NC STATE UNIVERSITY

Tacho Lycos

2023 NASA Student Launch

Proposal

High-Powered Rocketry Club at NC State University
911 Oval Drive
Raleigh, NC 27606

September 16, 2022

Common Abbreviations and Nomenclature

AGL	=	Above Ground Level
APCP	=	Ammonium Perchlorate Composite Propellant
AV	=	Avionics
BP	=	Black Powder
CDR	=	Critical Design Review
CG	=	Center of Gravity
CP	=	Center of Pressure
ECD	=	Electronics, Communication, & Data
EIT	=	Electronics and Information Technology
FAA	=	Federal Aviation Administration
FMEA	=	Failure Modes and Effects 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
MSDS	=	Material Safety Data Sheets
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

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1 General Information

1.1 Team Advisors and Mentors

i. Name: Dr. Felix Ewere

ii. Email: feewere@ncsu.edu

iii. Phone: (919) 515-8381

iv. Biography: Dr. Ewere is a teaching professor in the Mechanical and Aerospace Engineering department at North Carolina State University. He is currently teaching Aerospace Senior Design and is the academic advisor for undergraduates pursuing an Aerospace Engineering degree. Dr. Ewere holds a PhD in Mechanical Engineering and a Master's in Aerospace Engineering, both from the University of Alabama in Huntsville. Dr. Ewere's research interests include the scientific and technological combination of aerodynamics, structural mechanics, energy, and smart materials. His recent works have focused on using aeroelastic instabilities on piezoelectric structures for engineering applications. Recently, he received a patent for an airflow sensor which mimics protuberances on a humpback whale flipper. Dr. Ewere is a senior member of AIAA and an ASME member.

i. Name: Alan Whitmore

ii. Email: acwhit@nc.rr.com

iii. Phone: (919) 929-5552

iv. TRA Certification: 05945

v. Biography: Alan Whitmore first became involved in High-Powered Rocketry in 1997. Since then, he has earned a Level 3 certification for both NAR and TRA. From 2002 to 2021, Whitmore served as the prefect of the Eastern North Carolina branch of TRA. In 2006, he was accepted as a member of the TRA Technical Advisory Panel (TAP) to advise the TRA board of directors on the technical aspects of propellants, constructions material, and recovery techniques. Whitmore is also a current member of the NAR Level 3 Certification Committee (L3CC), allowing him to supervise individual members throughout the process of designing, manufacturing, and flying rockets for Level 3 certification for NAR and TRA. Whitmore was recently selected as the chairman of the Tripoli Motor Testing Committee which is responsible for testing and certifying all commercially manufactured hobby rocket motors made 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 Livingston joined TRA in 1993 and achieved his Level 3 certification in 1997. Since 1998, Livingston has served as a member of the TRA TAP and has supervised more than 20 TRA members in achieving their Level 3 certifications. He has also been involved in Tripoli research since 1997 and manufactures all of the motors he has flown (I through N sizes).

1.2 High-Powered Rocketry Club

The High-Powered Rocketry Club (HPRC), team name "Tacho Lycos," is an interdisciplinary student organization within the Department of Mechanical and Aerospace Engineering at North Carolina State University. The Club, operating since 2009, gives students the opportunity to gain real-world engineering design and construction experience through participation in the annual Student Launch (SL) competition hosted by NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama. Club officers regularly communicate with team mentors who supervise research, design, construction, testing, and the launch of high-powered rockets. While all club members participate in these activities, they are led by a group of Aerospace Engineering seniors who have elected to participate in the SL competition to satisfy the requirement of completing a senior design capstone project before graduation. These seniors receive a final grade corresponding to the final competition score. The club has recently expanded to include experimental projects run by underclassmen such as airbrakes systems, imaging systems, rail extension testing, and experimenting with rocket aerodynamics.

1.3 Safety Officer

i. Name: Megan Rink

ii. Email: mdrink@ncsu.edu

iii. Responsibilities: Megan is responsible for ensuring the safe operation of lab tools and materials, including, but not limited to, drill presses, hand tools, band saws, power tools, flammable items, and hazardous materials. Megan is required to attend all launches and must always be present during the construction of the launch vehicle, payload, and associated components. Additionally, she is responsible for maintaining all lab space and equipment up to and exceeding NASA, MAE, and Environmental Health and Safety standards. This includes, but is not limited to, displaying proper safety information and documentation, maintaining safe operation of a flame and hazardous materials cabinet, and stocking an appropriate first aid kit. In the event that Megan is not present in the lab, an appropriately trained team member will be appointed to perform all of Megan's in-lab responsibilities, including, but not limited to, ensuring proper usage of PPE, educating members on proper equipment operation, and fostering a culture of safety within and outside of the lab.

1.4 Student Team Leader

i. Name: Meredith Patterson

ii. Email: mapatter@ncsu.edu

iii. Phone: (919) 448-8001

iv. Responsibilities: Meredith will act as the NC State University Student Team Lead for the 2022-2023 NASA Student Launch Competition. Meredith serves as the leader of both the Senior Design Team, as identified in section **??**, and the High-Powered Rocketry Club President. In these roles, Meredith is responsible for managing each subsystem, as defined in section 1.7, and ensuring all documentation, vehicle design, and construction is cohesive and in the spirit of the challenge.

1.4.1 Senior Design Team

The senior design team, shown in Figure 1.1 below, consists of the Student Team Lead and seven Aerospace Engineering seniors using the SL competition to fulfill their senior capstone project requirements. These members and their respective roles are described below. Subsystems are defined in Section 1.7.

Figure 1.1: Senior Design Team 2022-2023

i. Name: Mike Pudlo

ii. Subsystem: Structures

iii. Previous years of club involvement: 3

iv. Biography and Responsibilities: Mike is responsible for material selection, component structural testing, and construction of the launch vehicle. He hopes to redesign the fin can to include removable fins so more parts of the rocket are recyclable and alterable. He also has level 2 certification from Tripoli Rocketry Association. When he is not at HPRC, he works as a research assistant for the NCSU Composite Design and Manufacturing Lab.

i. Name: J.W. Mason

ii. Subsystem: Aerodynamics

iii. Previous years of club involvement: 3

iv. Biography and Responsibilities: J.W is responsible for the design and aerodynamics simulation of the launch vehicle. His duties include motor determination, fin and nosecone design, predicted altitude determination through the use of RockSim and ANSYS simulations. He hopes to design a launch vehicle that will reach at least 4500 ft. at this year's competition. J.W. has previously worked as a student associate at Parker Lord working on circular force generators and developing sensors, as well as, an undergraduate researcher designing, and constructing NCSU's Hypersonic Wind Tunnel. He enjoys mountain biking, scuba diving, and snowboarding.

i. Name: Shaan Stephen

ii. Subsystem: Recovery

iii. Previous years of club involvement: 3

iv. Biography and Responsibilities: Shaan is responsible for the safely recovering the launch vehicle and payload. His duties include parachute selection, black powder calculations, and recovery harness design. His goal is to receive full points for the recovery portion of this year's NASA Student Launch competition. He is currently working as a research assistant for the Aerospace Engineering department developing and constructing NCSU's Hypersonic Wind Tunnel.

i. Name: Frances McBride

ii. Subsystem: Payload Systems

iii. Previous years of club involvement: 4

iv. Biography and Responsibilities: Frances's primary responsibility is managing overall payload design, and ensuring the payload electronics are correctly integrated to function smoothly with the payload's mechanical components. Frances hopes to build and manage a payload that relays reliable and good quality data. Previously, she worked as a Pathways intern for NASA Marshall Spaceflight Center, working on counterflowing jets, solar sails, and night-sky imaging for lunar lander positioning. She also researched a fin jitter-induced lift system for canard configuration missile systems. Now, she researches properties of twisted Liquid Crystal Elastomers (LCEs) and their abilities to autonomously navigate solid and fluid mazes.

i. Name: Ben Lewis

ii. Subsystem: Payload ECD

iii. Previous years of club involvement: 3

iv. Biography and Responsibilities: Ben is primarily responsible for the success of the payload RF communication system, payload related software, and camera data collection. He hopes to learn more about hardware and software integration in an aerospace context. Ben has worked as a Satellite Network Operations Engineer Intern at Iridium Communications and as a research assistant at Center for Additive Manufacturing and Logistics (CAMAL) at NCSU. In his spare time, he likes to design modular synths.

i. Name: Ashwin Sivayogan

ii. Subsystem: Payload Structures

iii. Previous years of club involvement: 2

iv. Biography and Responsibilities: Ashwin is primarily responsible for the design and construction of the payload's physical structure, as well as, the camera system mechanics for this years challenge. He hopes to learn more about imaging and the engineering design process, and he hopes to create a payload that completes the challenge successfully. He previously worked as an undergraduate researcher in the Intelligent Systems and Structures Research Lab (iSSRL) at NC State, and is currently assisting in the construction of the Hypersonic Wind Tunnel at NCSU. In his free time, he enjoys camping, hiking, and climbing.

i. Name: Chris Luzzi

ii. Subsystem: Integration

iii. Previous years of club involvement: 3

iv. Biography and Responsibilities: Chris is primarily responsible for integrating new concepts into the rocket. His duties include ensuring components such as the removable fin system and the payload will fit seamlessly into the launch vehicle. Chris's goal for this year's senior design project is to facilitate communication between the vehicle and payload teams and ensure the launch vehicle's space is utilized efficiently. In his spare time, he is an avid rock climber.

1.5 Leadership Team Organization

For the 2022-2023 school year, the leadership team consists of two primary groups: Senior Design and club officers. While they are each responsible for different aspects of the team's operation for the SL competition, both groups are responsible for guiding approximately forty undergraduate students through the SL project. Senior Design members and their duties are listed in Section 1.4.1 Club officers and their duties are listed below.

Figure 1.2: Leadership Team 2022-2023

i. Name: Meredith Patterson

ii. Position: President

iii. Previous years of club involvement: 4

iv: Biography and Responsibilities: Meredith is a Senior in aerospace engineering. As president, she facilitates all club activity, including but not limited to; launches, design and construction meetings, and documentation. She hopes to push the club to be more inclusive, organized, prepared for the future, and successful in competition this year. Meredith interned at NASA Langley in 2020 working on hypersonics, and at NASA Marshall Space Flight Center in summer of 2022 working on SLS acoustics testing. She has also done aerodynamics research with NC State's supersonic wind tunnel as well as rover research with NC State's Engineering Mechanics and Space Systems Lab. She loves to hike and watch Formula 1 with her dog Chewie.

i. Name: Joseph Alonso

ii. Position: Vice President

iii. Previous years of club involvement: 1

iv. Biography and Responsibilities: Joseph is a junior majoring in aerospace engineering. This year, as Vice President, he will be taking charge of Wolf Works Experimental, our club's subteam which constructs launch vehicles and payloads for science, fun, and underclassmen involvement. Joseph hopes to complete a successful interest launch, recruit new interdisciplinary members, and facilitate rocket-related technical workshops. In his free time, he likes to cheer on Premier League soccer club, Liverpool FC.

i. Name: Megan Rink

ii. Position: Safety Officer

iii. Previous years of club involvement: 1

iv. Biography and Responsibilities: Megan is a sophomore majoring in history, concentrating on the Space Race era. In addition to maximizing our safety score from NASA, she hopes to create a fun and safe environment this year and improve the overall safety awareness of the club as a whole. In addition to rocketry, Megan is also the Vice President of the Red Terrors Soccer Support Club. She is a massive audiophile and an avid record collector.

i. Name: Trent Couse

ii. Position: Treasurer

iii. Previous years of club involvement: 3

iv. Biography and Responsibilities: Trent is a junior majoring in aerospace engineering. He works to secure and manage funds for all HPRC projects. Aside from his typical routine as Treasurer, he plans to help contact new sponsors for the club and restructure the management of all club finances. In his free time, he enjoys climbing.

i. Name: Emma McDonald

ii. Position: Secretary

iii. Previous years of club involvement: 2

iv. Biography and Responsibilities: Emma is a senior majoring in mechanical engineering. As club secretary, she is responsible for sending weekly newsletters. This year, she hopes to expand HPRC through networking and by acquiring new sponsorships. She is also an equestrian and has a horse named Clue.

i. Name: Katelyn Yount

ii. Position: Outreach Officer

iii. Previous years of club involvement: 1

iv. Biography and Responsibilities: Katelyn is a sophomore majoring in aerospace engineering. She is responsible for all club outreach events for NC State University and the surrounding community. She hopes to do more outreach events at schools in person this year, in contrast to the last few years of virtual outreach. In person outreach events would allow for hands-on demonstrations such as building and launching bottle rockets and demonstrating the impact of parachutes on descent velocity of an object. In her free time, she enjoys swimming.

i. Name: Hanna McDaniel

ii. Position: Social Media Officer

iii. Previous years of club involvement: 1

iv. Biography and Responsibilities: Hanna is a senior majoring in aerospace engineering. She is responsible for maintaining the club's presence on social media platforms including Instagram, Facebook, Linked-in, and Youtube. Through social media posts, she hopes to keep people up to date on the club's activities, visually document our design and building process this year, and show off just how much fun we have as a team. She enjoys reading and writing in her free time, and dreams of being a published author in the future.

i. Name: Sofia Antinozzi

ii. Position: Webmaster

iii. Previous years of club involvement: 1

iv. Biography and Responsibilities: Sofia is a sophomore majoring in materials science and engineering. She is responsible for the design and maintenance of our team's website. She plans to renovate the HPRC website and join forces with the Social Media Officer and Secretary to promote events and activities. In her spare time, Sofia enjoys nature and reading crime novels.

1.6 Subsystem Definition

To better manage the workload associated with the SL project, the team is divided into several subsystem teams with each team being held responsible for a different aspect of the project. Each team will be responsible for a certain set of requirements, as identified in the "Subsystem Allocation" column of each Requirement Verification matrix. The team has been divided into the following subsystems:

- Project Management
- Safety
- Integration
- Aerodynamics
- Structures
- Recovery
- Payload Systems
- Payload ECD
- Payload Structures

The project management team, led by team lead Meredith Patterson, is responsible for managing the team's schedule and mitigating any conflicts that arise between subsystems. The team lead is also responsible for organizing launches, documentation, and communication with NASA, NAR, and TRA. The safety team, led by safety officer Megan Rink, is responsible for monitoring lab and launch field safety along with maintaining safety documentation. The aerodynamics team, led by senior J.W. Mason, is responsible for flight simulations, motor selection, fin and nosecone selection, apogee determination, and stability management of the launch vehicle. The structures team, led by senior design member Mike Pudlo, is responsible for material selection, structural testing and construction of the launch vehicle. The recovery team, led by Shaan Stephen, is responsible for the entirety of the recovery system, including altimeters, black powder charges, and parachutes. The payload systems team, led by senior Frances McBride, is responsible for management of the payload team and facilitation of the design and construction of the payload. This team also maintains the successful interaction between structural and electrical components of the payload system. The payload ECD team, led by Ben Lewis, is responsible for the RF communication system, image processing, collection of image data, and all payload related software. The payload structures team, led by senior design member Ashwin Sivayogan, is responsible for design and construction of all payload electronics housings, payload mechanics relating to the camera system, and camera system movement. Lastly, The integration team, led by Chris Luzzi, is responsible for the integration of all new designs into the launch vehicle. This team will ensure payload retention, and integration of both the payload system and the removable fin system.

1.7 Local NAR/TRA Chapter Information

The NC State University Student Launch team will be working with the Tripoli East NC prefecture (TRA Prefecture 65). The prefect for this chapter is currently Joseph Hill. His qualifications include TRA Level 3 certification under TRA number 12485. Club mentor, Alan Whitmore, whose qualifications are listed in Section 1.2, is responsible for the purchase and storage of all motors for vehicle launches during the competition. These motors are purchased only under his approval and are stored according to his specific safety requirements. At launches, all motors are assembled and installed under Alan's supervision. Jim Livingston, whose qualifications are listed in Section 1.2, is also Level 3 certified with TRA, and is capable of supervising the storage, assembly, and installation of motors. Alan and Jim will also serve as mentors and review designs and documents for the NC State University team.

1.8 Time Spent on Proposal

Including time spent on brainstorming, attending meetings, and writing this document, the team spent approximately 75 hours on the proposal.

2 Facilities and Equipment

2.1 Description

The team uses the MAE Student Fabrication Lab (referred to as the "Rocketry Lab") in Room 2003, Engineering Building III. This workspace is equipped with a small drill press, belt sander, band saw, scroll saw, and handheld power tools. Club members who have completed specialized training also have access to the Entrepreneurship Initiative Garage, located in the Partners I building on NC State's Centennial Campus. The Garage is equipped with a laser cutter and assorted handheld power tools.

HPRC also has access to a high-precision machine shop in Engineering Building III. The machine shop supervisor, J. Steve Cameron, is able to take machining requests and deliver the product within approximately one week. HPRC also has access, accompanied by lab supervisor, to the Aerospace Vehicle Structures Lab in Engineering Building III Room 2208, which allows for structural testing to be performed using a tensile and compressive loading machine. HPRC senior design members also have access to the NC State MAE Senior Design Machining Lab, which houses a Makerbot 3D printer, with completed training facilitated by the lab manager, Amos Tucker.

2.2 Hours of Accessibility

The Rocketry Lab in 2003 Engineering Building III is open for club leadership and senior design team access:

Monday – Sunday: 6 am – 12 am

The Entrepreneurship Initiative Garage is open for all trained undergraduates:

Monday - Wednesday: 8:30 am – 4:30 pm

Thursday – Friday: 11 am – 7 pm

All other facilities listed in Section 2.1 require specific approval and a scheduled appointment for use.

2.3 Necessary Personnel

The club safety officer, identified in Section 1.5, must be present for all construction or testing conducted in the Rocketry Lab. Dr. Jaideep Pandit, MAE Lab Director and Supervisor, must be present for any use of the Aerospace Vehicle Structures Lab. J Steve Cameron, Research Fabrication Facility Supervisor, must be present for any use of the precision machine shop.

2.4 Available Equipment

The team has access to a wide variety of tools, equipment, and supplies for use throughout the design and construction process. The team has access to a drill press with 12 in. of travel, scroll saw, band saw, belt sander, and soldering iron. Each of these are low power tabletop tools with lockout keys to prevent unauthorized use. The team also has access to a DeWalt 18V drill, DeWalt jigsaw, Dremel 4300 rotary tool, Rigid oscillating cutting tool, and Wagner heat gun. These tools are all handheld and stored in a locked cabinet to regulate usage. The Rocketry Lab is equipped with compressed air lines which are used for the vacuum bagging of composite layups. The team has access to an assortment of hand tools, including files, screwdrivers, wrenches, cutting implements, and clamps.

As discussed in Section 2.1, the team has access to additional equipment such as laser cutters, 3D printers, tensile testing machines, and high-precision machining equipment in other spaces on NC State's campus.

2.5 Supplies Required

A preliminary list of materials required to design and build the launch vehicle and payload is available in Section 6.2 In addition to these materials, the team already owns various components, such as parachutes of various sizes, a few RRC3 and Stratologger altimeters, aircraft-grade birch plywood, black powder, a Raspberry Pi, and an Arduino Uno. Additionally, the team requires safety equipment in the form of safety glasses, nitrile gloves, and dust masks. This PPE is purchased in bulk and made available to all club members when working in the lab.

The team also requires several software packages throughout the competition.The team has access to the Microsoft Office suite of applications, along with SolidWorks, ANSYS, and MATLAB through university licenses. The team has purchased a license for RockSim, which is used for launch vehicle flight simulations. Finally, the team has an educational license for Asana, a Kanban board and task management application.

3 Safety

3.1 Safety Requirements

The following table (3.1) contains the safety requirements outlined by the 2023 NASA Student Launch Handbook

Table 3.1: 2022-2023 Safety Requirements

NASA Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation
4.3.2.	Teams SHALL abide by all FAA and NAR rules and regulations	The safety team ensures all rules from FAA and NAR are followed	Validation of Records	All Subteams
5.1.	Each team SHALL use a launch and safety checklist. The final checklists will be included in the FRR report and used during the LRR and any Launch Day operations.	Checklists are included in the FRR and are used during LRR and Launch Day activities	Validation of Records	All Subteams
5.2.	Each team SHALL identify a student safety officer who will be responsible for all items in section 5.3.	The student safety officer, is identified in documentation	Validation of Record	Safety
5.3.1.1.	The safety officer SHALL monitor team activities with an emphasis on safety during design of vehicle and payload	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques	Demonstration	Safety
5.3.1.2.	The safety officer SHALL monitor team activities with an emphasis on safety during construction of vehicle and payload components	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques	Demonstration	Safety
5.3.1.3.	The safety officer SHALL monitor team activities with an emphasis on safety during assembly of vehicle and payload	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques	Demonstration	Safety
5.3.1.4.	The safety officer SHALL monitor team activities with an emphasis on safety during ground testing of vehicle and payload	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques	Demonstration	Safety
5.3.1.5.	The safety officer SHALL monitor team activities with an emphasis on safety during subscale launch test(s)	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques	Demonstration	Safety
5.3.1.6.	The safety officer SHALL monitor team activities with an emphasis on safety during full-scale launch test(s)	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques	Demonstration	Safety
5.3.1.7.	The safety officer SHALL monitor team activities with an emphasis on safety during competition launch	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques	Demonstration	Safety
5.3.1.8.	The safety officer SHALL monitor team activities with an emphasis on safety during recovery activities	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques	Demonstration	Safety
5.3.1.9.	The safety officer SHALL monitor team activities with an emphasis on safety during STEM engagement activities	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques	Demonstration	Safety

5.3.2.	The safety officer SHALL implement procedures developed by the team for construction, assembly, launch, and recovery activities	The safety team writes and implements procedures and checklists for assembling, launching, and recovering the launch vehicle	Demonstration	Safety
5.3.3.	The safety officer SHALL manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data	The student safety officer manages all safety documentation for the team	Inspection	Safety
5.4.	During test flights, teams SHALL abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	The safety team ensures all rules and regulations from the local rocketry club are followed by all team members	Demonstration	Safety
5.5.	Teams SHALL abide by all rules set forth by the FAA	The safety team ensures all rules from FAA are followed	Demonstration	All Subteams

3.2 Safety Plan/Agreement

3.2.1 Students Responsible

Megan Rink is serving as the 2022-2023 Safety Officer for HPRC. Megan is responsible for overseeing the safety of both lab and launch activities, generating accurate and comprehensive documentation, and ensuring safety plan completion. In her absence, members trained in accident avoidance, emergency management, and lab procedures can assist in maintaining lab safety practices and procedures.

3.2.2 Facilities/Hazardous Materials Involved + Risk Assessment

The High-Powered Rocketry Club's lab is in room 2003 of Engineering Building III on North Carolina State University's Centennial campus. Fabrication of launch vehicles and payload components takes place in this lab with the use of in-lab tools and materials. Below, tables of hazardous tools, equipment (3.3), and materials (3.2) are provided along with associated preliminary risks assessment and proposed mitigations.

Table 3.2: Hazardous Materials and Mitigation

Hazardous Material	Manufacturer	Hazard Type	Storage
Black Powder	Hodgden	Flammable, Explosive	Store in a cool, dry place. Handle with care. Keep out of reach of children.
105 Epoxy Resin	West System	Skin, lung, and eye irritant; Carcinogen; Toxic if ingensted	Store in a cool, dry place. Keep well-ventilated.
205 Epoxy Hardener	West System	Eye, skin irritant; Harmful if swallowed.	Store at room temperature. Keep containers closed to prevent contamination.
206 Epoxy Hardener	West System	Skin, lung, and eye irritant; Carcinogen; Toxic if ingested.	Store in a cool, dry place. Keep well-ventilated
406 Colloidal Silica	West System	Skin, lung, and eye irritant; Carcinogen; Toxic if ingested.	Store in a cool, dry place. Keep away from flames, fire starters, and heat.

Table 3.3: Hazardous Tools, Equipment and Mitigation

Tool	Location	Required PPE
Belt Sander	Tool Island	Eyeglasses, particle mask
Drill Press	Tool Island	Eyeglasses, particle mask
Band Saw	Tool Island	Eyeglasses, particle mask
3D Printer	Electronics Bench	n/a
Dremel	Tool Cabinet	Eyeglasses, particle mask
Soldering Iron	Electronics Bench	Eyeglasses

3.2.3 Team Member Safety Agreement

i. Range safety inspections will be conducted on each rocket before it is flown. Each team shall comply with the determination of the safety inspection or may be removed from the program.

ii. The Range Safety Officer has the final say on all rocket safety issues. Therefore, the Range Safety Officer has the right to deny the launch of any rocket for safety reasons.

iii. The team mentor is ultimately responsible for the safe flight and recovery of the team's rocket. Therefore, a team will not fly a rocket until the mentor has reviewed the design, examined the build and is satisfied the rocket meets established amateur rocketry design and safety guidelines.

iv. Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

By signing and dating below, I agree that I have read, understand, and agree to follow the safety guidelines as outlined above.

Senior Design Team		
Meredith Patterson	[illegible]	9/15/22
Nike Pudlo	[illegible]	9/15/22
J.W. Mason	[illegible]	9/15/2022
Shaan Stephen	[illegible]	9/15/2022
Frances McBride	[illegible]	9/15/22
Ben Lewis	[illegible]	9/15/22
Ashwin Sivayogan	[illegible]	9/15/22
Chris Luzzi	Christopher Luzzi	9/15/22
HPRC Officer Team		
Megan Rink	Megan Rink	9/15/22
Joseph Alonso	[illegible]	9/15/22
Trent Couse	Trent Couse	9/15/22

2022 NASA SLI Safety Acknowledgement

Emma McDonald		09/15/22
Katelyn Yount		9-15-22
Hanna McDaniel		9/15/22
Sofia Antinozzi		9/15/22

3.3 NAR/TRA Personnel Procurement and Performance Plan

3.3.1 NAR High Power Rocket Safety Code

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.
2. **Materials.** I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.
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 ft. of these 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.
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.
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.
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.
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.
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.
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 ft., whichever is greater, or 1000 ft. 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 ft.).
11. **Launcher Location.** My launcher will be 1500 ft. 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.**

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.
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.

3.4 Briefing Plan for Accident Avoidance

Prior to admittance to the HPRC lab, any new members receive a briefing that addresses hazards in the lab as well as general safety procedures. All members must be trained in the proper operation of lab machinery before use. Members must also know the location of first aid kits, personal protective equipment, fire extinguishers, and other safety materials.

Before any and all launches, the student safety officer will provide a briefing that is mandatory for all students attending the launch at the General Body Meeting closest to the planned launch date. Members who do not attend the safety briefing either in-person or on Zoom become ineligible to attend that launch. All briefings will include personnel checklist assignments and procedures, best safety practices, and an overview of any hazards that may be present at a specific launch. Weather forecasts and pollen counts may also be included in order for personnel to dress and prepare properly for the occasion.

3.5 Including Safety In Documentation

Throughout the year, the safety team will perform thorough analyses, primarily using risk assessment tables.

3.5.1 FMEA

Below is an example of the FMEA tables the safety team will complete throughout the competition. The tables will be accompanied with likelihood-severity (LS) matrices to provide a more visual and easily-accessible aid.

Table 3.4: FMEA Matrix

		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likelihood of Occurrence	A Very Unlikely	1A	2A	3A	4A
	B Unlikely	1B	2B	3B	4B
	C Likely	1C	2C	3C	4C
	D Very Likely	1D	2D	3D	4D

3.6 Lab Safety Handbook

3.6.1 Federal, State, and Local Law Compliance Plan

The High-Powered Rocketry Club and its mentors are committed to upholding all laws regarding safe use of airspace in order to reduce the risk of injury, death, or destruction of property that can be present while launching high-powered rockets. NAR/TRA personnel present and assisting at competition launches will ensure clear airspace and safe launching conditions on launch days.

Table 3.5: FMEA Table

Label	Hazard	Cause	Effect	LS Before (denoted on matrix)	Mitigation	LS After
Ex.A.1	Slips, trips, and falls	Material spills around the lab	Skin abrasion, bruising	3B	After handling liquid/powder materials, lab floors will be inspected for spills	2A
		Wet/uneven launch field conditions			Only required and listed personnel are allowed on launch field for recovery; closed toe shoes required,	
Ex.A.2	Bug sting/bite	Prolonged exposure to wildlife during launch	Itchiness, rash, and/or anaphylaxis	4A	Bug spray is provided to team members at the launch site	1A

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

The subparts of the Federal Aviation Regulations concerning general operating limitations a the launch of high-powered rockets details where and when high-powered rocket launches can take place, and how they should be operated. The team will comply with all general FAA operating regulations and will not fly a high-powered 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:

  i. Not less than one-quarter the maximum expected altitude;

  ii. 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.

3.6.3 NFPA 1127 Code for High Power Rocketry

The NFPA 1127 Code for High Power Rocketry establishes guidelines for the safe operation of high-powered rockets. These codes are put in place to protect users as well as the general public, and to minimize injury and deaths related to high-powered rocketry. Topics such as certification, pre-flight inspection, motor installation and components, payloads, and others are covered in this document. The team will comply with the guidelines listed in this document during all launch activities.

4 Technical Design

4.1 General Requirements

The following table (4.1) contains the general requirements outlined by the 2023 NASA Student Launch Handbook

Table 4.1: 2022-2023 General Requirements

NASA Req No	SHALL Statement	Success Criteria	Verification Method	Subsystem Allocation
1.1	Students on the team SHALL do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Teams SHALL submit new work. Excessive use of past work SHALL merit penalties.	The students of the High Powered Rocketry Club at NC State design and construct a solution to the requirements as listed in the Student Launch Handbook using past ideas and methods while also integrating new ideas.	Inspection	Project Management
1.2	The team SHALL provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	The project management team, consisting of the team lead, vice president, treasurer, secretary, safety officer, webmaster, and social media lead manage the project planning tasks pertaining to this requirement.	Inspection	Project Management
1.3	The team SHALL identify all team members who plan to attend Launch Week activities by the Critical Design Review (CDR).	The team lead identifies and reports the team members that will attend the launch week by January 9, 2023, in the CDR milestone documentation.	Inspection	Project Management
1.3.1	Team members attending competition SHALL include students actively engaged in the project throughout the entire year.	The project management team identifies the students that have been actively engaged throughout the year to be invited to launch week activities.	Inspection	Project Management
1.3.2	Team members SHALL include one mentor (see requirement 1.13).	The team lead invites the mentor listed in section 1.1 to attend launch week activities.	Inspection	Project Management
1.3.3	Team members SHALL include no more than two adult educators.	The team lead invites the adult educator listed section 1.1 to attend launch week activities.	Inspection	Project Management
1.4	Teams SHALL engage a minimum of 250 participants in Educational Direct Engagement STEM activities in order to be eligible for STEM Engagement scoring and awards. These activities can be conducted in person or virtually. To satisfy this requirement, all events SHALL occur between project acceptance and the FRR due date. A template of the STEM Engagement Activity Report can be found on pages 39–42.	The outreach lead implements STEM engagement plans with K12 student groups throughout the project life cycle and submits all STEM Engagement Activity Reports within two weeks of the event's conclusion.	Inspection	Project Management
1.5	The team SHALL establish and maintain a social media presence to inform the public about team activities.	The webmaster and social media officer cooperate to maintain our website and social media platforms to inform the public about all activities and events that the team performs throughout the year. Our social media platforms include, but are not limited to: our club website, Facebook, Instagram, and Twitter.	Inspection	Project Management

1.6	Teams SHALL email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file SHALL be sufficient. Late submissions of PDR, CDR, FRR milestone documents SHALL be accepted up to 72 hours after the submission deadline. Late submissions SHALL incur an overall penalty. No PDR, CDR, FRR milestone documents SHALL be accepted beyond the 72-hour window. Teamsthat fail to submit the PDR, CDR, FRR milestone documents SHALL be eliminated from the project.	The team lead sends all deliverables to the NASA project management team prior to each specified deadline. In the event that the deliverable is too large, the webmaster posts the document on the team's website, and the team lead sends the NASA project management team a link to the file.	Inspection	Project Management
1.7	Teams who do not satisfactorily complete each milestone review (PDR, CDR, FRR) SHALL be provided action items needed to be completed following their review and SHALL be required to address action items in a delta review session. After the delta session the NASA management panel SHALL meet to determine the teams' status in the program and the team SHALL be notified shortly thereafter.	Team members complete and submit each milestone review document before the provided deadline. In the event that a document is not satisfactorily completed, the team completes the action items provided and attends the delta review session to maintain their status in the program.	Inspection	Project Management
1.8	All deliverables SHALL be in PDF format.	The team lead converts all deliverables to PDF format prior to submission to the NASA project management team.	Inspection	Project Management
1.9	In every report, teams SHALL provide a table of contents including major sections and their respective sub-sections.	The team lead creates and manages a Table of Contents in each milestone report.	Inspection	Project Management
1.10	In every report, the team SHALL include the page number at the bottom of the page.	For each milestone report, the team uses a document template which includes page numbers at the bottom of each page.	Inspection	Project Management
1.11	The team SHALL provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.	Each team member participating in the video teleconference obtains the necessary equipment for them to perform a video teleconference with the review panel.	Inspection	Project Management
1.12	All teams attending Launch Week SHALL be required to use the launch pads provided by Student Launch's launch services provider. No custom pads SHALL be permitted at the NASA Launch Complex. At launch, 8-foot 1010 rails and 12-foot 1515 rails SHALL be provided. The launch rails SHALL be canted 5 to 10 degrees away from the crowd on Launch Day. The exact cant SHALL depend on Launch Day wind conditions.	The aerodynamics lead designs a launch vehicle to be launched from either an 8-foot 1010 rail or a 12- foot 1515 rail.The structures lead fabricates the launch vehicle according to this design.	Inspection	Aerodynamics; Structures

1.13	Each team SHALL identify a "mentor." A mentor is defined as an adult who is included as a team member, who SHALL be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor SHALL maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to Launch Week. One travel stipend SHALL be provided per mentor regardless of the number of teams he or she supports. The stipend SHALL only be provided if the team passes FRR and the team and mentor attend Launch Week in April.	The team lead identifies qualified community members to mentor team members throughout the design process.	Inspection	Project Management
1.14	Teams SHALL track and report the number of hours spent working on each milestone.	The team reports the number of hours spent on each milestone in the associated milestone report.	Inspection	Project Management

4.1.1 Launch Vehicle Requirements

The following table (4.2) contains the requirements for the launch vehicle as outline in the 2023 NASA Student Launch Handbook

Table 4.2: 2022-2023 Launch Vehicle Requirements

NASA Req No	SHALL Statement	Success Criteria	Verification Method	Subsystem Allocation
2.1	The vehicle SHALL deliver the payload to an apogee altitude between 4,000 and 6,000 ft. above ground level (AGL). Teams flying below 3,500 ft. or above 6,500 ft. on their competition launch SHALL receive zero altitude points towards their overall project score and SHALL not be eligible for the Altitude Award.	The aerodynamics lead designs a launch vehicle to reach an apogee between 4,000 and 6,000 ft. AGL. The team then constructs the vehicle as designed	Analysis; Demonstration	Aerodynamics
2.2	Teams SHALL declare their target altitude goal at the PDR milestone. The declared target altitude SHALL be used to determine the team's altitude score.	The aerodynamics lead reports the team's target altitude goal in the PDR milestone report, submitted by October 26, 2022.	Inspection	Aerodynamics
2.3	The launch vehicle SHALL be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	The recovery and structures leads design a recovery harness system that allows the launch vehicle to be recovered upon ground impact with minimal damage.	Demonstration	Recovery; Structures
2.4	The launch vehicle SHALL have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	The aerodynamics and recovery leads design the vehicle to have a maximum of 4 independent sections.	Inspection	Aerodynamics; Recovery
2.4.1	Coupler/airframe shoulders which are located at in-flight separation points SHALL be at least 2 airframe diameters in length. (One body diameter of surface contact with each airframe section).	The aerodynamics lead designs a airframe with couplers at in-flight separation points at least two airframe diameter in length. The structures lead constructs the couplers to the determined lengths.	Inspection	Aerodynamics
2.4.2	Nosecone shoulders which are located at in-flight separation points SHALL be at least ½ body diameter in length.	The aerodynamics lead designs the airframe such that nosecone shoulders at in-flight separation points are at least 1/2 body diameter in length.	Inspection	Aerodynamics
2.5	The launch vehicle SHALL be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	The project management and safety teams develop launch day checklists that can be executed in under two (2) hours.	Demonstration	Project Management; Safety
2.6	The launch vehicle and payload SHALL 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 , although the capability to withstand longer delays is highly encouraged.	The project management and safety teams monitor the power consumption of each electrical launch vehicle and payload component and verify functionality of each component after two (2) hours.	Demonstration	Project Management; Safety
2.7	The launch vehicle SHALL be capable of being launched by a standard 12-volt direct current firing system. The firing system SHALL be provided by the NASA-designated launch services provider.	The project management and safety teams choose a motor ignitor that can be ignited from a 12-volt direct current firing system.	Demonstration	Project Management; Safety
2.8	The launch vehicle SHALL require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).	The project management and safety teams ensure the launch vehicle is designed such that no external circuitry or ground support equipment is required for launch.	Demonstration	Project Management; Safety
2.9	Each team SHALL use commercially available ematches or igniters. Hand-dipped igniters SHALL not be permitted.	The project management and safety teams ensure proper purchase and use of commercially available ematches and igniters.	Inspection	Project Management; Safety

2.10	The launch vehicle SHALL 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).	The aerodynamics lead selects a commercially available solid motor propulsion system using APCP that is approved by NAR, TRA, and/or CAR for use in the launch vehicle.	Inspection	Aerodynamics
2.10.1	Final motor choices SHALL be declared by the Critical Design Review (CDR) milestone.	The aerodynamics lead declares the team's final motor choice in the CDR milestone report by January 9, 2023.	Inspection	Aerodynamics
2.10.2	Any motor change after CDR SHALL be approved by the NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment SHALL not be approved. A penalty against the team's overall score SHALL be incurred when a motor change is made after the CDR milestone, regardless of the reason.	The project management team requests approval from the NASA RSO for motor changes following submission of the CDR milestone report.	Inspection	Project Management
2.11	The launch vehicle SHALL be limited to a single motor propulsion system.	The aerodynamics lead designs the launch vehicle such that it only utilizes a single stage.	Inspection	Aerodynamics
2.12	The total impulse provided by a College or University launch vehicle SHALL not exceed 5,120 Newton-seconds (L-class).	The aerodynamics lead chooses a motor that does not exceed 5,120 Newtonseconds of total impulse.	Inspection	Aerodynamics
2.13	Pressure vessels on the vehicle SHALL be approved by the RSO.	The structures lead provides the necessary information on any on-board pressure vessels to the NASA RSO and home field RSO.	Inspection	Structures
2.13.1	The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) SHALL be 4:1 with supporting design documentation included in all milestone reviews.	The structures lead includes design documentation supporting a factor of safety of 4:1 for any pressure vessel on the launch vehicle in each milestone report.	Analysis; Inspection	Structures
2.13.2	Each pressure vessel SHALL 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.	The structures lead selects certain onboard pressure vessels such that they include a pressure relief valve that sees the full pressure of the tank and is more then capable of withstanding the maximum pressure and flow rate of the tank.	Analysis; Inspection	Structures
2.13.3	The full pedigree of the tank SHALL be described, including the application for which the tank was designed and the history of the tank. This SHALL include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.	The structures lead records the full history of each pressure vessel, including the number of pressure cycles, the dates of pressurization/ depressurization, and the name of each person or entity administering the pressure events.	Inspection	Structures
2.14	The launch vehicle SHALL have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	The aerodynamics lead designs the launch vehicle such that it has a minimum static stability margin of 2.0 at the point of rail exit.	Analysis	Aerodynamics
2.15	The launch vehicle SHALL have a minimum thrust to weight ratio of 5.0 : 1.0.	The aerodynamics lead designs the launch vehicle such that it has a thrust to weight ratio of at least 5.0:1.0.	Analysis; Inspection	Aerodynamics

2.16	Any structural protuberance on the rocket SHALL be located aft of the burnout center of gravity. Camera housings SHALL be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.	The aerodynamics lead designs the launch vehicle such that all structural protuberances are located aft of the burnout center of gravity. If any camera housings are included, the aerodynamics lead shows that the housings cause minimal aerodynamic effects on launch vehicle stability.	Analysis; Inspection	Aerodynamics
2.17	The launch vehicle SHALL accelerate to a minimum velocity of 52 fps at rail exit.	The aerodynamics lead designs the launch vehicle such that a velocity of 52 fps or greater is achieved by the launch vehicle at the rail exit.	Analysis	Aerodynamics
2.18	All teams SHALL successfully launch and recover a subscale model of their rocket prior to CDR. Success of the subscale is at the sole discretion of the NASA review panel. The subscale flight may be conducted at any time between proposal award and the CDR submission deadline. Subscale flight data SHALL be reported in the CDR report and presentation at the CDR milestone. Subscales are required to use a minimum motor impulse class of E (Mid Power motor).	The management team launches a subscale model of the launch vehicle using an impulse motor of E or greater. The management and safety teams successfully recover the subscale model of the launch vehicle. The team reports subscale flight data in the CDR milestone report by January 9, 2023.	Demonstration	Project Management
2.18.1	The subscale model should resemble and perform as similarly as possible to the full-scale model; however, the full-scale SHALL not be used as the subscale model.	The aerodynamics lead designs a unique subscale launch vehicle which performs similarly to the full-scale launch vehicle.	Inspection	Aerodynamics
2.18.2	The subscale model SHALL carry an altimeter capable of recording the model's apogee altitude.	The recovery lead installs an altimeter in the subscale launch vehicle capable of recording the vehicle's apogee altitude.	Inspection	Recovery
2.18.3	The subscale rocket SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The team constructs a new subscale launch vehicle, designed to meet the specifications for this year's project.	Inspection	Project Management
2.18.4	Proof of a successful flight SHALL be supplied in the CDR report.	The team includes proof of a successful subscale flight in the CDR milestone report by January 9, 2023.	Inspection	Project Management
2.18.4.1	Altimeter flight profile graph(s) OR a quality video showing successful launch, recovery events, and landing as deemed by the NASA management panel are acceptable methods of proof. Altimeter flight profile graph(s) that are not complete (liftoff through landing) SHALL not be accepted.	The recovery lead creates a altimeter flight profile graph that includes all altitudes recorded from liftoff through landing.	Analysis	Recovery
2.18.4.2	Quality pictures of the as landed configuration of all sections of the launch vehicle SHALL be included in the CDR report. This includes but not limited to nosecone, recovery system, airframe, and booster.	The recovery team takes pictures of the configuration of all sections of the launch vehicle after landing and include them in the CDR report to be submitted before January 9, 2023.	Analysis; Demonstration	Project Management; Recovery
2.18.5	The subscale rocket SHALL not exceed 75% of the dimensions (length and diameter) of your designed full-scale rocket. For example, if your full-scale rocket is a 4" diameter 100" length rocket your subscale SHALL not exceed 3" diameter and 75" in length.	The aerodynamics and structures leads design a subscale launch vehicle such that it does not exceed 75% of the dimensions of the designed full-scale launch vehicle.	Inspection	Aerodynamics; Structures

2.19.1	Vehicle Demonstration Flight—All teams SHALL successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown SHALL be the same rocket to be flown for their competition launch. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). The following criteria SHALL be met during the full-scale demonstration flight:	The team launches and recovers the full-scale launch vehicle in its final flight configuration prior to the FRR milestone.	Demonstration	Project Management
2.19.1.1	The vehicle and recovery system SHALL have functioned as designed.	No anomalies are detected in the performance of the launch vehicle and its recovery system.	Demonstration	Project Management
2.19.1.2	The full-scale rocket SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The team constructs a new full-scale launch vehicle that is designed and built according to the specifications for this year's project.	Inspection	Project Management; Aerodynamics
2.19.1.3.1	If the payload is not flown, mass simulators SHALL be used to simulate the payload mass.	If the payload is not flown during the VDF, the structures lead installs mass simulators to simulate intended payload mass.	Inspection	Structures
2.19.1.3.2	The mass simulators SHALL be located in the same approximate location on the rocket as the missing payload mass.	If the payload is not flown during the VDF, the structures lead installs mass simulators in the same approximate location on the launch vehicle as the missing payload mass.	Inspection	Structures
2.19.1.4	If the payload changes the external surfaces of the rocket (such as camera housings or external probes) or manages the total energy of the vehicle, those systems SHALL be active during the full-scale Vehicle Demonstration Flight.	If the payload changes the external surfaces or manages the total energy of the launch vehicle, the project management team activates those systems during the VDF.	Inspection	Project Management
2.19.1.5	Teams SHALL fly the competition launch motor for the Vehicle Demonstration Flight. The team may request a waiver for the use of an alternative motor in advance if the home launch field cannot support the full impulse of the competition launch motor or in other extenuating circumstances.	The aerodynamics lead installs the Launch Day motor for the VDF.	Inspection	Aerodynamics
2.19.1.6	The vehicle SHALL be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the maximum amount of ballast that SHALL be flown during the competition launch flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.	The aerodynamics lead decides on the final ballast configuration. The structures lead installs all required ballast for the VDF.	Inspection	Structures; Aerodynamics
2.19.1.7	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components SHALL not be modified without the concurrence of the NASA Range Safety Officer (RSO).	After successful completion of the VDF, the project management team does not allow further modification of the launch vehicle or any of its components without approval from the NASA RSO.	Inspection	Project Management
2.19.1.8	Proof of a successful flight SHALL be supplied in the FRR report.	The project management team provides all proof of successful VDF in the FRR milestone report.	Inspection	Project Management

2.19.1.8.1	Altimeter flight profile data output with accompanying altitude and velocity versus time plots is required to meet this requirement. Altimeter flight profile graph(s) that are not complete (liftoff through landing) SHALL not be accepted.	The recovery lead includes all altimeter data from the VDF in the FRR milestone report.	Inspection	Recovery
2.19.1.8.2	Quality pictures of the as landed configuration of all sections of the launch vehicle SHALL be included in the FRR report. This includes but not limited to nosecone, recovery system, airframe, and booster.	The recovery lead includes all pictures of the landing configuration of the launch vehicle in the FRR milestone report.	Inspection	Recovery
2.19.1.9	Vehicle Demonstration flights SHALL be completed by the FRR submission deadline. No exceptions SHALL be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. THIS EXTENSION IS ONLY VALID FOR RE-FLIGHTS, NOT FIRST TIME FLIGHTS. Teams completing a required re-flight SHALL submit an FRR Addendum by the FRR Addendum deadline.	The team completes the VDF by the FRR milestone report submission deadline. If a re-flight is required, the team submits an FRR addendum by the FRR addendum deadline.	Inspection	Project Management
2.19.2	Payload Demonstration Flight—All teams SHALL successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown SHALL be the same rocket to be flown as their competition launch. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. The following criteria SHALL be met during the Payload Demonstration Flight:	The team successfully launches and recovers the full-scale launch vehicle containing the completed payload prior to the PDF deadline.	Inspection	Project Management
2.19.2.1	The payload SHALL be fully retained until the intended point of deployment (if applicable), all retention mechanisms SHALL function as designed, and the retention mechanism SHALL not sustain damage requiring repair.	The payload is fully retained until the point of intended deployment, with each retention mechanism functioning as designed and not sustaining damage requiring repair during the PDF.	Inspection	Integration
2.19.2.2	The payload flown SHALL be the final, active version.	The payload flown during the PDF is the final, active version of the payload.	Inspection	Project Management
2.19.2.3	If the above criteria are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required.	The project management team ensures all criteria for the VDF are met and submitted before the FRR deadline. In the event that all criteria are not properly met, the team submits the additional flight and FRR addendum required.	Inspection	Project Management
2.19.2.4	Payload Demonstration Flights SHALL be completed by the FRR Addendum deadline. NO EXTENSIONS SHALL BE GRANTED.	The team completes the PDF by the FRR Addendum deadline.	Inspection	Project Management
2.20	An FRR Addendum SHALL be required for any team completing a Payload Demonstration Flight or NASA required Vehicle Demonstration Re-flight after the submission of the FRR Report.	If the team is completing the PDF or a NASA-required VDF re-flight after the submission of the FRR Report, the team lead submits an FRR Addendum by the FRR Addendum deadline.	Inspection	Project Management
2.20.1	Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline SHALL not be permitted to fly a final competition launch.	The project management team manages the schedule to ensure that a PDF is successfully completed by the FRR Addendum deadline.	Inspection	Project Management

2.20.2	Teams who successfully complete a Vehicle Demonstration Flight but fail to qualify the payload by satisfactorily completing the Payload Demonstration Flight requirement SHALL not be permitted to fly a final competition launch.	The project management team successfully completes VDF and PDF before the FRR Addendum deadline.	Demonstration	Project Management
2.20.3	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 SHALL not be granted if the RSO or the Review Panel have any safety concerns.	The project management team petitions the NASA RSO for permissions to fly the payload at launch week in the event that PDF is not fully successful.	Inspection	Project Management
2.21	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.	The project management team includes the team name and contact information on the launch vehicle such that it can be retrieved without the need to open or separate the vehicle.	Inspection	Project Management
2.22	All Lithium Polymer batteries SHALL be sufficiently protected from impact with the ground and SHALL be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.	The project management and safety teams clearly mark all lithium polymer batteries as a fire hazard and ensure they are sufficiently protected from impact with the ground.	Analysis; Inspection	Project Management; Safety
2.23.1	The launch vehicle SHALL not utilize forward firing motors.	The aerodynamics lead designs the launch vehicle to not utilize forward firing motors.	Inspection	Aerodynamics
2.23.2	The launch vehicle SHALL not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	The aerodynamics lead designs the launch vehicle to not utilize motors that are capable of expelling titanium sponges.	Inspection	Aerodynamics
2.23.3	The launch vehicle SHALL not utilize hybrid motors.	The aerodynamics lead designs a launch vehicle that does not utilize hybrid motors.	Inspection	Aerodynamics
2.23.4	The launch vehicle SHALL not utilize a cluster of motors.	The aerodynamics lead designs a launch vehicle such that it utilizes only one motor.	Inspection	Aerodynamics
2.23.5	The launch vehicle SHALL not utilize friction fitting for motors.	The structures lead designs a motor retention system such that it does not utilize friction fitting to hold the motor in place.	Inspection	Structures
2.23.6	The launch vehicle SHALL not exceed Mach 1 at any point during flight.	The aerodynamics lead designs the launch vehicle such that it does not exceed Mach 1 at any point during the flight.	Analysis	Aerodynamics
2.23.7	Vehicle ballast SHALL not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad (i.e. a rocket with an unballasted weight of 40 lbs. On the pad may contain a maximum of 4 lbs. of ballast).	The aerodynamics lead designs the launch vehicle such that the vehicle ballast does not exceed 10% of the total unballasted weight of the launch vehicle.	Analysis; Inspection	Aerodynamics
2.23.8	Transmissions from onboard transmitters, which are active at any point prior to landing, SHALL not exceed 250 mW of power (per transmitter).	The recovery and payload leads select onboard transmitters that do not exceed 250mW of power for each transmitter.	Analysis	Recovery; Payload
2.23.9	Transmitters SHALL not create excessive interference. Teams SHALL utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams.	The recovery and payload leads choose a transmitter that creates minimal interference. The safety lead then enforces the usage of unique frequencies to mitigate interference with other teams.	Analysis; Demonstration	Safety; Recovery; Payload

2.23.10	Excessive and/or dense metal SHALL not be utilized in the construction of the vehicle. Use of lightweight metal SHALL be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	The structures lead designs the launch vehicle such that the amount of metal utilized in the construction of the vehicle is minimized.	Inspection	Structures

4.2 Launch Vehicle Design

4.2.1 Launch Vehicle Dimensions

The proposed design for the launch vehicle consists of seven sections with two separation points and three bolted connections. Multiple sections will be bolted together during descent so that the rocket is separated into 3 tethered sections. Two of these sections will house recovery and payload electronics. The dimensions for all internal and external sections of the launch vehicle are shown below in Fig 4.1.

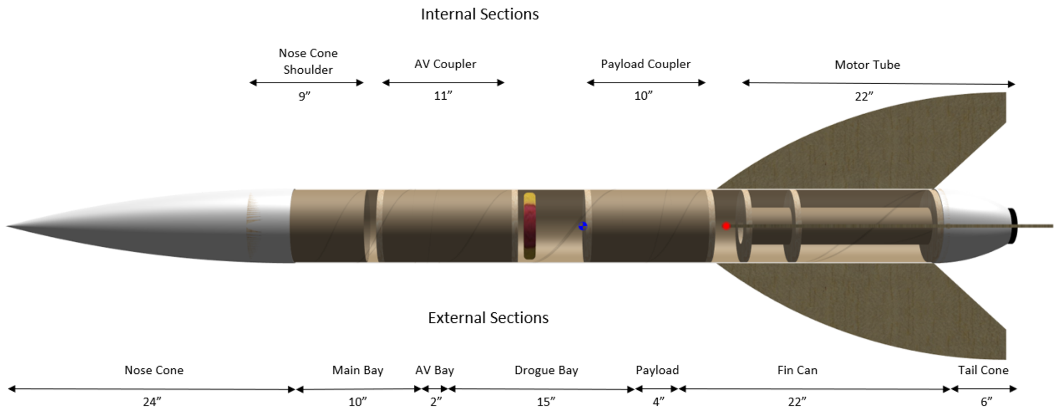

Figure 4.1: Launch Vehicle with Dimensions

4.2.1.1 Nose Cone

The nose cone will be a 4:1 ogive with an anodized aluminum tip. The base diameter will be 6 in. and the nose cone will be connected to the rest of the rocket using a 6 in. shoulder epoxied to the nose cone. A bulkhead will be secured inside the nose cone shoulder to mount recovery hardware. The nosecone will be secured to the main parachute bay using four #8-32 machine screws.

4.2.1.2 Main Parachute Bay

The main parachute bay will be a straight section of 6 in. diameter airframe. There are no coupler sections attached to the main parachute bay. However, it will be connected to the nose cone using four #8-32 machine screws.

4.2.1.3 Avionics Bay

The avionics bay will be constructed using an 11 in. length of coupler. A 2 in. length of coupler will be epoxied to the coupler 3 in. from one end. This exposed section of airframe will be used so that the pin switches and altimeters are accessible. The aft section of the AV bay will connect to the fin can using shear pins, and will separate at apogee releasing the drogue parachute. The forward section will be secured to the drogue parachute bay using #8-32 machine screws. At both ends of the AV bay there will be fabricated bulkheads to prevent the recovery electronics from contamination from the black powder charges.

4.2.1.4 Drogue Parachute Bay

The drogue parachute bay will be a straight section 6 in. diameter airframe. There are no coupler sections attached to the drogue parachute bay and will be bolted to the AV bay using four #8-32 machine screws.

4.2.1.5 Payload Bay

The payload section of the vehicle is allotted 10 in. of airframe with 4 in. of external body tubing centered on a 10 in. piece of internal coupler tubing with 3 in. of coupler tubing on each side. Forward of the payload section is separated by a bulkhead where a Kevlar shock cord will thread through to be attached in the fin can. Bolted to the aft of the payload section is the fin can section with a bulkhead separating the electronics from the motor casing. The payload section is expected to weigh less than 10 pounds with several openings for cameras to protrude out of the airframe.

4.2.1.6 Fin Can

The fin can will be made out of one long section of airframe and shall house the fins as well as several centering rings and bulkheads. There are two different methods for fin can fabrication. One includes all centering rings and fins permanently epoxied into the airframe and the other includes the option for removable fins. The fabrication and benefits of each design is discussed below.

i. Fixed Fin Design - The engine will be held in place by a motor tube. The motor tube will then be epoxied into two centering rings and a bulkhead on the forward end. The purpose of the centering rings is to hold the motor tube inside the airframe as well as provide a space for the fins to be mounted. A tab on the fins will be sandwiched between the two centering rings. This assembly is then epoxied to the airframe of the rocket. Fins will be inserted through slots in the airframe until they contact both the airframe and the motor tube. The fins are then epoxied into place. A preliminary model of this design is shown in Fig 4.2 below.

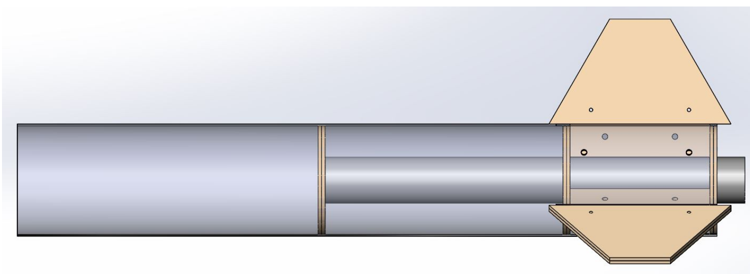

Figure 4.2: CAD Model of the Fin Can using a Fixed Fin Design

This design has been used by the team in past years and has proven to be strong and reliable. The main drawback of this design it is lacking in reusability. If a fin were to break it would not be replaceable, causing the team to have to fabricate a new fin can. A design with removable fins would solve this issue.

ii. Removable Fin Design - As with the fixed fin design, the motor will be held in place using a motor tube. Likewise, two centering rings shall be epoxied to the motor tube. An additional centering ring is also epoxied to the forward end of the motor tube. A bulkhead will be permanently epoxied into the airframe directly forward of where the motor tube terminates. This bulkhead will be used to later bolt the motor tube assembly into place. Plywood runners will be epoxied between the aft centering rings. The fins will then be secured to these runners using 2 #8-32 machine screws per fin. Two threaded rods will also connect the aft most centering rings providing additional structural support. This entire assembly will then be slid into the airframe and secured using #8-32 machine screws threaded through the airframe as well as four 1/4-20 bolts threaded through the forward bulkhead. A preliminary model of this design is shown in Fig 4.3 below.

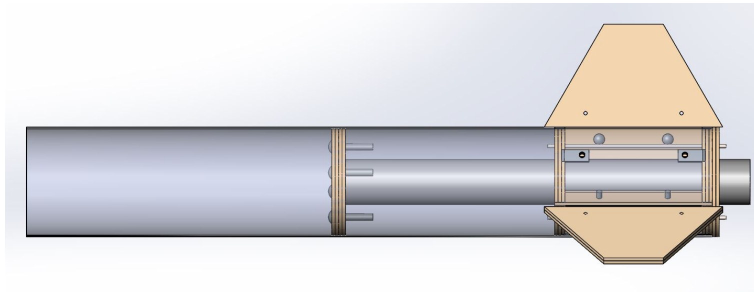

Figure 4.3: CAD Model of the Fin Can using a Removable Fin Design

This design fixes the repair issues presented by a fixed fin design. By having access to the motor tube and fins, the team will be able to replace any part that might break. This adds to the reusability of the rocket. Additionally, it allows for easier changes to be made to the fins and the motor assembly. One drawback of this design is the additional weight added by the extra hardware.

4.2.1.7 Tail Cone

The tail cone is designed be 6 in. long and manufactured via 3D printing using either PLA or ABS plastic. The purpose of the tail cone is to reduce drag on the launch vehicle by eliminating vortices at the trailing edge. The tail cone will be secured with epoxy to the threaded Aeropack motor retainer for ease of removal. The Aeropack motor retainer will be secured to the motor tube with epoxy fillets. This will allow it to be screwed onto the end of the launch vehicle after the motor insertion.

4.2.1.8 Fin Design

The proposed fin design will improve aerodynamics through the use of an ogive leading edge profile that sweeps aft past the root cord. Additionally, the fin's edges will be rounded with 1.5 in. fillets inward on all sides. Sweeping the fin back past the root cord generates a higher moment arm on the center of pressure. This allows for a fin area and drag reduction for an identical CP location.

i. Geometry - A tangent ogive is a shape that is formed from a circular section. The diameter of the circle is determined by a length and radius function of the desired shape. This geometry is often rotated to form nosecones such as the 4:1 ogive nosecone intended for use on this year's launch vehicle. This shape is depicted in the leading edge profile of the leftmost fin in Fig 4.4.

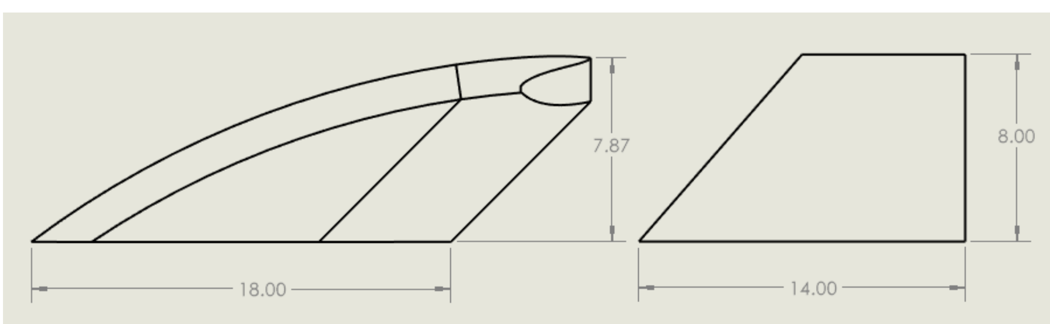

Figure 4.4: Drawing of Ogive Fin and Basic Fin Profile (in.)

ii. Simulation - ANSYS fluent simulations demonstrate the improvement of an ogive profile fin in comparison to a trapezoidal profile fin of the same area. The trapezoidal fin used for simulations is depicted on the right of Fig 4.4.

Both fin designs were simulated in a freestream velocity of 328 ft/s. This velocity was chosen because preliminary Rocksim simulations reported this value to be the approximate average velocity of flight. The ogive fins produced 0.90355 N of drag per fin while the basic fins produced 1.641 N per fin. A contour of the ogive fin turbulent energy is shown in Fig 4.5. From this figure, the efficiency of the ogive design is evident due to small boundary layers and low turbulence in the flow around the fin.

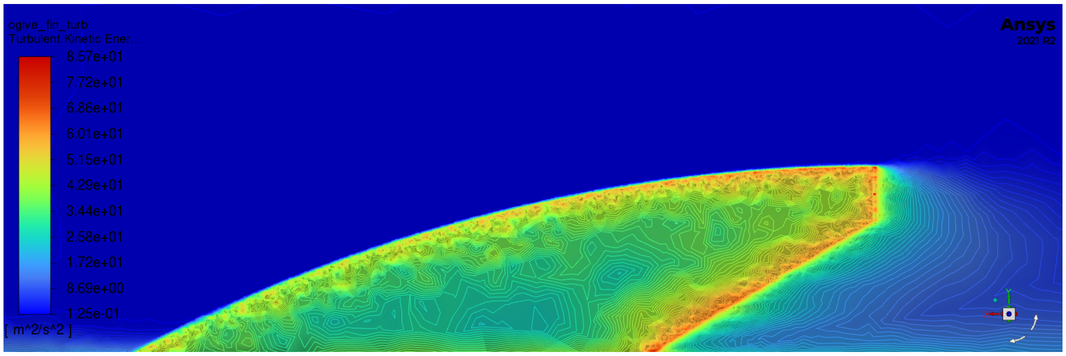

Figure 4.5: Turbulent Energy of Ogive Fin at 328 ft/s.

The proposed fin design currently reduces drag by almost 50 percent, but will continue to undergo performance optimization to tailor the location of the CP and manage stability.

4.2.1.9 Bulkhead Design

Bulkheads shall be fabricated out of 1/8 in. aircraft grade plywood. This material is both lightweight and strong and has been used by the team in the past for bulkhead construction. Sheets of plywood will be laminated together in order to reach the desired bulkhead thickness. The process for laminating bulkheads is described in section 4.2.3.1 below.

Bulkheads will be used for mounting U-bolts and other recovery hardware as well as components such as terminal blocks and blast caps. The thickness of bulkheads shall be determined based on the forces the bulkhead is expected to endure.

Based on the given motor and recovery options, the largest expected forces on any bulkhead is expected to be on the order of 360 lbf. Using this value, finite element analysis (FEA) was performed on bulkheads of several different thicknesses. The results of this FEA are shown in Fig 4.6 and 4.7 below.

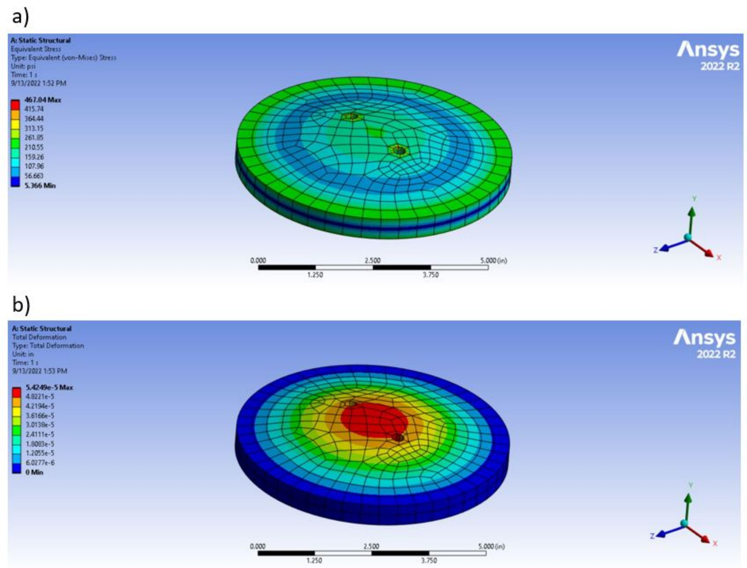

Figure 4.6: a) Stress concentrations on a 1/2 in. thickness bulkhead b) Total deformation on a 1/2 in. thickness bulkhead

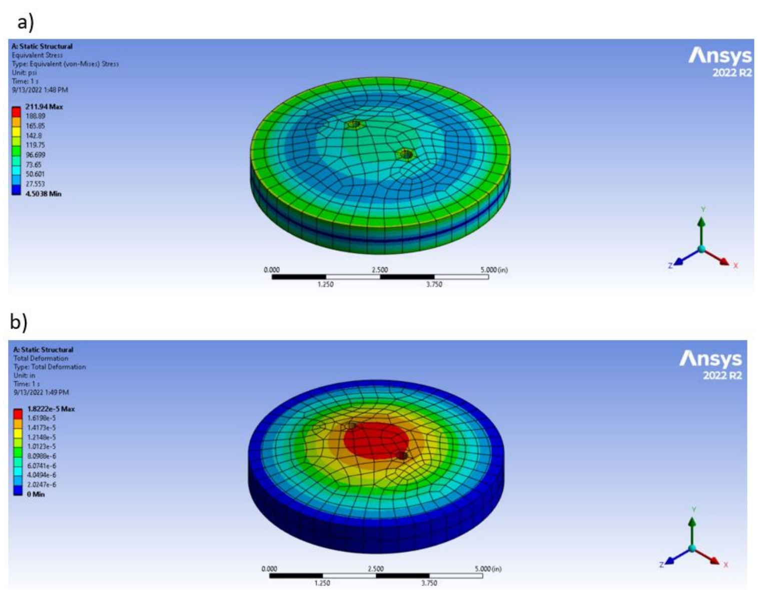

Figure 4.7: a) Stress concentrations on a 3/4 in. thickness bulkhead b) Total deformation on a 3/4 in. thickness bulkhead

The plywood used has an ultimate tensile stress of 4496.2 psi. Thus, either a 1/2 of 3/4 in. bulkhead is sufficient based on the application. Different bulkheads in the rocket will undergo varying forces. Once more specific force values are obtained more advanced FEA will be conducted in order to determine the required thickness of each bulkhead. All bulkheads shall be designed with a factor of safety of at least 2.0 in order to satisfy competition guidelines.

4.2.2 Material Selection

When selecting materials for use in launch vehicle construction the primary factors of concern are weight, durability, and price. These factors allow for the launch vehicle to be reusable while remaining within the teams budget.

Possible material options are detailed below.

4.2.2.1 Phenolic Tubing

Phenolic tubing is composed of resin-impregnated cardboard making it a stronger alternative to cardboard alone. Additionally, phenolic tubing is the least expensive of all airframe materials under consideration, costing $ 10/ft. for 6 in. diameter tubing on average. However, phenolic is prone to damage from impacts as well as punctures which harm the reusability of the rocket. Furthermore, phenolic tubing is not water-resistant. On the team's home launch field, it is common to have puddles of water and irrigation ditches. These are hazardous to all non-water resistant materials.

4.2.2.2 Blue Tube

Blue tube is a durable alternative to phenolic. It has a very strong impact and abrasion resistance while being lighter than similar materials such as carbon fiber or fiberglass. Blue Tube is also relatively inexpensive, costing $ 20/ft. for a 6 in. diameter airframe. However, Blue Tube is not water resistant and suffers from many of the same issues as discussed above.

4.2.2.3 G12 Fiberglass

G12 Fiberglass is a high strength composite that is frequently used for the construction of high-powered launch vehicles. It is extremely resistant to scratches as well as impact damage. Furthermore, fiberglass is waterproof which mitigates the risks discussed with phenolic and Blue Tube. Fiberglass is significantly heavier than either phenolic or blue tube. Given the current weight estimates for the launch vehicle, we do not believe that this additional weight will be an issue. The cost of fiberglass is approximately $48/ft. for a 6 in. diameter tube.

4.2.2.4 Carbon Fiber

Carbon fiber is another high strength composite that is excellent for structural applications. It has many of the same structural and reusable benefits that are also offered by fiberglass. Additionally, carbon fiber is waterproof. The largest drawback to carbon fiber is its cost. 6 in. diameter carbon fiber tubing can cost upwards of $106/ft..

4.2.2.5 Epoxy

High-strength epoxy shall be used for bonding all components to the launch vehicle. This is because it provides a high-strength chemical bond for both composite as well as wood products. All epoxy resins and hardeners pose health risks due to Volatile Organic Compounds. Mitigation to these risks are described in section 3 above. There are many different types of epoxies that offer different strengths and heat resistances. Two different possible epoxy choices are described below.

i. **West Systems** - West Systems 105 epoxy with 206 slow hardener has a tensile strength of 7,300 psi making it significantly stronger than JB Weld. Additionally, it is available with a working time of 90 - 110 minutes while curing to working strength in 1-4 days. The extended working time is ideal to ensure that manufacturing is not rushed. West Systems epoxy has a glass transition temperature of 139 F.

ii. **JB Weld** - JB Weld steel-reinforced epoxy is a commercially available two-part epoxy. It has a tensile strength of 5020 psi which is significantly lower than that of the West Systems epoxy. Additionally, it dries much faster than West Systems epoxy. JB Weld's decomposition temperature is 428 F, making it more heat-resistant than West Systems epoxy. In areas of the launch vehicle that sustain increased temperatures, such as the fin can, it may be necessary to use a more heat-resistant epoxy such as JB Weld. Further testing and measurements are necessary to ensure that epoxy will not be structurally compromised by heat.

Given the alternatives presented above, G12 fiberglass will be used for the airframe of the launch vehicle. Fiberglass has superior strength properties compared to phenolic and blue tube. Its water resistance also helps mitigate the risks of the Bayboro, NC launch field. Based on preliminary weight and flight calculations, the increased weight of the fiberglass will not contribute to a significant decrease in achieved altitude. Fiberglass was chosen over carbon fiber because the increased cost could not be justified by the benefits of its material properties.

4.2.3 Construction Methods

4.2.3.1 Bulkheads and Fins

Bulkheads and fins shall be fabricated using plies of ⅛ in. aircraft grade plywood. CAD designs of the plywood layers will be created and sent to the laser cutter for manufacturing. Once cut, the surface of each ply will be sanded in order to promote adhesion during bonding. Each ply will contain small holes used for the placement of alignment dowels. These dowels will prevent any plies from slipping during the fabrication process. Each ply's surface will be spread with a thin layer of epoxy. The plies will then be stacked together using the dowel rods for alignment, creating a bulkhead. Each bulkhead will then be wrapped in peel ply and breather material. These will then be wrapped in vinyl and put under vacuum for 24 hours until the epoxy is cured.

4.2.3.2 Airframe and Coupler Cutting

One of many available machine shops on NC State's campus will be used to cut fiberglass and other composite materials to minimize untrained personnel exposure to dangerous particulates. Airframe and coupler sections shall be marked where cutting is required and delivered to the machine shop. The shop professionals will then use either a wet saw or band saw to cut the material. Any sanding of composite materials shall be done under a fume hood capable of removing particulate matter.

4.2.3.3 Airframe and Coupler Adhesion

Airframe sections made out of composite materials shall be adhered using epoxy via the following procedure.

1. The contact areas of each airframe/coupler section will be measured and marked.
2. The contact surface will be cleaned using isopropyl alcohol or a similar solvent in order to remove any surface contaminants.
3. The surface will be lightly sanded using 150 or 220 grit sandpaper.
4. The surface will be cleaned to remove dust.
5. A thin layer of epoxy will be spread over the entire contact area.
6. The parts will be held together until the epoxy is cured.

4.2.3.4 Ballast

In the event that the center of gravity of the launch vehicle needs to be adjusted, ballast will be added to the nose cone. Ballast will be contained in a 3D printed casing that is secured to the nose cone bulkhead. Ballast will be secured into the 3D printed casing using epoxy.

4.2.3.5 Safety Standards

All team members shall be required to follow all safety procedures as put in place by the club and the safety officer. These regulations include but are not limited to:

- Team members shall wear proper PPE at all times. Proper PPE will vary based on the task being completed.
- Team members shall be trained on equipment prior to use.
- Team members shall follow the instructions of the safety officer at all times.

Further safety precautions are detailed in section 3 above.

4.3 Projected Altitude

The launch vehicle's target apogee is 5000 ft. which is in the middle of competition requirements. In the event that the launch vehicle's altitude is far from the target altitude, there is a large margin for the vehicle to still be within competition requirements. Current simulations performed in Rocksim show that a flight to 5000 ft. is attainable.

4.4 Launch Vehicle Recovery Specifications

The recovery of the rocket will be facilitated by a dual-deployment system. Two pressure based altimeters, wired and operated independently of each other, will allow activation and detonation of four separate black powder charges in the launch vehicle to release one drogue and one main parachute. The use of a primary and a secondary altimeter allows for redundancy and reliability in activation of these charges.

4.4.1 Recovery System Requirements

The following table (4.3) contains the recovery requirements as stated in the 2023 NASA Student Launch Handbook.

Table 4.3: 2022-2023 Recovery Requirements

NASA Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation
3.1	The full scale 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.	The recovery lead designs a dual-deployment recovery system	Demonstration	Recovery
3.1.1	The main parachute shall be deployed no lower than 500 ft..	The recovery lead designs a recovery system that deploys the main parachute no lower than 500 ft.	Demonstration	Recovery
3.1.2	The apogee event may contain a delay of no more than 2 seconds.	The recovery lead designs a recover system that has an apogee event delay of no more than 2 seconds	Demonstration	Recovery
3.1.3	Motor ejection is not a permissible form of primary or secondary deployment.	The recovery lead designs a recovery system where the motor does not separate from the launch vehicle	Inspection	Recovery
3.2	Each team will perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full scale vehicles.	The recovery lead shall conducts ejection tests prior to each launch confirming electronics functioning properly	Demonstration	Recovery
3.3	Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing. Teams whose heaviest section of their launch vehicle, as verified by vehicle demonstration flight data, stays under 65 ft-lbf will be awarded bonus points.	The recovery lead designs a recovery system such that the maximum kinetic energy experienced by the heaviest section of the launch vehicle does not exceed 65 ft-lbf	Analysis	Recovery
3.4	The recovery system will contain redundant, commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	The recovery lead designs a recovery system that utilizes a primary and secondary altimeter, each individually independent from the other	Inspection	Recovery
3.5	Each altimeter will have a dedicated power supply, and all recovery electronics will be powered by commercially available batteries	The recovery lead designs a recovery system that utilizes separate power sources for each altimeter used	Inspection	Recovery
3.6	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.	The recovery lead designs a recovery system that utilizes pin switches to activate each altimeter accessible from the exterior of the launch vehicle	Inspection	Recovery
3.7	Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	The recovery lead utilizes arming switches that can be locked in the ON position	Inspection	Recovery
3.8	The recovery system, GPS and altimeters, electrical circuits will be completely independent of any payload electrical circuits.	The recovery lead designs a recovery system that ensures all recovery electronics are all independent of the payload electronics	Inspection	Recovery

3.9	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	The recovery lead designs a recovery system that utilizes removable shear pins to secure separable section of the launch vehicle together on the pad	Inspection	Recovery
3.10	The recovery area will be limited to a 2,500 ft. radius from the launch pads	The recovery lead designs a recovery system that prevents the launch vehicle from drifting more than 2,500 ft radius from the launch pad in launch pad conditions	Analysis, Demonstraion	Recovery
3.11	Descent time of the launch vehicle will be limited to 90 seconds (apogee to touch down). Teams whose launch vehicle descent, as verified by vehicle demonstration flight data, stays under 80 seconds will be awarded bonus points.	The recovery lead designs a recovery system that safely descends the launch vehicle in under 80 seconds	Analysis, Demonstration	Recovery
3.12	An electronic GPS 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	The recovery lead designs a recovery system that utilizes a GPS tracking system that transmits the location of the launch vehicle at all points during flight	Inspection, Demonstration	Recovery
3.12.1	Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic GPS tracking device.	The recovery lead designs a GPS system and implements it on any payload component that lands separate from the launch vehicle	Inspection	Recovery
3.12.2	The electronic GPS tracking device(s) will be fully functional during the official competition launch.	The recovery lead tests and ensures all GPS devices remain fully functional the day of official competition launch	Inspection, Demonstration	Recovery
3.13	The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	The recovery lead designs a recovery system that recovery avionics are not affected by any other electronics onboard launch vehicle	Inspection, Demonstration	Recovery
3.13.1	The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	The recovery lead designs an avionics bay that is physically located in a separate compartment than any other radio frequency transmitting or magnetic wave producing devices	Inspection	Recovery
3.13.2	The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.	The recovery lead designs an avionics bay that is shielded from other onboard transmitting devices	Inspection	Recovery
3.13.3	The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	The recovery lead designs an avionics bay that is shielded from onboard magnetic wave generating devices	Inspection	Recovery
3.13.4	The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	The recovery lead designs an avionics bay that is shielded from any other onboard devices that may affect recovery system operations	Inspection	Recovery

4.4.2 Parachute Calculations

The drogue parachute will be deployed at apogee using a black powder charge located aft of the payload bay. For redundancy there will be two charges detonated, one by the primary altimeter, and the other by the secondary altimeter when they sense an apogee event has occurred. The secondary charge will be on a two second delay. These two sections will be connected to the drogue parachute bay by utilizing a 40 ft Kevlar shock cord specifically designed for high-powered launch vehicles. This cord will allow for a safe separation distance between the fin can section and the forward sections of the launch vehicle while descent under drogue. The drogue parachute shall be a Classic Elliptical 18-in. Fruity Chutes parachute. Fruity Chutes lists a drag coefficient of 1.43 and an area of 1.77 sq. ft. for this parachute. Using the descent velocity equation,

$$v_d = \sqrt{\frac{2gm}{SC_D\rho}} \tag{1}$$

where V_d is descent velocity, S is the parachute area, C_D is the drag coefficient of the parachute, and ρ is the density of air, we can calculate that the descent velocity of the launch vehicle under drogue is approximately 99.277 ft/s.

The main parachute is expected to be deployed at 550 ft., compliant with NASA requirement 3.1.1. The system will utilize dual black powder charges detonated by two independent pressure-based altimeters, with a delay of 1 second between the primary and secondary detonations, compliant with NASA requirement 3.1.2. This parachute shall be a 144-in. Rocketman Pro-X parachute, with a listed coefficient of drag of 0.79 and an area of 113.1 square ft.. Using the above descent velocity equation, the descent rate is calculated to be 16.4 ft/s under main which will impart a ground impact force of 54 lb/ft, compliant with NASA requirement 3.3.

This separation event will occur between the AV bay and the forward section of the rocket. Thus, the main parachute bay will be connected by a 40 ft. Kevlar shock cord to the upper payload bay. The payload bay will be bolted to the nosecone. The AV bay will be connected to the drogue parachute and fin can using another shock cord. The main parachute shock cords will be tethered to the main parachute at a certain distance from the AV bay to prevent different subsections of the body from impacting others on descent.

Considering a launch vehicle apogee of around 5000 ft., the total descent time will be around 75 seconds, which is within the 80-second limit to earn bonus points as defined in NASA requirement 3.11.

NASA requirement 3.10 stipulates that the launch vehicle must not drift over 2,500 ft. during a maximum wind speed of 20 mph. Assuming that the launch vehicle drift speed will be equal to the wind speed, drift distance and descent time of the vehicle under the main and drogue parachutes will be overestimated. Maximum drift distance is obtained using this approximation. The maximum drift distance for the launch vehicle under different wind conditions is shown below in Table (4.4).

Table 4.4: Maximum Wind Drift Distance

Wind Speed (mph)	Drift Distance (ft.)
0	0
5	558.3
10	1116.7
15	1675.1
20	2233.4

All sections designed to separate will be held together during flight by 4-40 nylon shear pins. Sections that are not designed to separate and that are under stress from black powder ejection charges will be held together using #8-32 machine screws.

4.4.3 Ejection Charges

The pyrotechnic charges activated by the altimeter signals are 777 grade FFF black powder. In total, there will be four separate ejection charges: one primary main, one secondary main, one primary drogue, and one secondary drogue. The secondary charges will be calculated by adding 0.5 oz. of black powder to the main charge in order to ensure separation. The primary charges will be calculated using Chuck Pierce's Ejection Charge Calculator, and double checked using hand calculations. These charges will be placed in PVC sectioned tubing, with an e-match placed on top of the charge for activation. The remainder of the PVC section not occupied by the black powder charge will be filled with flammable paper towel fragments to ensure ignition. These charges are then thoroughly sealed off using blue tape to ensure no leakage during transportation and takeoff.

Compliant with NASA requirement 3.2, ground ejection tests will be conducted prior to every launch of the launch vehicle to ensure separation is possible between required sections. These ejection tests will be performed with the launch vehicle fully assembled to simulate in-flight conditions.

4.4.4 Avionics Bay Design

The AV bay section of the launch vehicle will contain all recovery electronics. This section will consist of a coupler section with a two in. section of body tube three in. from one end. This body tube will have altimeter access holes so that altimeters can be armed immediately prior to flight, as well as pressure ports to prevent hoop stress from internal pressure during initial ascent. The aft coupler will connect to the fin can while the forward coupler will connect to the main parachute bay. Both sides of the AV bay will be protected by two bulkheads assemblies made from birch plywood and fabricated using epoxy, U-bolts, and PVC pipe. The bulkheads will be connected by two threaded rods running the length of the AV bay on which the AV sled will be mounted.

The AV sled will be modeled in SolidWorks and 3D printed using ABS plastic. The sled will have sectioned compartments for two RRC3 "Sport" Dual Deployment altimeters, an EggFinder GPS system, the mechanically armed pin switches, and three batteries. Inside each compartment will be sufficient insulation to prevent radio and magnetic wave interference with any of the other electronic systems onboard the launch vehicle, as specified by NASA requirements 3.13 through 3.13.4.

4.4.5 Recovery Avionics

As per NASA requirement 3.5, both of the Stratologger altimeters will be powered by commercially available 9V batteries. The onboard GPS, the Eggfinder TX, will be powered by a commercially available LiPo battery. All three systems will be separate from one another. They will also be sufficiently isolated from electric and magnetic signals and waves from each other and from other onboard electronics.

The primary altimeter will be designated as the competition altimeter. Both the primary and secondary altimeters will have control of two charges each, one for main and one for drogue parachute deployment. The secondary charge for the drogue chute will be deployed one second after apogee is experienced by the secondary altimeter, as compliant with NASA requirement 3.1.2. The primary charge for the main chute will be deployed at 600 ft., and the secondary charge at 500 ft., as per NASA requirement 3.1.1. Two pin switches will be utilized for arming each altimeter on the launch pad.

Prior to each flight, each altimeter will be individually calibrated in a previously prepared vacuum chamber. The altimeter will be powered on and connected to indicator lights before being placed in the vacuum chamber. A vacuum will then be drawn, slowly decreasing the pressure in the chamber to simulate an increase in altitude. The vacuum will then be slowly released to simulate the descent back to ground level. The indicator lights will be observed by personnel throughout the process to monitor for proper function. This will be corroborated with flight data extracted from the altimeters to ensure that the devices function properly.

4.5 Motor Brand and Class

Aerotech solid rocket motors will be used to propel the launch vehicle due to their long history of reliability and quality performance. Aerotech motors are demonstrably fail-safe and are the motor brand of choice for HPRC. Reusable Aerotech motor casings of various sizes are stored in the PPE cabinet of the lab and are ready to launch.

Rocksim calculations yield an ideal motor impulse between 3000 N-s and 5000 N-s. Thus, an Aerotech L1390G is considered for its reliability and legacy use. Its 3949 Ns of total impulse make it an ideal candidate for the competition vehicle. Additionally, an Aerotech L1420R is considered in the case that additional power is required to reach the desired altitude.

4.6 Payload Design

4.6.1 Payload Requirements

The following is a passage from the 2022-2023 NASA Student Launch Handbook, and defines the payload challenge: ”Teams shall design a payload capable upon landing of autonomously receiving RF commands and performing a series of tasks with an on-board camera system. The method(s)/design(s) utilized to complete the payload mission shall be at the team’s discretion and shall be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge.”

In the following Table (4.5), the year’s payload requirements and their shall statements, success criteria, verification methods, subsystem, and results thus far are defined.

Table 4.5: 2022-2023 Payload Requirements

NASA Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation
4.1	Teams shall design a payload capable upon landing of autonomously receiving RF commands and performing a series of tasks with an on-board camera system. The method(s)/design(s) utilized to complete the payload mission shall be at the team's discretion and shall be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge.	Payload team designs a payload system that is capable of receiving and interpreting RF commands and performing tasks with an on-board camera system, while obeying safety, FAA, and legal requirements, and adhering to the intent of the challenge	Demonstration	Payload Systems, Payload Electronics, Payload Structures, Integration, Safety
4.2.1	Launch Vehicle shall contain an automated camera system capable of swiveling 360º to take images of the entire surrounding area of the launch vehicle	Payload system contains a camera system that is able to rotate 360º, take pictures, and is able to take pictures of the entire area surrounding the launch vehicle	Demonstration	Payload Systems, Payload Electronics, Payload Structures, Integration
4.2.1.1.	The camera shall have the capability of rotating about the z axis. The z axis is perpendicular to the ground plane with the sky oriented up and the planetary surface oriented down.	Camera system rotational axis is about the described z axis	Demonstration	Payload Systems, Payload Electronics, Payload Structures
4.2.1.2.	The camera shall have a FOV of at least 100º and a maximum FOV of 180º	Camera used in payload system has a FOV of at least 100º and at most 180º	Inspection	Payload Electronics
4.2.1.3.	The camera shall time stamp each photo taken. The time stamp shall be visible on all photos submitted to NASA in the PLAR.	Payload system adds a time stamp to each photo taken before saving.	Demonstration	Payload Electronics, Payload Systems
4.2.1.4.	The camera system shall execute the string of transmitted commands quickly, with a maximum of 30 seconds between photos taken	Camera system takes less than 30 seconds to execute commands between photos	Demonstration	Payload Electronics, Payload Systems, Integration
4.2.2.	NASA Student Launch Management Team shall transmit a RF sequence that shall contain a radio call sign followed by a sequence of tasks to be completed.	The payload system is able to determine if the correct call sign is used, and then accept and perform RF commands	Demonstration	Payload Electronics, Payload Systems
4.2.3.	The NASA Student Launch Management Panel shall transmit the RAFCO using APRS.	The payload system is able to accept RAFCO using APRS	Demonstration	Payload Systems, Payload Electronics
4.2.3.1.	The NASA Management Team shall transmit the RAFCO every 2 minutes.	The payload system is able to accept RAFCO commands continuously	Demonstration	Payload Systems, Payload Electronics
4.2.3.3.	The payload system shall not initiate and begin accepting RAFCO until AFTER the launch vehicle has landed on the planetary surface.	The payload system is designed such that it does not accept RAFCO until after launch vehicle landing	Demonstration	Payload Systems, Payload Electronics
4.2.4.	The payload shall not be jettisoned	The payload system is designed such that no components are jettisoned	Inspection	Payload Systems, Payload Electronics, Payload Structures, Integration
4.2.5.	The sequence of time-stamped photos taken need not be transmitted back to ground station and shall be presented in the correct order in your PLAR.	The sequence of time-stamped photos are presented in correct order in the teams PLAR	Demonstration	Payload Systems, Payload Electronics
4.3.1.	Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics shall not be permitted for any surface operations.	The payload recovery system is designed such that any energetics are only utilized in flight.	Inspection	Integration
4.3.2.	Teams shall abide by all FAA and NAR rules and regulations.	The safety team verifies payload compliance with all FAA and NAR rules and regulations.	Demonstration	Safety
4.3.6	Any UAS weighing more than .55 lbs. shall be registered with the FAA and the registration number marked on the vehicle.	Any UAS weighing more than .55 lbs is registered with the FAA and the registration number of the vehicle is marked	Inspection	Payload Systems

4.6.2 Projected Designs

4.6.2.1 Multi-Camera Fin Orientation System

After landing, the camera system will need to self-orient such that the z-axis is pointing normal to the ground plane, no matter what orientation the launch vehicle lies on the ground. Due to the launch vehicle's fin configuration, there are a fixed number of orientations that the launch vehicle's fin can assembly can land in, and depending on the number of fins, either a fin (in the case of an uneven number of fins) or the space between two fins (in the case of an even number of fins) will always be pointing in the positive z-axis direction. By placing cameras in the fin can along the same axis as these positions, there will always be a camera with its z-axis oriented along the correct direction.

All cameras will be mounted on servos that are able to rotate the attached camera 360° about the z-axis. An additional servo will be attached to the camera to ensure that the camera FOV is oriented flat with respect to the ground plane.

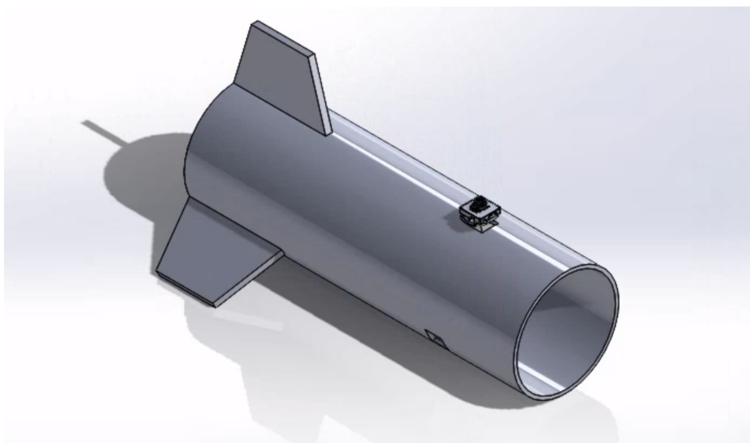

Figure 4.8: CAD Model of the Fin Can with an Extended Camera

The camera system will include an on-board computer, RF system, and inertial measurement unit (IMU). The IMU will be used to determine when the launch vehicle has landed, and will communicate with the on-board computer to start accepting RAFCO. The IMU will also determine the orientation of the launch vehicle, and will communicate this orientation to the on-board computer, which will then determine which camera to address commands.

4.6.2.2 Transparent Payload Cylinder

This design consists of a camera system that sits inside of a transparent cylinder inside of the launch vehicle that can point outwards upon landing in any configuration perpendicular to the axis of the vehicle. A single camera will sit in the middle of the cylinder and will be able to rotate about all three axes. This cylinder will be pulled from the launch vehicle during flight while being attached to the main parachute's shock chord. This camera will orient itself using a gravity assisted gimbal system. Servos then will be able to rotate the camera such that it has a clear view of the horizon and can execute RAFCO.

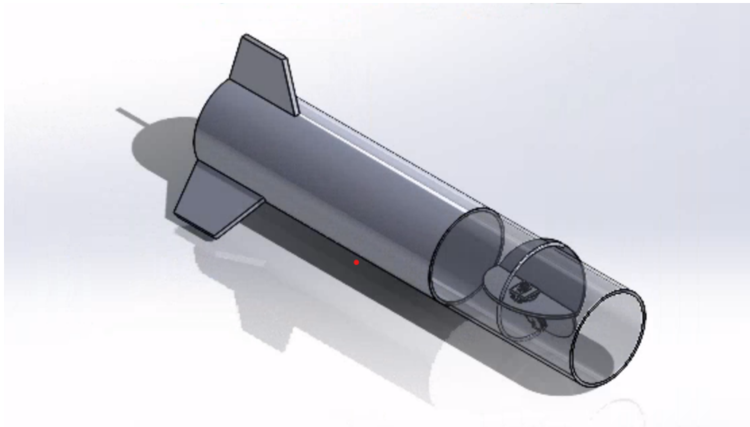

Figure 4.9: CAD Model of the Transparent Payload Cylinder with a Gimbal System

To ensure an optimal field of view, the ends of this section will be made of clear bulkheads that do not sustain loads. Since acrylic and polycarbonate are weak under loading, this section will be supported axially and tangentially using aluminum rods.

Like the previous design, this camera will communicate with an on-board computer, RF system, and IMU. The IMU will both determine the orientation of the launch vehicle and communicate with the on-board computer to begin accepting RAFCO commands. Once RAFCO commands are accepted, the computer will transmit instructions to the servo and camera.

4.6.2.3 Alternative Design Solutions

Several other proposed alternatives to the leading two designs were explored. These alternatives will be briefly discussed below, along with the reasons they will not be implemented into the final payload design.

Given that the camera system will need to be oriented such that the horizon is on the horizontal, gaseous buoyancy and gravity assistance systems were proposed.

A buoyancy-supported camera righting system would use a pressure vessel filled with a gas lighter than air, such as helium, to right the payload camera(s). This balloon-like pressure vessel would be deployed from the vehicle upon landing and be attached to the vehicle in such a way that it floats directly above the vehicle. The camera(s) would be attached to this buoyant device and would be able to capture level pictures of the surrounding field.

Difficulties were found with ensuring that the pressure vessel used had a 4:1 safety factor, a NASA requirement that can be found in Table (4.2). Additionally, camera stability (which is integral to capturing clear images) is difficult to achieve with a buoyancy-based camera righting system. Lastly, this system would not be applicable to every launch vehicle environment (such as those SLS would encounter upon landing on the Moon or Mars) due to a lack of an Earth-like atmosphere on every celestial body.

Next, a rotating body tube with a camera-sized cutout was considered to capture clear images of the launch field. This airframe section would rotate along the axis of the vehicle, allowing the camera to capture a full image of the launch field. This design was rejected because it would require both rotation of the airframe and rotation of the camera, which introduces unnecessary complexity and leads to an increased likelihood of system failure.

Finally, a telescoping counter-weighted rod was considered for the final payload design, but was ultimately scrapped due to concerns over system complexity and structural integrity. A long rod holding the camera would be pushed out on landing from one side of the payload section. After a weight on one end of the rod exits the vehicle, this weight would allow the camera rod to hinge and right the camera using gravity. Wire management, rod cracks and breaks, and camera rod instability contributed to this design being cut from consideration.

4.7 Payload Technical Challenges

The two leading designs have setbacks that, if not accounted for, will limit the capabilities of the payload and reduce likelihood that clear pictures will be captured. Below, we identify technical challenges that will be overcome should either design be chosen.

4.7.1 Challenges With Fin-Oriented Design

Any protrusion from the launch vehicle in proximity to the stabilizing fins will cause aerodynamic instabilities around these fins. These instabilities influence the center of pressure, which in turn influences the stability margin of the vehicle. Deviations from the stability margin simulated in RockSim will increase likelihood of instabilities that contribute to a lower altitude.

These aerodynamic challenges can be overcome by limiting or eliminating the length of protrusions from the vehicle. In the case that a protruding camera housing contributes to instabilities, a hole or gate will house the camera which extends out of the vehicle upon landing. However, this increases the complexity of the system by including an additional motorized actuation necessary to extend the camera away from the vehicle. The benefits and drawbacks of a protrusion versus a hole or gate will be compared as the final design is chosen.

4.7.2 Challenges With Transparent Cylinder Design

The clear cylinder will be made from polycarbonate, which has a tensile strength of 9,500 psi. Because the rest of the launch vehicle will be made from fiberglass, which has a tensile of 9,000-18,000 psi, the polycarbonate section of the launch vehicle may crumple or shatter from axial forces due to this difference in tensile strength. In order to prevent this, structural reinforcements on the inside of the section will need to be made, which will likely interfere with the camera system hardware.

Abrasions, cuts, or scratches sustained by the transparent airframe of the launch vehicle will increase its opacity. Given that the camera will be taking pictures through the transparent tube in this design, any imperfections on the outside of the tube will result in an obscured picture and will limit overall performance of camera. The launch vehicle will come into contact with debris and soil upon landing that will cover the outside of the airframe, blocking visibility and potentially scratching or gouging the polycarbonate.

5 STEM Engagement

5.1 Purpose and Description of STEM Engagement

Outreach events are organized and conducted throughout the 2022-2023 academic year in order to teach K-12 students about rocketry, current NASA projects, the engineering design cycle, and other STEM related topics. These events are coordinated with local schools, museums, and community organizations. Students shall be exposed to STEM subjects and encouraged to apply what they learn in the classroom through coordinated hands on activities. Direct engagement will lead to better understanding of these topics and encourage students to pursue careers in STEM.

The team shall reach out to elementary, middle, and high schools regarding the arrangement of outreach events. These events will be a mixture of both in person and virtual engagements. As a result of the circumstances of virtual learning in the past couple years, both the team and corresponding hosts of outreach events are all comfortable with working in a virtual setting. In person events are preferable as they result in an increase of direct engagement of participants. Nevertheless, virtual outreach events allow the team to hold events with schools and organizations that are not in close proximity to the location of the club, leading to an increase in overall participants engaged. Events shall include a presentation about the team, student launch, and an abstract of rocketry. Then, there will be interactive demonstrations of the topics covered in the presentation. In the past, these demonstrations have included helping younger students, grades K-8, construct straw and bottle rockets. For older students, grades 9-12, these demonstrations can include building and launching low power model rockets of their own. In a virtual setting, it is possible to give step-by-step instructions on how to build and launch straw rockets as well as talk through bottle rockets.

NASA requirement 1.5 states that the team shall engage a minimum of 250 participants in educational direct engagement activities. The events described in section 5.2 below exceed this requirement. The team has already begun to reach out to schools, museums, and other community organizations regarding planning STEM engagement activities for this school year. Last year the team engaged 326 students in STEM activities. The team's goal is to reach a greater number of students this year, as they are hoping that a couple of the outreach events are held in person. Additionally the team shall complete STEM engagement activity reports in compliance with NASA's requirement. This shall help the team analyze and improve these events. Furthermore, after events participants will be asked to complete a survey to give feedback on how events can be improved in the future.

5.2 Planned STEM Engagement Events

5.2.1 Joyner Science Go Round

The team shall travel to Joyner Elementary to participate in the school's annual Science Go Round. There will be four presentations given throughout the day. These presentations shall include information about the team and the NASA Student Launch. After the presentation, the team shall directly engage students in constructing and launching water bottle rockets. Additionally, students will be guided through evaluating their rocket's performance after the launch. The expected attendance of this event is 100 students.

5.2.2 Lacy Elementary STEM Night

Lacy Elementary holds a STEM night in the spring semester and invites professionals and industries in the STEM field to present about the topics that they work on. If the event is in person, people will come in and out of the room and the team will give multiple presentations throughout the day about rocketry and how our rockets are developed. After the presentation, the team shall lead students in making and launching their own straw rockets. If the event is virtual, the team will go through the same presentation and virtually engage students with straw rockets. The expected attendance of this event is 175 students.

5.2.3 Astronomy Days

Astronomy days is a weekend long event held by the North Carolina Museum of Natural Sciences. This event displays, talks, and provides demonstrations about astronomy. If the event is in person, the team will host an amateur rocketry booth in conjunction with Tripoli Rocketry Association. Students will be shown the construction of high powered rockets and be directly engaged by guiding them through the construction of a rocket motor. Additionally, they will be taught the basics of how rockets are launched through Newton's 3rd law. The attendance number of this event varies based on the year and attendance method. The team expects to reach at least 200 students if the event is held virtually and up to 1000 if the event is in an in person format.

6 Project Plan

6.1 Development Schedule

Figures 6.1 and 6.2 below depict the 2022-2023 Competition deadlines and project development schedule. Development schedule dates are subject to change due to supply chain delays.

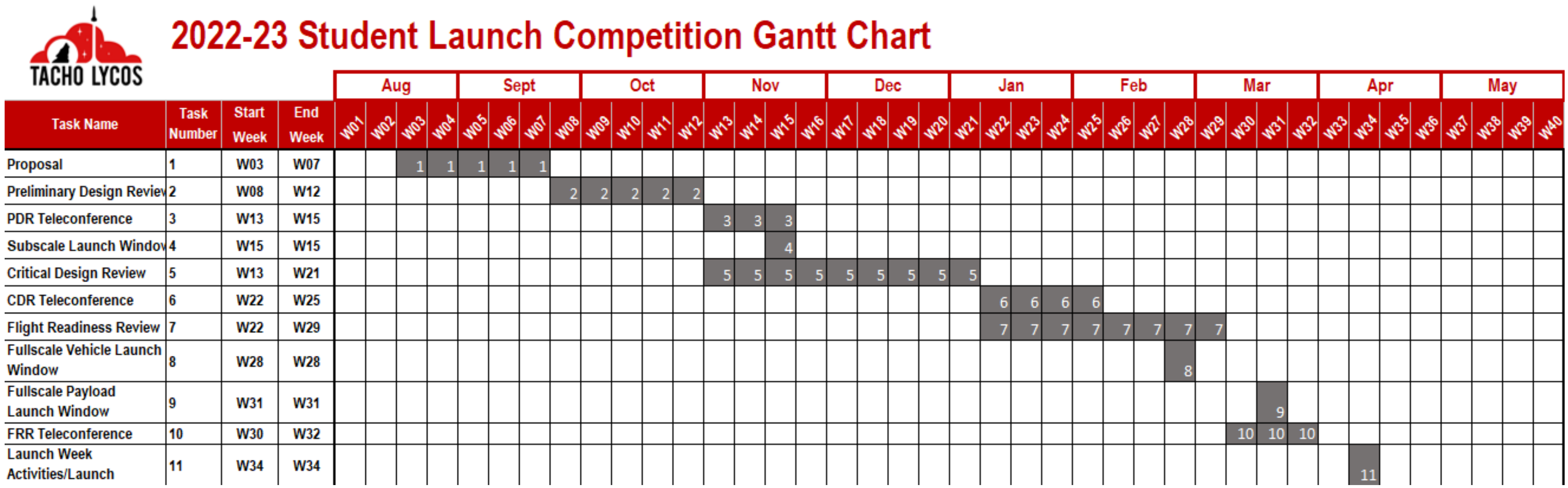

Figure 6.1: 2022-2023 Competition Deadlines

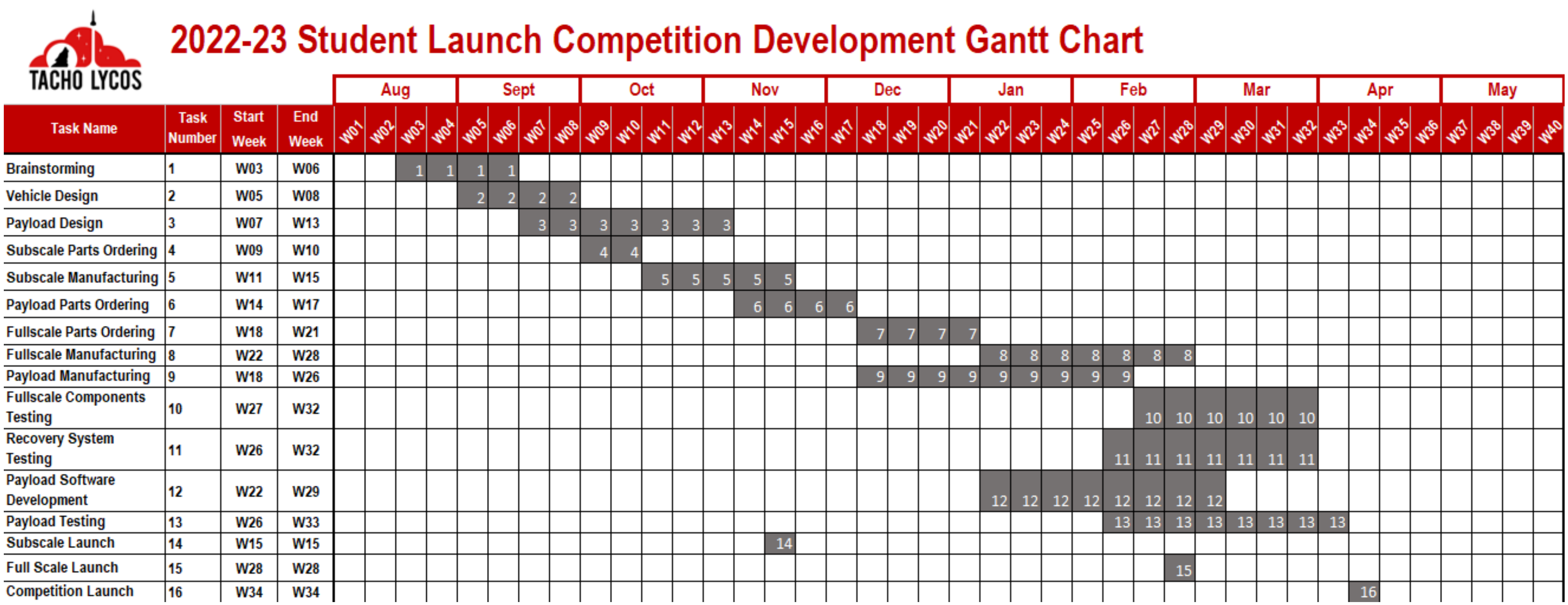

Figure 6.2: 2022-2023 Competition Development Schedule

6.2 Budget

Table 6.1 below details the year-long budget for the 2022-2023 Student Launch Competition.

Table 6.1: 2022-2023 NASA Student Launch Competition Budget

	Item	Quantity	Price Per Unit	Item Total
Subscale Structure	Plastic 4 in. 4:1 Ogive Nosecone	1	$ 29.80	$ 29.80
	4 in. Blue Tube	2	$ 43.95	$ 87.90
	4 in. Blue Tube Pre-Slotted	1	$ 53.50	$ 53.50
	AeroTech I435T-14A Motor	2	$ 80.24	$ 160.48
	Aero Pack 38mm Retainer	2	$ 29.17	$ 29.17
	AeroTech RMS-38/600 Motor Casing	1	$ 98.86	$ 98.86
	Large Rail Button -1515	1	$ 7.87	$ 7.87
	Standard Rail Button - 1010	2	$ 4.25	$ 8.50
	Blast Caps	4	$ 1.80	$ 7.20
	Terminal Blocks	4	$ 3.00	$ 12.00
	Double Pull Pin Switch	2	$ 11.95	$ 23.90
	Subtotal:			**$ 572.42**
Full Scale Structure	6 in. Nosecone Fiberglass Ogive 4:1	1	$ 149.99	$ 149.99
	6 in. G12 Fiberglass Tube (60 in.)	1	$ 259.00	$ 259.00
	6 in. G12 Fiberglass Tube (48 in.)	1	$ 207.20	$ 207.20
	6 in. G12 Fiberglass Coupler	4	$ 77.50	$ 310.00
	AeroTech High-Power L1390G-P Motor	2	$ 223.54	$ 447.08
	Aero Pack 75mm Retainer	1	$ 59.50	$ 59.50
	AeroTech RMS-75/3840 Motor Casing	1	$ 526.45	$ 526.45
	Large Rail Button -1515	2	$ 4.25	$ 11.40
	U-Bolts	8	$ 1.00	$ 8.00
	Blast Caps	4	$ 1.80	$ 7.20
	Terminal Blocks	4	$ 3.00	$ 12.00
	Double Pull Pin Switch	2	$ 11.95	$ 23.90
	Subtotal:			**$ 2021.72**
Payload	FPV Cameras	4	$ 19.99	$ 79.99
	Acrylic Sheets	2	$ 11.22	$ 44.88
	Stepper Motor	2	$ 173.97	$ 347.97
	Raspberry Pi	1	$ 120.00	$ 120.00
	IMU	1	$ 15.30	$ 15.30
	RTL-SDR Dongle	1	$ 39.95	$ 39.95
	Whip Antenna	4	$ 25.00	$ 100.00
	Servo	8	$ 10.00	$ 80.00
	Subtotal:			**$ 805.59**
Recovery and Avionics	Iris Ultra 120 in. Standard Parachute	1	$ 475.71	$ 475.71
	Iris Ultra 60 in. Standard Parachute	1	$ 212.85	$ 212.85
	18 in. Compact Elliptical Parachute	1	$ 70.95	$ 70.95
	RRC3 Sport Altimeter	4	$ 96.50	$ 386.00
	Eggfinder TX Transmitter	1	$ 70.00	$ 70.00
	6 in. Deployment Bag	1	$ 54.40	$ 54.40
	4 in. Deployment Bag	1	$ 47.30	$ 47.30
	18 in. Nomex Cloth	1	$ 26.40	$ 26.40
	13 in. Nomex Cloth	1	$ 17.60	$ 17.60
	5/8 in. Kevlar Shock Cord (per yard)	25	$ 6.99	$ 174.75
	3/16 in. Stainless Steel Quick Links	16	$ 2.00	$ 32.00
	AeroTech Ejection Charge - 1.4g	24	$ 1.25	$ 30.00
	Subtotal:			**$ 1,702.72**

Miscellaneous	Paint	12	$ 18.00	$ 216.00
	Domestic Birch Plywood 1/8 in.x2x2	12	$ 14.82	$ 177.84
	West Systems 105 Epoxy Resin	2	$ 109.99	$ 219.98
	West Systems 206 Slow Hardener	2	$ 62.99	$ 125.98
	ABS 3D Printer Filament Spool	1	$ 23.00	$ 23.00
	ClearWeld Quick Dry 2-Part Epoxy	1	$ 20.28	$ 20.28
	Wood Glue	1	$ 7.98	$ 7.98
	Misc. Bolts	1	$ 20.00	$ 20.00
	Misc. Nuts	1	$ 10.00	$ 10.00
	Misc. Washers	1	$ 8.00	$ 8.00
	Tinned Copper Wire Kit	1	$ 25.00	$ 12.00
	Zip Ties Pack	1	$ 6.59	$ 6.59
	Hook and Loop Strips Box	1	$ 10.00	$ 10.00
	9V Battery Pack	1	$ 12.00	$ 12.00
	Misc. Tape	1	$ 20.00	$ 20.00
	Estimated Shipping			$ 1,000.00
	Incidentals (replacement tools, hardware, safety equipment, etc.)			$ 1,500.00
	Subtotal:			**$ 3,410.63**
Travel	Student Hotel Rooms – 4 nights (# Rooms)	8	$ 898.45	$ 7,187.60
	Mentor Hotel Rooms – 4 nights (# Rooms)	2	$ 1022.03	$ 2,044.06
	NCSU Van Rental (# Vans)	1	$ 798.00	$ 2,394.00
	Subtotal:			**$ 11,625.66**
Promotion	T-Shirts	40	$ 15.00	$ 600.00
	Polos	15	$ 25.00	$ 375.00
	Stickers	500	$ 0.43	$ 215.00
	Subtotal:			**$ 1,190.00**
Total Expenses:				**$ 21,317.70**

As highlighted in Figure 6.3, our expenses can be divided into different sub-sections with travel funds taking up the majority of our spending for this year.

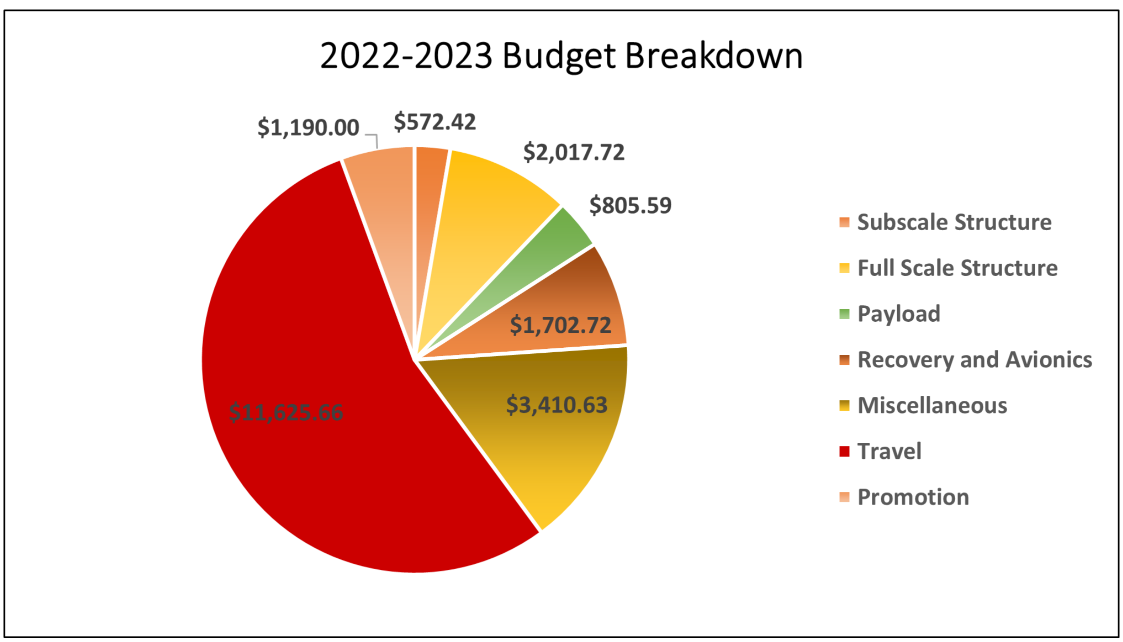

Figure 6.3: 2022 - 2023 Budget Breakdown

6.3 Funding Plan

HPRC receives the majority of funding from a variety of NC State's funding sources, as well as North Carolina Space Grant (NCSG). Below is an in depth breakdown of the team's current funding sources.

NC State's Student Government Association's (SGA) Appropriations Committee is responsible for distributing university funding to nearly 600 different organizations on campus. Each semester the application process persists of a proposal where we outline what we are requesting from SGA, how much money we estimate to receive from other sources, and our anticipated club expenses for the academic year. We then meet with representative from SGA and give a presentation outlining our club activities and how we benefit the university. SGA then collectively allocates money to each organization on campus. In the 2021-2022 academic year, HPRC received $1,766.81 from SGA: $451.81 in the fall semester and $1,315 in the spring semester. For this academic year, a request of $2,000 was submitted for the fall semester and another $2,000 request will be submitted in the spring semester, assuming SGA regulations and budget will remain the same.

The Educational and Technology Fee (ETF) is an NC State University fund that allocates funding for academic enhancement through student organizations. In the 2021-2022 academic year, we received $3,000 from ETF and the team anticipate to receive $2,500 for this academic year. This funding will be used primarily to pay for the student and team's faculty advisors' travel costs.

Student and mentor travel costs will primarily be covered by NC State's College of Engineering Enhancement Funds. These funds come from a pool of money dedicated to supporting engineering extracurricular activities at NC State. Based on the 2021-2022 academic year, it is estimated we will receive $7,500.

In addition to funding through NC State organizations, North Carolina Space Grant is a large source of HPRC's funds. 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 of the amount awarded. In previous academic years, this has been the maximum amount of $5,000, which will be available for use starting November 2022.

In the past, HPRC has held sponsorship's with Collins Aerospace, Jolly Logic, Fruity Chutes, and more. The team is currently seeking out new sponsorship's and reaching out to past sponsors. The team has found that companies are more likely to donate gifts in kind rather than provide monetary sponsorship. The team estimates to receive $2,500 in gifts of kind this academic year.

These totals are listed in Table 6.2 below, which outlines the projected costs and incoming revenue for the 2021-2022 academic year.

Table 6.2: Projected Funding Sources

Organization	Fall Semester	Spring Semester	Academic Year
Educational and Technology Fee	$0	$2,500	$2,500
Engineering Enhancement Fund	$0	$7,500	$7,500
NC State Student Government	$2,000	$2,000	$4,000
North Carolina Space Grant	$5,000	$0	$5,000
Sponsorship	$1.000	$1,500	$2,500
Total Funding:			**$21,500.00**
Total Expenses:			**$21,317.70**
Difference:			**$182.30**

6.3.1 Sustainability Plan

To sustain the High-Powered Rocketry Club as an organization, the team must focus on new member recruitment and retention. The team must also maintain a positive relationship with the Eastern North Carolina rocketry community. The club achieves these through:

- University-sponsored recruitment events

- Club enrichment
- North Carolina Rocketry volunteer opportunities
- Community outreach

HPRC recruits new members in the Fall and Spring semesters through several university-sponsored club exposure events. During these events, current club members advertise the club by showcasing previous launch vehicles and payloads and informing students of the club's activities and involvement in student launch, with a focus on this year's specific project. In addition to these events, the club is advertised on all of the team's social media outlets. By using these resources, the club typically recruits over one hundred new members for interest meetings per year. As of the submission of this document, the number of retained new members is approximately forty after several construction meetings.

In order to engage and retain new members, the club conducts enrichment opportunities such as an underclassmen-led interest launch in the beginning of the Fall semester. This year's interest launch will take place on September 24th, at which last year's competition rocket will be relaunched. HPRC also has an underclassmen-led sub-team for experimental payloads and previous club rocket relaunches entitled "Wolf Works Experimental." The Wolf Works Experimental group is currently working on a air brake system to implement into the 2021-2022 student launch vehicle for relaunch. Wolf Works will continue to increase underclassmen engagement with projects in the future such as multi-stage rockets, mach 1 rockets, as well as varying experimental payloads. In addition to these underclassmen focused teams, the club leads technical workshops at our general body meetings on topics such as the basics of high-powered rocketry, soldering, electronics, vehicle design, safety, and CAD. The club also organizes club social events such as game nights and group dinners.

Additionally, the club focuses on community relations, especially with local hobby rocketry enthusiasts. Throughout the competition year, Club members volunteer at local Tripoli Low-Powered launches with the team's mentor, Alan Whitmore. At these launches, club members assist with set-up and tear-down, all while learning from those with experience building hobby rockets. Providing help for these launches ensures access to a variety of resources for help and advice in designing the team's rockets. In addition to these events, the club works with local schools and museums through outreach events as described in Section 5

HPRC is largely self-sufficient, as all manufacturing equipment and materials are available onsite in the facilities described in Section 2.1 If any additional resources are required, the team will communicate with the team mentors listed in Section 1.1 for assistance in working towards a solution. In addition, the Club uses stable, regularly scheduled funding sources as described in Section 6.3 to ensure a sustainable availability of funds.