Tacho Lycos

2024 NASA Student Launch

Proposal

High-Powered Rocketry Club at NC State University
1840 Entrepreneur Drive
Raleigh, NC 27606

September 11, 2023

Common Abbreviations and Nomenclature

AGL = Above Ground Level
AIAA = American Institute of Aeronautics and Astronautics
APCP = Ammonium Perchlorate Composite Propellant
ASME = American Society of Mechanical Engineers
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
SAIL = STEMnauts Atmosphere Independent Lander
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
VTOL = Vertical Take-Off and Landing

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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 within the College of Engineering at North Carolina State University. He currently instructs the Aerospace Senior Design class and also acts as the academic advisor for Aerospace Engineering undergraduate students. Dr. Ewere holds a PhD in Mechanical Engineering and a Master's in Aerospace Engineering, both from the University of Alabama in Huntsville. His research interests include the science and technology involved in topics such as aerodynamics, structural mechanics, energy, and smart materials. His recent work focuses on the exploitation of aeroelastic instabilities on piezoelectric structures for engineering applications. Dr. Ewere is a senior member of AIAA and is also an ASME member.

i. Name: Alan Whitmore

ii. Email: acwhit@nc.rr.com

iii. Phone: (919) 929-5552

iv. TRA Flyer Number: 05945

v. Biography: Alan Whitmore first got involved with high-power rocketry in 1997. Since then, he has earned a Level 3 certification through both NAR and TRA. Whitmore served as the prefect for the Eastern North Carolina branch of TRA from 2002-2021. In 2006, he was accepted as a member of the TRA Technical Advisory Panel (TAP) which advises the TRA board of directors on the technical aspects of propellants, construction materials, and recovery techniques. Whitmore is also a member of the NAR Level 3 Certification Committee (L3CC) which supervises individual members of NAR and TRA throughout the process of designing, manufacturing, and flying Level 3 certification rockets. Whitmore was selected as the chairman of the Tripoli Motor Testing Committee which is responsible for testing and certifying 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 Flyer Number: 02204

v. Biography: Jim Livingston joined TRA in 1993 and received his Level 3 certification in 1997. Livingston has served as a member of the TRA TAP since 1998 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 (motor sizes I through N).

1.2 High-Powered Rocketry Club

The High-Powered Rocketry Club (HPRC), also known by the team name ”Tacho Lycos”, is an interdisciplinary student organization within the Department of Mechanical and Aerospace Engineering at North Carolina State University. The club has been in operation since 2009 and has provided students with the opportunity to gain real-world engineering design and construction experience through its participation in the annual Student Launch (SL) Competition hosted by NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama. Approximately 40 club members participate in SL competition design and construction and are led by a group of Aerospace Engineering seniors (Section 1.4.1) who's participation in the SL competition satisfies their senior design capstone project requirements. The final SL competition score given to the NC State University team will correspond to the final grade the Senior Design Team will receive for their capstone project. The Senior Design Team and club officers regularly communicate the research, design, construction, testing, and launch of high-power rockets with team mentors (mentioned in Section 1.1) who will supervise each of the steps the club takes throughout the SL competition. The club also includes an experimental subsystem, not connected to the SL competition, that is led by the acting Vice President and run by underclassmen to develop additional systems such as air brakes, rail extensions, and a rover payload prototype.

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 the safe use of lab materials, including, but not limited to, drill press, hand tools, band saw, miter saw, flammable items, and hazardous materials. Megan is required to attend all club launches and must be present in the lab during the construction of the launch vehicle, payload, and associated components. Additionally, Megan is responsible for maintaining the lab space and equipment and ensuring they meet or exceed 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 the flame and hazardous materials cabinet, stocking an appropriate first aid kit, ensuring the proper use of PPE, and educating members on safe equipment operation. In the event of Megan's absence in the lab or at the launch field, a qualified team member will be appointed to perform all of Megan's responsibilities.

1.4 Student Team Leader

i. Name: Hanna McDaniel

ii. Email: hgmcdani@ncsu.edu

iii. Phone: (336) 553-7882

iv. Responsibilities: Hanna will act as the NC State University Student Team Lead for the 2023-2024 NASA SL Competition. Hanna serves as both the leader of the Senior Design Team, as identified in Section 1.4.1, and President of the High-Powered Rocketry Club (HPRC). As Senior Design Team Lead, Hanna is responsible for managing each subsystem, defined in Section 1.6, overseeing vehicle and payload design and construction and ensuring all documentation is professional and cohesive.

1.4.1 Senior Design Team

The Senior Design Team, shown in Figure 1.1 below, consists of the Student Team Lead (Section 1.4) and seven Aerospace Engineering seniors who will use the SL competition to fulfill their senior design capstone project requirements. The members and their respective roles and responsibilities are described below, in order as pictured from left to right. The subsystems that the Senior Design Team members will lead are defined in Section 1.7.

Figure 1.1: Senior Design Team 2023-2024

i. Name: Franklin Rice

ii. Subsystem: Payload Electronics

iii. Previous years of club involvement: 3

iv. Biography and Responsibilities: Frank is the Aerospace Engineering senior in charge of the payload electronics. He has experience as an electronics technician prior to studying engineering. Frank currently has a Level 2 High-Power Rocketry Certificate through the Tripoli Rocketry Association and is currently working as a research assistant at NCSU studying the mixing of fuel and oxidizer for rocket engines.

i. Name: Cameron Brown

ii. Subsystem: Structures

iii. Previous years of club involvement: 2

iv. Biography and Responsibilities: Cameron is a senior studying Aerospace Engineering. He is responsible for selecting materials for components, the structural testing of such components, and constructing the subscale and full-scale versions of the launch vehicle. He hopes to refine the removable fin system design from the previous year to make it both stronger and lighter. He has worked under the guidance of the structures leads from the previous two years in preparation for this role. Cameron also has his Level 2 High-Power Rocketry Certification through the Tripoli Rocketry Association and has worked as a research assistant at NCSU making curved composites via the VARTM process.

i. Name: Matthew Simpson

ii. Subsystem: Aerodynamics

iii. Previous years of club involvement: 3

iv. Biography and Responsibilities: Matthew is the Aerospace Engineering senior in charge of analyzing and designing the primary structure of the rocket to meet the altitude challenge and comply with all NASA and rocketry safety guidelines. He has previously interned at SpaceX, NASA, and Aerojet Rocketdyne, where he completed various software and optimization projects. He currently works as a student researcher at the Engineering Mechanics and Space Systems Lab (EMSSL). In his free time, he enjoys disc golf and astrophotography.

i. Name: Joseph Alonso

ii. Subsystem: Payload Structures

iii. Previous years of club involvement: 2

iv. Biography and Responsibilities: Joseph is a senior in Aerospace Engineering. As the Payload Structures Lead, he is in charge of designing and building the payload structure. He has interned at Teledyne Scientific, building and testing an amphibious, fixed-wing UAV for autonomous, IRS missions. This past Summer, he did research at NCSU, making carbon fiber layups using the VARTM process. In his free time, he does rock climbing and is a big fan of the soccer team, Liverpool FC.

i. Name: Braden Rueda

ii. Subsystem: Recovery

iii. Previous years of club involvement: 1

iv. Biography and Responsibilities: Braden is the Aerospace Engineering senior in charge of developing the recovery subsystem and ensuring the launch vehicle has a safe descent and landing. He hopes to develop a successful avionics bay and get as many points as possible with recovery for NASA SL this year. Previously, he worked in the Lightweight Active Structures Laboratory and assisted in the Smart Composites Laboratory. In his free time, he enjoys watching and playing soccer as well as running.

i. Name: Shyanne Large

ii. Subsystem: Integration

iii. Previous years of club involvement: 2

iv. Biography and Responsibilities: Shyanne is a senior studying Aerospace Engineering. She is responsible for the implementation of new payload and structures ideas added to the launch vehicle. Additionally, Shyanne relays the various concepts discussed to the different subsystems and assists the Team Lead with project management. This year, Shyanne plans to help maintain project organization as well as assist both vehicle and payload teams with the design and fabrication process. When Shyanne graduates she would like to start a career related to the design and building of rockets and/or lunar bases. Outside of the club, She is a member of NC State's Women's Rugby Club.

i. Name: Michael Wax

ii. Subsystem: Payload Systems

iii. Previous years of club involvement: 2

iv. Biography and Responsibilities: Michael is a senior studying Aerospace Engineering and Computer Science. As Payload Systems Lead, he is responsible for designing and developing software that may be needed for payload deployment and/or operation, as well as ensuring the safety of the STEMnauts during landing. This year, he hopes to provide a solid underlying foundation for the deployment and landing of the SAIL so as not to harm the STEMnauts. Michael previously worked at Honda Aircraft Company's Integration Test Facility (ITF) as a Simulation and Software Engineer Intern. At Honda Aircraft, he worked on automating simulator operations as well as developing new physics-based models for the flight simulator's ground reaction. In his free time, Michael likes to read, play video games, and play the drums.

1.5 Leadership Team Organization

The 2023-2024 HPRC leadership team consists of two groups: the Senior Design Team and club officers. While both groups have different responsibilities for the operation of the club and SL competition, the group as a whole is responsible for leading the approximately 40 undergraduate students through the SL competition and other rocketry-related club activities. The Senior Design Team members and duties are described in Section 1.4.1 and the HPRC officers and their duties are introduced below, in order as pictured from left to right.

Figure 1.2: Club Leadership Team 2023-2024

i. Name: Trent Couse

ii. Position: Treasurer

iii. Previous years of club involvement: 4

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 reach out to new partners for the club and restructure the management of all club finances. In his free time, he enjoys climbing.

i. Name: Lauren Scott

ii. Position: Social Media Officer

iii. Previous years of club involvement: 1

iv. Biography and Responsibilities: Lauren is a sophomore in Mechanical Engineering. She intends to make sure HPRC is active on all social media platforms in an aesthetic and informative way, as well as revamp some of the older, underutilized accounts. She enjoys creating art and dancing ballet in her free time.

i. Name: Megan Rink

ii. Position: Safety Officer

iii. Previous years of club involvement: 2

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 also a massive audiophile and an avid record collector.

i. Name: Sofia Antinozzi

ii. Position: Secretary

iii. Previous years of club involvement: 2

iv. Biography and Responsibilities: Sofia is a junior in Material Science and Engineering. She plans to keep the club on track by communicating with club members and outside organizations as HPRC's primary point of contact. She works in the Corrosion and Advanced Materials Lab at NC State.

i. Name: Hanna McDaniel

ii. Position: President

iii. Previous years of club involvement: 2

iv: Biography and Responsibilities: Hanna is a senior in Aerospace Engineering. Her responsibilities as Club President and Senior Design Team Lead include managing both the club and senior design team, and maintaining order in the Rocketry Lab. She aims to make work in the lab more comfortable and welcoming to newer members and instill in them the confidence to apply their engineering knowledge to real-world problems. In her free time, Hanna enjoys reading, writing, and studying animation.

i. Name: Elizabeth Bruner

ii. Position: Outreach Officer

iii. Previous years of club involvement: 1

iv. Biography and Responsibilities: Elizabeth is a sophomore in Aerospace Engineering. This year she will be focusing on hosting more outreach events on campus and also building more connections with local schools. In her free time she likes to hike and crochet.

i. Name: Katelyn Yount

ii. Position: Vice President

iii. Previous years of club involvement: 2

iv. Biography and Responsibilities: Katelyn is a junior in Aerospace Engineering and is responsible for leading WolfWorks Experimental. She hopes to improve the design and recovery system of the rover payload for this year's interest launch, then start new projects that will get more people interested and experienced in high-power rocketry. She also has a Level 1 High-Power Rocketry Certificate through the Tripoli Rocketry Association. In her free time, she enjoys swimming and hiking.

i. Name: Craig Abell

ii. Position: Webmaster

iii. Previous years of club involvement: 1

iv. Biography and Responsibilities: Craig is a sophomore in Computer Science. He plans to keep the website looking good and up to date, and help the Senior Design Team stay organized to facilitate knowledge transfer to less experienced members. In his free time, he enjoys rock climbing and playing roundnet.

1.6 Subsystem Definition

For the ease of task delegation, the team has been divided into subsystems that are responsible for the design and fabrication of the primary components of the vehicle and payload. Each subsystem, led by a member of the Senior Design Team, identified in Section 1.4.1, is responsible for the incorporation and verification of a subset of requirements identified in the "Subsystem Allocation" column of each requirement verification table. The team has been divided into the following subsystems:

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

The Project Management Team, led by Team Lead Hanna McDaniel, is responsible for managing the team's university communications for the fulfillment of senior design capstone project requirements, ensuring project schedules are being followed, and mitigating any conflicts that arise between subsystems. The Project Management Team is also responsible for organizing launches, documentation, and communication with NASA, NAR, and TRA. The Safety Team, led by Megan Rink, is responsible for the implementation of risk mitigation procedures developed by the team. These procedures include dedicated safety briefings, the monitoring of lab and launch field activities, and maintaining safety documentation. The Integration Team, led by Senior Design Team member Shyanne Large, is responsible for system-level integration between the launch vehicle and the payload and verification of correct subsystem interfaces required for mission success. The Aerodynamics Team, led by Senior Design Team member Matthew Simpson, is responsible for vehicle flight simulations, motor selection, fin and nose cone design, apogee determination, and stability management. The Structures Team, led by Senior Design Team member Cameron Brown, is responsible for vehicle material selection, structural verification and testing, and construction of the subscale and full-scale launch vehicle. The Recovery Team, led by Senior Design Team member Braden Rueda, is responsible for the design and fabrication of the recovery system of the vehicle. This includes, but is not limited to, black powder charges, altimeters, and parachutes. The Payload Electronics Team, led by Senior Design Team member Franklin Rice, is responsible for the design, implementation, and verification of the electrical hardware required to satisfy payload requirements. The Payload Structures Team, led by Senior Design Team member Joseph Alonso, is responsible for the design and construction of the primary load-bearing structure of the payload. Lastly, the Payload Systems Team, led by Senior Design Team member Michael Wax, is responsible for designing and implementing any software required for the deployment and operation of the payload during decent as well as ensuring the safety of the STEMnauts during landing.

1.7 Local NAR/TRA Chapter Information

The NC State University SL team will be working with the Tripoli East NC prefecture (TRA Prefecture 65). The prefect for this chapter is currently Kurt Hesse. Club mentor, Alan Whitmore, whose qualifications are listed in Section 1.1, is responsible for the purchase and storage of all motors for vehicle launches during the SL competition. These motors will be purchased only under his approval and will be stored according to his specific safety requirements. At launches, all motors will be assembled and installed under Alan's supervision. Jim Livingston, whose qualifications are listed in Section 1.1, is also 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

The team has spent approximately 88 hours on proposal. This includes time spent on brainstorming, attending meetings, and writing this document.

2 Facilities and Equipment

2.1 Description

The team will use 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, miter saw, and handheld power tools. Club members who have completed additional training may also access 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 various handheld power tools.

Additionally, HPRC has access to a high-precision machine shop in Engineering Building III. The shop supervisor, J. Steve Cameron, takes machining requests and delivers the product within approximately one week. HPRC also has supervised access to the Aerospace Vehicle Structures Lab in Engineering Building III Room 2208, which provides a tensile and compressive loading machine for structural testing. Senior Design Team members have access to the NC State MAE Senior Design Machining Lab, which includes a Makerbot 3D printer, with required training facilitated by the lab manager, Amos Tucker. The Senior Design Team also has access to the Aerospace Engineering Senior Design Space Lab in Engineering Building III Room 1224.

2.2 Hours of Accessibility

The Rocketry Lab in 2003 Engineering Building III is open to HPRC officers and Senior Design Team members from:

Monday – Sunday: 6 am – 12 am

The Entrepreneurship Initiative Garage is open to all trained undergraduates at NC State from:

Monday - Wednesday: 8:30 am – 4:30 pm

Thursday – Friday: 11 am – 7 pm

The NC Sate MAE Senior Design Machining Lab is open to all trained members of the Senior Design Team from:

Monday - Thursday: 8 am - 5 pm

Friday: 10 am - 4 pm

The Aerospace Engineering Senior Design Space Lab is open to all members of the Senior Design Team from:

Monday - Friday: 7 am - 10 pm

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

2.3 Necessary Personnel

The club Safety Officer, identified in Section 1.5, or a qualified individual from the Safety Team, 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 high-precision machine shop.

2.4 Available Equipment

HPRC members have access to a variety of tools, equipment, and supplies that can be utilized throughout the design and fabrication process. Within the Rocketry Lab, the team has access to a drill press with 12 in. of travel, scroll saw, band saw, belt sander, miter saw, and soldering iron. Each of these tools are kept in the lab to prevent unauthorized use. Additionally, the team also has access to handheld tools including a DeWalt 18V drill, DeWalt jigsaw, Dremel 4300 rotary tool, Rigid oscillating cutting tool, and Wagner heat gun. Each of these tools are also kept in the Rocketry Lab. HPRC members can also utilize smaller handheld tools in the lab such as files, screwdrivers, wrenches, cutting implements, and clamps. Finally, the Rocketry Lab is equipped with compressed air lines that can be used to vacuum bag composite layups.

As mentioned in Section 2.1, additional equipment such as laser cutters, 3D printers, tensile testing machines, and high-precision machining equipment are available for the team in other lab spaces on NC State's campus.

2.5 Supplies Required

An initial list of materials needed to design and build the launch vehicle and payload is shown in Section 6.2. The team owns certain materials accumulated from previous years such as parachutes of various sizes, two Stratologger altimeters, an Eggtimer Quasar, aircraft-grade birch plywood, black powder, a Raspberry Pi, ESP-32, and an Arduino Nano. Additionally, the team will purchase and utilize PPE, including safety glasses, nitrile gloves, and particle masks, throughout the year.

Furthermore, the team makes use of different software packages throughout project development. This software includes applications through Microsoft's Office Suite, SolidWorks, ANSYS, and MATLAB, all of which are acquired using a university license. The team has purchased a license for RockSim, which is used for launch vehicle flight simulations, but also has access to OpenRocket as a backup. Finally, the team has an educational license for Asana, a Kanban board and task management application.

3 Safety

3.1 Safety Requirements

Table 3.1 below contains the safety requirements outlined by the 2024 NASA Student Launch Handbook.

Table 3.1: 2023-2024 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
4.3.3.	Any payload experiment element that is jettisoned during the recovery phase SHALL receive real-time RSO permission prior to initiating the jettison event, unless exempted from the requirement by the RSO or NASA.	The Safety Team works with the RSO to ensure all guidelines are followed.	Demonstration	All
5.1	Each team SHALL use a launch and safety checklist. The final checklists SHALL be included in the FRR report and used during the Launch Readiness Review (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
5.2.	Each team SHALL identify a student Safety Officer who will be responsible for all requirements in Section 5.3.	The student Safety Officer, is identified in documentation.	Validation of Records	Safety
5.3.1.1.	The designated 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 designated 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 designated 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 designated student 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 designated student 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 designated student 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 designated student 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 designated student 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 designated student 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 designated student 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 designated student 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 SHALL 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 local rocketry club rules and regulations are followed by all team members.	Demonstration	Safety
5.5.	The team SHALL abide by all rules set forth by the FAA.	The Safety Team ensures all rules from the FAA are followed.	Demonstration	All

3.2 Safety Plan/Agreement

3.2.1 Students Responsible

Megan Rink is serving as the 2023-2024 Safety Officer for HPRC. Megan is responsible for overseeing the safety of both lab and launch activities, generating accurate and comprehensive safety documentation, and ensuring safety plan adherence. In her absence, other Safety Team 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. Most fabrication of launch vehicles and payload components will take place in this lab with the use of in-lab tools and materials. Below, tables of hazardous tools, equipment (Table 3.3), and materials (Table 3.2) are provided along with associated preliminary risk 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
Band Saw	Tool Island	Safety glasses, particle mask
Belt Sander	Tool Island	Safety glasses, particle mask
Drill Press	Tool Island	Safety glasses, particle mask
Miter Saw	Tool Island	Safety glasses
Dremel	Tool Cabinet	Safety glasses, particle mask
Soldering Iron	Electronics Bench	Safety glasses
3D Printer	Electronics Bench	n/a

3.2.3 Team Member Safety Agreement

2023-24 NASA SLI Safety Acknowledgement

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 Hanna McDaniel	[signature]	8/31
Cameron Brown	[signature]	8/31
Franklin Rice	[signature]	08/31
Joseph Alonso	[signature]	08/31
Matthew Simpson	[signature]	08/31
Michael Wax	[signature]	8/31
Shyanne Large	[signature]	8/31
Braden Rueda	[signature]	8/31
HPRC Officer Team Megan Rink	[signature]	8/31
Katelyn Yount	[signature]	8/31
Trent Couse	[signature]	9/01

2023-24 NASA SLI Safety Acknowledgement

Lauren Scott	Lauren Scott	8/31
Elizabeth Bruner	Elizabeth Bruner	8/31
Craig Abell	CAbell	8/31
Sofia Antinozzi	Sofia Antinozzi	8/31

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 will 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, PPE, fire extinguishers, and other safety materials. Before admittance into the lab, all club members must pass a cursory lab safety quiz created by the Safety Officer.

Before all launches, the student Safety Officer will provide a briefing that is mandatory for all students attending the launch at the General Body Meeting before the planned launch date. Members who do not attend the safety briefing either in-person or on Zoom become ineligible to attend the 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 will also be included in order for personnel to dress and prepare properly for the launch field.

3.5 Including Safety In Documentation

Throughout the year, the Safety Team will perform thorough analyses, primarily using Failure Mode and Effects Analysis (FMEA) tables. In future documents, Fault Tree Analysis (FTA) will also be utilized.

3.5.1 FMEA

The FMEA tables will be accompanied by likelihood-severity (LS) matrices for a more visual and understandable graphic. Below is an example of the LS matrices the Safety Team will complete throughout the competition.

Table 3.4: FMEA LS 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

Table 3.5: FMEA Example

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 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 the airspace in order to reduce the risk of injury, death, or destruction of property while launching high-power rockets. NAR/TRA personnel present and assisting at competition launches will ensure clear airspace and safe launching conditions on launch days.

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

The sub-parts of the Federal Aviation Regulations concerning general operating limitations of the launch of high-power rockets details where and when high-power 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-power rocket:

(a) At any altitude where clouds or obscuring phenomena of more than five-tenths coverage prevails;

(b) At any altitude where the horizontal visibility is less than five miles;

(c) Into any cloud;

(d) Between sunset and sunrise without prior authorization from the FAA;

(e) Within 9.26 kilometers (5 nautical miles) of any airport boundary without prior authorization from the FAA;

(f) In controlled airspace without prior authorization from the FAA;

(g) Unless you observe the greater of the following separation distances from any person or property that is not associated with the operations:

  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;

(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-power 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-power 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

Table 4.1 below contains the general requirements outlined by the 2024 NASA Student Launch Handbook.

Table 4.1: 2023-2024 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.	Members of NC State's High-Powered Rocketry Club fabricate a solution to the criteria given in the Student Launch Handbook, implementing past ideas while developing new ones.	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, Integration Lead, Treasurer, Secretary, Safety Officer, Webmaster, and Social Media Lead manage the tasks related to this requirement.	Inspection	Project Management
1.3	Team members who will travel to the Huntsville Launch SHALL have fully completed registration in the NASA Gateway system before the roster deadline.	The Team Lead determines the team members attending Huntsville and ensures team members register in the NASA Gateway system no later than January 8, 2024.	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 determines the students that have been actively engaged to invite them to competition.	Inspection	Project Management
1.3.2	Team members SHALL include one mentor (see Requirement 1.13).	The Team Lead invites the mentor(s) identified in Section 1.1 to attend competition.	Inspection	Project Management
1.3.3	Team members SHALL include no more than two adult educators.	The Team Lead invites the adult educator(s) shown in Section 1.1 to attend competition.	Inspection	Project Management
1.4	Teams SHALL engage a minimum of 250 participants in Educational Direct Engagement STEM activities. These activities can be conducted in-person or virtually. To satisfy this requirement, all events SHALL occur between project acceptance and the FRR addendum due date. A template of the STEM Engagement Activity Report can be found on pages 86 – 89.	The Outreach Lead offers STEM engagement opportunities to K12 students for the duration of project development and submits STEM Engagement Activity Reports within two weeks of the event.	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 collaborate to maintain our website and social media presence to educate the public about activities and events held by the team. Our social media platforms include, but are not limited to: our club website, TikTok, Facebook, and Instagram.	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, and FRR milestone documents SHALL be accepted up to 72 hours after the submission deadline. Late submissions SHALL incur an overall penalty. No PDR, CDR, and FRR milestone documents SHALL be accepted beyond the 72-hour window. Teams that fail to submit the PDR, CDR, and FRR milestone documents SHALL be eliminated from the project.	The Team Lead emails all documents to the NASA project management team before the specified deadlines. If a deliverable is too large, the Webmaster uploads the document to the club's website, and the Team Lead emails the NASA Project Management Team a link to view said document.	Inspection	Project Management
1.7	Teams who do not satisfactorily complete each milestone review (PDR, CDR, FRR) SHALL be provided action items 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 team's status in the program and the team SHALL be notified shortly thereafter.	If a milestone review is not completed satisfactorily, the team completes any action items given 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 sends all deliverables in PDF format 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 adjusts a table of contents in every report.	Inspection	Project Management
1.10	In every report, the team SHALL include the page number at the bottom of the page.	The team uses a template which displays the page number at the bottom of each page for every report.	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.	The team obtains the equipment needed to attend 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 ft. 1010 rails and 12 ft. 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 that utilizes 8 ft. 1010 rails or 12 ft. 1515 rails. The Structures Lead builds the launch vehicle according to these specifications.	Inspection	Aerodynam-ics, 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 launch vehicle 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 Leader determines a qualified adult to mentor the team throughout project development and attend Launch Week.	Inspection	Project Management
1.14	Teams SHALL track and report the number of hours spent working on each milestone.	The team records the number of hours spent working on each milestone and documents this in the designated report.	Inspection	Project Management

4.1.1 Launch Vehicle Requirements

Table 4.2 below contains the requirements for the launch vehicle as outline in the 2024 NASA Student Launch Handbook.

Table 4.2: 2023-2024 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 will receive zero altitude points towards their overall project score and will not be eligible for the Altitude Award.	The Aerodynamics and Structures Leads design a launch vehicle to deliver the payload to an apogee between 4,000 and 6,000 ft. AGL. The team fabricates the launch vehicle as designed.	Analysis, Demonstration	Aerodynamics, Structures
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 target altitude goal by October 26, 2023 in the PDR milestone.	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 Lead designs a recovery system that prevents the launch vehicle from being damaged upon ground impact.	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 launch vehicle to have no more than four 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 the coupler/airframe shoulders at in-flight separation points at least 2 airframe diameters in length. The Structures Lead builds the couplers to the specified lengths.	Inspection	Aerodynamics, Structures
2.4.2	Coupler/airframe shoulders which are located at non-in-flight separation points SHALL be at least 1.5 airframe diameters in length (0.75 body diameter of surface contact with each airframe section.)	The Aerodynamics Lead designs the coupler/airframe shoulders at non-in-flight separation points at least 1.5 airframe diameters in length. The Structures Lead builds the couplers to the specified lengths.	Inspection	Aerodynamics, Structures
2.4.3	Nosecone shoulders which are located at in-flight separation points SHALL be at least 0.5 body diameters in length.	The Aerodynamics Lead designs the nosecone shoulders at in-flight separation points to be a minimum of 0.5 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 Team and Safety Officer creates a launch day checklist that can be completed within two 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 3 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged.	The Project Management Team and Safety Officer ensure functionality of electrical components for a minimum of three hours by monitoring power consumption.	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 Team and Safety Officer pick a motor from a designated launch services provider that can be ignited by 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 Team and Safety Officer design the launch vehicle such that no external circuitry or special ground support equipment is needed for launch.	Demonstration	Safety
2.9	Each team SHALL use commercially available e-matches or igniters. Hand-dipped igniters SHALL not be permitted.	The Project Management Team and Safety Officer utilize commercially available e-matches 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 purchased solid motor propulsion system with APCP certified by NAR, TRA, and/or CAR.	Inspection	Aerodynamics
2.10.1	Final motor choice SHALL be declared by the Critical Design Review (CDR) milestone.	The Aerodynamics Lead states the finalized motor choice in the CDR milestone by January 8, 2024.	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 NASA RSO for a motor changed after the CDR milestone deadline.	Inspection	Project Management
2.11	The launch vehicle SHALL be limited to a single motor propulsion system.	The Aerodynamics Lead designs the launch vehicle to use a single motor propulsion system.	Inspection	Aerodynamics
2.12	The total impulse provided by a College or University launch vehicle SHALL not exceed 5,120 Ns (L-class).	The Aerodynamics Lead picks a motor that does not exceed a total impulse of 5,120 Ns.	Inspection	Aerodynamics
2.13	Pressure vessels on the vehicle SHALL be approved by the RSO.	The Structures Lead gets RSO approval for any on-board pressure vessels.	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 provides design documentation in each milestone report supporting a minimum factor of safety of 4:1.	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 picks pressure vessels which include a pressure relief valve system that sees the full pressure of the tank and can withstand 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 will 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 describes the entire history of each pressure vessel, including the number of pressure cycles, the dates of pressurization/depressurization, and name of the person or entity administering each pressure event.	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 to have a minimum static stability margin of 2.0 at the rail exit.	Analysis	Aerodynamics
2.15	The launch vehicle SHALL have a minimum thrust to weight ratio of 5:1.	The Aerodynamics Lead designs the launch vehicle to have a minimum thrust to weight ratio of 5:1.	Analysis, Inspection	Aerodynamics
2.16	Any structural protuberance on the launch vehicle SHALL be located aft of the burnout center of gravity. Camera will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the launch vehicle's stability.	The Aerodynamics Lead designs the launch vehicle to have any protuberances located aft of the burnout center of gravity. If camera's are included, the Aerodynamics Lead will prove the housings cause minimal aerodynamic effect on the launch vehicle's stability.	Analysis, Inspection	Aerodynamics
2.17	The launch vehicle SHALL accelerate to a minimum velocity of 52 ft/s at rail exit.	The Aerodynamics Lead designs the launch vehicle to reach a minimum velocity of 52 ft/s at the rail exit.	Analysis	Aerodynamics

2.18	All teams SHALL successfully launch and recover a subscale model of their launch vehicle 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 Project Management Team launches a subscale model of the launch vehicle before CDR using an impulse motor of class E or higher. The Project Management Team and Safety Officer successfully recovers the subscale and reports flight data in the CDR milestone by January 8, 2024.	Demonstration	Project Management, Safety
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 subscale model that performs similarly to the full-scale model.	Inspection	Aerodynamics
2.18.2	The subscale model SHALL carry an altimeter capable of recording the model's apogee altitude.	The Recovery Lead attaches an altimeter to record the apogee altitude of the subscale model.	Inspection	Recovery
2.18.3	The subscale launch vehicle SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The Aerodynamics and Structures Leads design and fabricate a new subscale launch vehicle that meets the criteria for this year's project.	Inspection	Aerodynamics, Structures
2.18.4	Proof of a successful subscale flight SHALL be supplied in the CDR report.	The Project Management Team shows proof of successful subscale flight in the CDR report by January 8, 2024.	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 makes an altimeter flight profile graph which displays 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 is not limited to nosecone, recovery system, airframe, and booster.	The Project Management Team and Recovery Lead takes pictures of the landing configuration of all sections of the launch vehicle and includes them in the CDR milestone by January 8, 2024.	Analysis, Demonstration	Project Management, Recovery
2.18.5	The subscale launch vehicle SHALL not exceed 75% of the dimensions (length and diameter) of the designed full-scale launch vehicle (if the full-scale launch vehicle is a 4 in. diameter, 100 in. length rocket, your subscale SHALL not exceed 3 in. diameter and 75 in. in length).	The Aerodynamics and Structures Lead design the subscale launch vehicle to not exceed 75% of the dimensions used for the full-scale launch vehicle.	Inspection	Aerodynamics, Structures
2.19.1	**Vehicle Demonstration Flight**. All teams SHALL successfully launch and recover their full-scale launch vehicle prior to FRR in its final flight configuration. The launch vehicle flown SHALL be the same launch vehicle flown at competition launch. Requirements 2.19.1.1-9 SHALL be met during the Vehicle Demonstration Flight:	The Project Management Team launches and recovers the full-scale vehicle, to be flown for competition, in its final flight configuration before the FRR milestone.	Demonstration	Project Management

2.19.1.1	The vehicle and recovery system SHALL function as designed.	The Project Management Team identifies no abnormalities in the performance of the vehicle and recovery system.	Demonstration	Project Management
2.19.1.2	The full-scale launch vehicle SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The Aerodynamics and Structures Leads design and build a new full-scale launch vehicle, meeting the criteria for this year's project.	Inspection	Aerodynamics, Structures
2.19.1.3.1	If the payload is not flown during the Vehicle Demonstration Flight, mass simulators SHALL be used to simulate the payload mass.	The Structures Lead installs mass simulators to mimic payload mass if the payload is not flown during VDF.	Inspection	Structures
2.19.1.3.2	The mass simulators SHALL be located in the same approximate location on the launch vehicle as the missing payload mass.	The Structures Lead installs mass simulators at the approximate location on the launch vehicle as the missing payload if the payload is not flown during VDF.	Inspection	Structures
2.19.1.4	If the payload changes the external surfaces of the launch vehicle (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.	The Payload Team activates systems during VDF if the payload changes the external surface or manages the total energy of the vehicle.	Inspection	Payload
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 selects the same motor for both competition launch and the VDF. If the selected motor cannot be flown for VDF due to extenuating circumstances, the Project Management Team requests a waiver for an alternative motor in advance.	Inspection	Aerodynamics, Project Management
2.19.1.6	The launch 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 SHALL not be added without a re-flight of the full-scale launch vehicle.	The Aerodynamics Lead determines the fully ballasted configuration. The Structures Lead installs the needed ballast for the full-scale test.	Inspection	Aerodynamics, Structures
2.19.1.7	After successfully completing the full-scale Vehicle Demonstration Flight, the launch vehicle or any of its components SHALL not be modified without the concurrence of the NASA Range Safety Officer (RSO).	The Project Management Team does not allow any further modifications of the launch vehicle or its components after VDF without NASA and RSO approval.	Inspection	Project Management
2.19.1.8	Proof of a successful Vehicle Demonstration Flight SHALL be supplied in the FRR report.	The Project Management Team provides proof of successful VDF in the FRR report.	Inspection	Project Management
2.19.1.8.1	Altimeter flight profile graph(s) that are not complete (liftoff through landing) SHALL not be accepted.	The Recovery Lead provides complete altimeter data acquired from the VDF in the FRR milestone.	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 is not limited to nosecone, recovery system, airframe, and booster.	The Project Management Team and Recovery Lead takes pictures of the landing configuration of all sections of the launch vehicle and includes them in the FRR milestone.	Inspection	Project Management, Recovery
2.19.1.9	The Vehicle Demonstration Flight 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. Teams completing a required re-flight SHALL submit an FRR Addendum by the FRR Addendum deadline.	The Project Management Team completes the VDF by the FRR submission deadline. If re-flight is necessary, 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 launch vehicle containing the completed payload prior to the Payload Demonstration Flight deadline. The launch vehicle flown SHALL be the same launch vehicle to flown at competition launch. Requirements 2.19.2.1-4 SHALL be met during the Payload Demonstration Flight.	The Project Management Team launches and recovers the full-scale launch vehicle containing the completed payload before 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 Integration and Payload Leads ensure the payload is fully retained until the intended point of deployment, with each retention mechanism functioning as designed and not sustaining damage during flight.	Inspection	Integration, Payload
2.19.2.2	The payload flown SHALL be the final, active version of the payload.	The Project Management and Payload Teams ensures the payload flown during the PDF is the final active version of the payload.	Inspection	Project Management, Payload
2.19.2.3	If Requirements 2.19.2.1-2 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 SHALL not be required.	The Project Management Team verifies all requirements are met for the VDF and are submitted prior to the FRR deadline. If all requirements are not met, the team performs an additional flight for PDF and submits the FRR Addendum.	Inspection	Project Management
2.19.2.4	Payload Demonstration Flights SHALL be completed by the FRR Addendum deadline.	The Project Management Team ensures the PDF is completed 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.	The Project Management Team submits an FRR Addendum if the team completes the PDF or NASA required re-flight after the submission of the FRR.	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 ensures PDF and re-flight completion before the FRR Addendum deadline.	Inspection	Project Management
2.20.2	Teams who complete a Payload Demonstration Flight which is not successful may petition the NASA RSO for permission to fly the payload at the final competition launch. 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 permission to fly the payload at the final competition launch if the PDF is not successful.	Demonstration	Project Management
2.21	The team's name and launch day contact information SHALL be in or on the launch vehicle 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 launch day contact information on the launch vehicle airframe, and any sections that separate during flight, 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 Team and Safety Officer clearly mark all lithium polymer batteries as a fire hazard and sufficiently protects them 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 selects a motor that is not forward firing.	Inspection	Aerodynamics
2.23.2	The launch vehicle SHALL not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	The Aerodynamics Lead selects a motor that does not utilize motors that expel titanium sponges.	Inspection	Aerodynamics
2.23.3	The launch vehicle SHALL not utilize hybrid motors.	The Aerodynamics Lead selects a motor that is not hybrid.	Inspection	Aerodynamics
2.23.4	The launch vehicle SHALL not utilize a cluster of motors.	The Aerodynamics Lead designs the launch vehicle to be launched on a single motor.	Inspection	Aerodynamics
2.23.5	The launch vehicle SHALL not utilize friction fitting for motors.	The Structures Lead fabricates a motor retention system that does not use friction fitting to hold the motor.	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 so that it does not reach Mach 1 at any point in flight.	Analysis	Aerodynamics

2.23.7	Vehicle ballast SHALL not exceed 10% of the total unballasted weight of the launch vehicle as it would sit on the pad (i.e. a launch vehicle 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 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 choose onboard transmitters that do not exceed 250 mW of power (per 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 select transmitters that create minimal interference. The Safety Lead ensures the use of unique frequencies to mitigate interference with other teams.	Analysis, Demonstration	Recovery, Payload, Safety
2.23.10	Excessive and/or dense metal SHALL not be utilized in the construction of the launch 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 fabricates the launch vehicle to have the minimal amount of metal used in the construction of the vehicle.	Inspection	Structures

4.2 Launch Vehicle Design

4.2.1 Launch Vehicle Dimensions

The dimensions for all internal and external sections of the launch vehicle are shown below in Figures 4.1 and 4.2.

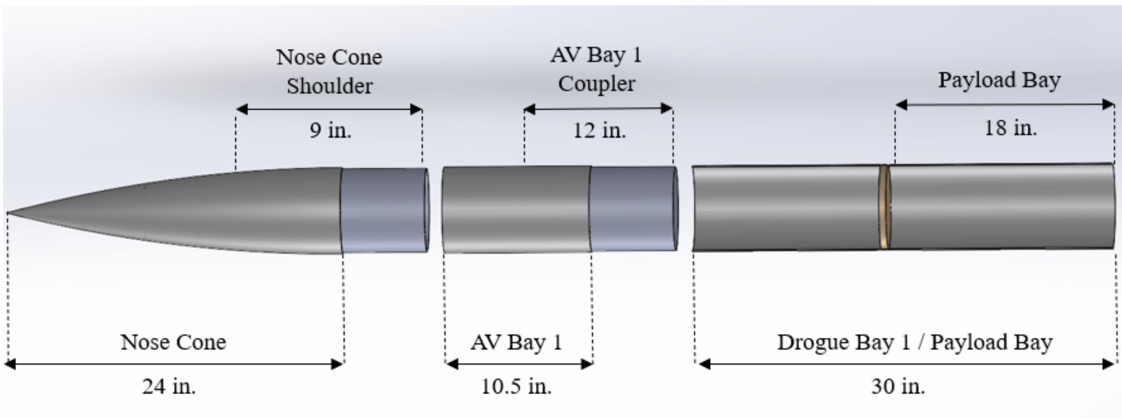

Figure 4.1: CAD model of the top half of the launch vehicle with dimensions.

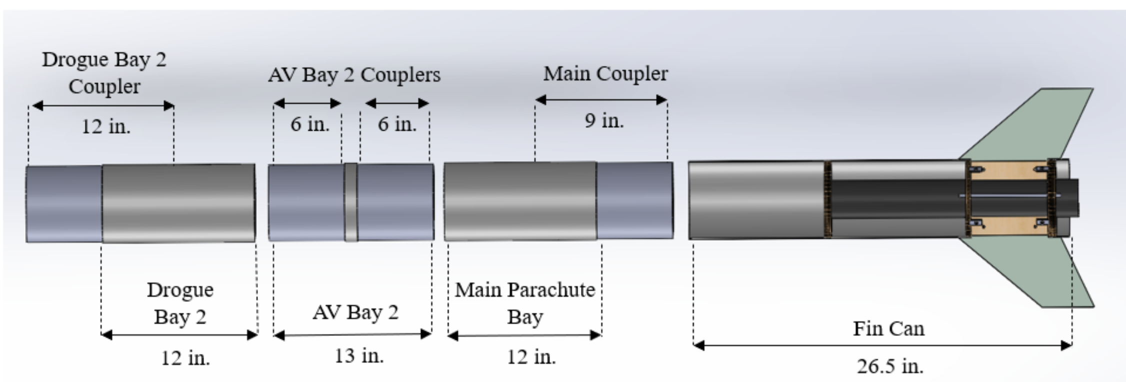

Figure 4.2: CAD model of the bottom half of the launch vehicle with dimensions.

Nose Cone

The nose cone will be a 6 in. diameter 4:1 tangent ogive with an anodized aluminum tip. A 9 in. coupler per Requirement 2.4.2 will be epoxied to the nose cone to connect it to the launch vehicle. 4.5 in. of the coupler will be located within the nose cone and 4.5 in. of the coupler will extend past the nose cone aft to interface with AV bay 1. The nose cone will be connected to AV Bay 1 with 4 #8-32 machine screws. A bulkhead will be secured in the nose cone to mount recovery hardware for drogue parachute 1.

Main Parachute Bay

The main parachute bay is located between AV bay 2 and the fin can. It consists of a 12 in. long body tube with a 9 in. coupler epoxied to one end, per Requirement 2.4.2. 4.5 in. of the coupler will be located within the main parachute bay and 4.5 in. of the coupler will extend past the main parachute bay aft to interface with the fin can. The main parachute bay will be connected to the fin can and AV bay 2 using 4 nylon rivets and 4 shear pins, respectively.

Avionics Bay

The launch vehicle will contain two avionics bays, hereafter known as AV1 and AV2. AV1 will be located between the nose cone and the drogue parachute and payload bay. AV1 consists of a 10.5 in. section of body tube with a 12 in. coupler epoxied to one end, leaving 6 in. of exposed coupler per Requirement 2.4.1. At the end of this coupler will be a bulkhead containing blast caps and mounting hardware for recovery. AV1 will be connected to the nose cone with 4 #8-32 machine screws with permanently fixed nuts, and connected to the drogue parachute and payload bay via 4 shear pins.

AV2 is located between the second drogue parachute bay and the main parachute bay on the bottom half of the launch vehicle. AV2 consists of a 13 in. coupler with a 1 in. section of airframe epoxied on the outside, leaving 6 in. of coupler on each end per Requirement 2.4.1. Bulkheads with blast caps and mounting hardware for recovery will be located on each end of the coupler section. AV2 will be secured to drogue parachute bay 2 with 4 nylon rivets and to the main parachute bay with 4 shear pins.

Drogue Parachute Bay

The first drogue parachute bay is shared with the same 30 in. section of airframe as the payload bay with a bulkhead separating the two sections. This drogue parachute bay is 12 in. long and is secured to AV1 using 4 shear pins.

The second drogue parachute bay is located between the payload bay and AV2. This parachute bay is made of a 12 in. section of airframe with a 12 in. coupler epoxied to one end, leaving 6 in. of exposed coupler per Requirement 2.4.1. The second drogue parachute bay will be secured to the payload bay using four shear pins, and to AV2 using 4 nylon rivets.

Payload Bay

The payload bay is located between drogue parachute bay 1 and drogue parachute bay 2. This 30 in. section of airframe houses both drogue parachute bay 1 and the payload bay, which are separated by a bulkhead. In this section of the airframe, 18 in. is dedicated to the payload. The payload bay will be secured to drogue parachute bay 2 with 4 shear pins.

Fin Can

The fin can will be constructed out of a section of airframe and will house the motor tube, centering rings, and a bulkhead for mounting recovery hardware. The fins can be attached by either permanently epoxying the interior face to the airframe or by securing them in place via a removable fin system. Designs and considerations of both options are shown and discussed below.

i. Fixed Fin Design - The motor casing is held in place by a motor tube that will have two centering rings epoxied around it so that it can be held securely in the larger-diameter airframe. A bulkhead is also epoxied at the forward end of the motor tube. The motor tube assembly is then epoxied into the airframe. The space between the two centering rings is designed to enclose the fin tabs. The edges of these tabs will be epoxied to the motor tube. The remainder of the contact points between the fins and the airframe are sealed permanently with epoxy. A basic CAD model of the fixed-fin design is shown below.

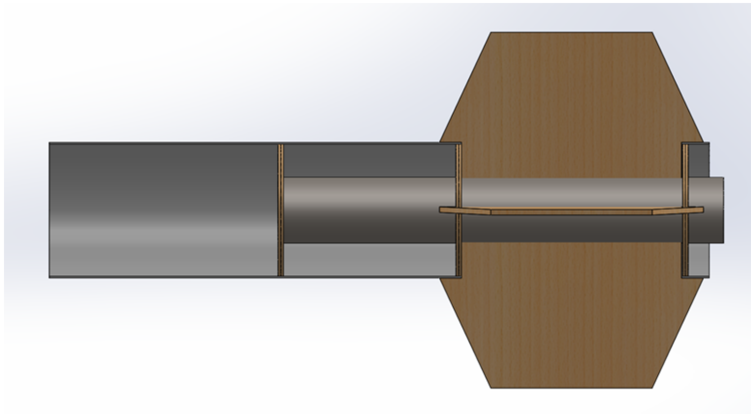

Figure 4.3: CAD model of the fin can using a fixed-fin design.

This method has been used by the team for years to make strong and reliable fin connections. However, if a fin breaks the entire fin can must be replaced.

ii. Removable Fin Design - Two centering rings are connected by threaded rods with enough space between them to sandwich the fin tabs lengthwise. Two runners are then epoxied to the centering rings at the location of each fin with enough space between them to accept the thickness of the fin tabs. Such tabs will have holes drilled into them (as well as the runners) to accept two #8-32 machine screws. Tightening the screws pinches the runners around the fin tab thus keeping the fin in place. Attached to the aft centering ring will be another centering ring with a section of motor tube epoxied to the end of it to accept the motor casing, as well as a motor retaining ring. Between the two aft centering rings will be an aluminum thrust plate which will support the removable fin system structure from the thrust of the motor. Slots for the fins are created in the airframe so that the entire assembly can be slid into the fin can. Finally, two #8-32 machine screws are screwed into the airframe between each fin to hold the removable fin system in place. A basic CAD model for the removable fin design is shown below.

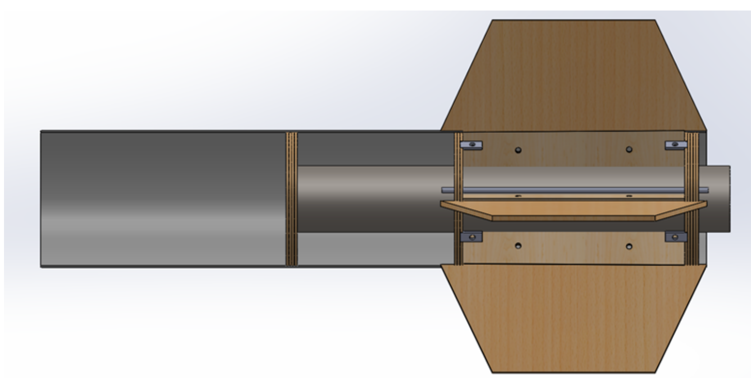

Figure 4.4: CAD model of the fin can using a removable fin design.

The removable fin system retains the strength and reliability of a fixed fin design while also being easy to repair. This design makes the fin can more reusable because the fin can will not have to be rebuilt in the case of fin damage.

Fin Design

The launch vehicle will have 4 aft-swept fins secured to the fin can by a removable fin system.

i. Geometry - The fins will be aft-swept 55 degrees about the leading edge of the fins. Many aerodynamic simulations utilize the quarter chord for this dimensional definition, so this distinction is necessary for further analysis. The launch vehicle interface, or root chord, will be 20.5 cm., the tip chord will be 10.5 cm., and the span will be 12 cm. from root to tip chord, as depicted in Figure 4.5 below. An aft-swept fin geometry was selected instead of a symmetric geometry because the aft-swept fin, with a shift in its mean aerodynamic chord, provides a reduction in chord-wise flow velocity, thus reducing drag. The mean aerodynamic chord of the fin profile is also shifted further aft, shifting the center of pressure of the launch vehicle aft to enhance stability. The advantages of aft-swept fins in transonic flight are not utilized due to the maximum launch vehicle design velocity being approximately mach 0.52.

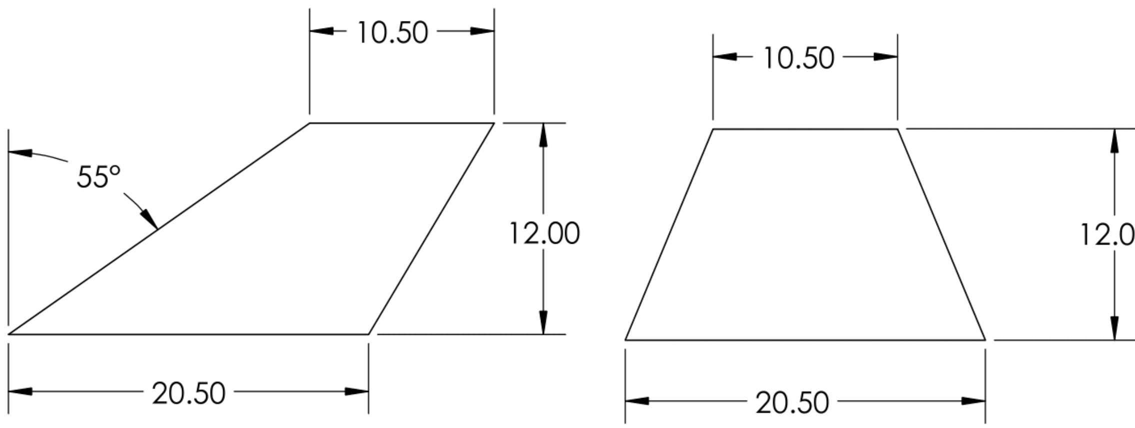

Figure 4.5: Drawing of swept and symmetric basic fin profile (cm.).

ii. Simulation - A preliminary aerodynamic simulation in ANSYS Fluent 3D was used to validate the aerodynamic performance of the fins within the flight envelope. This model will be refined in future documentation. Preliminary results indicate a reduction in the total drag of the aft-swept fins tested against the symmetric design displayed in 4.5. Based on the turbulent kinetic energy profile displayed in 4.6, the flow over the aft-fin shape is highly laminar on the leading edge improving fin control authority. Turbulence only appears along the trailing edge due to a high flow turning angle which can be remediated with fillets or chamfers along that edge on the final fin design.

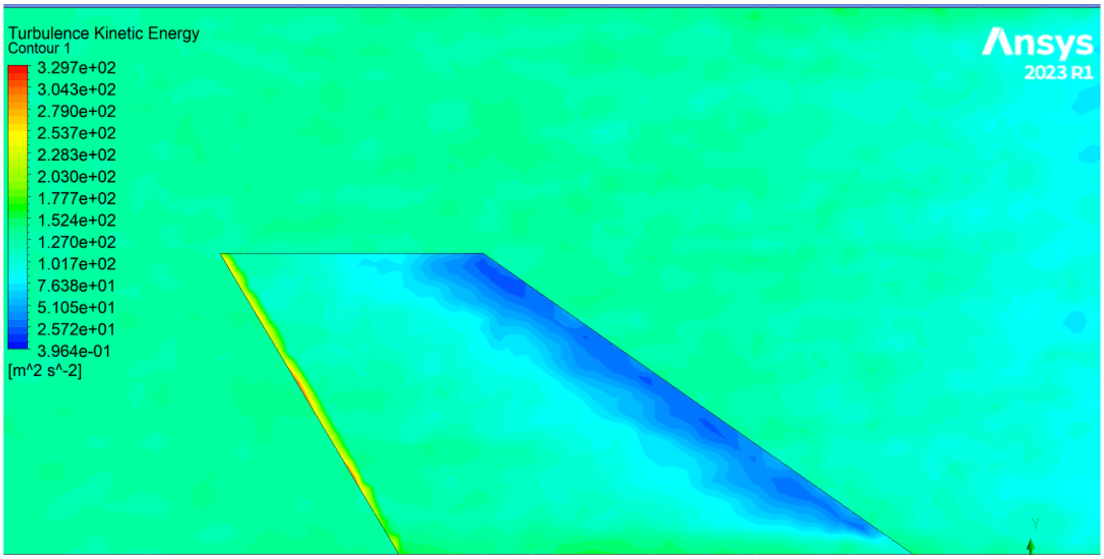

Figure 4.6: Turbulent energy of swept fin profile at 180 m/s.

Bulkhead Design

Bulkheads will be constructed out of 1/8 in. thick sheets of aircraft-grade plywood. Aircraft-grade plywood is lightweight, strong, and reliable which is adequate for the construction of bulkheads. To achieve the desired thickness of bulkheads, the sheets of plywood are laminated with epoxy and stacked atop one another. This process is covered in detail in Section 4.2.3.

Bulkheads will be used to mount recovery hardware, as well as blast caps and terminal blocks. The thickness of the bulkheads shall be determined based on the loads the bulkhead is expected to experience during flight.

4.2.2 Material Selection

The three most important factors for material selection for the launch vehicle are weight, durability, and cost. Analysis of these characteristics ensures that the material chosen allows for a launch vehicle that is light, reusable, and within the team's budget. Material options and their respective characteristics are described below.

Phenolic Tubing

Phenolic tubing is a resin-impregnated cardboard that is spiral-wrapped and heat-cured. It is also heat resistant and lightweight which makes this material popular for use in high-power rocketry. For a 6 in. diameter tube, it costs about $14/ft, making it the most cost-effective option. This material, however, is not water resistant which is a problem since our home launch field contains irrigation ditches which the launch vehicle risks landing in. Furthermore, this material is prone to punctures and damage from high impacts and abrasions. Therefore, this material is not great for the launch vehicle's reusability.

Blue Tube

Blue tube is a lightweight and much stronger alternative to phenolic tubing. It is highly impact and abrasion-resistant, ensuring no cracking or brittleness that could compromise the reusability of the launch vehicle. Furthermore, it is only slightly more expensive than phenolic tubing at about $20/ft. The only downside is that blue tube is not water resistant either, which of course means it suffers from the same issues as phenolic tubing in this respect.

Carbon Fiber

Carbon fiber is yet another high-impact strength and highly abrasive-resistant composite material that is used not only for high-power rocketry but for structural applications all over the world, from automotive racing to prosthetic limbs. Carbon fiber is also relatively lightweight and waterproof. The biggest problem with carbon fiber is its cost. It can cost up to $106/foot which does not fit within the team's budget.

G12 Fiberglass

G12 fiberglass is a high-impact strength and highly abrasive-resistant composite material that is commonly used in high-power rocketry. This material is waterproof which will protect the launch vehicle should it land in an irrigation ditch. G12 fiberglass is about $45/ft for a 6 in. diameter tube and is significantly heavier than phenolic or blue tube. The level of protection this material offers and its cost makes G12 fiberglass the preferred material for the launch vehicle body.

Aircraft-Grade Birch Plywood

Aircraft-grade birch plywood will be the material used for the construction of bulkheads, centering rings, and potentially the fins if the budget does not allow for composite fins. This material has been used in all three applications in the team's history with no structural failures to report. A 24 x 48-in. sheet of 1/8-in. thick aircraft-grade birch plywood is about $42. More details on bulkhead construction are described in section 4.2.3.

G10 Fiberglass

G10 fiberglass is a lighter, similar material to G12 fiberglass which is commonly used for the fins on endurance flights of high-powered launch vehicles. It costs about $45 for 1 sq. ft. of a 1/8-in. sheet of G10 fiberglass, making it more expensive than traditional aircraft-grade plywood, but about the same as the materials for a composite layup which could be challenging to fabricate correctly. Overall, it is preferred to use this material for fins given that it provides the strength of a composite without the potential for error in the layup process. More details on fin construction are described in section 4.2.3.

Epoxy

Epoxy will be used for the bonding of all permanent components of the launch vehicle since it can produce a high-strength chemical bond with both wood and composite materials. All epoxy resins and hardeners pose health risks due to volatile organic compounds. Mitigations to such health risks are discussed further in Section 3.2.2 above. There are multiple brands of epoxies and hardeners that offer different benefits. Two options different options are considered below.

i. **West System** - West System's 105 Epoxy Resin and 206 Slow Hardener provide excellent high-strength adhesions to both wood and fiberglass while also being water-resistant. This combination of resin and hardener has an ultimate tensile strength of about 7,300 psi and a heat deflection temperature of about 124 °F. It also has a working time of about 90-110 minutes, ensuring that the fabrication process will not be rushed, and fully cures within 24 hours. The pairing of West System's 105 Epoxy Resin and 206 Slow Hardener will be used for airframe and coupler adhesion (explained in Section 4.2.3), for the adhesion of bulkheads to the inside of the launch vehicle body, and for any other permanent material bonds.

ii. **JB Weld** - JB Weld's Steel Reinforced Epoxy is a two-part epoxy that is water-resistant, has a tensile strength of 5,020 psi, and a higher performance temperature of about 300 °F. It also has a longer working time of about 4 hours and fully cures in 15 hours. Due to its high-heat capabilities, JB Weld will be used for some permanent component bonds near the motor tube that are exposed to higher temperatures, provided that the maximum loads the components experience are below the JB Weld tensile strength. In the case that the maximum loads are higher, the West System epoxy and hardener pair will be used instead.

4.2.3 Construction Methods

Bulkheads

Bulkheads will be constructed out of 1/8 in. plies of aircraft-grade plywood. CAD drawings of the bulkhead design will be created and sent to the laser cutter. Each ply of plywood will then be sanded with sandpaper to promote adhesion between the layers. Each ply will contain small holes for the placement of alignment dowels which will prevent the plies from slipping during the bulkhead fabrication process. Each ply will be covered with a thin layer of epoxy and then aligned with the other plies using the dowels. Once all the plies have been epoxied together, the assemblies will be wrapped in peel ply and breather material, then placed under a vinyl sheet and held under vacuum for 24 hours or until the epoxy is fully cured.

Fins

Fins will be constructed out of 1/8 in. plies of G10 fiberglass. CAD drawings of the fin design will be created and sent to NC State's machine shop for manufacturing. Each ply of fiberglass will then be sanded to promote adhesion between the layers. Once sanded, the plies will be epoxied together. After the epoxy has cured, the leading edges of the fins will be sanded so as to not hinder aerodynamic performance. Note that all fiberglass sanding will be done in the Aerospace Engineering Senior Design Lab which has a ventilated room with a fume hood for sanding hazardous materials.

Airframe and Coupler Cutting

Any airframe or coupler made from fiberglass or any other composite material shall only be cut by trained personnel in one of NC State's many machine shops. Airframes and couplers will be measured, labeled, and marked for cutting prior to submitting them to the machine shop. A wet saw or a band saw will then be used to cut the material. Any sanding required after cutting will only be done in one of the machine shop's fume hoods which will remove any of the harmful particulates from the air.

Airframe and Coupler Adhesion

Airframes and couplers shall be bonded using the following process:

1. The adhesion areas of the airframes/couplers will be measured and marked.
2. The adhesion areas will be cleaned thoroughly using isopropyl alcohol to remove any surface contaminants.
3. The adhesion areas will be lightly sanded with 220-400 grit sandpaper to promote a mechanical bond.
4. The surface will be cleaned with acetone to remove the dust from sanding and to promote a chemical bond.
5. A thin layer of epoxy will be spread evenly across the entire adhesion area.
6. The parts will be pieced together and held in place until the epoxy is cured.

Ballast

In the event that the center of gravity of the launch vehicle needs to be shifted forward, ballast will be added to the nose cone via a removable nose cone bulkhead. This bulkhead will have a threaded rod that extends into the nose cone on which any ballast can be screwed onto. A centering ring will be epoxied into the nose cone which the removable nose cone bulkhead can be secured to using four #8-32 machine screws.

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 4500 ft. This target apogee has been selected to satisfy recovery Requirements 3.3, 3.11, and 3.12. Current simulations performed in OpenRocket with the most accurate mass distribution of the launch vehicle at this stage of vehicle development yields a projected altitude of 4478 ft. The ascent profile of the vehicle has been supplied in figure 4.7.

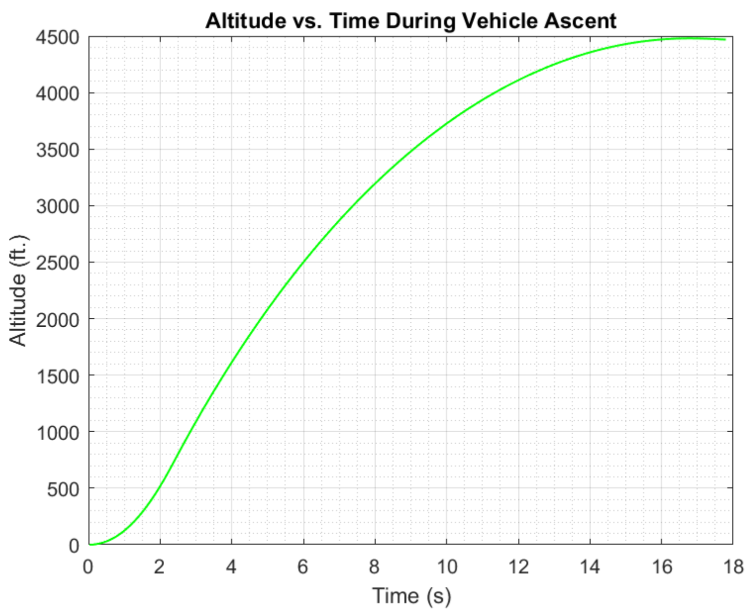

Figure 4.7: Launch vehicle vscent profile (ft.).

4.4 Launch Vehicle Recovery Specifications

The recovery system design has the launch vehicle separating into two independent sections at apogee. Therefore there will be a recovery system for each independent half. The bottom half, containing the fin can, main parachute bay, AV2, and drogue parachute bay 2, will contain a standard duel-deployment recovery system. Two completely independent air pressure-based altimeters will be used in AV2 for redundancy and reliability. Four separate black powder chargers will be used for recovery events involving half 2. Two charges for the separation of the launch vehicle halves, one for the release of drogue parachute 2, in half 2 at apogee, and one for the release of main parachute 2 in half 2 before 500 ft AGL. The top independent section containing the nose cone, AV1, drogue parachute bay 1, and the payload bay will contain a single charge, dual-deployment recovery system. Two completely independent air pressure-based altimeters will also be used in AV1 for half 1 for redundancy and reliability. Two separate black powder charges will be used in half 1 to ensure the release of drogue parachute 1 and main parachute 1. Main parachute 1 is attached to the same shock cord as drogue parachute 1 and is deployed before 500 ft AGL by a tender descender. It is important to note that we are aware of the concerning complexity of this design, and are actively seeking other launch vehicle design options in order to simplify the recovery system and payload deployment.

4.4.1 Recovery System Requirements

Table 4.3 below contains the recovery requirements as stated in the 2024 NASA Student Launch Handbook.

Table 4.3: 2023-2024 Recovery Requirements

NASA Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation
3.1	The full scale launch vehicle SHALL 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 Team ensures the launch vehicle is configured to fire a drogue parachute at apogee and a main parachute no later than 500 ft. AGL for both halves of the launch vehicle.	Demonstration	Recovery
3.1.1	The main parachute SHALL be deployed no lower than 500 ft.	The Recovery Team ensures the main parachute deployment charge is programmed to fire prior to reaching 500 ft. for any and all independently descnedning launch vehicle segments.	Demonstration	Recovery
3.1.2	The apogee event SHALL contain a delay of no more than 2 seconds.	The Recovery Team designs a recovery 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 Team designs a recovery system that does not utilize motor ejection.	Inspection	Recovery
3.2	Each team SHALL perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full-scale launch vehicles.	The Recovery Team performs ejection tests prior to each launch, confirming all recovery electronics are performing correctly.	Demonstration	Recovery
3.3	Each independent section of the launch vehicle SHALL 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 Team 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 SHALL contain redundant, commercially available barometric altimeters that are specifically designed for initiation of launch vehicle recovery events. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	The Recovery Team designs a recovery system that uses primary and secondary altimeters for any and all AV bays.	Inspection	Recovery
3.5	Each altimeter SHALL have a dedicated power supply, and all recovery electronics SHALL be powered by commercially available batteries.	The Recovery Team designs a recovery system that uses a separate, dedicated power supply, utilizing commercially available batteries, for any and all AV bays.	Inspection	Recovery

3.6	Each altimeter SHALL be armed by a dedicated mechanical arming switch that is accessible from the exterior of the launch vehicle airframe when the launch vehicle is in the launch configuration on the launch pad.	The Recovery Team designs a recovery system that uses pin switches to activate any and all altimeters from the exterior of the launch vehicle.	Inspection	Recovery
3.7	Each arming switch SHALL be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	The Recovery Team designs a recovery system that uses arming switches that can be locked in the ON position for launch.	Inspection	Recovery
3.8	The recovery system, including GPS and altimeters, electrical circuits SHALL be completely independent of any payload electrical circuits.	The Recovery Team designs a recovery system containing recovery electronics that are completely independent of the payload electronics.	Inspection	Recovery
3.9	Removable shear pins SHALL be used for both the main parachute compartment and the drogue parachute compartment.	The Recovery Team designs a recovery system that uses removable shear pins such that separable sections of the launch vehicle are secured together on the pad and during launch.	Inspection	Recovery
3.10	Bent eyebolts SHALL not be permitted in the recovery subsystem.	The Recovery Team designs a recovery system that does not use any bent eyebolts.	Inspection	Recovery
3.11	The recovery area SHALL be limited to a 2,500 ft. radius from the launch pads.	The Recovery Team designs a recovery system containing parachutes that does not allow any separately descending segment of the launch vehicle to drift more than a 2,500 ft radius from the launch pad.	Analysis, Demonstration	Recovery
3.12	Descent time of the launch vehicle SHALL 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 SHALL be awarded bonus points.	The Recovery Team designs a recovery system containing parachutes that allows any separately descending segments of the launch vehicle to safely land within 80 seconds of launch.	Analysis, Demonstration	Recovery
3.13	An electronic GPS tracking device SHALL be installed in the launch vehicle and SHALL transmit the position of the tethered vehicle or any independent section to a ground receiver.	The Recovery Team designs a recovery system containing a GPS tracking device that transmits the position of each independent section of the launch vehicle.	Inspection, Demonstration	Recovery
3.13.1	Any launch vehicle section or payload component, which lands untethered to the launch vehicle, SHALL contain an active electronic GPS tracking device.	The Recovery Team installs GPS tracking devices on any independent sections that land untethered to the launch vehicle.	Inspection	Recovery

3.13.2	The electronic GPS tracking device(s) SHALL be fully functional during the official competition launch.	The Recovery Team tests GPS devices to ensure they remain completely functional during the official launch competition.	Inspection, Demonstration	Recovery
3.14	The recovery system electronics SHALL not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	The Recovery Team designs a recovery system containing recovery electronics that are not affected by any other on-board electronic device.	Inspection, Demonstration	Recovery
3.14.1	The recovery system altimeters SHALL be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	The Recovery Team designs an AV bay containing altimeters in a compartment that is physically separate from any other radio frequency transmitting or magnetic wave-producing devices.	Inspection	Recovery
3.14.2	The recovery system electronics SHALL be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.	The Recovery Team designs an AV bay containing recovery electronics that is shielded from all other onboard transmitting devices.	Inspection	Recovery
3.14.3	The recovery system electronics SHALL be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	The Recovery Team designs an avionics bay containing recovery electronics that is shielded from all other onboard magnetic wave generating devices.	Inspection	Recovery
3.14.4	The recovery system electronics SHALL be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	The Recovery Team designs an AV bay containing recovery electronics that is shielded from all other onboard devices that may adversely affect the proper operation of the recovery system electronics.	Inspection	Recovery

4.4.2 Recovery Event Timeline

The current recovery system contains 5 individual recovery events which are explained below.

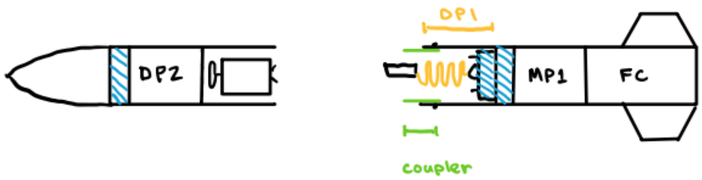

Figure 4.8: Recovery Event 1.

Figure 4.8 above depicts the first recovery event. This event occurs at apogee, where a black powder charge located forward of AV bay 2 ignites. Two charges will be fired in this event for redundancy when the altimeter senses apogee; one by the primary, and one by the secondary altimeter with a 1-second delay. This charge goes through drogue parachute bay 2 and into the payload bay, which will separate the launch vehicle into Half 1 (nose cone half) and Half 2 (fin can half).

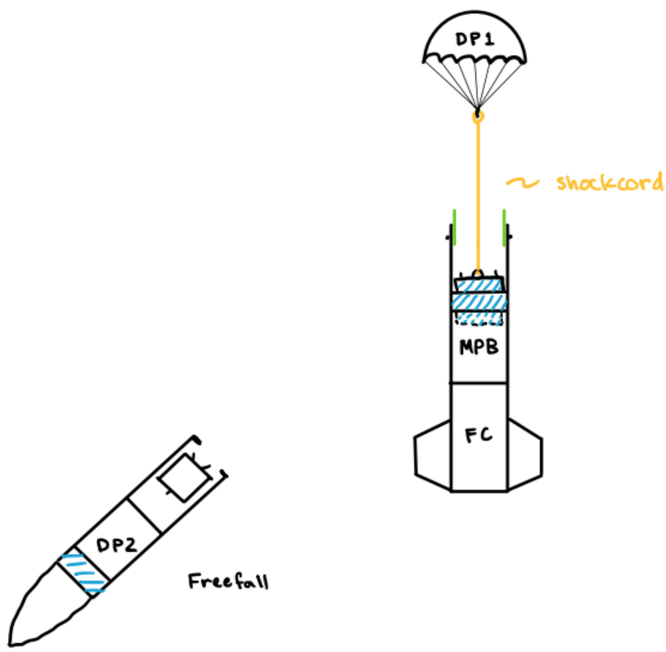

Figure 4.9: Recovery Event 2.

Figure 4.9 above depicts the second recovery event. Upon successful separation, the drogue parachute for Half 2 deploys at apogee, while Half 1 begins its free fall.

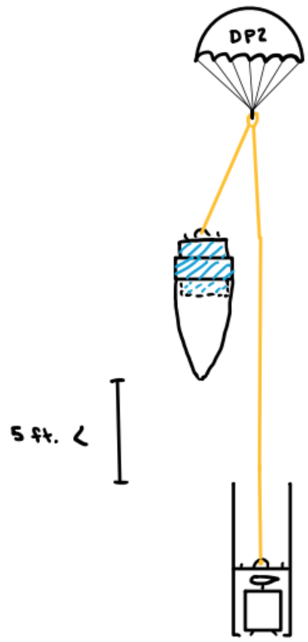

Figure 4.10: Recovery Event 3.

Recovery event 3, depicted above in Figure 4.10, includes the ejection of two black powder charges (primary and secondary), 1 second after apogee is detected to eject the drogue parachute for Half 1. The main parachute for Half 1 is also ejected, but is not deployed yet.

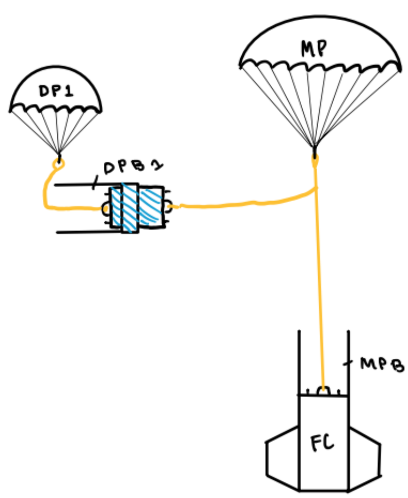

Figure 4.11: Recovery Event 4.

Figure 4.10 above depicts the fourth recovery event. In order to comply with NASA Requirement 3.1.1, the main parachute for Half 2 will be deployed at 550 ft. A black powder charge located aft of AV bay 2 ignites when the altimeter senses 550 ft, and a secondary charge is fired with a 1 second delay for redundancy. This redundancy complies with Requirement 3.1.2. The charge creates separation between the fin can and the main parachute bay for

Half 2. Upon successful separation, the main parachute for Half 2 deploys.

Recovery event 5 (not pictured) consists of deploying the main parachute 1 for Half 1 through the use of a Tinder Rocketry tender descender. However, the use of a piranha line cutter from Tinder Rocketry is also under consideration. The main parachute is attached to the same shock cord as the drogue parachute for Half 1. The black powder charge located in the tender descender is ignited by the pressure-based altimeter in AV bay 1, and the parachute deployment bag is released. A second tender descender will be used for redundancy to comply with Requirement 3.1.2.

4.4.3 Parachute Calculations

The drogue parachute for Half 2 shall be a Compact Elliptical 12-in Fruity Chutes parachute. Fruity Chutes lists an area of 0.7854 sq. ft. and a drag coefficient of 1.4 for this parachute. Using these parameters, and the weight of Half 2 after burnout, the descent velocity for Half 2 can be calculated using Equation 1 below.

$$v_d = \sqrt{\frac{2gm}{SC_D\rho}} \quad (1)$$

Let S be the parachute area, C_D the drag coefficient of the parachute, ρ the density of the air, m the mass of Half 2, and v_d the descent velocity. For drogue parachute 2, the descent velocity of Half 2 is approximately 122.89 ft/s. A 10 ft Kevlar shock cord designed for high-powered launch vehicles will the used for the drogue 2 recovery harness, giving an appropriate separation distance from the deployed parachute and the top of Half 2 (drogue parachute bay 2).

In Half 1, the nose cone and drogue and payload bay will be connected via a 25 ft Kevlar shock cord designed for use in high-power rocketry. The drogue parachute for Half 1 shall be a Compact Elliptical 12-in Fruity Chutes parachute. Fruity Chutes lists an area of 0.7854 sq. ft. and a drag coefficient of 1.4 for this parachute. Using these parameters, and the weight of Half 1 after burnout, the descent velocity for Half 1 can be calculated using Equation 1. Under the drogue 1 parachute, the descent velocity of Half 1 is approximately 115.98 ft/s.

In Half 2, the AV bay and fin can will be connected via a 20 ft Kevlar shock cord designed for use in high-power rocketry. The main parachute for Half 2 shall be an Iris Ultra Compact 72 in. Fruity Chutes parachute. Fruity Chutes lists an area of 28.27 sq. ft. and a drag coefficient of 2.033 for this parachute. Using these parameters, and the weight of Half 2 after burnout, the descent velocity under main parachute deployment for Half 2 can be calculated using Equation 1. Under main parachute 2, the descent velocity of Half 2 is approximately 13.91 ft/s.

The main parachute for Half 1 shall be a Classic Elliptical 60 in. Fruity Chutes parachute. Fruity Chutes lists an area of 19.63 sq. ft. and a drag coefficient of 1.39 for this parachute. Using these parameters, and the weight of Half 1 after burnout and payload deployment, the descent velocity under main parachute deployment for Half 1 can be calculated using Equation 1. Under main parachute 1, the descent velocity of Half 1 is approximately 14.98 ft/s.

4.4.4 Descent Time

Using a launch vehicle apogee of 4475 ft., the total descent time for Half 1 will be approximately 84.53 seconds, and 68.64 seconds for Half 2, which is within the 90 second limit for Requirement 3.12.

4.4.5 Drift Distance

Per Requirement 3.11, the launch vehicle must not drift more than 2,500 ft from the launch pad during a maximum wind speed of 20 mph. It is important to note that the launch vehicle drift speed will be equivalent to the wind speed. The descent time and drift distance of each half of the launch vehicle under main and drogue parachutes will be overestimated. These assumptions are used in the calculations for the maximum drift distance of each half of the launch vehicle. Presented in Table 4.4 is the maximum drift distance of Half 1, and in Table 4.5 is the maximum drift distance for Half 2 under various wind conditions up to 20 mph.

Table 4.4: Computed Drift Distances for Half 1

Wind Speed (mph)	Drift Distance (ft)
0	0
5	619.88
10	1239.77
15	1859.65
20	2479.53

Table 4.5: Computed Drift Distances for Half 2

Wind Speed (mph)	Drift Distance (ft)
0	0
5	503.39
10	1006.78
15	1510.17
20	2013.56

4.4.6 Ejection Charges

In total, there will be eight separate ejection charges. For Half 1: a primary and secondary drogue charge, a charge for the first tender descender to release the main parachute, and a charge for the second tender descender for redundancy. For Half 2: a primary and secondary main parachute charge and a primary and secondary drogue parachute charge. As mentioned before, we are aware of the complexity of this current design and are actively seeking other options.

The altimeter will signal to the e-matches connected to the pyrotechnic charges which are 777 grade FFF black powder. There will be an additional 0.5 oz of black powder added to the secondary charges in order to ensure separation. Chuck Pierce's Ejection Charge calculator along with hand calculations will be used to calculate the primary charges. A cap made of PVC will be used to store the black powder charges and will be located on the bulkheads of the AV bay. An e-match will be attached on the top of the cap for black powder ignition. For the space in the cap not filled with black powder, flammable paper towel fragments will be placed on top in order to ensure it ignites. The caps are then sealed off using blue tape in order to prevent black powder leakage during launch and transportation.

Before each launch of the launch vehicle, the Recovery Lead will run a ground ejection test in order to ensure separation between the designated sections. The launch vehicle will be fully assembled during ejection testing to simulate in-flight conditions.

4.4.7 Avionics Bay Design

Both AV bays of the launch vehicle will contain all recovery electronics. The AV Bay 2 will contain a 1 in. section of airframe tube that is 6 in. away from the end. The body tube will have holes to access the altimeters so they can be armed on the launch pad in flight configuration. The body tube will have pressure ports in order to prevent hoop stress created from internal pressure during launch. The aft coupler will connect to the fin can and the forward coupler will attach to the drogue parachute bay 2. AV Bay 1 will contain a 10.5 in. body tube, with a 12 in. coupler. This body tube will also have holes to access altimeters and pressure ports. The aft coupler of this AV bay will connect to the drogue parachute bay 1, and the forward coupler will attach to the nose cone. Each side of both AV bays will be protected by two bulkhead assemblies created from aircraft-grade birch plywood. Attached to the bulkheads are PVC pipe sections, bonded with epoxy, and U-bolts. The two bulkheads surrounding each AV bay will be connected via two threaded rods going through the entire AV bay, where the AV sled holding the electronics will be mounted on the rods.

Each AV sled will be designed in SolidWorks, and created via a 3D printer using ABS plastic. Both sleds will have sectioned compartments for the StratoLogger dual deployment altimeter, the Eggtimer Quasar dual deployment altimeter, a GPS tracking system, the mechanically armed pin switches, and two batteries. In order to meet Requirements 3.14 through 3.14.4, there will be sufficient insulation in each compartment to prevent radio and magnetic wave interference with any other electronic systems on the launch vehicle.

4.4.8 Recovery Avionics

As per NASA Requirements 3.4 and 3.5, each half of the launch vehicle will have redundant altimeters with their own power supplies. Half 1 and Half 2 will have their own Eggtimer Quasar to act as the GPS transmitter for each section powered from a commercially available LiPo battery. The Eggtimer Quasar will also act as a redundant deployment altimeter. A StratoLogger will also be in each half. Each altimeter will be sufficiently isolated from any nearby electric and magnetic signals or waves from the launch vehicle or any other set of electronics.

The primary altimeter will be the Half 2 StratoLogger altimeter and the data received from the StratoLogger will be used for competition reporting. The primary and secondary altimeters for each half of the launch vehicle will control a drogue and main deployment charge. The Half 2 drogue deployment charge on the primary altimeter will be the first to deploy at apogee. 1 second after will be the secondary altimeter drogue charge, this will ensure the physical separation of each half as specified by NASA Requirement 3.1.2. 5 seconds after the launch vehicle has physically separated, the Half 1 primary drogue deployment charge will be fired. 1 second after the Half 1 primary charge fires, the secondary altimeter will deploy the redundant charge. Half 1 will fire its primary altimeter charge at 850 ft, and Half 2 will fire its primary altimeter charge at 550 ft. 1 second after, each secondary charge will fire the redundant charge. Each altimeter will have its own pull-pin switch for arming the altimeter at the launch pad.

Before flight, each altimeter will be individually tested and calibrated in a vacuum chamber. The altimeter will be powered and then connected to a circuit board with indicator lights. A vacuum will slowly decrease the pressure of the chamber to simulate an increase in altitude. By slowly releasing the chamber from the vacuum, the altimeter will experience a decrease in altitude. The indicator lights will be observed to verify the proper deployment of apogee and main deployment events. The data from the calibration test will be extrapolated to plots and ensure that the observations are accurate with what was recorded on the altimeter.

4.5 Motor Brand and Class

The motor brand selection is based on previous team experience and mentor advice. The team has successfully utilized AeroTech solid rocket motors for several years, and an AeroTech motor will be used for all 2024 NASA SL Competition flights.

To estimate the required motor class, basic first-order principals have been implemented along with simulation software. This approach guarantees that higher fidelity simulations are within reasonable margins of expected results. The first-order equations utilize a simplified launch vehicle model neglecting drag forces.

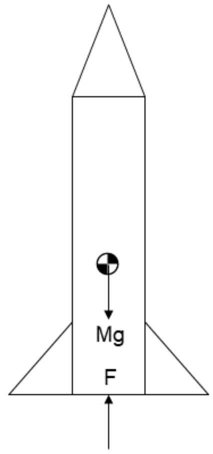

Figure 4.12: Simplified free-body diagram used in motor estimation.

From this free-body diagram (Figure 4.12) and basic one-dimensional kinematic equations, the following equations can be derived.

$$t = \frac{I_{total}}{F_{avg.}} \tag{2}$$

$$\ddot{x} = \frac{F_{avg.}}{m_{total}} - g \tag{3}$$

$$x_{burnout} = \frac{1}{2}\left(\frac{F_{avg}}{m_{total}} - g\right)t^2 \tag{4}$$

$$x_{apogee} = \frac{F_{avg.}x_{burnout}}{m_{burnout}g} \tag{5}$$

Using equations 2, 3, 4, and 5 yields a curve of solutions which results from having more unknown variables than equations. This curve is displayed in Figure 4.13.

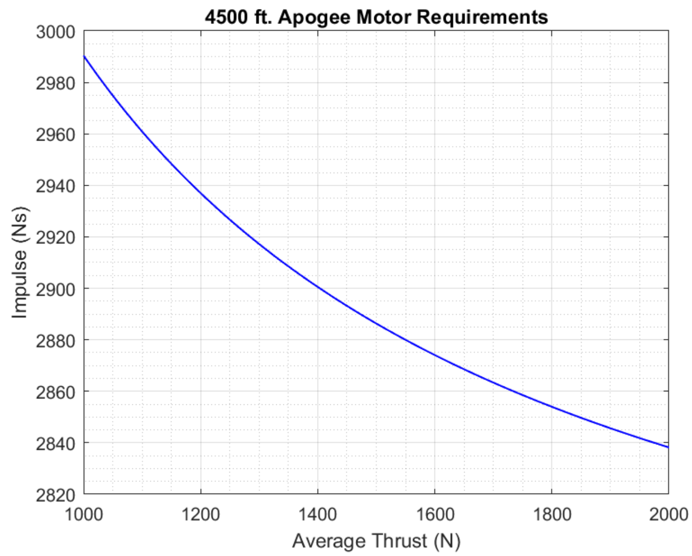

Figure 4.13: 4500 ft. apogee motor requirements.

Given the impulse requirements along with the reasonable average thrust of commercially available solid rocket motors and the assumptions of this first-order approximation neglecting drag, the L class of rocket motors with a total impulse of 2,560–5,120 Ns is required to satisfy vehicle Requirement 2.1.

Using OpenRocket simulation with L-class motors, the L1520T motor manufactured by AeroTech with a total impulse of 3,715.9 Ns has been selected to reach a predicted apogee of 4478 ft. This software utilizes a numerical solution to incorporate drag into the model, producing higher fidelity results.

4.6 Payload Design

4.6.1 Payload Requirements

The following is a passage from the 2023-2024 NASA SL Handbook that defines the payload challenge: ”Teams shall design a STEMnauts Atmosphere Independent Lander (SAIL). SAIL is an in-air deployable payload capable of safely retaining and recovering a group of 4 STEMnauts in a unique predetermined orientation without the use of a parachute or streamer. The landing shall occur under acceptable descent and landing parameters for the safe recovery of human beings. A STEMnaut shall be defined as a non-living crew member, to be physically represented as the team chooses, and is assumed to have human astronaut survivability metrics. The method(s)/design(s) utilized to complete the payload mission shall be at the team's discretion and will be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge.”

Table 4.6 below contains the payload requirements as stated in the 2024 NASA Student Launch Handbook.

Table 4.6: 2023-2024 Payload Requirements

NASA Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation
4.1	**SL Payload Mission Objective** — College/University Division — Teams SHALL design a STEMnauts Atmosphere Independent Lander (SAIL). SAIL is an in-air deployable payload capable of safely retaining and recovering a group of 4 STEMnauts in a unique predetermined orientation without the use of a parachute or streamer. The landing SHALL occur under acceptable descent and landing parameters for the safe recovery of human beings. A STEMnaut SHALL be defined as a non-living crew member, to be physically represented as the team chooses, and is assumed to have human astronaut survivability metrics. The method(s)/design(s) utilized to complete the payload mission SHALL be at the team's discretion and will be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge. NASA reserves the right to require modifications to a proposed payload.	The Payload and Integration Teams design a payload that is capable of safely returning the STEMnauts from the flight, follows all safety, FAA and NAR requirements, and is in accordance with the spirit of the competition.	Demonstration	Payload Electronics, Payload Structures, Payload Systems, Integration
4.2.1	Teams SHALL not use parachutes or streamers that are commercially available or custom made. A parachute is defined as an open-faced canopy whose primary function is to reduce descent speed or increase drag. A streamer is defined as a long, narrow strip of material (typically affixed at one end) whose primary function is to reduce descent speed or increase drag.	The Payload Structures Team designs a SAIL that does not utilize any parachutes or streamers for recovery operations.	Inspection	Payload Structures
4.2.2	The SAIL SHALL be a minimum of 5 lbs inclusive of the jettisoned or separated landing capsule and the 4 STEMnauts.	The Patload Structures Team designs a SAIL that has a final weight of at least 5 lbs.	Inspection	Payload Structures
4.2.3	Deployment of the SAIL SHALL occur between 400 and 800 ft. AGL. See Requirement 4.3.3 for deployment/jettison of payloads.	The Payload Structures, Recovery, and Integration Teams ensure SAIL ejection is designed to be within 400 and 800 ft. AGL.	Demonstration	Payload Structures, Recovery, Integration
4.2.4	The team SHALL pre-determine and land in a unique landing orientation to be verified by NASA personnel in Huntsville or by a non-affiliated NAR/TRA rep for at-home launches.	The Payload Teams design a SAIL that has a clear and defined landing orientation.	Demonstration	Payload Electronics, Payload Structures, Payload Systems

4.2.5	Teams SHALL design and implement a method of retention and ingress/egress for the STEMnauts.	The Payload Teams design a SAIL that retains the STEMnauts and allows easy access to the crew cabin for ingress/egress operations.	Inspection	Payload Electronics, Payload Structures, Payload Systems
4.2.6	Teams SHALL determine acceptable descent and landing parameters, to be approved by NASA, and design their lander to meet those requirements.	The Payload Teams design a SAIL that has a final landing speed of 20 mph (according to criteria for NASA's Orion spacecraft) and limits angular velocity so that the STEMnauts experience a maximum of 3gs (according to NASA's Space Shuttle launch criteria).	Demonstration	Payload Electronics, Payload Structures, Payload Systems
4.3.1	Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics will not be permitted for any surface operations.	The Payload, Recovery, and Integration Teams ensure that no energetics are used outside of in-flight recovery operations.	Inspection	Payload Structures, Recovery, Integration
4.3.2	Teams SHALL abide by all FAA and NAR rules and regulations.	The Safety Team reviews the SAIL design throughout the design process to ensure compliance with all FAA and NAR rules and regulations.	Inspection	Safety
4.3.3	Any payload experiment element that is jettisoned during the recovery phase SHALL receive real-time RSO permission prior to initiating the jettison event, unless exempted from the requirement by the RSO or NASA.	The Payload Systems and Safety Teams ensure that payload is not jettisoned without receiving RSO authorization.	Demonstration	Payload Systems, Safety
4.3.4	Unmanned aircraft system (UAS) payloads, if designed to be deployed during descent, SHALL be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAS.	The Payload Systems and Safety Teams ensures that any UAS that is deployed during the descent phase of flight is tethered to the vehicle and released on command after RSO permission is received.	Demonstration	Payload Systems, Safety
4.3.5	Teams flying UASs SHALL abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112–95 Section 336; see https://www.faa.gov/uas/faqs).	The Payload and Safety Teams ensure that any UAS is flown in full compliance with FAA regulations.	Inspection	Payload Electronics, Payload Structures, Payload Systems, 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.	The Payload and Safety Teams ensure that any UAS weighing more than .55 lbs is registered with the FAA and the registration number is clearly marked on the vehicle.	Inspection	Payload Structures, Payload Systems, Payload Electronics, Safety

4.6.2 Projected Designs

Auto-rotation

Without the use of parachutes, the SAIL will need an alternative method for creating enough drag to bring the vertical speed to low levels to ensure a safe landing for the four STEMnauts. The leading idea involves rotating propellers to generate a lift force opposing the descent of the lander. The propellers' motion would be instigated through the flow of air around the SAIL as it descends, providing an opposing force to the gravitational acceleration of the payload.

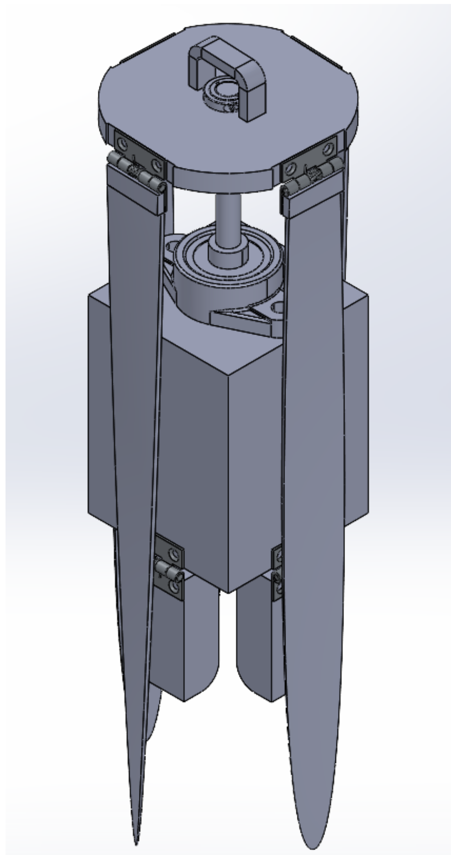

Figure 4.14: CAD model of projected design for auto-rotation with body and landing legs.

The main payload section houses the STEMnauts and electronic equipment that will be located directly underneath the rotor. The SAIL will then be orientated vertically inside the payload bay section and retained by a powered latch. Upon RSO approval, this latch will be opened via RF commands and the payload will drop from the payload bay already in the proper orientation (rotor lift vector pointed up). Once the SAIL is deployed, the vehicle will be free-falling. Upon exiting the launch vehicle, the propeller blades will rotate to a horizontal position due to a spring-loaded system and latch on rigidly. Once separated from the launch vehicle, airflow over the rotor will start the auto-rotating propellers. Once the SAIL has reached a specified altitude, the landing legs will unfold from the SAIL to ensure a stable landing in a predetermined orientation.

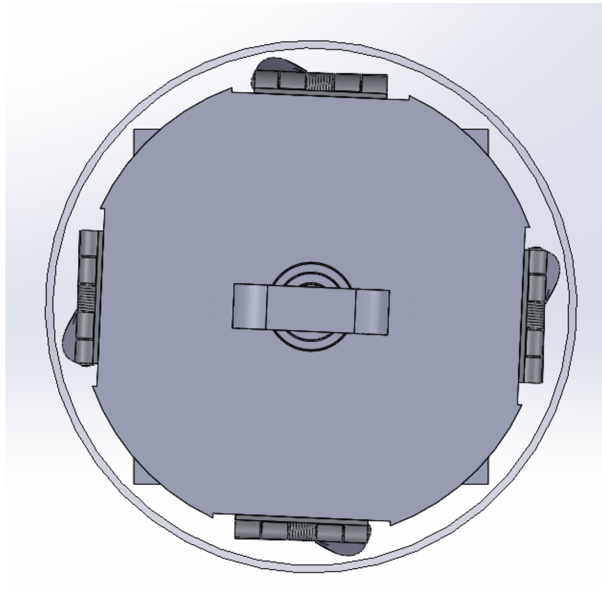

Figure 4.15: CAD Model of Projected Design for Auto-rotation (Top View)

As seen in Figure 4.15, the propeller blades will be secured against the body tube, keeping the spring-tensioned hinges from moving. These hinges will move to the horizontal position, parallel to the ground, once the payload exits the launch vehicle.

Powered VTOL Drone

An alternative solution for the STEMnaut recovery is to use a powered rotation system (a vertical take-off and landing drone (VTOL), for example) to reduce the descent of the SAIL. Once the SAIL is released, the propellers will be powered by a motor to produce enough lift to decrease the SAIL's vertical velocity to a safe level.

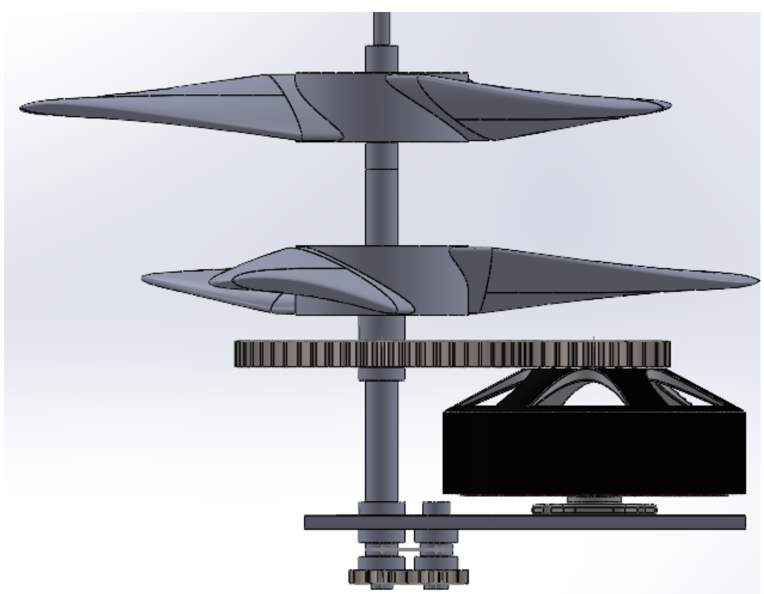

Figure 4.16: CAD model of projected design for VTOL drone

A powered VTOL drone will allow for a higher fidelity control during descent due to programmable electronics that will be needed to power the propeller motor. Deployment and landing will be very similar to that of the auto-rotation configuration, utilizing both the free-fall jettison method and deployable landing legs to ensure the SAIL lands in a predetermined orientation.

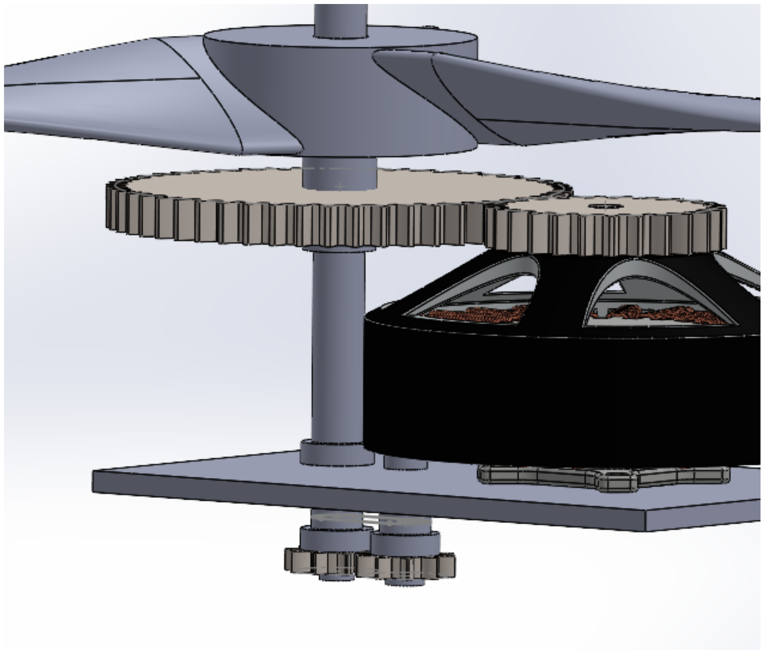

Figure 4.17: CAD model of projected design for VTOL drone gearing

To accommodate for the motor torque, a coaxial propeller system will be required. One idea, as seen in Figure 4.17, is to have an outer and inner rod controlling each propeller, respectively. The motor will be down-geared to adjust for necessary torque. A belt connecting the outer rod to a secondary rod attached to the base of the SAIL will spin another set of gears (1:1). This reverses the direction with the same rotations per minute (rpm) of the inner rod. The upper propeller connects to the inner rod, finishing the coaxial propeller system.

Both of the main ideas include a housing bay where the STEMnauts will be secured for the duration of liftoff, deployment, descent, and landing. The STEMnauts will be secured in the housing bay while still being removable for ingress/egress purposes.

Alternative Design Solutions

Besides propeller-based designs, other ideas were also considered for the SAIL. After some discussion, these ideas were not chosen as front-runners for the final payload design, however, elements from each may be used as additional safety measures for a more controlled descent/landing.

One idea that was discussed was the use of cold gas thrusters to control the landing of the SAIL as it approaches the ground. This would allow for the descent velocity to be decreased by releasing pressurized gas opposite the direction of motion. This implementation would prove challenging due to the use of highly pressurized gas in a small compartment, as well as the inherent complications with such a landing maneuver. Additionally, in the event of a thruster failure the payload would have no other method of slowing down the velocity at all, resulting in serious damage to the SAIL.

Bluff bodies were also considered with the idea of utilizing air resistance to decrease the vertical velocity of the SAIL. A large surface area would be required for the SAIL's speed to be impeded by drag alone, so unfolding or inflatable materials would be required to fit within the launch vehicle's payload bay. This idea was ultimately decided against due to concerns with the amount of time required to inflate such a large aerodynamic surface and probable issues with maintaining the proper orientation during the inflation sequence. However, inflatables in the form of airbags may still be useful as a way to reduce the force of impact that the SAIL experiences upon landing.

Another idea that brought up concerns about available bay space was that of a glider. A glider would allow for a controlled descent of the housing bay, however, due to the required wingspan of a glider being more than the internal diameter of the launch vehicle itself, it would be challenging to work with the space we are given. A glider would also be difficult to apply to a multi-atmosphere lander while still being able to fit in a confined space during launch.

Landing Designs

To land in a predetermined orientation, a landing design must be crafted. The leading idea is to have deployable legs that have shock absorbers. One design involves hinged legs that have a coil-wrapped spring to reduce the landing impact. Another design involves air shock absorbers where the legs will run through a tube with a small hole at the top to absorb the landing shock. As seen in Figure 4.14, the landing legs will deploy underneath the main payload body, which will hinge outwards to keep the payload in the predetermined landing position.

4.7 Payload Technical Challenges

The two leading designs require the use of propellers to slow down the SAIL's descent, and while these seem to be the best candidates for completing the project goals, some challenges have already been identified and will need to be further explored. Some examples of challenges already encountered are listed below.

4.7.1 Challenges with Auto-rotation Design

As more research has been conducted, auto-rotation was found to have some uncertainties when it comes to initial deployment. Due to turbulent flow around the body of the payload, the propellers are not guaranteed to begin spinning solely due to airflow. This implies that a method for applying a force to allow for an initial propeller startup would be required.

Some ideas to start the propellers include a torsional spring that would be wound prior to launch and would release once the SAIL is released into free fall. Once this spring is released, torque would be applied to the propeller blades, starting their motion, which would continue through the airflow as the SAIL falls.

Another concern is that auto-rotation may not produce enough force to slow down the SAIL to acceptable levels. This leads to the idea of implementing an airbag system to reduce the shock experienced by the STEMnauts upon landing. A spring-damper system on the landing legs may also be worth looking into.

4.7.2 Challenges with VTOL Drone

While a powered VTOL drone will provide enough of a lift force to safely land the SAIL, this method will add complexity to the overall design, and thus create additional failure points. The construction of a powered drone will also require registration with the FAA, adding extra steps to the process of payload construction.

With the addition of a motor to apply torque to the propellers to generate lift, an issue arises with the reactionary rotation on the STEMnaut housing bay itself. This will require a counteraction of the rotation, with the leading idea being coaxial rotors with equal torque being applied in opposite directions so that the net moment on the SAIL is zero. This will require a two-motor system and increases the complexity of the payload design even further.

While a powered drone reduces the simplicity of the overall design, it will allow for a more controlled descent as compared to auto-rotation, and so it may be desirable if auto-rotation proves too difficult to perfect.

4.7.3 Challenges with Rotors

One major constraint with any rotor design is fitting the rotors inside the payload bay. The launch vehicle diameter will be 6 in., meaning that any fixed rotor would be limited to roughly 5.5 in. in diameter. A solution to this size restraint is to fold the rotors along the side of the payload and then deploy them after the payload is jettisoned. This will allow for a rotor diameter of at least 4 times greater than the diameter of the body tube. The limiting factor for rotor length with a folding rotor is the length of the payload bay, which is currently designed to be 18 in.

5 STEM Engagement

5.1 Purpose and Description of STEM Engagement

The STEM engagement element of NASA student launch allows the High-Powered Rocketry Club to connect with and instruct their community. During these events, elementary through high school students will have the opportunity to learn about STEM subjects, model rocketry, Newton's laws of motion, and the engineering design process. During direct engagement interactions, students are also exposed to hands-on activities that enforce the topics they have learned. Because hands-on learning is being used as an education supplement, direct engagement will lead to higher comprehension levels and will help inspire students to pursue STEM careers.

The team shall reach out to elementary, middle, and high schools as well as community organizations that host STEM events. The team is also fully prepared to participate in virtual events similar to ones that have occurred in previous years during the pandemic. However, the team will focus on coordinating in-person events because they are more successful at directly engaging students. During an outreach event, the team will first present on a STEM topic they are knowledgeable about. These presentations may include information on the team, the SL competition, and hobby rocketry, as well as STEM topics appropriate for the age level of the students being presented to. This will be followed by a hands-on demonstration that reinforces knowledge gained through the presentation. For students in elementary and middle school, the team prefers to aid students in making their own bottle rocket or straw rocket. For students in high school, the demonstration will also include building and launching lower-power model rockets.

According to NASA student launch Requirement 1.4, the team shall engage with at least 250 students between the acceptance of the project and the FRR due date. The events detailed in Section 5.2 will meet this requirement, however, the team will plan more events to reach out to more schools and organizations in order to maximize their impact on the community. Last year, the team reached out to 1194 students through a variety of events. The team's goal is to reach or exceed that number of students this year. The team aims to plan more events targeted at high school students to increase interest in STEM for post-secondary education.

5.2 Planned STEM Engagement Events

5.2.1 Apex Friendship High School

The team will work in collaboration with a teacher at Apex Friendship High School to supplement a unit on rocketry and building model rockets. The team will travel to the high school and give a presentation on model rocketry and Newton's Laws of Motion. After this, the team will aid the students in building and launching their own bottle rockets. The expected attendance for this event is approximately 70 students.

5.2.2 Durham Parks and Recreation

This event will be held in partnership with Durham Parks and Recreation, specifically a subsection that focuses on planning events for students ages 13-18 years old. The team will travel to Old Farm Park in Durham where they will give a presentation on model rocketry, the engineering design process, and general safety guidelines for the event. After this, the team will lead the students through building and launching their own low-power model rocket. The expected attendance for this event is approximately 50 students.

5.2.3 Astronomy Days

Astronomy Days is a weekend-long event hosted by the North Carolina Museum of Natural Sciences. This event hosts displays, seminars, and demonstrations about astronomy. During this event the team will co-host an amateur rocketry booth with the Tripoli Rocketry Association. After teaching students about model rocketry concepts, the team will lead them through the construction of a rocket motor. Furthermore, the team will talk to students about NASA SL and how to get involved in local rocket launches. Though the attendance levels of this event varies, the team is expecting to reach out to around 500 students throughout the weekend.

6 Project Plan

6.1 Development Schedule

Figures 6.1 and 6.2 below depict the 2023-2024 SL competition deadlines and the project development schedule. Development schedule dates are subject to change due to supply chain delays.

2023-24 Student Launch Competition Gantt Chart

TACHO LYCOS

				Aug				Sept				Oct				Nov				Dec				Jan				Feb				Mar				Apr			
Task Name	Task Number	Start Week	End Week	W01	W02	W03	W04	W05	W06	W07	W08	W09	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35	W36
Proposal	1	W02	W06		1	1	1	1	1																														
PDR Q&A	2	W10	W10										2																										
PDR	3	W07	W12							3	3	3	3	3	3																								
PDR Presentation Window	4	W13	W16													4	4	4	4																				
Subscale Launch	5	W14	W14														5																						
CDR Q&A	6	W17	W17																	6																			
CDR	7	W13	W21													7	7	7	7	7	7	7	7	7															
CDR Presentation Window	8	W22	W25																						8	8	8	8											
FRR Q&A	9	W25	W25																									9											
Vehicle Demonstration Flight Window	10	W25	W28																									10	10	10	10								
FRR	11	W22	W29																						11	11	11	11	11	11	11	11							
FRR Presentation Window	12	W30	W32																														12	12	12				
Payload Demonstration Flight Window	13	W25	W32																									13	13	13	13	13	13	13	13				
FRR Addendum	14	W29	W33																													14	14	14	14	14			
Launch Week Q&A	15	W33	W33																																	15			
Huntsville Launch Week	16	W34	W34																																		16		
Competition Launch	17	W34	W34																																		17		
PLAR	18	W34	W36																																		18	18	18

Figure 6.1: 2023-2024 SL Competition Deadlines

2023-24 Student Launch Competition Development Gantt Chart

TACHO LYCOS

				Aug				Sept				Oct				Nov				Dec				Jan				Feb				Mar				Apr			
Task Name	Task Number	Start Week	End Week	W01	W02	W03	W04	W05	W06	W07	W08	W09	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35	W36
Brainstorming	1	W02	W05		1	1	1	1																															
Vehicle Design	2	W05	W08					2	2	2	2																												
Payload Design	3	W05	W16					3	3	3	3	3	3	3	3	3	3	3	3																				
Subscale Parts Ordering	4	W08	W09								4	4																											
Subscale Manufacturing	5	W10	W14										5	5	5	5	5																						
Subscale Launch	6	W14	W14														6																						
Payload Parts Ordering	7	W16	W17																7	7																			
Fullscale Parts Ordering	8	W18	W21																		8	8	8	8															
Fullscale Manufacturing	9	W21	W25																					9	9	9	9	9											
Payload Manufacturing	10	W21	W28																					10	10	10	10	10	10	10	10								
Fullscale Components Testing	11	W23	W26																							11	11	11	11										
Recovery System Testing	12	W23	W26																							12	12	12	12										
Vehicle Launch Window	13	W25	W28																									13	13	13	13								
Payload Testing	14	W25	W29																									14	14	14	14	14							
Payload Launch Window	15	W29	W32																													15	15	15	15				
Competition Launch	16	W34	W34																																		16		

Figure 6.2: 2023-2024 SL Competition Development Schedule

6.2 Budget

Table 6.1 below details the year-long budget for the 2023-2024 Student Launch Competition.

Table 6.1: 2023-2024 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
	4 in. Blue Tube Coupler	4	$ 12.31	$ 49.24
	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
	Standard Rail Button - 1010	2	$ 4.25	$ 8.50
	U-Bolts	4	$ 1.00	$ 4.00
	Blast Caps	4	$ 1.80	$ 7.20
	Terminal Blocks	4	$ 3.00	$ 12.00
	Double Pull Pin Switch	2	$ 11.95	$ 23.90
			Subtotal:	**$ 564.55**
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 L1520T-PS Motor	2	$ 289.99	$ 579.98
	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	$ 8.50
	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:			**$ 2,151.72**
Payload	Rotor Blades	2	$ 99.99	$ 199.98
	12” Axle	1	$ 19.99	$ 19.99
	Hinges	8	$ 6.99	$ 55.92
	Rotor Bearings	2	$ 4.99	$ 9.98
	Locking Collars	2	$ 9.99	$ 19.98
	Shock Absorbers	1	$ 13.99	$ 13.99
	Motor	1	$ 49.99	$ 49.99
	Carbon Fiber PETG Filament	1	$ 29.99	$ 29.99
	Arduino	1	$ 50.00	$ 50.00
	IMU	1	$ 15.30	$ 15.30
	RC Transmitter/Receiver	1	$ 19.99	$ 19.99
	Structural/Housing Materials	1	$ 300.00	$ 300.00
	Subtotal:			**$ 785.11**

Recovery and Avionics	Iris Ultra 72 in. Standard Parachute	1	$ 313.37	$ 313.37
	Iris Ultra 60 in. Standard Parachute	1	$ 266.07	$ 266.07
	12 in. Compact Elliptical Parachute	2	$ 67.41	$ 134.80
	Eggtimer Quasar	2	$ 99.99	$ 199.98
	Eggfinder TX Transmitter	1	$ 70.00	$ 70.00
	6 in. Deployment Bag	2	$ 54.40	$ 108.80
	4 in. Deployment Bag	2	$ 47.30	$ 94.60
	18 in. Nomex Cloth	2	$ 26.40	$ 52.80
	13 in. Nomex Cloth	2	$ 17.60	$ 35.20
	5/8 in. Kevlar Shock Cord (per yard)	25	$ 6.99	$ 174.75
	3/16 in. Stainless Steel Quick Links	14	$ 6.98	$ 97.72
	Firewire Electric Match	16	$ 2.00	$ 32.00
	AeroTech Ejection Charge - 1.4g	24	$ 1.25	$ 30.00
	Small Nylon Shear Pins	40	$ 0.18	$ 7.20
	Subtotal:			**$ 1,404.20**
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
	PLA 3D Printer Filament Spool	1	$ 26.00	$ 26.00
	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:			**$ 3,413.63**
Travel	Student Hotel Rooms – 4 nights (# Rooms)	8	$ 898.45	$ 7,187.60
	Mentor Hotel Rooms – 4 nights (# Rooms)	2	$ 556.03	$ 1,112.06
	NCSU Van Rental (# Vans)	3	$ 798.00	$ 2,394.00
	Subtotal:			**$ 10,693.66**
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:				**$ 20,202.87**

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.

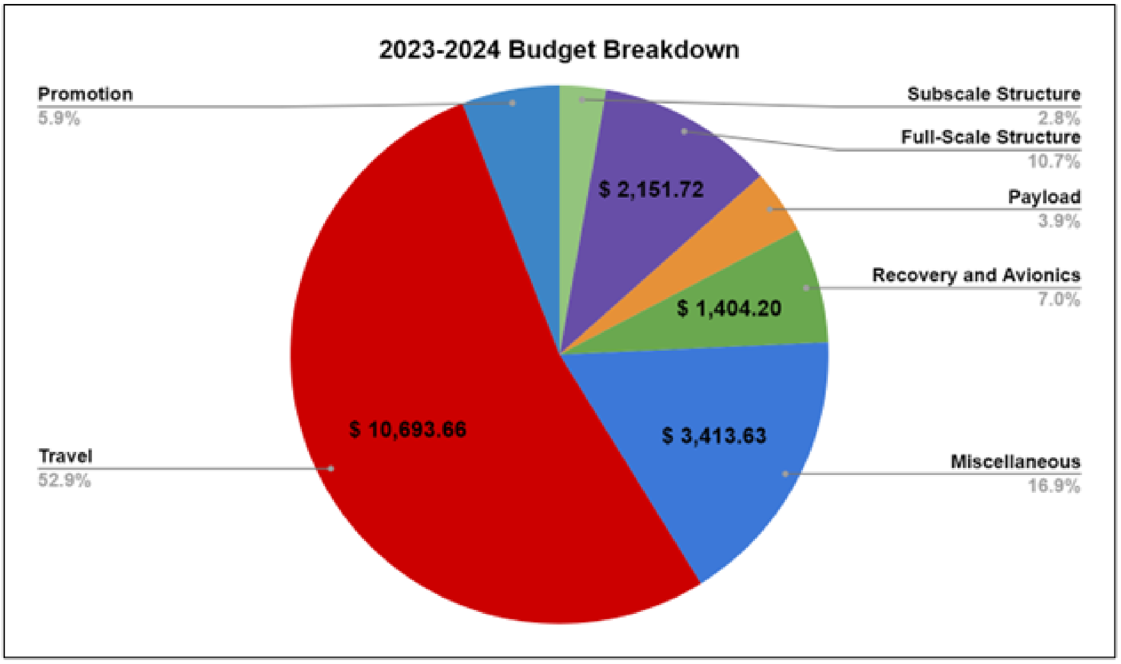

Figure 6.3: 2023 - 2024 Budget Breakdown

6.3 Funding Plan

HPRC receives funding from a variety of NC State University's resources, 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 consists of a proposal where the club outline's what they are requesting from SGA, how much money they estimate to receive from other sources, and the anticipated club expenses for the academic year. The club then meets with representatives from SGA and give a presentation outlining club activities and the overall benefit the club provides the university. SGA then collectively allocates money to each organization on campus. In the 2022-2023 academic year, HPRC received $1,592.00 from SGA; $796.00 in the fall semester and $796.00 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 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 2022-2023 academic year, HPRC received $3,000 from ETF and the club anticipates to receive $2,000 for this academic year. This funding will be used primarily to pay for the team's faculty advisors' travel costs.

Student 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 2022-2023 academic year, it is estimated HPRC will receive $7,500 this year.

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 2023.

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 $1,000 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 2023-2024 academic year.

Table 6.2: Projected Funding Sources

Organization	Fall Semester	Spring Semester	Academic Year
Educational and Technology Fee	$0	$2,000	$2,000
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	$500	$500	$1,000
Total Funding:			**$20,500.00**
Total Expenses:			**$20,202.87**
Difference:			**$297.13**

6.3.1 Sustainability Plan

Since HPRC is a North Carolina State University student organization, the club's sustainability depends on new member recruitment and retention. During both Fall and Spring semesters, HPRC is able to recruit new members through participation in university-sponsored events. Current club members advertise the club at these events by showcasing previous launch vehicles and payloads and informing interested students on how they can get involved with the current year's challenge. Additionally, club activities are showcased on all of the team's current social media profiles. Through these resources, the club recruits about 100 new members at the beginning of the year. About 40-50 of the 100 new members are retained throughout the school year.

To engage and retain new members, the club provides enrichment opportunities specifically for new members. The first main engagement event is an underclassmen-led Interest Launch held at the beginning of every Fall semester that is geared towards introducing new members to the hobby of high-power rocketry. HPRC also has an underclassmen-led team for experimental payloads called ”WolfWorks Experimental.” The WolfWorks Experimental group is currently working on rebuilding last year's WolfWorks rover payload and putting together a new launch vehicle configuration to deploy it. WolfWorks will continue to pursue more projects in the future, separate from the SL team, to keep underclassman actively engaged. In addition to the underclassmen-led subsystem, HPRC also leads technical workshops throughout the year during the club's general body meetings. These workshops cover topics including, but not limited to, the basics of high-power rocketry, soldering, electronics, launch vehicle design software tutorials, safety, and CAD tutorials. The club also holds social events, such as game nights and group dinners, to promote a feeling of community and belonging within the club.

HPRC also focuses on maintaining their relations with their local communities. Club members assist the East NC Tripoli Prefecture with set-up and tear-down on launch days. This also provides an opportunity for the club members to interact and learn from the experienced hobby rocketeers. The club also works with local schools and museums to plan outreach events as described in Section 5.

HPRC is mostly self-sufficient regarding funding and equipment. All manufacturing equipment and materials are available at the university in the facilities described in Section 2.1. If the club requires any additional resources, club leadership will communicate with the team mentors, listed in Section 1.1, in order to work out a solution. The club also receives stable, regularly scheduled funding sources, described in Section 6.3 which ensures the sustainability of funds.