at launch. Pre-launch weight is estimated to be 38.6 pounds and burnout weight is estimated to be 34.41 pounds. During the motor burn, the center of gravity of the launch vehicle shift forward, further increasing the static stability and keeping it above the competition mandated value of 2.0 caliber.

4.2.1.1 Nosecone Design

The rocket nosecone will be a 4:1 ogive shape with a 5.5-inch outer diameter and length from tip to shoulder of 22 inches. This nosecone was selected principally for its commercial availability.

Historically, the club has utilized nose ballast to achieve proper stability margins. The current launch vehicle model does not require nose ballast to remain statically stable. This is based on an estimated payload weight of 11 pounds. Once the payload section is completed, updates will be made to the model. These updates will determine if nose ballast needs to be added to achieve a stability margin greater than 2.0 caliber.

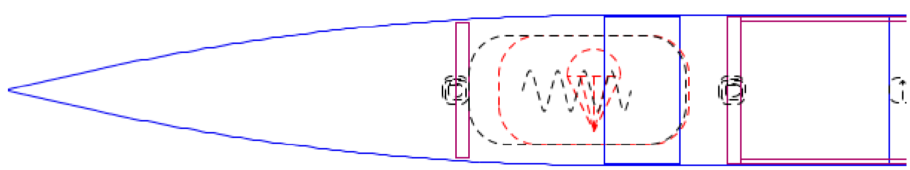

Figure 4--2 OpenRocket Side View Schematic of Nosecone

A bulkhead will be located 5 inches forward of the nosecone shoulder. This bulkhead will allow the nosecone and avionics bay sections to be tethered with shock cord. This shock cord will be attached to the nosecone bulkhead via a U-bolt. Placed aft of the nosecone shoulder will be a section of coupler permanently attached to a 10.5 inches long segment of body tube. This assembly will be connected using epoxy and will not separate in flight. This section of body tube serves to house the main parachute as the forward end of the avionics bay is comprised of a section of coupler.

4.2.1.2 Avionics Bay Design

The avionics Bay (AV bay) is comprised of a section of coupler 12 inches in length with a 1-inch band of body tube at its midpoint. The AV bay will house the recovery avionics, described in section 4.2.5. This design choice seeks to remedy a recurring problem with the club's rocket designs: avionics accessibility. Historically the club has utilized an integrated payload and avionics bay design to minimize the number independent sections of the launch vehicle. As a result, the blast caps used to store black powder charges have been recessed into the rockets' body tubes. This poses several challenges at the launch field when the rocket is being prepared for launch. The first is that club members often struggle to load the black powder into the blast caps. Further, clearance issues make it difficult to seal the blast caps with electrical tape. Lastly, the aforementioned steps can be done only after the payload has been placed into the rocket. Because of this, the payload and avionics sub teams are unable to work in parallel when assembling the rocket, thereby doubling the assembly time. Figure 4-3, below, shows how the avionics bay bulkheads will be easily accessibly during assembly.

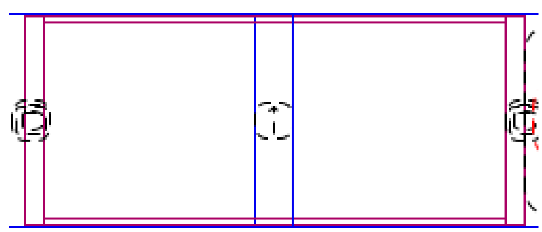

Figure 4--3 OpenRocket Side View of Midsection

The aft coupler of the AV bay will be rigidly attached to a 14-inch-long section of body tube using metal screws. This body tube will not separate from the AV Bay during flight but will be removable on the ground to provide access to the black powder charges. This section of body tube will house the drogue parachute and shock cord and will attach the AV bay to the forward coupler of the fin can. The AV bay section will be attached to the shock cord via a U-bolt anchored to the AV bay aft bulkhead. The 1-inch band of body tube in the middle of the AV bay serves as a mounting point for the avionics activation switches.

4.2.1.3 Fin Can Design

The Fin can will house both the payload and fin-motor tube assembly. This configuration was chosen based on analysis of the 2018 NASA student launch competition. The 2018 design team cited payload deployment as the greatest threat to mission success. To this end, the current design team prioritized payload deployment over all other team derived requirements. By merging the payload bay and fin can, the team hopes this heavier section with its long fins will aid in stabilizing the launch vehicle once it touches down. The fin can section will be attached to the payload bay via a coupler. This coupler will be 5.5 inches in length and fixed to the fin can with epoxy. During pre-launch assembly, the fin can coupler will be attached to the payload bay using metal screws to prevent separation in flight.

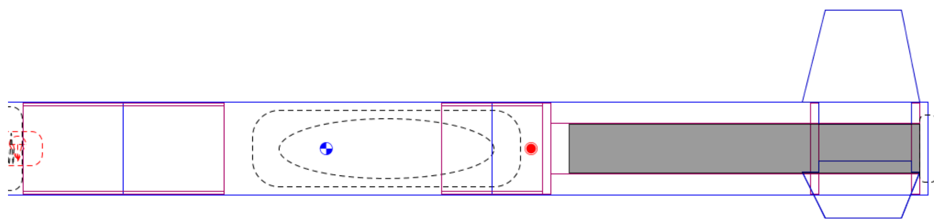

Figure 4--4 OpenRocket Side View Schematic of Fin Can

For additional security, the shock cord connecting the fin can to the AV bay will be routed through the payload section and fixed to a U-bolt mounted on the bulkhead just forward of the motor tube. This will be achieved by way of channels cut in the outboard portion of the payload bay centering rings. Once the shock cord is in place, the channel in the forwardmost centering ring will be sealed with plumbers' putty to preserve the effectiveness of the black powder charges.

A 3-fin configuration was chosen because it provides a lower profile when the rocket touches down. That is, it places the opening of the payload bay at a shallower angle than a 4-fin configuration. The fins will be a trapezoidal shape with the following specifications:

- Root chord length: 7 inches
- Tip chord length: 4.5 inches
- Sweep Angle: 14.3 degrees
- Thickness: 0.25 inch

The fin tabs will extend into the body of the rocket allowing the fins to be attached to the motor tube by means of epoxy resin. Additionally, epoxy fillets will be used to fix the fins to the fin can body tube on both the outer and inner diameters. These fillets will reduce stress concentrations and, in the case of the outer diameter fillets, reduce aerodynamic drag. The fin tabs will be flanked on either side by the engine block and a centering ring. This configuration is popular in the hobby rocketry community as it aids in fin alignment and simplifies the assembly of the fin can. Lastly, the fins will be mounted such that the trailing edge of the root chords will be located 0.5 inch from the aft end of the fin can body tube. This will reduce risk of fin damage during landing as well as during assembly.

4.2.2 Material Selection

Based on OpenRocket analysis, the rocket will not experience supersonic flight and therefore a wider range of materials are available. The rocket diameter will be 5.5 inches, a common diameter among commercially available body tubes. Because the diameter is relatively small, use of fiberglass body tubes will not cause the rocket to be excessively heavy; initial calculations give a total weight of approximately 38.6 pounds, assuming an 11 pound payload. Fiberglass will be sufficiently strong for any loads seen in flight and will resist delaminating in adverse field conditions or from moisture, thus increasing the reusability of the rocket. This is favorable based on issues experienced by last year's team, when the rocket made of Blue Tube was deemed unable to fly again after landing on wet ground. The body tube section to be used as the fin can will be pre-slotted by the vendor for the three fins to ensure accuracy of the slot locations and to make the fabrication process easier. The surface of the rocket will be lightly sanded and ultimately painted before flight.

The nose cone of the rocket will also be made of fiberglass so that it adds weight at the nose of the rocket which will shift the center of mass forward and therefore affect the static margin in a positive way. Fiberglass nose cones are readily available from commercial vendors. If it is determined that ballast is necessary based on the final payload weight, a machined metal tip will be added to the nose cone.

The motor tube will also be made of fiberglass to provide greater strength and better load sharing of the thrust. The rocket will have three fins made of two layers of 1/8" birch aircraft plywood. While the rocket will not reach transonic speed in order to avoid fin flutter, the use of two layers will help to prevent effects of fin flutter during flight. The layers will be laser cut and epoxied together using on campus facilities for ease of production and low cost.

Bulkheads will be placed to support the fin can, midsection, and nose cone internally and will be made of layers of 1/8" birch aircraft plywood. The layers will be epoxied together via wet layup and will be held under vacuum and allowed to cure for at least 8 hours.

4.2.3 Motor Selection

With a takeoff weight of over 30 pounds, an L-class motor was needed to achieve the minimum altitude requirement of 4000 ft AGL. There are several motors in this class capable of lifting the launch vehicle past this desired altitude, but it was determined that the smallest of these motors, the Aerotech L-1150R-PS, would be the best motor to satisfy this requirement. The L-1150R offers several advantages over the alternatives. Namely, it is contained within an Aerotech model 75/3840 casing which the club already has in its possession. This motor casing fits securely in the motor tube as designed and will not require any adaptors. The specifications for the motor are as follows:

- Total Impulse: 3560 N-sec (800 lb-sec)
- Burn Time: 3.0 sec

- Peak Thrust: 300 lbs
- Propellant Weight: 4.19 lbs

Please note that the total impulse for the L-1150 is below the competition limit of 5120 N-sec. Additionally, OpenRocket simulations predict that this motor will accelerate the launch vehicle to a rail exit velocity of 145 ft/s. This is above the competition minimum of 52 ft/s.

4.2.4 Projected Altitude

The OpenRocket model estimates that the launch vehicle will reach an apogee of 4635 feet AGL in ideal conditions. The simulation assumes standard temperature and pressure, a 12 ft launch rail, and a launch orientation of 5 degrees from vertical. The plot below shows altitude, vertical velocity, and vertical acceleration.

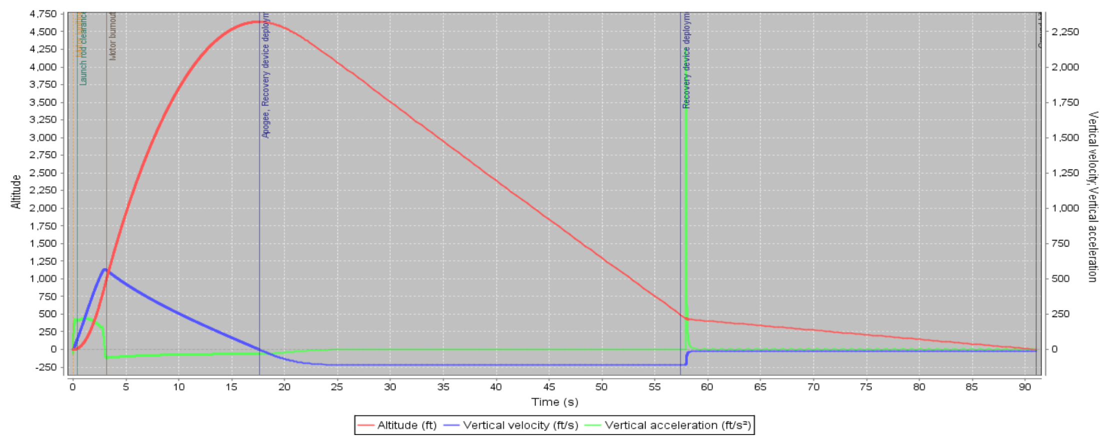

Figure 4--5 Open Rocket Simulation Results for Full Scale Ideal Conditions

During the 2018 competition, dramatic differences were observed in the OpenRocket simulation and launch day data. This resulted in the rocket exceeding the waiver altitude for the competition field. This forced the club to conduct additional launches of the full-scale launch vehicle. The final of these launches resulted in an unrepairable loss of the launch vehicle and disqualified the team from competition. To avoid this issue, the club will be utilizing a copy of RockSim, a software developed by Apogee components, to determine if OpenRocket is indeed underestimating apogee. The club's advisor is in the process of securing an academic license of this software at a discounted rate. In the meantime, the club will continue to use OpenRocket for apogee and stability calculations.

4.2.5 Rocket Recovery System

The rocket will feature a dual-deployment parachute recovery system to ensure the vehicle lands safely after each flight and meets the competition requirement to be flight-worthy again on the same day without repairs. The use of two independent altimeters to control the recovery events provides redundancy and ensures reliable operation of the rocket's recovery systems. The altimeters will be programmed prior to launch day to control the pyrotechnic charges that will actuate the rocket's deployment events. The recovery system relies on two events: drogue deployment and main parachute deployment, as shown in Figure 4--6 below.

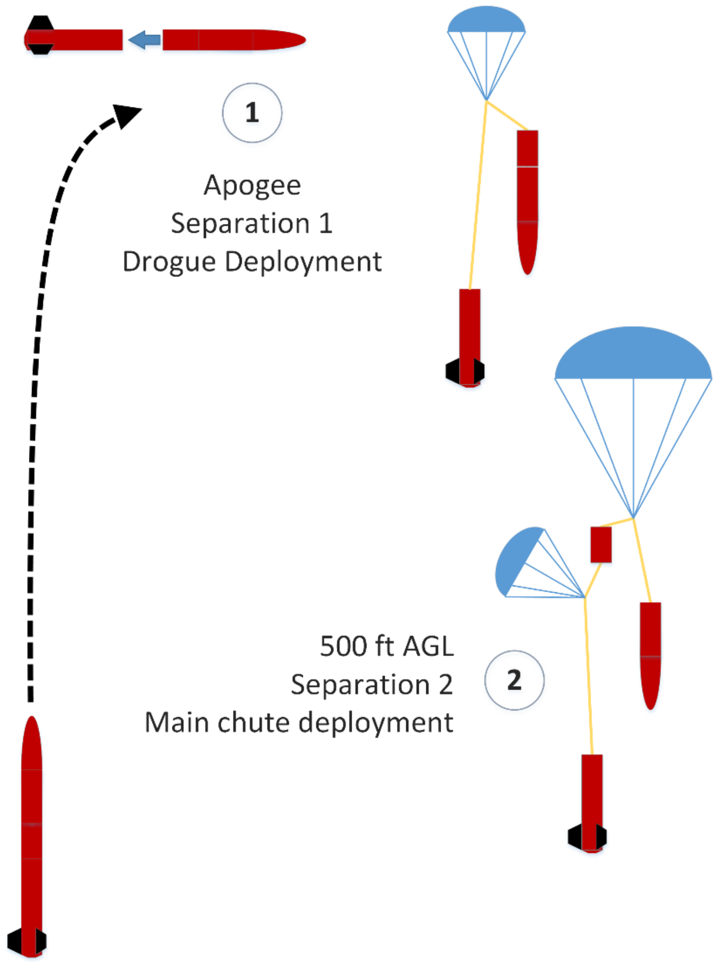

Figure 4--6 Rocket Recovery Stages

The rocket's first recovery event occurs once it reaches its projected apogee altitude of 4,635 ft AGL. Upon detecting apogee, the altimeters will fire a pyrotechnic charge to separate the midsection and fin can. The redundant altimeter will fire its charge with a delay of one second following apogee. This separation deploys the 18 inch diameter drogue parachute, a Fruity Chutes 18 inch Classic Elliptical parachute. Equation 1 was used to determine the descent rate of the empty rocket, weighing 34.41 lbf after burnout, while under drogue.

$$V = \sqrt{\frac{2\,g\,m}{S\,C_D\,\rho}} \qquad (2)$$

Where *V* is the descent velocity, *g* is gravitational acceleration, *m* is empty mass of the vehicle under parachute, *S* is the projected area of the parachute, C_d is the coefficient of drag, ρ is air density. *S* and C_d were varied in calculations based on information from the Fruity Chutes website. For the chosen parachute, $S = 1.77$ ft^2 and $C_d = 1.43$, which led to a calculated velocity of descent of 105 ft/s when assuming standard sea-level conditions for the remaining variables. After using this parachute in OpenRocket rocket launch and recovery simulations, it was determined that the drogue size and descent rate of the rocket were acceptable. To ensure a safe separation distance between the fin can and midsection/nosecone while descending under drogue, a total length of 30 ft of shock cord will be used.

At approximately 500 ft AGL, the altimeters will initiate the second recovery event by detonating a pyrotechnic charge. This event separates the nosecone and midsection to deploy the 120 inch diameter main parachute. The main parachute is a Fruity Chutes 120 inch Iris Ultra Compact parachute, which is shown as “Separation 2” in Figure 4--6. While stowed in the main parachute bay, the parachute will be housed in a deployment bag to protect it from the black powder ejection charge. The flame-resistant properties of the Nomex cloth the deployment bag is constructed from will shield the parachute from the heat of the ejection charges until it is clear of the rocket. Using S = 78.5 ft^2 and C_d = 2.10, both taken from the Fruity Chutes website, the velocity of descent for the rocket after main parachute deployment was calculated to be 13 ft/s. This descent rate ensures that the rocket will land safely. The OpenRocket simulation using this recovery configuration results in a landing velocity between 12.7 ft/s and 13.5 ft/s depending on the wind speed, which matches the results calculated above.

Table 4--1, below, shows the results of the descent rate calculations and the descent rates in the OpenRocket simulation for the rocket in its two stages of descent.

Table 4--1 Descent Velocity of Rocket during Various Stages of Descent

Stage	OpenRocket Simulation Descent Velocity	Hand-Calculation Descent Velocity
Under drogue parachute	107 ft/s	105 ft/s
Under main parachute	13.5 ft/s	13 ft/s

Table 4--2, below, details the time of descent and wind drift distance from the launch pad experienced by the vehicle at various wind speeds from calm winds up to the maximum permissible surface wind velocity at launch, 20 mph. The results of the calculations demonstrate the recovery system’s ability to achieve both the required descent time limit and drift distance limit.

Table 4--2 Descent Times and Drift Distances at Various Wind Speeds

Wind Speed	OpenRocket Descent Time	OpenRocket Drift Distance	Hand-Calculated Descent Time	Hand-Calculated Drift Distance
0 mph	72.1 s	8 ft	78 s	0 ft
5 mph	70.9 s	100 ft	78 s	572 ft
10 mph	73.9 s	365 ft	78 s	1144 ft
15 mph	72.0 s	665 ft	78 s	1716 ft

20 mph	70.0 s	936 ft	78 s	2288 ft

The OpenRocket simulations used to generate the data above were configured with the specified wind speed and a launch angle of zero degrees from vertical, per the competition requirements.

To ensure a safe separation distance between the fin can and midsection/nosecone while descending under the main parachute, a total length of 30 ft of shock cord will be used. This total length of shock cord is sufficient to allow the two sections to slow after the black powder event to reduce the shock loads on the shock cord, recovery hardware, and bulkheads once the shock cord is fully extended and is pulled in tension.

The maximum permissible kinetic energy of any independent section is 75 ft-lbf. The selected recovery system, with its descent rate at landing of 13 ft/s, keeps the kinetic energy of all sections under the 75 ft-lbf limit. Table 4--3, below, lists the post-burnout mass and kinetic energy of each section at landing.

Table 4--3 Kinetic Energy upon Landing of Each Independent Section

Section	Post-Burnout Weight	Kinetic Energy
Nosecone	3.283 lbf	8.67 ft-lbf
Midsection	4.506 lbf	11.89 ft-lbf
Fin can	23.623 lbf	62.35 ft-lbf

All shock cord used in the recovery system will be 5/8 inch tubular Kevlar, which is rated to 2000 lbf, making it capable of withstanding the decoupling forces. The team has used this particular type of shock cord successfully in the past for rockets of similar size and weight to the vehicle, thus the team expects it to perform safely.

At each joint between separable sections, four nylon shear pins will be used to ensure no pre-mature separations of sections occur during flight. Following the competition rules, the team will always conduct ground tests of black powder ejection events to confirm the quantity necessary to confidently separate rocket sections without damaging any components before each flight. Following the competition rules, the team will always conduct ground tests of black powder ejection events to confirm the quantity necessary to confidently separate rocket sections without damaging any components before each flight. Following the competition rules, the team will always conduct ground tests of black powder ejection events to confirm the quantity necessary to confidently separate rocket sections without damaging any components before each flight.

The AV bay sled will hold two 9 V alkaline batteries, one StratoLogger CF altimeter, one Entacore AIM 4.0 altimeter, and one BigRedbee 900 GPS tracker powered by an integral 3.7 V, 1000 mAh, Lithium Polymer (LiPo) battery. The altimeters and GPS tracker will all be independently powered. The StratoLogger altimeter will be designated the competition altimeter for altitude scoring purposes. The StratoLogger altimeter, pictured in Figure 4--7, will be wired to two ejection charges: one for the separation of the fin can for drogue deployment and one for the separation of the nosecone for main parachute deployment. The Entacore altimeter, pictured in Figure 4--8 will be connected to two backup, black powder charger, one for each separation even. Each of these backup charges will contain slightly more black powder than the primary charge and will be activated with a 1 second delay following the primary charge activation. Since each altimeter will have its own battery, they will have independent circuits and will be independently redundant.

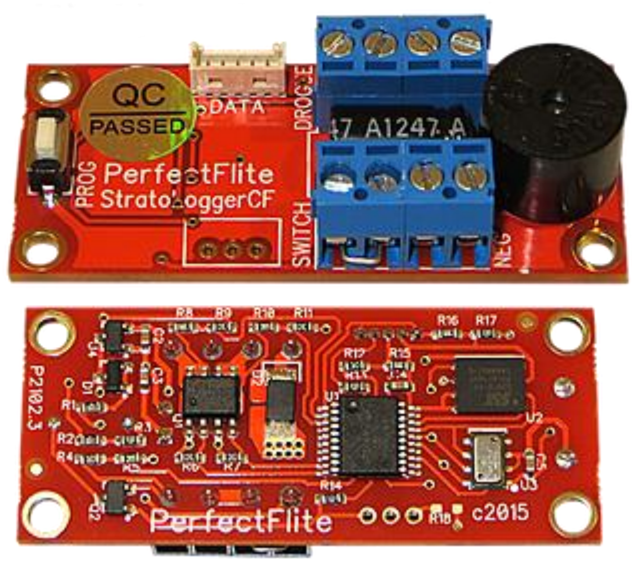

Figure 4--7 PerfectFlite StratoLogger CF Altimeter

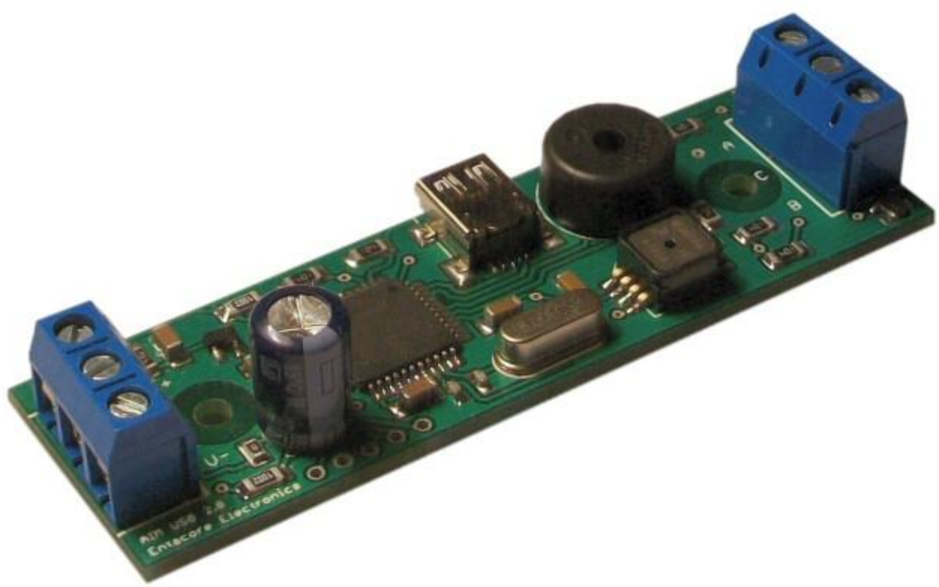

Figure 4--8 Entacore AIM 4.0 Altimeter

The AV sled will be constructed from aircraft-grade birch plywood. The sled will be assembled from sections of plywood sheeting laser cut to shape. These joints will be sanded for surface preparation before being bonded using wood glue. The StratoLogger CF altimeter will be affixed to the AV sled by four aluminum M3 machine screws. The Entacore AIM 4.0 altimeter will be mounted on the sled by two aluminum M3 machine screws. Each of the two 9 V batteries powering each altimeter rest snugly within compartment in the AV sled. Plastic zip ties secure the batteries within the compartments and ensure the power connectors remain attached to the batteries' terminals.

Two rotary switches will be mounted to the body tube of the rocket, flush with the external airframe, to allow the altimeters to be powered on using a flathead screwdriver or other similar device. Other types of switches considered include rotary key switches, which require a specific key to operate, and sliding two-position switches. The two-position sliding switches were not selected because their design risks possible unintended movement of the switch if the switch were to be subjected to high g-forces or aerodynamic forces on the switch in the direction of the switch sliding motion. Rotary switches and rotary key switches do not suffer that same vulnerability. The rotary key switches were not selected because the requirement for use of a key to operate the switch presents a safety hazard. The key would need to be kept with personnel closest to the vehicle at all times in order to allow the altimeters and their connected energetics to be disarmed safely without unnecessary delay. Furthermore, in the event of the rocket landing with un-detonated black-powder charges still contained within the vehicle, it is hazardous to remain near the vehicle until all altimeters controlling the charges have been powered off. Any recovery personnel not possessing the required key would be unable to complete this urgent task. This ability to actuate the altimeter power switches using only a screwdriver, edge of a blade, or fingernail enhances the safety of the rocket and mitigates risks associated with the recovery system. For these reasons, the team selected the non-key-activated rotary switches to control power to the altimeters.

The altimeters, due to their design, are not sensitive to RF radiation, so there will be no interference from the GPS tracker location transmitter, and no risk from placing the GPS tracker transmitter device in the same bay as the altimeters. Nonetheless, a portion of metal foil will be installed between the GPS transmitter and the altimeters to further mitigate any risk of RF interference with the altimeters. Likewise, because the payload will contain radio transmitters, shielding will be installed between the altimeters within the AV bay and the payload compartment. As with the shielding between the GPS transmitter and the altimeters, this shielding is purely to further mitigate the already low risks of RF radiation from the payload systems affecting the altimeters.

The team chose to use two different altimeters from two different manufacturers to reduce the risk of both altimeters failing due to a manufacturers defect affecting a product line of altimeters. To ensure that the altimeters are working correctly, both altimeters will be tested by connecting an LED in place of the electronic match in the circuit and sealing them within a vacuum chamber. The vacuum chamber will then be depressurized and re-pressurized in a manner roughly analogous to the pressure changes experienced in the flight profile of the rocket to confirm that the LED is powered on at the pressure it was programmed to. Following these tests, the team will review the pressure and altitude data from the altimeter collected during the test to further ensure the device functioned properly.

To mitigate risk of pressure anomalies within the AV bay during flight, openings must be drilled in the walls of the AV bay. Four static ports will be spaced evenly around the circumference of the avionics bay. The use of four static ports will reduce the risk of pressure fluctuations from wind or flight at any angle of attack. The diameter of the static ports is determined using the following equation, from the manufacturer's manual for the StratoLogger CF altimeter:

$$H = D^2 * L * 0.0008\ in^{-2} \quad (3)$$

Where *H* is the diameter of the static ports, *D* is the internal diameter of the avionics bay, *L* is the internal length of the avionics bay.

To ensure uninterrupted power for the recovery avionics systems, batteries for altimeters are only used for a single flight. Prior to flight, the batteries are tested to ensure their voltage is sufficient for flight.

As discussed previously, the rocket will be equipped with a BigRedbee 900 GPS tracker which will transmit the rocket's GPS location on the 900 MHz band. This will be received by a ground station connected by USB cable to a laptop operated by a team member. The laptop will display graphically in three dimensions in the mapping software Google Earth the latitude, longitude, and altitude received from the GPS tracker. This data can be viewed in real-time to track the rocket. The location data is also logged for post-flight analysis and review. In addition, the receiver ground station displays the tracker status and received latitude and longitude coordinates on an LCD display on the receiver device without need to be connected to the laptop computer. This provides a redundant method of tracking the rocket in case the laptop malfunctions or is otherwise inoperable.

The GPS tracker within the rocket will be powered by a 3.7 V, 1000 mAh, Lithium Polymer (LiPo) battery. This battery will solely be powering the GPS tracker. This is sufficient to meet the required 2-hour required pad time, flight time, and post-flight time needed to locate and recover the rocket. The device will be powered on during the assembly of the AV sled and closure of the AV bay within which it is mounted. This will give the device time to acquire satellite signal and establish its location prior to flight.

There is no second tracking device in the vehicle because failure of the tracking device would not result in any safety risks or failure to meet the mission success criteria. Thus, it is not considered a flight-critical or mission-critical component. The tracking device itself is considered a redundant solution to the primary means of locating the rocket during and after flight: visually tracking the rocket during its flight and descent. The tracking device serves as a backup to this method if any abnormal flight events render this method unsuccessful.

4.3 Experimental Payload Specifications

Per competition requirements for the deployable UAV experimental payload, the team must successfully design a UAV that will be stowed within the launch vehicle and remotely deployed after landing to fly from the rocket land site to a Future Excursion Area, designated by a 10ftx10ft tarp, where a simulated beacon will be dropped.

4.3.1 Payload Bay Design

There are multiple challenges that must be overcome by the payload bay: securing the payload, getting the payload safely out of the body tube, and ensuring the UAV is autonomously in flight-ready orientation and condition.

The payload will be secured within a 3-sided pod during flight. The pod pictured in Figure 4--9 is composed of 3 flaps, forming an egg-like shape. Two of the 3 edges are hinged, with the edge by the narrow side of the egg shape held together with a pin. Inside of the pod will be foam cushioning and support structures designed to keep the UAV immobile until the pod opens. Within the closed pod, the UAV will have zero degrees of freedom. The pod itself will slide smoothly into a series of non-load-bearing centering rings, spread throughout the payload bay, seen in Figure 4--10. Because the pod is non-circular, it cannot rotate in any direction with respect to the rocket. The centering rings also prevent the pod from moving in any direction other than axially. This leaves one degree of freedom. The pod will be secured axially by a pair of electronically activated latches, preventing it from moving until it is activated on the ground. These latches will each be strong enough to withstand the expected forces, as well as atypical forces the pod may experience. This leaves the UAV and pod secured for the entire flight.

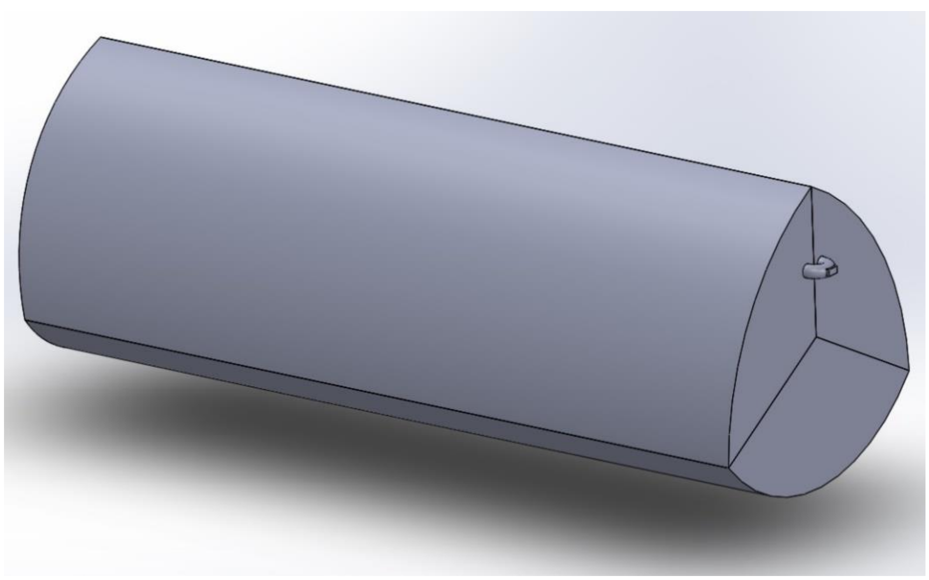

Figure 4--9 Computer Model of 3-Sided Pod

For deployment, the primary actuator is a threaded rod that spans the length of the payload bay, seen at the bottom of Figure 4--10. This rod is driven by a motor attached to the bulkhead at the base of the payload bay. The “pusher” is comprised primarily of a plate riding on top of a threaded nut that can move up and down the threaded rod. There is also an extrusion that contacts the pod, and, being larger than the last centering ring, can push the pod completely out of the payload bay. The pusher also rides on a smooth rod, which prevents it from rotating, turning the rotational motion of the rod and motor into linear motion of the pusher and pod.

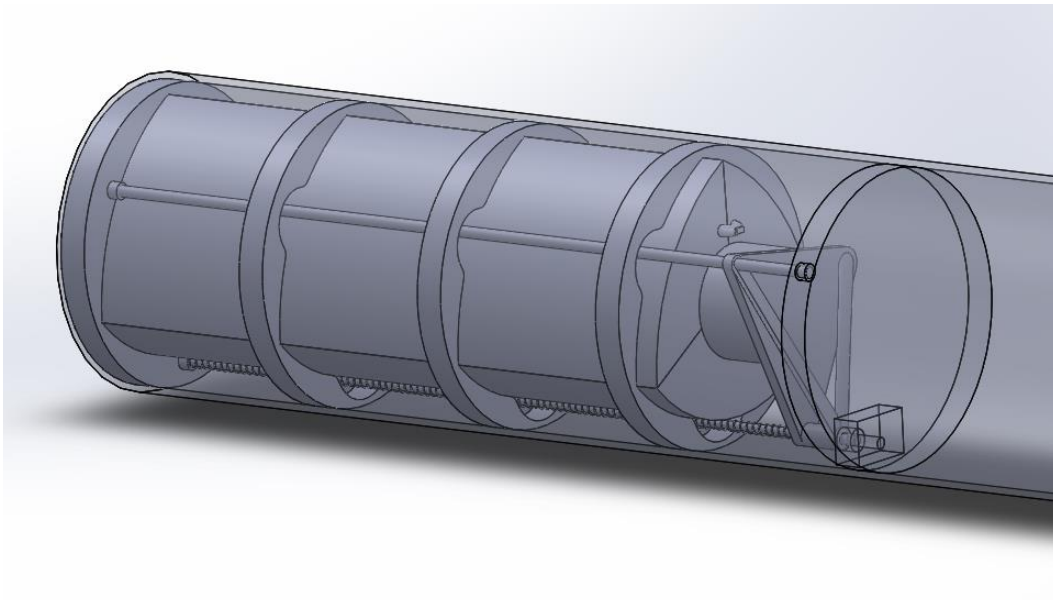

Figure 4--10 Computer Model of Payload Bay

Finally, the UAV must end the deployment process flight-ready. The payload bay is attached to the fin can, which creates the near guarantee that the open end of the payload section will have a slight angle into the ground. To combat this, as well as other potential ground irregularities, the pod will have a dome shaped front, hopefully preventing it from digging into the ground. Once the pod is completely free of the body tube, the pod will self-right. The weight of the UAV will be off-center, forcing the entire pod to roll until the weight is at the bottom. The pin is still in place, giving the pod time to orient as close to vertical as possible. To assist this process, the top of the pod will be aligned with one of the external fins. As rockets tend to land supported between two fins, this makes it very unlikely the pod will need to self-right a full 180 degrees. Next, the pusher will retract, pulling the pin by a cord out of the pod. Ideally, the pod will be upright, allowing the left and right flaps to fall open. However, if the pod is still laying on its side, an elastic cord will be threaded along the wall of the pod, forcing the flaps open, and the pod to orient as flat as possible.

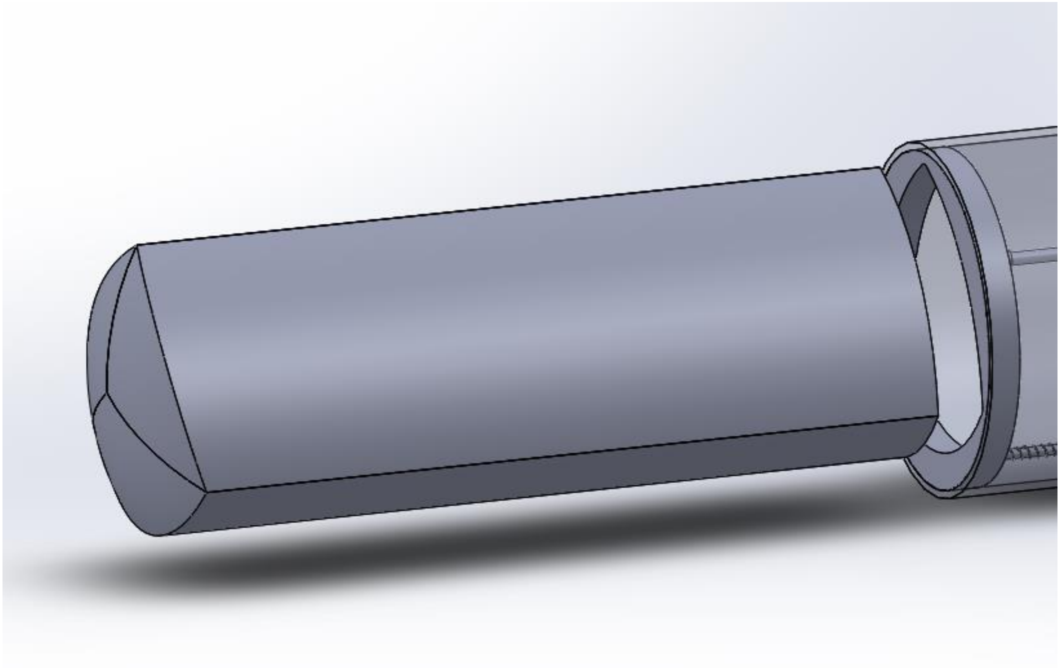

Figure 4--11 Computer Model of 3-Sided Pod with Dome Shaped Front Face

Finally, the UAV, secured only by the foam padding and vertical structures, will be able to lift vertically out of the pod of its own power.

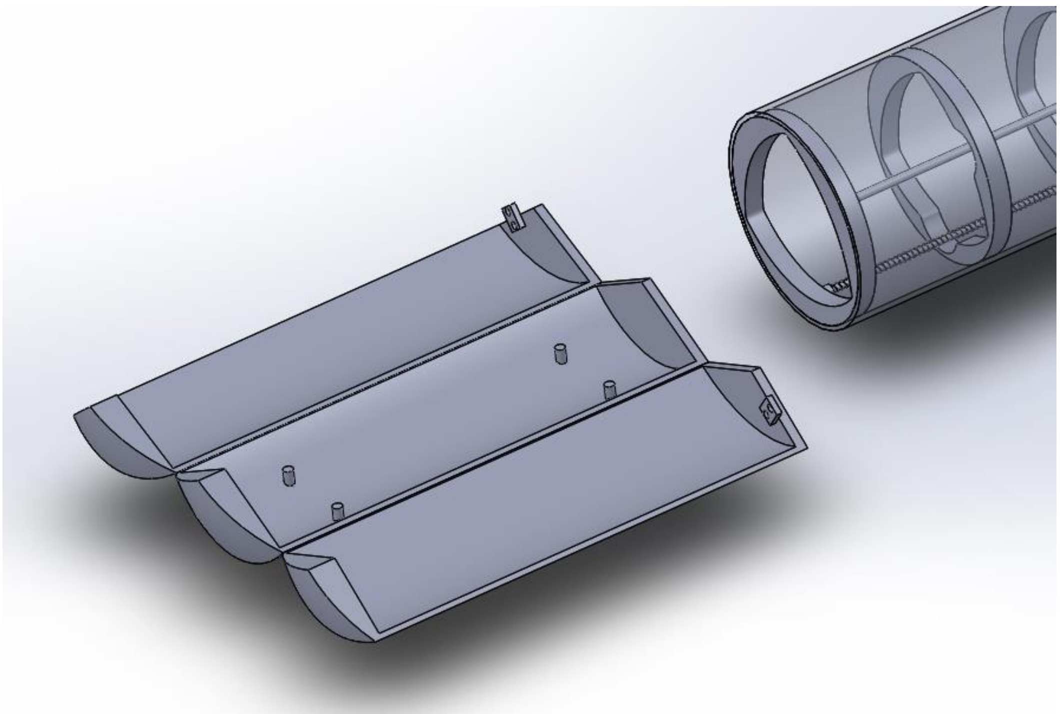

Figure 4--12 Computer Model of Fully Opened 3-Sided Pod with Standoffs

4.3.2 UAV Design

To simplify construction of the UAV body itself, the team opted to search for and purchase a body that is commercially available via hobby shops and online vendors. The primary concerns in choosing a UAV body design are space, weight, flight time, and transmission distance, and with these concerns in mind, the team decided on a carbon-fiber quadcopter design. With the recent surge in popularity of the racing UAV community, carbon-fiber quadcopters are both plentiful and inexpensive on the open market, which allowed for the team to choose from the greatest variety of commercially available bodies.

Once the team decided on the type of UAV body that would be the most successful, more stringent and recursive criteria were crafted to select the wheelbase. After discussing the matter with experienced quadcopter pilots, builders, and retail staff, the team decided that a quadcopter on the scale of the popular TinyWhoop would not be feasible, due mainly to the incredibly short flight times and lack of customizations the team could make. Further research showed a relationship between quadcopter frame sizing, weight of components, and battery life that narrowed down the selection of the UAV body to a 220mm wheelbase.

Such a large diameter wheelbase contradicts one of the main problems the team anticipated: payload compartment size. The smaller UAV's could easily mount in the rocket flat against a bulkhead that supported it until launch, but as previously stated, they were not an option. The selection of a 220mm wheelbase would result in a rocket diameter of well over 8 inches, which the team was reluctant to pursue, due to past teams' challenges in dealing with large diameter rockets. To mitigate this issue, a simple hinge will be designed and added to the UAV to allow the arms to fold.

The hinges, which will operate via three bolts and a sliding rod, can be visualized using the models in Figure 4--13 Proposed quadcopter hinge design in open (flight) configuration and Figure 4--14. Figure 4--13 is the UAV in flight configuration, while Figure 4--14 is the UAV in a stored configuration. In order to create this modification to the UAV, the arms will each be cut 1 inch from the origin of the arm, as measured on the longest side. Holes of 0.1 inch diameter will be drilled in both the cut arm and remaining stub, and bolts will be placed in three static locations on the hinge. The fourth hole in the hinge, the slot, will have a steel rod that is epoxied into place on the arm, and allowed to slide freely through the slotted holes. This will allow for a 34 degree rotation about the static bolt on the arm. Each arm will also have a fillet of radius 0.3 inch on the rotating corner so that the arm does not stop itself from rotating.

Hinges will be placed on the top and bottom of the arm, which will allow for maximum load carriage through the hinge-bolt-arm system. Damping rubber washers can also be used in this system to dampen any vibration caused by the rotating motors and propellers. The hinges will be constructed out of fiberglass sandwich composite with a honeycomb core, which will allow for a minimum weight, maximum strength, and the ability to make multiple parts quickly and easily.

The designed hinges will allow the UAV arms to unfold once the containment pod is ejected from the payload section. The primary force that will cause the arms to unfold is the reaction torque on the arms resulting from the spinning rotors. For example, if the front-left motor spins clockwise, to conserve angular momentum of the arm-motor system, the arm itself will rotate counterclockwise about the rotator pin. Typically, this phenomenon is used as a method to manipulate the yaw moment of quadcopters, but the hinge design does not allow for the reaction moment to be transferred to the rest of the body until the arm is fully extended.

Due to the nature of quadcopter flight, this method of arm extension cannot reliably used for the entirety of flight. To remedy this problem, a plastic socket will be installed on each arm that will lock the arm in an open position and withstand flight forces.

The overall result of the hinge design and installation is a drastic reduction in the overall diameter that the UAV needs to fit inside the rocket. According to SolidWorks models and measurements, the quadcopter width will not exceed 4.4 inches wide, even if the team decides in the future that a larger wheelbase will be required based on testing. The current design shows that the quadcopter in a folded position will be approximately 13.8 inches long, which fits inside the proposed containment system.

Furthermore, this design allows for an aft-mounted beacon deployment mechanism that will save vertical space in the UAV containment pod. The proposed mechanism is more closely detailed in the payload electronics section 4.3.3.

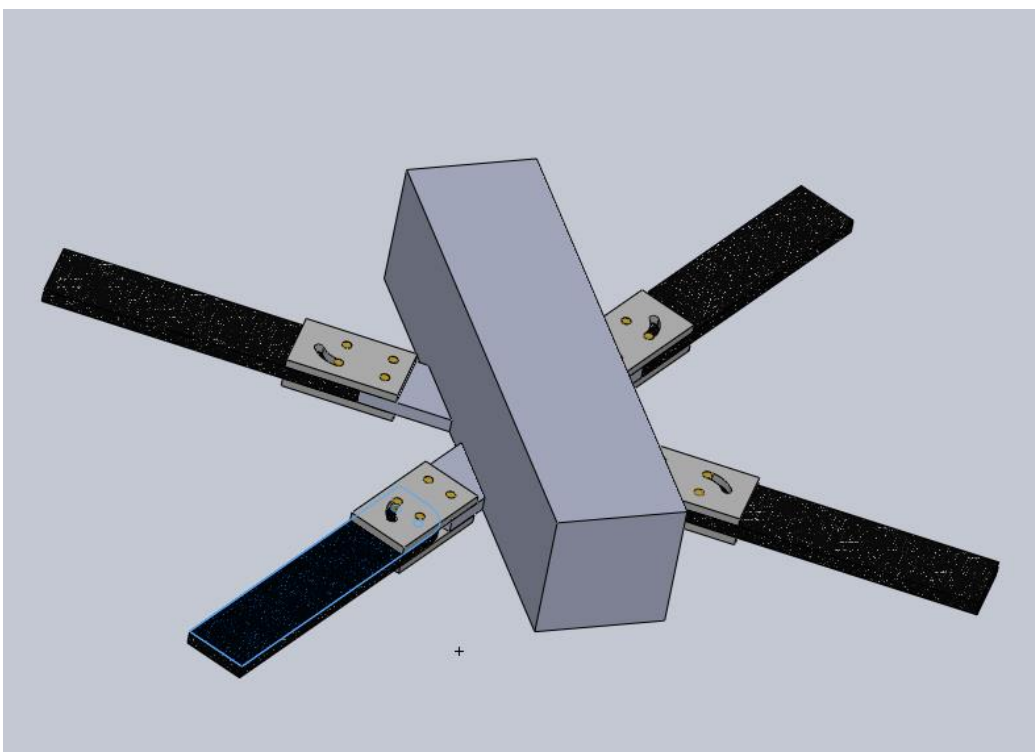

Figure 4--13 Proposed quadcopter hinge design in open (flight) configuration

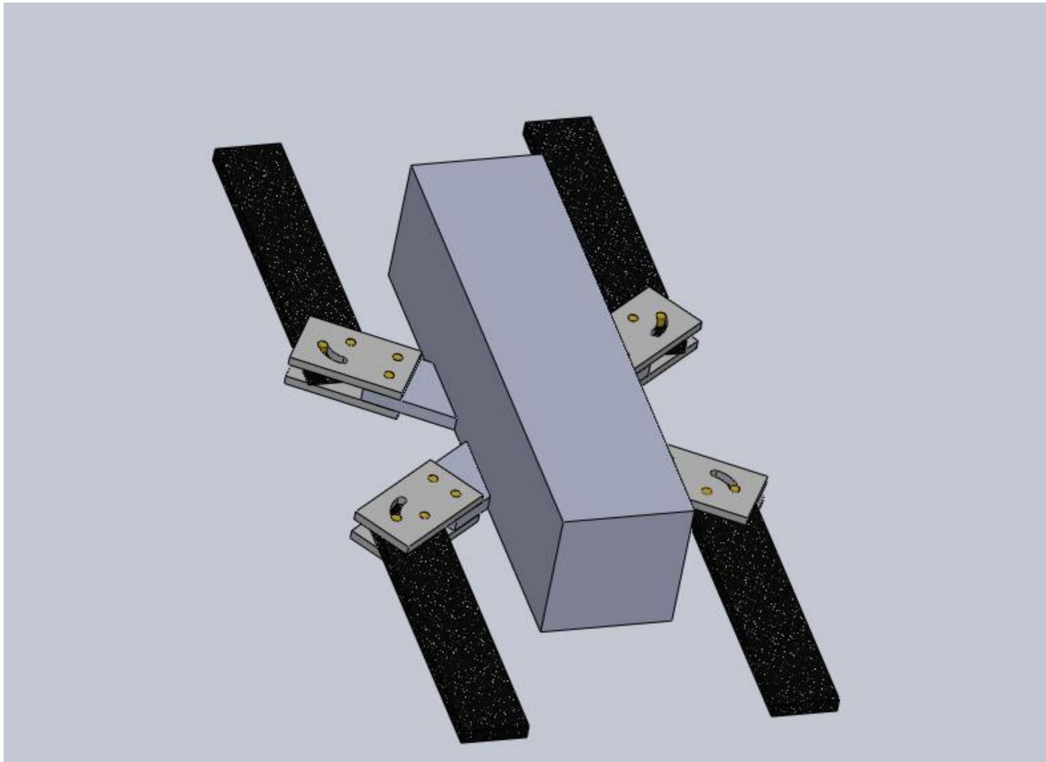

Figure 4--14 Proposed quadcopter hinge design in in folded (storage) configuration

4.3.3 UAV Electronics

In order to make the UAV work, its onboard electronic components and power supply are critical, in addition to the mechanism to carry and place the simulated beacon. Thus, the components will be sourced from commercially available suppliers to avoid any complications. These components will include a flight controller, black-box data recorder, power distribution board, electronic speed controller, electronic switch, first-person view camera, video transmitter, radio antenna, and video antenna. To secure and deploy the beacon, an electronic payload latch will be installed on the UAV and will secure the beacon during the UAV's flight, and once the UAV reaches the FEA, the latch will be disengaged by the UAV operator and deploy the beacon safely. A four-cell lithium polymer battery will be the UAV's power supply, which is commonplace for UAVs of this size, and will be brightly marked to comply with the corresponding requirement.

A key requirement, both for safe rocket operation and to prevent unnecessary draining of the UAV battery, is that the UAV power must be off while inside the rocket. To ensure the UAV is turned off while inside the payload bay, an electronic switch with a magnetic key will be installed on the bottom of the UAV, with an electromagnet armed by exterior key switch set inside the payload section of the rocket body and adjacent to the deployment mechanism, and this magnetic key will be called the Magnetic Arming System, or MAS.

Consider a circular solenoid with 500 loops and a diameter of 1.2 cm, with a permeability constant of μ = 1.257 * 10^-6 T*m/A. Assuming a radial distance of 1 centimeter between the switch and center of the solenoid, a required current of 0.035 amps can achieve the necessary strength to activate the switch, as predicted by Equation 4, where n = 500 and the required field strength B = 0.01 T, equivalent to a refrigerator magnet:

$$I = \frac{2\pi B r^3}{\mu_0 A} \quad (4)$$

Though a theoretical prediction is presented above, the MAS will be fine-tuned to only trigger the electronic switch as the UAV exits the rocket to avoid as much interference and/or damage with other components of the payload and launch system as possible. Though the UAV power will be turned on as the UAV exits the rocket, it will not deploy until communication with the operator is established and the UAV is under the supervision of the Remote Deployment Officer. The UAV once engaged will utilize the 2.4 GHz radio band to communicate with the operator, while the onboard camera will utilize the 5.8 GHZ radio band to transmit video to the operator to locate the FEA and shall not exceed 0.250 Watts of power at any point.

4.4 Alternate Payload Designs

4.4.1 Alternate Payload Bay Design – Bottom of UAV Facing Out

Another potential idea for the payload bay was a similar pod to our proposed solution, but with the bottom of the UAV facing the opening in the payload bay. Instead of the flaps of the pod being hinged together, each would only be hinged and elastically connected to the floor, which faces the opening. The arms of the UAV would fold straight down against the central body.

The team chose not to pursue this design because the floor of the UAV would have to be flat, which could dig into the ground upon being pushed out. The most pressing issue however was that UAV cannot be designed with the central components in a vertical layout effectively. For example, commercially purchasable UAV batteries are long rectangular prisms with a small cross section. This would not be conducive to a tall, skinny UAV body design.

4.4.2 Alternate Payload Design - True X-fold wings

An alternative quadcopter design utilizes a different method of folding the arms. In this scenario, each diagonal motor pair would be joined by a single arm that ran from motor to motor. These arms would be bolted to the center of the main body in a manner that allows them to freely rotate about the center joint. Torsional springs would be mounted to the arms on the forward and aft of the pivot joint and oriented in a way that pushes the arms outward when not retained by the UAV containment pod. V-shaped stops would be mounted on both sides of the arms which would keep the arms from over extending.

The team chose not to pursue this design because of the structural instability caused by a single point of contact for both arms to the center body. Furthermore, this design requires that the arms be mounted one atop the other, which would result in difficulties tuning the motors to be aerodynamically stable in turning flight when the motors are at different heights. This design also prohibits mounting any large batteries beacon deployment mechanisms to the bottom of the UAV.

5. Educational Engagement

5.1 Description of Outreach

Outreach events are coordinated with local communities and serve the purpose of guiding students to develop an understanding and interest of current applicable topics in science, engineering, and technology. During these events, students will first learn about a selection of a few STEM topics ranging from the NASA SL competition to engineering applications. These topics will be introduced to students using presentations and open group discussions. After the students develop a basic comprehension of the topic, they will be encouraged to engage in a hands-on activity that relates to the discussed subject. The intention of the activity is to provide the students with the opportunity to visualize, apply, and develop a clear understanding of what they have learned. With every outreach event HPRC aims to increase and facilitate the interest in STEM careers within local schools and organizations.

5.2 Last year in Review

During the span of the NASA SL competition last year, HPRC reached approximately 12,000 students and adults in the local community around Raleigh, NC and at NASA Langley Research Center. The team's outreach helps inspire future scientists, engineers, and others pursuing STEM careers. The team strives to make a difference in the lives of youth by introducing them to STEM careers and by building relationships with local organizations and K-12 schools in the community. The focus for these events is always on quality over quantity and to make a lasting impact on everyone through small group discussions and hands-on activities.

Figure 5--1 HPRC members engaging in STEM Outreach at a Local Elementary School

5.3 Planned Outreach

JY Joyner Science Go Round

At this year's Science Go Round, HPRC will be will be introducing students to the basics of rocketry and physics. Groups of students will be rotating through presentations given by different STEM organizations from the area. Students will benefit by learning from a variety of STEM subjects.

Location: JY Joyner Elementary School

Time: November 9th

Weatherstone Elementary STEM Expo

HPRC will continue to attend the STEM Expo at Weatherstone Elementary school. At the event, student and parents will be able to interact with club members and learn about our organization and modeled rocketry. Students will be able to engage in a hands-on activity in which they will be able to gauge the effects of a nosecone and fins on a water bottle rocket.

Location: Weatherstone Elementary School

Time: February 9th

NCSU Family STEM Night

STEM Night is a family-oriented event organized by the NCSU Engineers' Council. STEM organizations from NCSU volunteer to go to local elementary and middle schools to engage students and families in math, science, and engineering related activities. HPRC will be planning to attend on two separate dates.

Location: TBD

Time: October 25th & February 13th, 4:30pm – 8pm

6. Project Plan

6.1 Development Schedule

Table 6--1**Error! Reference source not found.** below shows the development schedule for this year's project.

Table 6--1 2018-19 NASA SL Competition Development Schedule

Event/Task	Start Date	End Date/Submission
Request for Proposal Released	Aug. 22, 2018	
Proposal	Aug. 22, 2018	Sep. 19, 2018 3:00 pm CDT
Preliminary Design Review (PDR) Q&A	Oct. 12, 2018	
PDR	Oct. 12, 2018	Nov. 03, 2018 8:00 am CDT
PDR Team Teleconference	Nov. 06-29, 2018	
Subscale Launch Opportunity		Nov. 17, 2018
Critical Design Review (CDR) Q&A	Nov. 27, 2018	
CDR	Nov. 27, 2018	Jan. 04, 2019 8:00 am CST
CDR Team Teleconference	Jan. 07-22, 2019	
Full-Scale Launch Opportunity		Feb. 23, 2019
Flight Readiness Review (FRR) Q&A	Jan. 25, 2019	
FRR	Jan. 25, 2019	Mar. 04, 2019 8:00 am CST
FRR Team Teleconference	Mar. 08-21, 2019	
Team Travel to Huntsville, AL	Apr. 03, 2019	
Launch Readiness Review (LRR)	Apr. 03, 2019	
NASA Safety Briefing	Apr. 04, 2019	
Rocket Fair and Tours of MSFC	Apr. 05, 2019	
Launch Day	Apr. 06, 2019	
Backup Launch Day	Apr. 07, 2019	
Post-Launch Assessment Review (PLAR)	Apr. 08, 2019	Apr. 26, 2019 8:00 am CDT

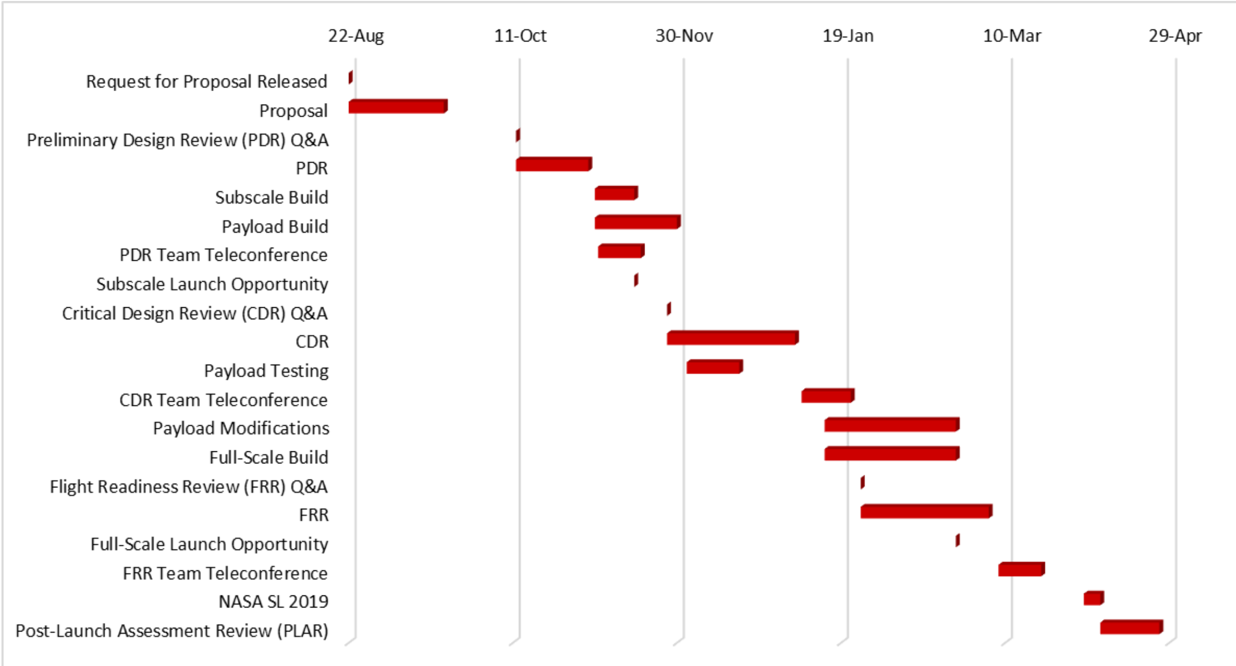

Figure 6--1 HPRC 2018-19 NASA SL Competition Gantt Chart

Officer meetings occur monthly to communicate needs between the design team and operational officers. Senior Design meetings occur weekly on Fridays where design team members discuss new ideas.

6.2 Project Budget

Table 6--2**Error! Reference source not found.** below details the year-long budget for the 2018-2019 competition year.

Table 6--2 HPRC Budget for 2018-2019 Competition Year

	Item	Quantity	Price per Unit	Item Total
Subscale Structure	Aerotech I435T-14A	2	$56.00	$112.00
	Aero Pack 38mm Retainer	1	$27.00	$27.00
	Motor Casing	1	$340.00	$340.00
	38mm G12 Airframe, Motor Tube	1	$64.00	$64.00
	4" Phenolic Airframe, 3 Slots	1	$33.50	$33.50
	4" Phenolic Airframe	2	$26.00	$52.00
	4" Phenolic Coupler	4	$21.00	$84.00
	Plastic 4" 4:1 Ogive Nosecone	1	$23.00	$23.00
	Domestic Birch Plywood 1/8"x2x2	6	$12.68	$76.08
	3/4" L Brackets	4	$1.97	$7.88
	Rail Buttons	4	$2.50	$10.00
	U-Bolts	4	$1.00	$4.00
	Blast Caps	4	$2.50	$10.00
	Terminal Blocks	3	$7.00	$21.00
	Paint	1	$100.00	$100.00
	Key Switches	2	$12.00	$24.00
	Subscale Payload	1	$300.00	$300.00
	Subtotal:			**$1,288.46**
Full-Scale Structure	5.5" G12 Airframe, Half Length (30"), 3 Slots	1	$130.00	$130.00
	5.5" G12 Airframe, Full Length (60")	1	$188.00	$188.00
	3" G12 Airframe, Half Length (30"), Motor Tube	1	$100.00	$100.00
	5.5" G12 Coupler 12" Length	3	$55.00	$165.00
	5.5" Fiberglass 4:1 Ogive Nosecone	1	$84.95	$84.95
	Domestic Birch Plywood 1/8"x2x2	4	$12.68	$50.72
	Aerotech 75/3840 Motor Case	1	$360.00	$360.00
	Motor Retainer	1	$44.00	$44.00
	3/4" L Brackets	4	$1.97	$7.88
	Rail Buttons	4	$2.50	$10.00
	U-Bolts	4	$1.00	$4.00
	Aerotech L1150R-PS	2	$200.00	$400.00
	Aerotech 75mm Forward Seal Disk	1	$37.50	$37.50
	Blast Caps	4	$2.50	$10.00
	Terminal Blocks	3	$7.00	$21.00

	Paint	1	$150.00	$150.00
	Key Switches	2	$12.00	$24.00
	Poster Printing (feet)	4	$10.00	$40.00
	Subtotal:			**$1,827.05**
Payload	UAV Brushless Motor A1510 2200KV	8	$14.00	$112.00
	Electronic Speed Controller	2	$26.00	$52.00
	4GB MicroSDHC Memory Card	2	$10.00	$20.00
	11.1V Drone Racing LiPo Battery	2	$31.73	$63.46
	FPV Tiny Whoop Camera	2	$20.00	$40.00
	Readytosky 220mm FPV Racing Drone Frame	2	$47.00	$94.00
	Lumenier Pagoda 2 5.8GHz Antenna	4	$9.18	$36.72
	Lumenier 5x3.5 - 2 Blade Propeller	8	$1.61	$12.88
	RC4WD Mini On/Off Switch	2	$8.00	$16.00
	Taranis X-Lite Compact RC FPV Transmitter	1	$140.00	$140.00
	Electric Switch	2	$0.00	$0.00
	Rotary Switch	2	$5.00	$10.00
	Mini AV FPV Transmitter	2	$12.00	$24.00
	Betaflight F405-CTR	2	$39.00	$78.00
	Dual Stepper Motor Driver Shield for Arduino	2	$13.00	$26.00
	Arduino Uno R3 USB Microcontroller	2	$22.00	$44.00
	36oz-in Unipolar Stepper Motor	2	$15.50	$31.00
	Threaded Rod	4	$1.50	$6.00
	Aluminum Honeycomb Grid Core	1	$24.00	$24.00
	Hinges	10	$1.00	$10.00
	Subtotal:			**$840.06**
Recovery and Avionics	Iris Ultra 120" Compact Parachute	1	$504.00	$504.00
	18" Elliptical Parachute	1	$53.00	$53.00
	Quick Links	8	$1.25	$10.00
	Kevlar Shock Cord (yard)	20	$4.34	$86.80
	Black Powder	1	$30.00	$30.00
	E-Matches	2	$29.00	$58.00
	Shear Pins	3	$3.00	$9.00
	StratoLogger CF Altimeter (Full-scale)	2	$60.00	$120.00
	Entacore AIM 3 Altimeter (Full-scale)	2	$115.00	$230.00
	6" Deployment Bag	1	$43.00	$43.00
	18" Nomex Cloth	1	$24.00	$24.00
	BRB 900 Transmitter	2	$200.00	$400.00
	4" Deployment Bag	1	$39.00	$39.00
	13" Nomex Cloth	1	$13.00	$13.00
	Iris Ultra 60" Compact Parachute	1	$225.00	$225.00

	StratoLogger CF Altimeter (Subscale)	2	$60.00	$120.00
	Entacore AIM 3 Altimeter (Subscale)	2	$115.00	$230.00
	Subtotal:			**$2,194.80**
Miscellaneous	Epoxy Resin	2	$86.71	$173.42
	Epoxy Hardener	2	$45.91	$91.82
	Nuts (box)	1	$5.50	$5.50
	Screws (box)	1	$5.00	$5.00
	Washers	1	$5.00	$5.00
	Wire	1	$13.00	$13.00
	Zip Ties	1	$11.00	$11.00
	3M Electrical Tape	4	$8.00	$32.00
	9V Batteries	2	$14.00	$28.00
	Wood Glue	2	$3.00	$6.00
	Rubber Bands	1	$5.00	$5.00
	Paper Towels	1	$25.00	$25.00
	Battery Connectors	3	$5.00	$15.00
	Shipping			$1,200.00
	Incidentals (replacement tools, hardware, safety equipment)			$1,500.00
	Subtotal:			**$3,115.74**
Travel	Student Hotel Rooms (# rooms)	4	$791.70	$3,166.80
	Mentor Hotel Rooms (# rooms)	3	$1,178.10	$3,534.30
	Van Rentals (# cars)	2	$198.00	$396.00
	Gas (Miles)	1144	$0.60	$686.40
	Subtotal:			**$7,783.50**
Promotional	T-Shirts	40	$14.00	$560.00
	Polos	30	$25.00	$750.00
	Stickers	500	$0.37	$185.00
	Banner	1	$250.00	$250.00
	Subtotal:			**$1,745.00**
Total Expenses:				**$18,794.61**

6.3 Funding Plan

HPRC gets all its funding from multiple NC State University organizations, North Carolina Space Grant (NCSG), as well as a sponsorship from Rockwell Collins.

The Engineers’ Council (E-Council) at NC State University is a student-led organization that oversees events hosted by the College of Engineering. E-Council also allocates funds to different engineering organizations through a proposal, presentation, and appeals process that occurs twice per school year. In the 2017-18 academic year, HPRC received a total of

$1,300 from E-Council: $850 in the fall semester and $450 in the spring semester. A request for $2,000 has been placed for the current fall semester and a similar request will be placed in the spring semester, assuming that the E-Council budget will remain the same.

The NC State University Student Government Association's Appropriations Committee is responsible for distributing university funds to campus organizations. The application process is similar to the Engineers' Council with a proposal, presentation, and an in-person interview. In the 2016-17 academic year, HPRC received a total of $2,315: $865 in the fall semester and $1,450 in the spring semester. A request for $2,000 has been placed for the current fall semester and the same amount will be requested in the spring semester, assuming that the Appropriations Committee budget will remain the same.

Student and faculty advisor travel costs will be covered by NC State's College of Engineering Enhancement Funds. These funds come from a pool of money dedicated to supporting engineering extracurriculars at NC State. The total travel cost for University affiliated attendees comes to $5,500.

In addition to funding through NC State organizations, the North Carolina Space Grant will provide a large amount of monetary support to the club. NCSG accepts funding proposals during the fall semester and teams can request up to $5,000 for participation in NASA competitions. NCSG will review the proposal and inform the club on the amount awarded, which will likely be the full amount requested. These funds will be available for use starting November 2018.

Our sponsor, Rockwell Collins, has given $5,000 to be put toward the construction and launch of our competition rockets.

These totals are listed in **Error! Reference source not found.**, below, which compares the projected costs and incoming grants for the 2018-19 school year.

Table 6--3 HPRC Projected Funding for 2018-19 Competition Year

Organization	Fall Semester Amount	Spring Semester Amount	School Year Total
E-Council	$900.00	$600.00	$1,500.00
SGA Appropriations	$900.00	$900.00	$1,800.00
NC Space Grant	-	-	$5,000.00
Rockwell Collins			$5,000.00
College of Engineering			$5,500.00
Total Funding:			**$18,800.00**
Total Expenses:			**$18,795.00**
Difference:			**$5.00**

6.4 Plan for Sustainability

In order to sustain our club, we must focus on recruitment and membership retention as well as maintaining our positive relationship with the Eastern North Carolina rocketry community. The club achieves this through:

- University Sponsored Recruitment Events
- Club Enrichment
- North Carolina Rocketry Volunteer Opportunities
- Community Outreach

HPRC recruits new members in both the spring and fall semesters when the university holds several club exposure events. Current members advertise the club by explaining the competition and rocketry in general, focusing on this year's project. In addition to these in person events, the club is also advertised on all of our social media outlets. Using these resources, the club usually brings in over 100 new members per year, but has struggled with member retention in the past. In the 2018-2019 competition year, the club is introducing more enrichment opportunities early in the semester to engage and mentor our underclassmen. This includes lab safety training, weekly lessons during our general body meetings, and an interest launch in early October. These events will provide hands-on training to new members during the report intensive parts of our project.

The club also focuses on our community relations, especially with the local hobby rocketry enthusiasts. Over the summer and into the start of the school year, our club members volunteer at local Tripoli low-powered launches with our mentor, Alan Whitmore. At these launches the club learns from those who have experience building hobby rockets and helps with set-up and tear-down for the events. Helping with these launches allows us a variety of resources for when we need help designing our rockets. In addition to the events within the rocketry community, the club also works with various schools and museums in the area to work with students through outreach events, as described in Section 5.

HPRC is largely self-sufficient since all the machines and materials needed for rocket design and manufacturing are available on-site, whether in the rocketry lab or machine shops. If outside help is needed, the team will communicate with the NAR/TRA mentors (listed in Section 1.1) and other resources to find a solution.

APPENDIX A FMECA Tables

System	Subsystem/ Component	Failure Mode	Causal Factors	Failure Effects: Subsystem	Failure Effects: System	Hazard	Recommendations
Launch Vehicle	Nosecone	Cracks or breaks	Object in flight path	Loss of nosecone recoverability	Loss of controlled and stabilized flight	2	Ensure that skies are clear of any foreign objects per NAR operations
			Damaged during handling or assembly			2	Inspect for cracks, chips, or other damage during assembly
			Nosecone collides with other rocket component during recovery		Damage to itself and other rocket components	2	Ensure shock cord is long enough to separate nosecone from other components
			Ground impact			2	Two different altimeters used for redundancy in mission safety, to prevent electronic errors.
		Premature separation from midsection	Damaged during handling or assembly	Potential for permanent structural damage	Loss of controlled and stabilized flight	2	Inspect for cracks, chips, or other damage during assembly
			Shear pins not installed correctly			2	Follow design specifications for sizing, inspecting, and installing shear pins during assembly
			Epoxy not cured properly			2	Follow proper procedures for mixing, applying, and curing epoxy
	Fiberglass Airframe	Cracks or breaks	Manufacturing defect	Loss of structural integrity or usability of Fiberglass body sections or components	Premature separation of launch vehicle sections during flight	1	Visual inspection after shipping and before assembly

			Loads experienced beyond design specifications			1	Ensure body tube components can hold flight forces in accordance with design specifications Ensure that all components can maintain a factor of safety of at least 1.5 during all regimes of flight
			Damaged during handling or assembly			1	Inspect each body tube component for cracks, bends, warping, or other damage during assembly Replace any damaged components if possible
			Improper storage			2	Do not store items on top of Fiberglass, and reduce exposure of Fiberglass to
	Fins	Severe weather-cocking	Fin dimensions are not cut according to design	N/A	Decreased flight stability, unpredictable flightpath, and possible damage to other components	2	Laser cut fins to ensure manufacturing precision Ensure that excessive material is not removed during sanding.
			Fins not installed at even increments around fin can (90 degrees to each other)			2	Use laser-cut jig with slots for fins exactly 90 degrees from each other

			Assembled rocket CG is too far forward (Stability Margin >> 2.0)			2	Ensure components and masses are installed according to design specifications
		Fin separation	Loads experienced beyond design specifications	N/A	Any one failure of a fin could lead to additional fin failures which will decrease flight stability and will likely cause a catastrophic failure	1	Analyze flight data and simulations to confirm that factor of safety is sufficient
			Damaged during handling or assembly			1	Inspect for cracks, chips, or other damage during assembly Replace any damaged components
			Fin flutter			2	Rocket will not exceed velocity necessary to induce significant flutter
			Ground impact			2	Implement a recover system design that ensures a low-speed surface impact
	Motor	Motor fails to ignite	Igniter not installed correctly	Failure of vehicle to start launch	Team member and RSO must insert new igniter and restart launch sequence	4	Follow launch checklist and use mentor/RSO supervision to install igniter correctly
			Faulty igniter used			4	Test batch of igniters prior to launch day to ensure quality
			Motor assembled incorrectly			4	Follow launch checklist and use mentor/RSO supervision to install motor correctly

		Catastrophic motor failure	Damaged during handling or assembly	Possible destruction of launch vehicle	Complete mission failure and additional hazard to ground crew and spectators	1	Carefully inspect for cracks, chips, or other damage during assembly
			Motor assembled incorrectly			1	Follow launch checklist and use mentor/RSO supervision to install motor correctly
			Motor casing dislodged during motor burn			1	Ensure all connection points between motor tube, centering rings, and fins are joined properly using epoxy Perform careful inspection of joints prior to launch
		Damage to motor casing	Superficial damage	Motor casing cannot be used	Rocket is not safe to launch if damage is major	4	Carefully inspect for cracks, chips, or other damage during assembly
		Propellant contamination	Rocket fails to launch	Reduced performance of rocket motor	Rocket does not launch or perform as expected	2	Store and maintain motor fuel properly and in isolation/ order from reputable source
			Over-oxidized reaction			2	
			Reduced fuel efficiency			3	
	Bulkheads	Bulkhead separation from airframe during motor burn	Manufacturing defect			1	Visual inspection after shipping and before assembly
			Loads experienced beyond design specifications			1	Ensure body tube components can hold flight forces in accordance with design specifications Ensure that all components can maintain a factor of safety of at least 1.5 during all regimes of flight

			Damaged during handling or assembly			1	Inspect each bulkhead for cracks, warping, chips, or other damage during assembly Replace any damaged bulkheads
			Epoxy not cured properly			1	Follow proper procedures for mixing, applying, and curing epoxy
		U-bolt separation from bulkhead during recovery	Loads experienced beyond design specifications	Launch vehicle components not tethered to a parachute will continue accelerating during descent	Loss of safe and effective recovery system	1	Ensure body tube components can hold flight forces in accordance with design specifications Ensure U-bolt fasteners can handle near-instantaneous loading from parachute deployment
			Epoxy not cured properly			1	Follow proper procedures for mixing, applying, and curing epoxy
	Rail Buttons/ Launch Rail	Vehicle does not leave launch rail as intended	Rail button(s) separate from launch vehicle	Vehicle leaves rail at unpredictable orientation and velocity	Possible mission failure and additional hazard to ground crew and spectators	1	Epoxy rail buttons into body tube to mitigate risk of separation
			Damaged during handling or assembly			1	Inspect each pin for cracks, bends, chips, or other damage during assembly Replace any damaged components
			Launch rail breaks			2	Ensure that the rail is assembled correctly prior to launch

		Vehicle does not leave launch rail at all	Rail button(s) becomes stuck in launch rail	N/A	Mission failure as flight does not take place	2	Ensure that rail buttons match size of launch rail slot Lubricate the launch rail and rail buttons prior to launch Ensure that the vehicle moves smoothly on the launch rail during assembly and launch rail erection
	Shear Pins	Pins break before charge detonation	Manufacturing defect	Loose assembly of compartment	Premature rocket separation and recovery system deployment	2	Visual inspection after shipping and before assembly
			Damaged during handling or assembly			2	Inspect each pin for cracks, bends, chips, or other damage during assembly Replace any damaged components
			Pins fall out of respective holes			2	Ensure size of holes drilled in body tube match diameter of shear pins
			Loads beyond design specifications			2	Ensure pins can hold flight forces in accordance with design specifications
		Pins don't break at charge detonation	Manufacturing defect	Failure to separate compartment	Loss of safe and effective recovery system	1	Inspect each pin for cracks, bends, chips, or other damage during assembly Replace any damaged components
			Pins too tight in body tube holes			1	Ensure size of holes drilled in body tube match diameter of shear pins

			Poor design			1	Use calculations to ensure that pins will break from forces of detonation
	Shock Cord	Incorrect or partial deployment of shock cord	Snags, tears, or rips during ejection	Parachute no longer tethered to entirety of launch vehicle airframe	Loss of safe and effective recovery system	1	Inspect shock cord for damage prior to launch Ensure high-strength shock cord is used with a maximum loading greater than 1,500 lb Ensure shock cord is folded and stowed properly in launch vehicle Reduce/eliminate sharp edges in design to mitigate risk of snagging shock cord and parachutes
			Shock cord disconnects from airframe or parachutes			1	Ensure that connections between the shock cord, airframe, and parachutes are tight and secure
			Shock cord stuck within launch vehicle airframe	Parachute not entirely deployed		1	Ensure that the shock cord and parachutes are folded and stowed properly in launch vehicle Reduce/eliminate sharp edges in design to mitigate risk of blocking shock cord and parachutes
	Parachute Deployment	Drogue parachute fails to deploy correctly	Drogue shock cord tangling	Parachute does not deploy correctly	Rocket is recoverable	2	Ensure that shock cords and parachutes are folded correctly

			Shock cord connections come loose			2	Test shock cord connections before flight, make sure secure
			Parachute bag does not fully open			2	Fold bags correctly and make sure nothing can snag bags
		Parachute does not perform as expected	Tears/holes	Parachute deploys but does not perform as expected	Rocket is recoverable	2	Inspect parachute before folding and packing
		Main parachute fails to deploy correctly	Charge is inadequate	Parachute does not deploy correctly	Separation 2 is not successful, rocket is not recovered safely	1	Test charge measurements before flight
			Payload blocks parachute		Separation 2 is not successful, rocket is not recovered safely	1	Make sure payload ejection hardware does not impact parachute release path
			Shock cords tangled		Rocket is recoverable	2	Ensure shock cords and parachutes are folded correctly
			Shock cord connections loose		Rocket is not recovered safely	1	Test shock cord connections before flight, make sure secure
	Black Powder Charges	Single detonation failure	E-match doesn't light	Failure of one or more black powder charges	Will result in loss of safe and effective recovery system if redundant black powder charge(s) do not detonate	2	Conduct ground tests to ensure that enough black powder will be used for proper separation Thoroughly check redundant systems prior to launch Confirm that wires are attached per design specifications

			Altimeter Malfunction			2	Ensure altimeters are functional prior to launch Test altimeters regularly to ensure component integrity
		Redundant detonation failure	E-match doesn't light	Failure of both ejection charges	Rocket fails to separate and deploy parachutes	1	Conduct ground tests to ensure that enough black powder will be used for proper separation Thoroughly check redundant systems prior to launch Confirm that wires are attached per design specifications
			Altimeter Malfunction			1	Ensure altimeters are functional prior to launch Test altimeters regularly to ensure component integrity
		Charge causes damage to any component other than shear pins	Charge is too big	Causes violent separation and/or damage to surrounding area	Potential to cause permanent damage to bulkheads or shock cord, resulting in a possible failure of parachute deployment	2	Verify that charges are sealed properly and the correct amount of black powder is used with pre-flight checklist Conduct ground tests to ensure that enough black powder will be used for proper separation without damage to other components

		Charge ignites but fails to cause separation	Charge is too small	No ejection	Failure of parachute deployment	1	Conduct ground tests to ensure that enough black powder will be used for proper separation
	Altimeters	No power to altimeters	Uncharged or insufficiently charged batteries	Loss of real-time altitude data, failure to ignite e-match	Failure of parachute deployment	1	Install new/unopened batteries at each launch Confirm that all batteries have the correct voltage before flight using a multimeter
			Battery becomes disconnected from altimeter			1	Ensure that altimeters are properly wired and that wires are secure prior to launch Listen for appropriate beeps when powering on altimeters
			Wiring short			1	Ensure that all wire is properly insulated and that all wires are securely contained in their respective terminals
		No launch detected	Manufacturing defect	Lack of flight data	Failure of parachute deployment	1	Test altimeters in vacuum chamber prior to launch Listen for fault codes at launch site
		False apogee detected	Manufacturing defect	Premature/late ejection of drogue parachutes	Increased load on drogue recovery hardware and bulkheads	2	Test altimeters in vacuum chamber prior to launch Listen for fault codes at launch site

			Incorrect altimeter readings			2	Ensure that pressure ports are sized correctly and listen for fault codes at launch site
		Main parachute deploys at wrong altitude	Incorrect pressure readings or improper programming	Main deployment between apogee and 900 ft	Excessive drift, but surface impact will remain below required maximums	2	Verify each altimeter beeps the appropriate program at the launch site Test altimeters in vacuum chamber prior to launch date Ensure pressure ports are sized correctly
				Main deployment lower than 500 ft	Kinetic energy at surface impact will likely exceed 75 ft-lb parachute	1	
	GPS	Ground system failure	Loss of power to ground receiver or the laptop	Inability to receive data from the GPS	Inability to track and recover the rocket in less than an hour	3	Ensure that the receiver and laptop are fully charged at least 6 hours prior to flight
		Loss of signal	Environment or rocket materials blocking signal			3	Perform range tests to ensure reliability of the system at simulated altitudes and ground distances
		Radio interference	Multiple radio devices on the same local frequency and channel			3	Ensure that all transmitting devices are on separate channels and confirm with other teams and launch officials that no frequency conflict exists

		Loss of power	Flight forces cause GPS to disconnect from power supply			3	Ensure that all GPS units are fully charged and use simulated load tests to determine the necessary procedures to secure the units
	Avionics Sled	Detaches from secure position	Loads beyond design specifications	Damage to/loose wiring of avionics components	Loss of recovery system initiation	1	Use simulated load tests and add a sufficient factor of safety when designing sled
			Damage during handling			1	Team members will be taught proper handling and installation procedures for the avionics sled
			Improper maintenance			1	Pre- and post-launch thorough inspections of the avionics sled
Payload	Payload Parachute	Payload parachute fails to deploy correctly	Charge is inadequate	Parachute does not deploy correctly	Payload does not deploy, rocket is not recovered safely	1	Test charge measurements before flight
			Shock cords tangled		Rocket recoverable, Payload failure	3	Ensure shock cords and parachutes are folded correctly
			Shock cord connections loose		Rocket recoverable, Payload failure	3	Test shock cord connections before flight, make sure secure
			Payload caught in recovery system		Rocket recoverable, Payload potentially recovered	4	During construction ensure payload has clean path for ejection
		Parachute does not perform as expected	Tears/holes	Parachute deploys but does not perform as expected	Rocket is recoverable	2	Inspect parachute before folding and packing
	Payload Exterior	Payload deployment pod fracture	Manufacturing defects	UAV system at risk	Electronics and UAV can be damaged	3	Visual inspection prior to use

	Door fails to open	Servo fails	UAV deployment	UAV will not complete its task	3	Test servo connection prior to use
		Blocked by dirt after landing	Prevents UAV deployment		3	Shape the end of the payload to ensure it falls
	Cap detaches	Screws not properly set	Prevent inner tube from rolling freely	Possible structural damage to the payload	3	Perform visual inspection prior to use
		Manufacturing defect	Damage structure at landing		3	
Payload Bulkhead	Separation of bulkhead from the payload	Poor design	Unable to transfer loads	Increased loads on other structural members	2	FEA of bulkhead fixed support
		Manufacturing defect			2	QC of manufacturing process
		Loads greater than designed			2	Maintain vehicle within planned design
		Damaged during handling			2	Ensure analysis includes handling loads/adhere to proper handling procedure
		Improper attachment			2	Pre/post launch inspection
	Damage/ separation from parachute deployment	Poor design	Unable to support loads of chute deployment	Loss of safe and effective recovery system	2	FEA of bulkhead stress
		Manufacturing defect				QC of manufacturing process
Payload Bay	Separation of weight from platform	Improper attachment	Rocket weight imbalance during flight	Rocket flight disrupted	3	Test the attachment of the weight
			UAV fails to rest at bottom of tube	Prevents proper UAV deployment	3	
	Electronics Fails	Circuitry is disrupted/damaged	Payload hardware experiences catastrophic failure	UAV fails to deploy	3	Electronics tested thoroughly
Parachute Deployment	Fails to deploy	Jolly Logic fails	Payload landing	Payload decent velocity is not decreased	1	Test the Jolly Logic prior to use
		Does not open			1	

			Shock cord connections come loose			1	Carefully packing of parachute recovery system
		Premature detonation	Improper wiring/attachment	Jolly Logic releases prematurely	Payload drifts farther than planned	3	Complete testing of electronic devices
			RF Interference			3	
	UAV Containment Pod Deployment System	Failure to enter motion in the payload tube	Motor failure	Prevention of UAV Containment Pod exit from the payload tube	Mission Failure (failure of UAV to deploy)	4	Motor will be tested before installation for current, voltage, and output parameters. The motor will undergo an integrated test with the screw-drive deployment system. Finally, the motor will be simulated for compressive stress undergone during initial takeoff and separation stages.
			Failure of electronically activated latch release			4	Electronically activated latches will be tested prior to installation for mechanical and electrical operational success. Electronically activated latches will then undergo integration testing to prove that they release the UAV Containment Pod under vertical and horizontal orientations.
		Failure to exit payload tube	Motor failure			4	Motor will be tested before installation for current, voltage, and output parameters. The motor will undergo an integrated test with the screw-drive deployment system. Finally, the motor will be simulated for compressive stress undergone during

							initial takeoff and separation stages.
			Buckling of threaded rod			4	Threaded rod will be tested for an ultimate stress, with a factor of safety of 1.5 from the reported maximum compressive stress provided in the material documentation of the part. Additionally, the threaded rod will be secured by a journal bearing on the open deployment direction to reduce compressive loading conditions.
			Centering Ring misalignment			4	Follow proper procedures for mixing, applying, and curing epoxy for the adhesive of the Centering Rings.
			Shock cord entanglement			4	Shock cord will be routed inline through channels positioned at the outer edges of the bulkheads to prevent an excess of shock cord disturbing the exit cavity. Additionally, the convex design of the UAV Containment Pod's front end shifts any obstruction in the exit cavity out of its path.
	UAV Containment Pod	Failure to open UAV Containment Pod in a favorable position for vertical takeoff	Elastic surgical tubing detachment	Prevention of UAV deployment	Mission Failure (failure of UAV to deploy safely)	4	The UAV Containment Pod is designed and will be tested to deploy in multiple orientations. The egg-shaped cross section design and the off-center center of gravity location prevents the UAV Containment Pod from deploying in an "unfavorable orientation".

UAV Arm System	Failure to extend to fully deployed position	Avionics package-to-motor wiring failure	Hindrance of UAV performance	Mission Failure (failure to deliver beacon)	4	Avionics package-to-motor wiring will be given some slack to account for tensile stress experienced due to UAV Arm extension.
		Motor failure			4	Motor will be tested before installation for current, voltage, and output parameters. The motor will undergo an integrated test with the screw-drive deployment system. Finally, the motor will be simulated for compressive stress undergone during initial takeoff and separation stages.
		Improper installation of ball-and-socket latches			4	Ball-and-socket latches will be tested prior to launch under numerous angular acceleration conditions.
	Failure to secure into fully deployed position	Improper installation of ball-and-socket latches	Hindrance of UAV Performance		4	Ball-and-socket latches will be tested prior to launch under numerous angular acceleration conditions, and rigidity of UAV Arm position.
UAV Body Structure	Structural integrity failure	Damage during rocket flight	Hindrance of UAV performance	Mission Failure (failure to deploy UAV)	4	Run structural analysis
		Manufacturing defect	Hindrance of UAV performance		4	Follow proper additive manufacturing technique

	UAV Electronics System	Wiring disconnection	Damage during flight	UAV cannot complete mission	N/A	4	Test the structural integrity of the parts and run structural analysis
			Manufacturing defect	UAV cannot complete mission		4	Follow proper additive manufacturing technique
			Damage during UAV operation	UAV cannot complete mission		4	Run tests to determine UAV capabilities
		Jammed	Foreign objects get stuck in the gears/motor	UAV performance hindered		4	Run tests in similar conditions to landing site
		Do not operate	Dead battery	UAV cannot complete mission		4	Ensure proper battery charging and handling techniques are followed
			Signal is not sent properly	Rover cannot complete mission		4	Extensively test transceiver in all conditions
			Programming bug	Rover cannot complete mission		4	Run tests on electronics system to ensure high performance
	UAV Battery	Low Charge	Improper charging techniques	UAV performance hindered	N/A	4	Adhere to proper charging technique
			Improper storage	UAV performance hindered		4	Adhere to proper storage technique
		Fire	Not following proper safety protocol	UAV cannot complete mission	Damage to payload	3	Maintain a high level of safety