Northville High School Aerospace Club

Project Rooni Proposal

9/11/2024

45700 Six Mile Rd, Northville, MI 48168

1 Table of Contents

1.1 Abstract

The Northville High School SLI Team is a subset of the Northville High School Aerospace Club. The NHS Aerospace Club is a student-run club affiliated with Northville High School in Northville, Michigan. The club aims to participate in and educate students in all aspects of aerospace. After a successful second place in the 2024 Rockets for Schools competition, the Northville High School Aerospace Club was invited to the NASA Student Launch Initiative and is responding to the 2025 NASA SLI request for proposal. Our project name, Project Rooni, is an anagram of Orion, the Artemis capsule. Since Orion will be launching astronauts, we chose this name with the project goal of launching STEMnauts.

After reading the SLI handbook, the team concluded that a scaled-back version of the USLI payload would be an appropriate goal. We will be transmitting telemetry to a laptop on the ground using a LoRa radio instead of a 2-M radio band, and rather than simply transmitting telemetry. We plan to code an application that detects the stage of the launch (launch, apogee, descent), and display appropriate data, such as STEMnaut orientation, vertical velocity, max Gs, and recovery status.

This proposal details the team information, facilities, equipment, initial safety plan, technical design, STEM engagement plan, project plan, and project deliverable compliance plan of our participation in SLI.

2 General Information

2.1 Team Composition

Within the club, we have subsets focusing on airplanes, drones, and rocketry. The SLI team is a 9-person subset, with potentially more joining as the school year progresses, of the rocketry group composed of ambitious students with the goal of excelling in high-power rocketry. These students are veterans of successful TARC/ARC and Rockets For Schools teams as well as students either with or working towards Jr L1, L1, and L2 high-power certifications.

While this is the first year participating in SLI, the NHS Aerospace Club SLI Team has successfully demonstrated many of the key skill sets to be successful. This includes, but is not limited to:

- Placing 1st and 2nd in the TARC technical presentation contest in 2021 and 2022, respectively
- Experience with scratch building and optimizing rockets through TARC/ARC.
- Successfully building and launching a Class 2 High Power rocket in the Rockets for Schools competition, claiming the Curtis Jackson Memorial Award for top rocket construction in both years of participation (2023 and 2024) and placing 3rd (2023) and 2nd (2024) overall

- The majority of the team is either holding or quickly working towards NAR/Tripoli Jr Level 1 High Power certification
- At least one team member is proficient in full redundant dual deploy flying with others working towards it
- Members who routinely fly with various local high-power clubs constantly gaining experience and knowledge

During the summer of 2024, several members of the NHS Aerospace SLI team decided to build 54 mm fiberglass rockets as a team-building exercise. Where age permits, they will use their rockets for Jr L1 and L2 certification flights. The construction skills for building these rockets are very similar to those used for a 98 mm airframe suggested in this proposal. Several of the members will also be flying dual deploy, demonstrating key competency necessary for SLI.

Figure 1. Team photo

2.1.1 Adult Educators

Figure 2. Patricia Krebs at Kennedy Space Station with Saturn V rocket

<u>Patricia Krebs</u>
Northville High School
45700 Six Mile Rd
Northville, MI 48168
krebspa@northvilleschools.org
248-344-3800 x3845

The position of adult educator will be served by Patricia Krebs. Mrs. Krebs has served as the faculty advisor for the Northville High School Aerospace Club since 2021 assisting from an administrative standpoint for one season of TARC/ARC and two seasons of Rockets for Schools.

Mrs. Krebs holds a bachelor's degree in Mechanical Engineering from Rochester Institute of Technology and currently works as a Physics and Engineering teacher at Northville High School. She has been an enthusiastic supporter of all things aerospace since watching the very first space shuttle events back in the day.

2.1.2 Team Mentor

Figure 3. Andrew Brown with 98 mm Alien Interceptor

<u>Andrew Brown, (NAR L2 108157/TRA L3 20959)</u>
46055 Bloomcrest Dr.
Northville, MI 48167
andrew.r.brown@sbcglobal.net
734-674-7869

The position of Team Mentor will be served by Andrew Brown. Mr. Brown has served as the team mentor for the Northville HS Aerospace Club since 2019 assisting in five seasons of TARC/ARC, two seasons of Rockets For Schools, mentoring three students through Jr. L1 High Power Certification and one through L2, and currently mentoring five students for Jr L1 Certification. Mr. Brown has a PhD in Electrical Engineering from the University of Michigan and works at Microchip Technology. He holds a Tripoli L3 certification and regularly flies high-power rockets at various national and local launches. Mr. Brown is a member of Tripoli Mid-Ohio, the Michiana Rocketry Club, and the North Ohio Tripoli Rocketry Club.

2.1.3 Team Members

Reyan Ahmad (NAR L1 #113177/TRA #31480)
ahmadre@northvilleschools.net
947-336-0682

Figure 4. Reyan's mood after launching a sparky motor

The position of **Student Team Lead** will be served by Reyan. Reyan is currently serving as a co-president of the NHS Aerospace Club. He is entering his Senior year and has been a member of the club for the previous three years successfully participating in Rockets For Schools as well as ARC/TARC. Reyan was a member of the TARC team placing 2nd place nationally in the Presentation Competition in 2022 and on the Rockets For Schools team placing 3rd in 2023 and 2nd in 2024 for the Class 2 category.

Reyan currently holds a Jr L1 Certification and has successfully constructed redundant dual deploy altimeters, flown dual deploy flights, and is working towards his L2 certification when he turns 18 in the fall. Reyan is currently building a Mach 1 54mm Alien Interceptor. Other hobbies include playing guitar, badminton, and cricket. As Reyan wraps up his last year of high school, he is interested in pursuing a degree in Aerospace/Electrical Engineering in college.

Naoki Matsumoto (NAR 118660)
matsuotona@northvilleschools.net
248-704-7635

Figure 5. Naoki fiberglassing a fin

Naoki is serving as the **Safety Officer**, and is a co-president of the NHS Aerospace Club. Heading into senior year, this is his fourth school year in the club. He was part of the TARC team representing NHS that won second place in the 2022 presentation competition, and the team that won third and second place in Rockets for Schools Class 2, in 2023 and 2024 respectively. He also designed and painted the rockets that won the "Fit and Finish" award two years in a row. He is currently working towards his Jr L1 high-power certification.

After a hopefully successful last year of high school, Naoki is interested in pursuing chemical/materials engineering in college. Aside from aerospace, he is part of the mountain biking team, engages in music composition and production, playing guitar, 3D modeling and animation, video design, motion graphics, 2D art, and animation, among other random projects to pass the time.

Muaaz Ahmed (NAR 120106)

Muaaz Ahmed is currently in 10th grade at Northville High School. He has been in the Northville Aerospace Club for one year. He participated in the Northville ARC Launches and was a member of the team that placed 2nd place in the Rockets For Schools Competition in 2024.

Figure 6. Muaaz leading the Rockets For Schools crowd

Muaaz has built many model rockets and shifted to learning how to build high-power rockets. He is currently working on building a 54mm fiberglass Viper rocket to get his JR L1 high-power certification in late summer or early fall. Muaaz has interests in Aerospace, Science, Medicine, and Astronomy. Muaaz likes cooking, playing video games, and gardening and has played Hockey, winning his District 4 championship in 2020. After High School, Muaaz aspires to become either a doctor or a dentist.

Matthew McClure (NAR 120313)

Matthew is a senior at Northville High School and has been a part of the Northville Aerospace Club for one year. He was introduced to high-powered rocketry through the Rockets For Schools competition, where his main contributions lay in the payload electronics and programming along with partaking in the overall rocket build. Matthew is currently building a 54 mm fiberglass kit for his Jr. L1 high-power certification.

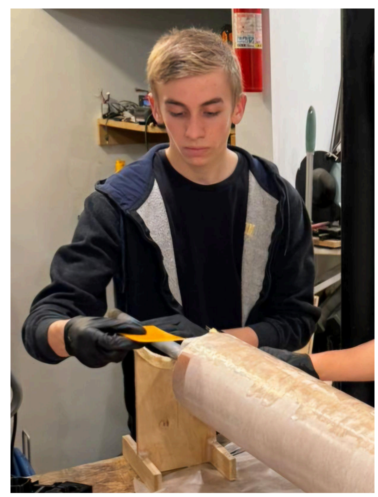


Figure 7. Matthew fiberglassing the Rockets For Schools rocket

Beyond rocketry, Matthew has a strong interest in software, particularly in AI development. In 2024, he began Sensei.AI LLC intending to make personalized, project-based software education more accessible and affordable through the use of generative AI. Matthew also has a strong passion for using STEM to benefit society. In 2023, he founded EDGE (Engineering and Design for Growth and Empowerment), a club dedicated to completing engineering projects that benefit the community. Matthew's additional interests include CAD, 3D printing, Isshinryu Karate, and mountain biking.

Henry Roberts(NAR 303785)

Henry is a sophomore at Northville High School and joined NHS Aerospace last year. He participated in the team that won 2nd Place at the Rockets For Schools Competition in 2024.

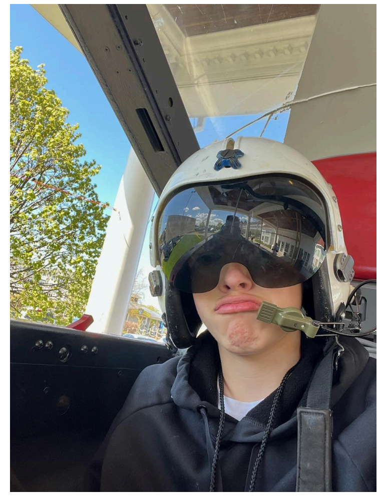


Figure 8. Henry in a training jet at Rockets For Schools

Henry gained interest in aerospace and spaceflight through his dad and is currently working on his JR L1 high-power certification with a fiberglass Mach 1 54 mm Viper rocket. After high school, Henry aspires to become an aerospace engineer in the private sector. His interests include soccer (specifically Bolton Wanderers FC and the England Men's National Team), video games, history, and movies.

Arjun Srinivasan (NAR 303668)

Arjun is a MENSA member and Space Camp graduate currently building his Jr L1 rocket. He is entering his senior year and he was a member of the Northville High School Aerospace Club that won second place in Rockets For Schools, specializing in presentations and public speaking. Aside from rocketry, Arjun is a chess player and coach, representing Australia on numerous occasions, placing second in a tournament against Israel in 2022. He has completed a virtual internship with Altair specializing in CAD proficiency via the prototype software Altair Inspire, and an in-person internship with SK International, an engineering and manufacturing company specializing in automobiles.

Figure 9. Arjun taking a picture with former astronaut Mark C. Lee

He plans to go into aerospace engineering in college and pursue a career with NASA. In his free time, he boxes and plays tennis and chess alongside his mentorship position tutoring a 1st-grader in Uganda. Furthermore, he is currently building an L1 high-powered rocket: a 54mm Alien Interceptor.

Veronica Wu (NAR #115476)

Veronica is a rising high school senior and a third-year member of the Aerospace Club. Previously, she has participated in TARC/ARC and Rockets for Schools, placing 2nd overall in 2024's Class 2 division. Following her graduation, Veronica hopes to pursue further education in Economics and Mathematics. She is interested in the finance aspects of the competition following her completion of Accounting I and AP Micro and Macro Economics.

Figure 10. Veronica (middle) making Tanghulu alongside her classmates

Other interests include CAD modeling and 3D printing. Veronica is also President of the Chinese Honors Society and the Northville High School Debate Team, planning several cultural events and participating in Public Forum competitions throughout the calendar year.

Ritvik Ellendula (NAR # 303772)

Ritvik is a new and eager member of the NHS Aerospace Club, passionate about building specifically biomedical applications and stretching the limits of what technology and engineering can do. He is entering his senior year and while not possessing much experience directly with the NHS Aerospace club, he did compete in an FAA International STEM competition, where he and his team placed 1st internationally, where he learned vital skills about the engineering process as well as completing educational modules related to aerospace engineering. Aside from rocketry, he's passionate about mentorship and empowering others, serving as the International President of America's largest student-run tutoring non-profit: Connect Me Tutoring.

Figure 11. Ritvik serving as a state officer at the Michigan State HOSA Conference

Ritvik is also an avid video production enthusiast, learning about the world of media after being inspired by his economics teacher, who runs the school news station. He has created several media projects, his favorite being his personal social media account, where he discusses chemistry, physics, and gastronomical content to 300+ followers. He also loves running Cross Country as well as Track and Field, maintaining a 4-year varsity letter winner position on a 2x state champion and a national champion team. In the future, he hopes to create tools to help and inspire others around the world regarding biomedical engineering, medicine, and more.

<u>Kien Nguyen (Tripoli 32272)</u>
Kien is a high school senior and a member of the Aerospace Club. He is passionate about electronics, technology, and robotics. Kien developed these skills by dismantling and repairing old electronics as well as participating in robotics since fifth grade. He also has a strong interest in small engines, particularly lawn mower and generator engines. Additionally, Kien serves as the Finance Lead for the FIRST Robotics team of Northville High School and has experience in business management and entrepreneurship. He hopes to attend college and major in business after graduation.

Figure 12. Kien (left) winning first place at a regional robotics competition

By joining the Aerospace club, Kien looks forward to exploring a new field and seeks hands-on experience in physics and chemistry beyond the school curriculum while also gaining insights into the financial aspects of running an aerospace organization.

2.1.4 Individual Roles and Responsibilities

All team members will be involved in all project steps; however, to prevent disorganization and optimally place everyone where their skills work best, each aspect of the project will have a "lead" that oversees the execution of that step or project section. Current lead and sub roles are outlined in the chart and table below, but rebalancing the workload and redistributing responsibilities may be necessary if the team expands going into the new school year.

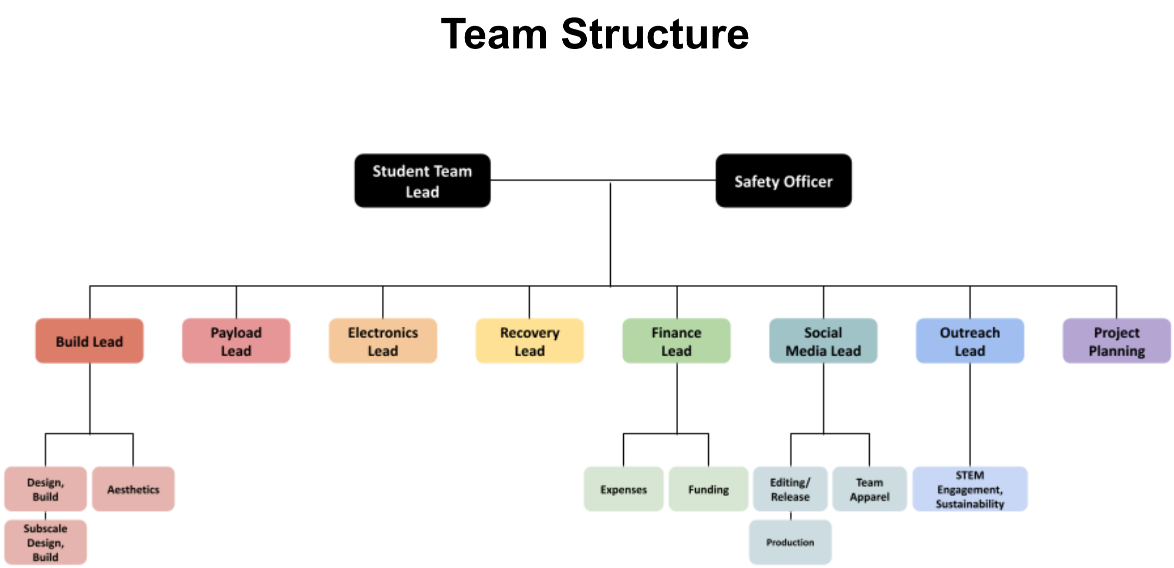


Figure 13. Team structure flowchart

Role	Name	Responsibilities
Student team lead	Reyan	Across the board, ensure team organization and direction. Making sure that the leads are working cohesively with each other and their teammates, as well as putting the team or members back on track if discussion derails.
Safety officer	Naoki	Handle execution of safety plan. (**Section 4.8**.)
Build lead	Reyan	Ensure that the physical building of the rocket is going according to spec and the timeline, and take part in instructional responsibility along with the mentor when needed. Ensure the rocket is soundly built and each step is correctly executed, especially on structural parts such as motor mount assembly and attachment, motor retainer attachment, fin root attachment, and fillets.
Design+build	Reyan, Henry	Be the main people to handle build and design coordination of launch rocket
Sub-scale design+build	Reyan, Muaaz	Be the main people handling the design, build, and launch coordination of the sub-scale rocket
Aesthetics	Naoki	Handle rocket exterior design and finishing
Payload lead	Naoki	Ensure that payload design, theory, and build are going according to spec and the timeline. Across each design and construction step, ensure that all parts work together as intended. Especially when drafting or using CAD, document progress and products made. Work together with other members to ensure the main project of the rocket fits, works, and is within budget.
Electronics lead	Matthew	Ensure that all electronics work accordingly. This includes risk mitigation (vibration, fragile components, etc) and physical integrity verification, coding, and anything else required to make sure the electronics do not malfunction.
Recovery lead	Muaaz	Design the overall recovery system and ensure that recovery devices are working properly. This includes the design of the overall stress margin of the recovery chain, determining safe recovery velocities, impact energies, dual deployment systems, deployment charge calculations, setup of ground test experiments, redundancies, and risk mitigation.
Finance lead	Veronica	Create and manage the team's budget and funding. Track expenses and ensure the team remains on

			budget. Make sure sponsorship outreach happens accordingly. Communicate with other team sections (build, payload, recovery, etc) about monetary needs and spending.
	Funding	Kien	Handle outreach to sponsors and coordinate with the social media lead and team. Keep the budget lead informed of all sponsor-related discussions.
	Expenses	Veronica	Manage expenses and ensure the team adheres to budgetary plans. *(see Finance Lead)*
Social media lead		Ritvik	Ensure our social media is active and up-to-date. This person will be the main person in charge of all things social media, including creating that media, editing, and posting, or ensuring another student is creating, editing, and/or posting. Also, work with those in merchandise to make sure anything made is properly representative of the team.
	Social media production	Ritvik	Handle the production of media to be posted to social media websites
	Media editing and release	Ritvik	Edit media and ensure it is released appropriately
	Team apparel	Henry, Muaaz	Handle the design and creation of team merchandise
Outreach and student interaction lead		Arjun	Ensure that team outreach and student interaction are meeting or exceeding the hours specified by NASA. This person should be the main person looking for, organizing, and leading student interaction events, or making sure the most appropriate person is leading an event.
	Project planning	Arjun	Ensure that the team meets the milestones set by NASA and plan the completion of said milestones.
	Sustainability	Arjun	Carry out activities and events to ensure the continued success of the club in the proceeding years, even after seniors have graduated. This ties with STEM Engagement in terms of outreach to potential Aerospace Club members.

Table 1. Initial team structure and responsibilities

2.1.5 Student Team Leader

Reyan Ahmad (NAR 113177/TRA 31480)
Email: ahmadre@northvilleschools.net
Phone: 947-336-0682
Certification: NAR Jr L1 (Anticipating L2 in December 2024)

2.1.6 Safety Officer

Naoki Matsumoto (NAR 118660)
Email: matsumotona@northvilleschools.net
Phone: 248-704-7635
Certification: Anticipating Jr L1 in November 2024

2.1.7 Affiliated NAR/Tripoli Sections

Finding an appropriate, safe, and legal flying site for high-power rocketry in the upper Midwest is a challenge. High-power flights are only done at club sites. These sites are corn fields and can only be done between harvest and planting, typically between November and April. NHS Aerospace is affiliated with NAR Section #859 where the club mentor serves as the section leader. However, this section is strictly low and mid-power rocketry, primarily used for club launches and TARC/ARC activities that require insurance for the use of city/township property. Mid-power launches are used as introductions to new members to demonstrate building methods, composite motors, and characteristics of stable flight.

High-power launches are performed typically at one of three locations, with a preference towards Michiana Rocketry and Tripoli Mid-Ohio due to the size of the field and the ability to interact with other USLI/SLI teams and mentors.

Organization	Section/Prefecture	Point of Contact	Key Features
Michiana Rocketry	NAR Section #721 TRA Prefecture #78	Dave Brunsting dacsmema@gmail.com	• 12,000 ft FAA Waiver • Large, open recovery area • Caters to academic teams (Notre Dame University, Rose Hulman, Purdue University, Western Michigan, etc). • NHS Aero members and mentors fly here regularly. • Scheduled launches monthly Nov through April
Tripoli Mid-Ohio	TRA Prefecture #31	Todd Knight jtknight42@gmail.com	• 15,000 ft FAA Waiver • Large, open recovery area • Caters to academic teams (Ohio State, Kent State, Univ of Akron, Toledo Univ, etc). • NHS Aero members and mentors fly

			here regularly. ● Scheduled launches approximately bi-weekly Nov through April.
Michigan Team-1	TRA Prefecture #9	Norm Nazaroff njnazaroff@fascominc.com	● 5,000 ft FAA Waiver before crops harvested, 18,000 ft waiver after harvest. ● The summer field serves as a good location for student certification launches, the winter field is ample for sub-scale and full-scale. ● Approximately monthly launches.

Table 2. Local NAR/TRA clubs that have granted permission to NHS Aerospace Club

All of the sections/prefectures listed above fly in accordance with NAR and TRA safety regulations with well-maintained flight equipment. Many of the clubs have a very rich history in either competition flying and/or working with academic teams. In addition, many of the NHS students and former students fly at these clubs and are in good standing with the club members and officers.

One aspect of flying at these clubs that cannot be overemphasized is the ability to meet, interact, and learn from various other academic teams, particularly with the university teams. This provides constant feedback on how we are doing, and what we can do better, and helps with constant improvement. Several of the NHS Aerospace Club members know and are familiar with university team mentors who can be used as valuable resources during our first year of participation in SLI.

2.2 Proposal Time Tracking

Our team has dedicated a significant amount of time and effort across various key areas to ensure the success of this proposal. From team meetings and proposal writing to design and outreach, each category reflects the hard work and collaboration of our members. Below is a breakdown of the hours spent on essential areas of the proposal.

Category	Time (hrs)
Team meeting	15.5
Proposal writing	305
Finance and fundraising	21
Website	45
Social media	19
Rocket design	43
Payload Design	37
Total:	***485.5***

Table 3. Time tracking

2.3 Design Review Time Slots

We have selected the following time slots for our design reviews to ensure flexibility and accommodate everyone's schedules. The available times are listed below

- Monday: 1:30-2:30 CST
- Monday: 2:30-3:30 CST
- Tuesday : 1:30-2:30 CST

We are open to conducting our design reviews on the chosen days within the scheduled weeks.

2.4 Letter of Support

Northville High School
45700 Six Mile Road • Northville, MI 48168 • Phone: 248-344-3800 • Fax: 248-344-3801
Principal: Tony Koski
Assistant Principals: Emily Aluia • Jim Gordon • Janice Loomis • Krystal Muhammad
Athletic Director: Brian Samulski

TO: The NASA Student Launch Initiative Committee
FROM: Tony Koski, Northville HIgh School Principal
DATE: August 23, 2024
SUBJECT: SUPPORT FROM NHS TO PARTICIPATE IN THE NASA STUDENT LAUNCH INITIATIVE

The Administration of Northville High School is in full support of our NHS Aerospace Club in their endeavors in the 2024-25 NASA Student Launch Initiative. We will allow needed time and resources during school hours for the team members and our teacher advisor to attend the required NASA SLI video teleconferences for their Milestone Design Reviews and presentations as well as the Milestone Question and Answer sessions.

We truly appreciate this awesome learning opportunity you are providing for our students. Thank you.

Figure 14. Letter of support.

3 Facilities/Equipment

3.1 Facilities and Equipment

All team meetings in school will occur in our teacher advisor, Mrs. Krebs', room. Due to a lack of equipment, no rocket construction will occur here; however, weekly club meetings happen in this room, where we plan to make headway in documentation and presentations to prepare for meetings with the NASA panel. Furthermore, if teleconferences happen during the school day, it may become necessary to borrow various meeting spaces that exist within our school. Organization of the team will occur in school and rocket build will happen in our mentor's workshop.

Figure 15. Rocket assembly workspace

All rocket construction will be done in our team mentor's workshop. Mr. Brown will provide the team with access to the equipment needed to complete the project, as seen in Table 3. As a first-year team, we will be using pre-slotted fiberglass tube G10 fiberglass fins rather than cutting our own, eliminating the need for slotting equipment. Additionally, we will be using vendor-cut G10 fiberglass fins cut to our specifications to compensate for the lack of a CNC mill and avoid any potential hazards of milling fiberglass. Most of the equipment we will be using is minor and commonly available. A full list of the equipment we will be using can be seen in **Table 4**.

Equipment	Purpose
Drill Press	Machining fiberglass
Router Table	Chamfer fiberglass fins
Dremel Tool	Body tube minor modifications, cutting threaded rods
Screw Drivers	Tightening various fasteners
3D Printer	Fabrication of assembly jigs, rocket components
Kevlar shears	Cutting Kevlar to length
Soldering iron	Assembly of altimeter bay, payload
Dual action polisher	Polishing clear coat
Ambient air cleaner	Removes dust and particulates from the air

Table 4. Fabrication equipment

Prefabricated components reduce the need for infrequently used, expensive, and time-consuming processes, and the use of our team mentor's well-equipped workshop ensures that our team has everything we need to successfully build our rocket. All members of our team have previous experience working with the machines above from prior competitions or rocket builds, ensuring that our construction is both safe and of high quality.

3.2 Software and Design Tools

We will be using a multitude of software tools, many of them available through our district's educational licensing, to help design our rocket and payload. These software tools allow us to model and simulate rocket parts, reducing the need for physical iterations. The simulations range from testing the durability of components to simulating the velocity in different situations whether it be on landing or takeoff. Below are the following software tools and the simulations we will be using with them:

Software necessary	Tasks requiring software	What they are used for
Autodesk Inventor Professional	Solid modeling for structural design	Create 3D models of the payload. Test the payload under various conditions.
OpenRocket	Target altitude	Predict the rocket's maximum altitude based on its design and propulsion system.
	Static stability	Assess the rocket's stability, center of gravity, and center of pressure while on the launch pad.
	Dynamic stability at the rail exit	Evaluate rocket behavior as it exits the launch rail.
	Thrust-to-weight ratio	Measure the ratio of the rocket's thrust to its weight, determined by the type of rocket motor and the materials used to construct the rocket.
	Rail exit velocity	Determine the speed of the rocket as it leaves the last launch rail.
	Maximum velocity	Determine the maximum velocity based on the type of motor and materials used.
	Descent time	Determine the time required for the rocket to return to the ground after reaching its peak altitude.
	Impact kinetic energy	Estimate the energy the rocket will have upon impact with the ground.
	Drift vs. wind	Analyze how wind conditions will affect the rocket's flight path.
Python	Fin flutter	Calculate the maximum velocity until

		stress-induced fin oscillation and vibration through a formula explained more in-depth in **section 5.7.7**.
	Data analysis and plotting	Analyze data from simulations and measurements.

Table 5. Software description

3.2.1 OpenRocket

The purpose of using OpenRocket is to design and simulate most aspects of their rocket including testing materials and masses. OpenRocket is a free model rocket simulator, and the simulations will be used to select the motor and recovery methods. The software includes data like the rocket's stability, center of gravity, and expected flight performance.

3.2.2 Autodesk Inventor Professional

Autodesk Inventor is a commercially available computer-aided design (CAD) software. It is a commercial software tool that we are using under an education license. We aim to use Inventor for the 3D modeling of the payload, altimeter bay interior structure, and design of all assembly jigs. It allows us to create detailed 3D models of payload components, ensuring they fit within the rocket's payload bay and meet size and weight constraints. Inventor also includes simulations that can allow us to analyze how payloads will withstand launch forces, vibrations, and potential impact scenarios.

3.2.3 Python

This is a programming language that we will be using to calculate the fin flutter of our rockets and analyze data from simulations and measurements. The fin flutter code allows the team to input our specific fin design and launch conditions. The code will then calculate the approximate fin flutter velocity of the design. Additional details of the fin design and how the program works including the formula will be in **section 5.7.7** Fin flutter.

3.3 Collaboration and Productivity Platforms

The following software are used for collaboration. This includes communication with fellow team members, mentors, or educators as well as the softwares used to house our community documents. These are all free softwares or are valid educational licenses provided by the school district.

Softwares necessary	Tasks requiring software	What they are used for
WhatsApp, Google Workspace	Project Scheduling and tasking	This is used to ensure that the team works on time, and has all the announcements and meeting agendas/minutes in a centralized place and more.
	Team Collaboration	Ensuring that all the documents used in Student Launch are centralized
	Presentation	Used for our outreach program or meetings where we need to either teach a group of people or share our progress with the team.
Github/Wix	Website Design	Used to market our mission, show what we have been working on so far, and give a portal for potential sponsors to donate.
Canva/Adobe Software Suite	Brochure design	Used for sustainability purposes as well as marketing our mission to potential sponsors
	Rendering for publication	Used for finalizing our promotional videos on social media
React	Website development	Framework to develop our club website.
GitHub	Website Hosting	Host our club website at **https://nhsaerospace.github.io**.
	Git repository hosting	Host our website code at **https://github.com/nhsaerospace/nhsaerospace.github.io**.

Table 6. Collaboration program descriptions

3.3.1 WhatsApp Communities

Whatsapp is a communication platform. The team will utilize it for planning meetings and emergency contacts. The main benefit of WhatsApp though is the easy streamlining of sharing ideas and providing constant communication between the members, mentor, and educator. All participating mentors and team members have been added to a WhatsApp community where topic-organized discussion can occur. For the SLI project, we have created a community where all team members have access to channels for specific topics such as Build, Payload, Finance, etc.

3.3.2 Google Drive

Google Drive is a file-sharing platform. The team will utilize Google Drive to document, store, and share any files related to this competition. All team members, mentors, and teachers will have access to this shared drive, allowing them to add/edit any relevant files. Google Drive contains many folders and sub-sections allowing for better organization and delegation of tasks, sectioning off items for members to complete.

3.3.3 Google Docs

Google Docs will be used as our main way of writing reports to make it easier for the whole team to participate. Any proposals created will be made through Google Docs and subsequently placed in the Shared Drive. Furthermore, it's easily shareable through emails, making it much more efficient when we send out sponsorship proposals to different corporations.

3.3.4 Google Sheets

Google Sheets will be utilized to log data and create graphs. Such graphs may include Gantt Charts as well, used for creating a timeline of the work we will need to finish, or a spreadsheet of all the tasks we need to finish and the percentage of completion. As the Student Launch progresses, we will be using Google Sheets to track our data and use the built-in functions to extrapolate the raw data and transfer it into a digestible format in later documentation.

3.3.5 Google Slides

Google Slides is a presentation platform that we will be using for our outreach and sustainability as well as meetings. In outreach, alongside activities and discussions, mini-lessons might utilize a Slides presentation to effectively communicate the topics that will be discussed. Furthermore, the lessons will be for middle school students, some of which might be going to Northville High School next year, acting as a sustainability action as well because they will see the lessons and potentially join the Aerospace Club as a result. Lastly, in meetings, whether it be explaining the handbook, delegating tasks, or teaching a new concept we might be implementing, Google Slides is always necessary.

3.3.6 Remind

Remind is a communication platform that the team will be using to post announcements. Team members join the Remind group and get streamlined notifications on their phones outlining any immediate announcements.

3.3.7 React

React is the front-end web app framework that we used to develop our website. Along with the use of Typescript, HTML, and CSS, we were able to successfully program our website to be functional and aesthetically pleasing.

3.3.8 GitHub

GitHub is a web-based platform that allows developers to manage and publish their code. We used GitHub to host the Git repository for our website. GitHub also offers a web hosting service called GitHub Pages, which we used to host our website at **https://nhsaerospace.github.io**.

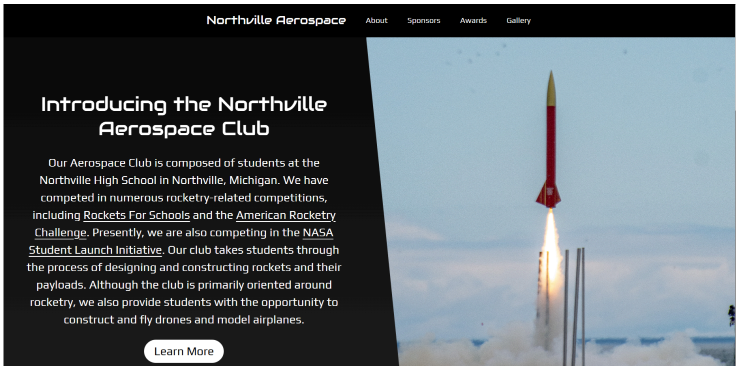


Figure 16. NHS Aerospace Club's website through GitHub pages

3.3.9 Adobe Illustrator

We will be using this software to design sketches of our rocket, payload, and the individual parts. Furthermore, we might be using this for any outreach art we may need to use for the STEM engagement. Adobe Illustrator is a paid vector graphics editing and design software; however, the team receives access to the software through the school district and will be using it for any artwork related to the club or this competition.

3.3.10 Adobe Premiere Pro

Adobe Premiere Pro is an industry-standard timeline-based software that has a multitude of features for the video production pipeline. We will be using this software to edit any promotional footage we film, such as videos for the school's video announcements and social media posts.

3.3.11 Adobe Photoshop

Adobe Photoshop is a layer-based image editing and digital drawing program with various features to create image-based media. It will be used to edit and create image media. It will also be used in conjunction with other software such as Adobe Illustrator to create raster and vector art for our rocket.

3.3.12 Blender

Blender is a comprehensive software supporting the entire 3D pipeline: modeling, sculpting, animating, simulating, rendering, tracking, and compositing. Its features will be used to create 3DCG media for various purposes, such as model mockups, rocket external graphic drafting, and images/videos for social media.

4 Safety

4.1 Safety Plan and Risk Mitigation

Our team has initiated a safety plan and risk mitigation process by identifying potential hazards that could arise during the competition. This includes outlining the cause of each hazard, its possible effects, and the mitigation strategies we plan to follow to prevent such hazards. We recognize that this is just the beginning of our efforts, and there are hazards we have not yet identified. It is important to note that we have not performed a detailed analysis to determine the probability and severity of these hazards. Being a first-year team, we are learning the process of classifying severe risks. We plan to update such risks by utilizing the hazard analysis workshops conducted by NASA between the acceptance and the preliminary design review. The Lists below are a rough idea based on the properties of the materials and standard procedures that we utilize and we will keep adding on to this list as we gain more experience.

4.1.1 Fabrication Hazards

Fabricating rocket components involves managing potential health hazards to ensure the safety of the team and project success. The process requires handling materials and procedures that pose potential risks. Implementing effective mitigation strategies is crucial to remove hazards, use proper equipment to isolate the hazard, and ensure the safety of the personnel and equipment. Below is a list of potential hazards and corresponding mitigation strategies that our team may encounter during this project.

Hazard	Cause	Effect	Mitigation strategy
Direct contact with edges of fiberglass	Handling fiberglass	Skin irritation, minor cuts, and possible infection	• Eliminate sharp edges by taping when possible. • Wear protective gloves and clothing. • Have a first aid kit available at all times should an incident arise.
Exposure to fiberglass dust	Sanding fiberglass	Possible respiratory complications like coughing, wheezing, and soreness in the nose and throat. Long-term effects include complications such as dermatitis	• Wet sand when possible to eliminate dust becoming airborne. • Work in areas with adequate ventilation including air filtration. • Wear a respirator or a dust mask • Dispose of all extra dust formed into a closed-off container to prevent it from being airborne
Exposure to solvents	Cleaning fiberglass	Headaches, nausea, unconsciousness, skin irritation, permanent eye damage.	• Work in a well-ventilated area or work outside. • Wear gloves and a respirator at all times while handling solvents

Exposure to toxic gasses	Working with epoxy resins	Respiratory injury, allergic reactions, and possible asphyxiation.	• Use the least hazardous type of epoxy that performs the desired functions • Wear a respirator at all times and work in a well-ventilated area.
Dangerously high-temperatures	Thermal runaway exothermic reactions from epoxy curing	Burns, the container melting, and possible exposure of skin and/or wounds to hot, uncured epoxy.	• Mix the appropriate amount of epoxy when in use. • Apply epoxy in thin layers, especially in large cavities, and ensure the working area is well-ventilated • To prevent heat buildup, transfer epoxy from the mixing container to a wide shallow container to increase surface area.
Direct contact of epoxy with skin	Working with epoxy	Development of irritation and allergic contact dermatitis.	• Maintain safe working distance when working with epoxies, and use appropriately sized applicators when possible. • Wear nitrile gloves while working with epoxy. • If epoxy gets on the skin, immediately clean the contact area with isopropyl alcohol.
Exposure to epoxy filler additives	Altering epoxy using additives	Skin irritation, respiratory complications, silicosis	• Minimize the possibility of additives becoming airborne by keeping additives confined. • Wear a particulate mask/respirator to prevent inhalation.
Exposure to a sharp, spinning edge	Use of a drill press	Cuts, hair removal, and abrasion.	• Eliminate risk by securing the workpiece with clamps or a vise before starting the machine, and make sure that the drill bit is functioning as intended. • Reduce risk by utilizing protective barriers or guards on the drill press, wearing appropriate PPE • Prevent accidents by keeping hands, loose clothing, and long hair away from drill bits, and turn off the drill press before making any adjustments.
Exposure to intense sound and a sharp, spinning edge	Use of a router table	Hearing loss, cuts, hair removal, and abrasion	• Maintain a safe distance from the machinery when in operation. • Use sound-dampening materials to reduce sound produced and wear proper hearing protection while operating such machines.
Exposure to toxic substances in Bondo and other	Use in filling surface imperfections	Skin, eye, and respiratory irritation, detrimental effects on the nervous	• Reduce risk by using an appropriate amount of Bondo and other solvent-dissolved surface

similar solvent-dissolved surface fillers		system, and reproductive harm.	fillers • Wear gloves and a respirator at all times. Work in a well-ventilated area.
Exposure to aerosolized surface filler and primer	Sanding paint layers	Skin, eye, and respiratory irritation, and long-term detrimental effects to the cardiovascular and reproductive systems.	• Wet sand when possible to reduce the amount of dust generated and regularly clean the workspace and equipment to prevent the accumulation of hazardous materials • Wear a respirator at all times while working with surface fillers and primers • Work in a well-ventilated area or outside • Wear nitrile gloves.
Exposure to toxic substances in paint and clearcoat	Used for adding aesthetic elements to the rocket	Skin, eye, and respiratory irritation, and long-term detrimental effects to the nervous, cardiovascular, and reproductive systems.	• Prevent exposure by using less toxic, Low Volatile Organic compounds paint and clear coats when possible • Wear a respirator at all times while working with paint and clear coat, Wear gloves at all times • • Work in a well-ventilated area or outside
Exposure to aerosolized paint and clearcoat	Used for adding aesthetic elements to the rocket	Skin, eye, and respiratory irritation, and long-term detrimental effects to the nervous, cardiovascular, and reproductive systems.	• Minimize overspray and runs and regularly maintain and clean equipment. • Wear a respirator at all times while working with paint and clear coat, and wear gloves at all times • Work in a well-ventilated area or outside
Exposure to highly flammable gasses	Use of aerosolized paint and clearcoat	High risk of ignition from a spark or heat source causing first/second/third degree burns and injury	• Eliminate risk by avoiding the use of aerosolized paint and clearcoat near open flames, sparks, or any heat sources • Work in a well-ventilated area or use ventilation systems that safely disperse flammable gasses. • Prevent build-up of flammable gasses by storing aerosolized paint and clearcoat cans in cool, well-ventilated areas and follow all guidelines for handling and disposal
Exposure to intense sounds and a fast-moving polishing wheel	Use of a dual-action polisher	Clothes and hair being caught and polishing compounds entering the eyes, causing physical injury.	• Wear appropriate ear protection while working with a dual-action polisher • Maintain a firm grip on the polisher and use it at the recommended speed settings. • Keep all lose clothing, and hair

			away from the dual action polisher at all times
Exposure to a sharp-moving blade	Use of a vinyl cutter	Physical injury, minor cuts	• Eliminate risk from sharp moving blades by ensuring that the machine's safety guards are functional and in the proper place. • Maintain a safe working distance while the machine is in operation • Always turn off and unplug the machine when making adjustments or removing vinyl.
Exposure to hot materials	Soldering electrical components	First/second/third-degree burns	• Eliminate risk by using a soldering iron with temperature control and holding the soldering rod by the insulated handle at all times • Work in a well-ventilated area and wear heat-resistant gloves, wear proper PPE at all times • Prevent accidents by keeping the soldering iron in a designated stand and make sure to turn it off and wait for the soldering iron to cool before changing tips.
Exposure to metal shrapnel	Trimming or cutting electrical components	Eye injury, skin injury	• Eliminate risk by using the appropriate tools such as precision cutters and wearing protective safety goggles at all times • Perform cutting operations in a controlled environment where debris can be contained and cleaned up • Prevent the generation of metal shrapnel by securing the electrical components before trimming to minimize the risk of accidental debris.
Exposure to flux	Handling solder	Inflammation of the nose, eye, throat, skin rashes, and long-term effects like asthma and dermatitis.	• Eliminate risk by working in a well-ventilated area or under a fume extraction system to prevent inhalation of fumes. Additionally, wear gloves to avoid direct skin contact with flux • Reduce the effects of exposure by avoiding prolonged exposure and using a flux with low volatility or less harmful substances. • Store solder in a sealed container and away from direct contact to reduce the risk of accidental exposure or spillage
Exposure to HF gas	Mishandling of lithium batteries	Lead to skin burns and lung damage.	• Eliminate the risk of exposure to HF gas by handling batteries according to manufacturer

			instructions and avoid any actions that could lead to leakage or overheating. • Use proper containment and disposal methods for damaged or defective batteries to prevent the release of hazardous gases • Reduce the effects of exposure by working in a well-ventilated area. If the battery leaks or emits gas, evacuate the area immediately and utilize chemical-resistant gloves and goggles at all times • Regularly inspect the lithium batteries for damage and store them in a cool, dry place away from flammable materials.
Exposure to a powerful laser	Use of a laser engraver	Vision impairment and burns.	• Eliminate risk by ensuring that the engraver is equipped with functioning safety enclosures or shields. • Wear appropriate safety goggles at all times and avoid looking directly at the laser
Exposure to the sharp edge of a blade	use of hobby knives, utility knives, and scissors	Cuts and infection	• Eliminate risk by using safety features like retractable blades or blade guards, ensure the tools are in good condition, and avoid using excessive force • Use cutting tools on stable, non-slip surfaces and wear protective gloves designed to resist cuts and avoid distractions. • Store knives and scissors in a safe container and cover the blades when not in use.
Exposure to high-temperatures	Handling the hot end of a 3D printer	First/second/third-degree burns	• Avoid touching the hot end of a 3d printer • Ensure that the 3D printer is turned off and unplugged before approaching and use heat-resistant gloves or wait a sufficient amount of time before lifting hot components
Exposure to fast-moving mechanical components	Working with a 3D printer	Impact injury and trauma	• Ensure that all moving components are properly enclosed or guarded. Avoid reaching in or attempting to adjust the printer when in operation • Maintain a safe distance and ensure that the printer is equipped with emergency stop buttons.
Exposure to a sharp tip from a tapping tool	Working with a tapping tool	Minor cuts	• Always handle the tool carefully and ensure that it is properly secured before use.

			Avoid placing fingers near the sharp tip during operation. • Always wear protective gloves, use a proper tapping tool, and maintain control to reduce the risk of accidental contact

Table 7. Fabrication hazards

4.1.2 Launch Hazards

The following table represents an estimation of the potential hazards associated with launching a class 2 rocket. This is a preliminary assessment and serves solely as a foundation for identifying risks and developing mitigation strategies. A more detailed version of this table will be provided after completing the NASA risk assessment workshop.

This assessment is crucial because it allows members to proactively recognize and manage risks, ensuring the safety of team members, equipment, and the success of the mission. By anticipating potential issues and implementing mitigation strategies, we can prevent catastrophic failures.

Hazard	Cause	Effect	Mitigation strategy
Premature motor ignition	Electrostatic discharge	Severe burns Hearing loss	• Motor components are stored unassembled in ESD-safe packaging. • The motor is only assembled immediately before launch. • Ignitor leads are shorted until ready to hook up to ignition leads.
	Faulty wiring or connectors	Severe burns Hearing loss	• Check all electronic equipment including the electronic igniters. • Verify ignitor leads are un-energized before connecting to the ignitor.
	Delayed ignition after initial ignition attempt.	Severe burns Hearing loss	• Standard NAR/Tripoli protocol is to be followed by waiting at least 60 seconds before approaching the launch vehicle. • Wait to approach the rocket for clear range and only under the permission of LCO.
Black powder ignition	Premature ignition during ground test	Severe burns Hearing loss	• Only allow authorized personnel to handle any flammable or potentially explosive materials and ensure safety protocols are followed. • Black powder is not added until the flight computer is verified to be off. • Wear protective PPE.
	Static electricity ignition	Severe burns Hearing loss	• Only allow authorized personnel to handle any flammable or potentially explosive materials and ensure safety

			protocols are followed. • Use twisted pairs for leads to e-matches to prevent magnetic field coupling from other electronic devices.
Drogue parachute deployment failure	Failed electronic deployment, miscalculated ejection charges	Severe impact injury, damage to property, or death	• Redundant altimeters and ejection charges • Ground testing • Angle launch vehicle away from personnel/spectators. • Enable failsafe mode on the flight computer to deploy the main if it detects no drogue separation.
Main parachute deployment failure	Failed electronic deployment, miscalculated ejection charges	Severe impact injury, damage to property, or death	• Redundant altimeters and ejection charges • Ground testing • Angle launch vehicle away from personnel/spectators. • Enable failsafe mode on the flight computer to deploy the main if it detects no drogue separation.
Parachutes do not open after ejection	Improper folding of the parachute, tangled parachute, improper preparation	Severe impact injury, damage to property, or death	• Ensure shroud lines are not obstructed. • Verify that the Nomex material does not interfere with parachute deployment • Rehearse rocket preparation before conducting a launch and make sure that team members are well-versed in recovery processes.
No separation events after planned ejection altitudes	Electronics turned off/not working, miscalculated ejection charges.	Severe impact injury, damage to property, or death	• Ground test and make sure the black powder charges are sufficient enough to separate the rocket. • Verify no binding in the couplers. • Perform e-match conductivity checks and inspect all wiring. • Use a checklist with independent confirmation to ensure the altimeter is armed and all necessary steps are performed.
Trajectory change	Winds or drift due to early parachute deployment	Loss of the rocket, property damage	• Identify trajectory and stand clear of the landing path. • Use a GPS tracker for recovery • Follow Standard NAR protocols.
Missing recovery connection points	Improper rocket prep, absence of checklist, not following checklist	Severe impact injury, damage to property or death, and loss of the rocket	• Ensure all connection points are secured and functional without damage • Follow a checklist to minimize mistakes
Ripped parachutes due to drag separation	Failure to anticipate aerodynamic forces	Severe impact injury, damage to property or death, and loss of the rocket	• Shear pin calculations are done correctly

Structural failure in air.	Fin failure	Severe impact injury, damage to property, or death	• Use best practices for assembly (clean epoxy surfaces, adequate filletting, material selection, etc.). • Perform margin analysis to avoid fin flutter velocities.
Motor failure	Motor overpressurization	High-speed metal shrapnel and fiberglass debris	• Make sure that the motor has been assembled according to the manufacturer's descriptions. • Incorporate pressure relief systems like vent holes to prevent damage to other components
	Motor under pressurization	Inconsistent or failure of flight	• Select a motor with a history of proven starts • Select an easily ignitable, low-oxidation propellant • Check the simulation of motor internal pressures to ensure the motor design is pressurizing adequately. • Ensure the ignitor and pressurization cap are correctly installed per motor instructions and verify that the ignitor is secured

Table 8. Launch hazards

4.2 Hazard Labeling and Recognition

The Team will be implementing a Hazard Labeling and Recognition Program to add and maintain clear descriptions of warning signs on all potentially hazardous equipment, tools, and materials. These warnings will be placed on hazardous materials such as energetic material, sharp or trauma objects, or any item that may pose a safety risk.

Title	Symbol	Meaning
Warning/caution		Designed to indicate that awareness is required. One must use caution and utilize all safety equipment
Explosive		Indicates that the material contains an explosive release of energy
Electrical		Indicates a potentially dangerous voltage and the possibility of electrical shock and/or electrocution.
Fine particulates (breathing hazard)		Handling of this material will release fine particulates into the air.
Safety equipment	   	Designed to remind people to utilize PPE before doing tasks. 1) General mandatory action 2) Safety goggles: worn while working with a material /process that can harm the user's eyes 3) Ear protection: worn while working with machines causing loud noises. 4) Breathing Mask: worn while working with material creating fine particulates and/or hazardous fumes that may present a breathing hazard.

Chemical reaction		Designed to warn users about the possibility of a chemical substance or mixture that might present a health hazard.
Noise		Design to serve as an indication that severe noise will be produced and proper ear protection is to be worn at all times.
Fire hazard		Designed to indicate a serious risk of ignition or fire outbreak.
Sharp implement		Warning placed on sharp tools to indicate potential cutting hazards which might cause harm to the user.

Table 9. Hazard labeling and recognition

4.3 Pre-Launch Briefing Statement

Before every launch or ground testing event, the assigned Safety officer and the NAR/TRA mentor will conduct a pre-launch/test briefing to inform the students participating in the tests about the process, conditions, etc. A detailed version is given below.

- **Ground Testing, Northville, MI:**
    - Discuss ground testing goals and team expectations.
    - Go over safety and PPE required of black powder ignition
    - Double-check deployment charge calculations.
    - Ensure no component is armed before being on the actual test site.
    - Ensure each student is a safe distance away from the armed rocket according to **table 11.**
    - Review policy of verifying all energetics are consumed and proper disposal/cleanup.
    - Ensure proper protocols are followed in the case of a misfire or pre-ignition according to **section 4.1.2**
- **Sub-Scale, Full-Scale, and Final Launch, Various NAR/TRA Launch Sites:**
    - Brief the team of on-site weather conditions including local and aviation forecasts. Review expected performance based on current conditions.
    - Set expectations for the launch day.
    - Ensure all events are done according to NAR/TRA/SLI regulations. If additional information was presented at the flier meetings, convey that information to the team.

- Ensure that no team member is allowed to handle the motor or energetics other than the mentor.
- Review pre-flight checklists and stress that all items need to be completed or reviewed for exception before any launch.
- Review the policy on arming electronics.
- Review readiness requirements for the payload, if applicable.
- Ensure every student is a safe distance away from the rocket when it is armed for launch according to **table 11.**
- Review team roles.

4.4 High Power Launch Procedures

All launch procedures will comply with NAR and Tripoli safety standards. The NAR Safety Standards for high-power launches are shown in the table below along with a description of how the Northville Aerospace Club will comply with each standard.

NAR Safety Standard	How the Club will Comply
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.	Most of the team is either Jr. L1 or in the process of obtaining Jr. L1 certification. The mentor is certified as Tripoli L3 and will be the flier of record for all launches. As the team members are under the age of 18, and cannot legally handle or possess high-power motors, all inventory, handling, and preparation of the motors will be handled by the mentor.
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.	The team will ensure the use of materials approved by NAR. These include fiberglass airframes and 3D-printed non-structural items. Durable metal will be used for items like threads for avionics bay assembly and other harness attachment points ensuring a safe connection while keeping the rocket as light as possible.
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, or heat sources within 25 feet of these motors.	Our team will only utilize motors that are commercially available, certified, and unmodified. These motors will be transported by the team mentor in compliance with NAR regulations. These motors will be transported safely to minimize risk. As per SLI regulations, sparky motors are prohibited hence they will not be used.

Ignition System. I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch and will use a launch switch that returns to the “off” position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.	The team will only launch rockets with an electrical launch system and we will use the launch equipment which has been approved by the NAR/Tripoli club. The electrical motor igniters will only be installed after the rocket is at the launch pad or any designated preparation area if applicable.
Misfires. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher’s safety interlock or disconnect its battery and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	The team will ensure safety in the event of misfires. All launch procedures will be performed under the guidance of an RSO/LCO. Misfires will be handled using NAR and Tripoli safety protocols. The team will wait at least 60 seconds after a misfire, consult the LCO, and approach the rocket only after clearance is approved.
Launch Safety. I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high-power rocket I will observe the additional requirements of NFPA 1127.	The team’s experience with TARC has conditioned them to always use a 5-second countdown before launch only after all aspects of the rockets have been given a go or no go. In the event of a problem, all team members are required to be behind the minimum safety distance for every type of motor. When arming onboard electronics only authorized personnel including a mentor are allowed to approach the rocket. The stability of the rocket is evaluated during the pre-flight preparations and if a fault is found it is either to be corrected or the rocket is not allowed to be loaded on the launch pad.
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	The rocket will be launched using a launch pad which can sustain the acceleration of the motor and can hold the weight of the rocket. We will use a launch rail tall enough to ensure that the rocket can achieve its safe launch velocity while being stable. The launch pad will be fitted with a blast deflector to ensure that no damage is done to the surroundings as the rocket lifts off. The area surrounding the launch pad will be clear of anything flammable or anything that can take damage.

launched uses a titanium sponge in the propellant.	
Size. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high-power rocket motor(s) intended to be ignited at launch.	Our team is only using one solid motor between the high school range of H-K with a total impulse range of 160.01Ns (H) to 2560 Ns (K). Our rocket will be simulated in OpenRocket and we are keeping the thrust-to-weight ratio exceeding 5:1 as per SLI rules superceeding the NAR requirement of 3:1.
Flight Safety. I will not launch my rocket at targets, into clouds, near airplanes, or 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.	Our team will not fly if the conditions outside do not permit the launch of a rocket as per NAR standards. Including clouds, and winds over 20 miles an hour. Our team will also fly in clear airspace with an optimal waiver. Our rocket will not include any flammable or explosive payload to minimize risk and we will make sure not to exceed the altitude waiver of the launch site.
Launch Site. I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).	The team will only launch at a site that has been sanctioned by a reputable organization. The launch site will be cleared of any obstructions. The team will ensure any person who is not involved in the launch does not present a hazard.
Launcher Location. My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.	The team will launch at a launch site that has been sanctioned and properly set up. Our team will set up behind the minimum safety boundary from the launch site and will approach the site only when loading/ recovering the rocket with clearance.
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	Our team will utilize parachutes as the recovery system. The parachutes will be connected via the appropriate strength Kevlar. Our parachutes will be wrapped in fire-resistant Nomex. We will use dual deploy as the main way to deploy our parachutes. The team will size parachutes based

wadding in my rocket.	on the rate of descent calculations to ensure safe speeds and meet the maximum allowable landing velocity based on SLI rules. Recovery will be sized based on simulation loads done in software.
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, or attempt to catch it as it approaches the ground.	Our team will recover the rocket if it is safe to do so. If the rocket lands on a power line or any tall tree, we will notify the appropriate authorities.

Table 10. High-power launch procedures

The team will be utilizing the minimum distance that the NAR has set to minimize risk. The distances are created to provide a layer of safety preventing accidents or fires caused by a launch.

NAR Minimum Distance Table			
Installed Total Impulse (Newton-seconds)	**Equivalent High Power Motor Type**	**Minimum Diameter of Cleared area (ft.)**	**Minimum Diameter of Personnel Distance (ft.)**
0-320.00	H or smaller	50	100
320.01-640.00	I	50	100
650.01-1280.00	J	50	100
1280.01-2560.00	K	75	200
2560.01-5120.00	L	100	300
5120.01-10240.00	M	125	500
10240.01-20480.00	N	125	1000
20480.01-40960.00	O	125	1500

Table 11. NAR minimum distance table

As per SLI rules, the high school teams will utilize a motor with a maximum impulse of 2560.00 N-s, or a K motor or smaller.

4.5 Personal Protective Equipment

In hazard identification and mitigation, not all dangers can be eliminated. Users must wear protective equipment to reduce potential exposure and injury when handling fabrication and physical hazards. PPE will be added to the standard operating procedures (SOP) for each building phase.

PPE	Steps Required	Purpose
Long-sleeved clothing and close-toed shoes	All phases of build.	To protect against various fabrication and physical hazards such as chemicals, shrapnel, and heavy equipment.
Nitrile Gloves	Fin Can Construction, Epoxy and Additives, Priming and Painting, Buffing	To protect against irritants within all epoxies and additives used during construction
Leather Work Gloves	Fiberglass Preparation, Fin Prep, Internal Fillets, Altimeter Bay, and Nose Assembly	To protect against cuts, abrasions, and possible impalings
D5, Z87 Safety Glasses	Fiberglass Prep, Fin Prep, Fin Can Construction, Epoxy and Additives, Altimeter Bay, and Nose Assembly	To protect against chemical irritants and material and tool breakage, including potential shrapnel.
N95 Respirator Masks	Fiberglass Prep, Fin Prep, Fin Can Construction, Internal and External Fliets, Priming and Painting, Buffing	To protect against air particulates posing biological hazards and illnesses.
Ear plugs	Fin Prep, Fin Can Construction, Internal Fillets, Altimeter Bay and Nose Assembly, Buffing	To protect against loud noises posing potential hearing damage.

Table 12. Personal protective equipment

The table above is the initial list of PPE required for this project. Between submitting the proposal and PDR, we'll review and augment as needed.

4.6 Federal, State, and Local Compliance

The federal regulations that cover high-power rocketry can be confusing and seemingly contradictory. In order to describe how this team will comply with the Federal, State, and Local regulations, one must first understand what these regulations are. Many aspects of high-power rocketry can be considered hazardous from a chemical standpoint, dangerous from an explosive perspective, and certainly would seem to violate normal considerations for the safe use of airspace. To protect everyone involved from the shipping of propellent through the act of flying a rocket to high altitudes, several regulations need to be in place. This is complicated in that many federal agencies need to be involved.

4.6.1 Federal Regulations

Prior to examining the regulations pertaining to propellants, it is crucial to establish a clear understanding of their composition. Many high-power propellants are composed of ammonium perchlorate composite, a mixture of ammonium perchlorate as an oxidizer, and a composite binder serving as the fuel. The composite consists of several chemicals that burn efficiently in the presence of the oxidizer. Furthermore, ammonium perchlorate is also often used as an oxidizer in explosives, sometimes leading to confusion when discussing propellant.

The federal government regulates the sale, storage, and use of known explosives and components of explosives. This government body that regulates such factors is known as the Bureau of Alcohol, Tobacco, and Firearms (BATF). BATF had stated the following regarding the relationship between ammonium perchlorate and explosives in *Commerce in Explosives; 2024 Annual List of Explosive Materials*: "Ammonium Perchlorate Explosive Mixtures (excluding ammonium perchlorate composite propellant (APCP))." Hence, the solid propellant that is proposed for use in this document is not classified as an explosive.

Next, although the sale, transport, and storage of high-power rocket motors would fall under the *Code of Federal Regulations (CFR) Title 27 Part 55: Commerce in Explosives*, this portion of regulations only pertains to the sale, shipping, and possession of explosive materials as defined by the BATF. As stated above, however, the BATF does not consider APCP propellant as an explosive. The one exception to this concerning high-power rocketry is the use of black powder for deployment charges. Black powder is still regarded as an explosive material. Luckily for the use of rocketry, the BATF calls out an exception for black powder in quantities less than 50 lbs. This exception is described in *CFR Title 27 CFR §555.141(b)*, exemptions for black powder.

The actual purchase of high-power rocket motors is restricted under the *Consumer Protection Safety Commission, 16 CFR §1500.85(a)* stating that all high-power motors require the purchaser to be at least 18 years old.

The FAA (Federal Aviation Administration) is the branch of the US government that oversees the use of US airspace. Some of the things that the FAA regulates include US airspace, airports, aircraft, airmen certifications, and space travel. Along with planes, the FAA also has major authority over rocketry. Their regulations are set in place to make sure that Rocketry properly shares the airspace with all other users.

This club will follow *Federal Aviation Regulations, 14 CFR, Subchapter F, §101.22*, which states the FAA definition of a class 2 amateur high-power rocket. A single motor must be selected that will produce a confirmed amount of 40,960 N-s or less to comply with the definition. *§101.23* defines general limitations that rockets must follow a suborbital trajectory, not cross international boundaries, be unmanned, and not create a hazard to persons, property, or other aircraft.

For rockets specific to this proposal, or class 2 rockets, the FAA provides further limitations in *§101.25*. This states that it is important to not launch the rocket at any height where there is more than 5/10ths cloud cover or where the horizontal visibility is less than 5 miles. A launch is also not allowed from sunset to sunrise without proper authorization or if the launch site is within 5 Nautical miles of an airport. 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 a high-power rocket flight, we cannot launch the rocket. The launch may also be scrubbed if reasonable precautions are provided to report and control a fire caused by rocket activities.

The club will ensure that no launches occur in areas that meet any of these criteria by only launching in FAA-authorized launch zones. The club also understands that the FAA may specify additional operating limitations necessary to ensure that air traffic is not adversely affected, and public safety is not jeopardized.

4.6.2 State of Michigan Regulations

MCL Code 333 in 1965 - Model Rockets
The article outlines regulations for the use of model rockets in Michigan. It defines model rockets as aero-models propelled by model rocket engines. However, much of this regulation applies to model rockets, not high-powered rockets.

MCL 28.451 – 28.471 - Fireworks Safety Act
28.459 - Propellant Restrictions:
While rocket propellant has many similarities to conventional fireworks, the propellant used for our proposed activities does not include regulated pyrotechnics as covered by MCL 28.451-28.471

NFPA 1127: Code for High Power Rocketry

The National Fire Protection Association, or NFPA, is not a governing body. However, *NFPA 1127: Code for High Power Rocketry*, has been adopted by the State of Michigan, as well as most other states, as the requirement for all high-power rocket launches. It was also the basis for both NAR and Tripoli's Safety Code. This code aims to establish guidelines for all aspects of high-power rocketry to ensure reasonably safe operation of high-power rockets to protect the user and the public. It applies to the design, construction, power limitations, and parts purchasing of parts. The code defines numerous items including launch sites, high-power rockets, high-power rocket motors, and rocket propellants. Based on high-power rocket motors, NFPA 1127 says that only certified high-power rocket motors, motor reload kits, or motor components shall be used in a high-power rocket and a high-power rocket motor or its components shall not be used in a manner or for a purpose other than that specified by the high-power rocket motor manufacturer.

4.6.3 Local Regulations

Local regulations are more difficult to find. In all cases, the club will not be flying within their local community. All high-power launches are conducted at one of three different club fields located many miles from our school and hence local jurisdiction. Local regulations are generally included within the club rules where we would be flying.

4.6.4 Compliance Plan Summary

- Federal Aviation Administration
Our safety officer will verify that FAA approval has been obtained for all rocket launches. Our rockets will be launched only if they maintain a safety distance of at least one-quarter of their maximum expected altitude or 1,500 feet from people and property not directly involved in the operation. The team mentor will serve as a qualified individual over 18 years old to oversee the launch operations, ensuring they have final authority on safety matters. We will establish procedures to report and control any fires caused by rocket activities, We will verify adequate fire suppression equipment at the launch site.

- Code for High-Power Model Rocketry
All rockets will be constructed per NFPA 1127 standards. This includes ensuring structural integrity, using certified propellants, and following recommended procedures for assembly and testing. Launches will be conducted only at designated and approved sites that meet NFPA 1127 guidelines. We will maintain safe distances from spectators, flammable materials, and structures. The launch area will be clearly marked and controlled to prevent unauthorized access.

- BATF Regulations
We will use rocket propellants specifically designed for amateur rocketry and exempted by the BATF as explosive elements. All quantities of black powder will be confirmed to be well below the legal limit of 50 lbs.

- State of Michigan Regulations
We will ensure that our rockets meet state requirements for propellant and construction. Rockets will only be launched in designated areas that satisfy minimum size and safety criteria. We will use restraint devices and remote ignition as required and adhere to restrictions on pyrotechnic use and engine tampering.

- **Local Launch Requirements**
All launches will be conducted at local club launch sites. These clubs are either members of NAR, Tripoli, or both. All launches will be conducted following the NAR Safety Code and/or the Tripoli Unified Safety Code, plus any additional safety requirements specified by the local club.

4.7 Regulatory and Logistical Aspects for High-Power Rocketry

At the time of writing this proposal, all students are either under the age of 18 or do not hold a certification high enough to permit the handling of high-power or L2 impulse APCP motors per CFR Title 16, section 1500.85. In addition, students are not permitted to handle electronic matches or any quantity of black power used for ejection charges. The team mentor, Andrew Brown (Tripoli L3), will be the only personnel to handle the rocket motors, e-matches, and black powder deployment charges used for this project.

The team mentor will legally source all motors, electronic matches, and black powder. Electronic matches will be purchased from MJG Industries (MJG Firewire) which produces the only non-ATF-regulated electronic match product on the market. Black powder will be purchased from a reputable vendor in compliance with ATF regulations (Chris' Rocket Supplies). Rocket motors will be sourced from either Wildman Hobbies, Chris' Rocket Supplies, BuyRocketMotors.com, or direct from Aerotech depending on availability. All vendors listed are reputable motor vendors with a history of complying with federal and local regulations. Required HAZMAT shipping will be applied in compliance with all required regulations for all materials where required.

Storage of rocket motors, electronic matches, and black powder will be performed only by the team mentor. The motors will be stored at a minimum of 25 feet from any combustion source. Black power and electronic matches will be stored away from each other. All electronic matches will be stored with the leads shorted together in an appropriate ESD-safe storage container to prevent accidental activation from electromagnetic interference. Quantities of black powder will be well below the BATF and NFPA limits requiring storage regulation. A common sense approach will be maintained by storing black powder separate from other flammable items in ESD-safe storage containers.

All energetics will be transported separately from each other and assembled at the launch site. Transport will comply with CFR Title 49, section 172.504(b). It is proposed to use a reloadable motor. If this motor requires the grains to be bonded to the liner, this will be performed by the mentor in advance. However, the grains and liner will not be inserted into the casing and closed until final preparations at the launch site. At the launch site, the motor will be assembled by the mentor as well as the installation of the electronic matches and black powder for ejection events. Students will maintain a safe distance and wear appropriate PPE during this process.

All post-flight removal of energetics will be handled by the team mentor. This includes, but is not limited to the inspection of all deployment charges to ensure that they were fired, removal of spent deployment charges, removal of the motor, disposal of spent fuel grains, smoke delay grain, liners, etc, and cleaning of the motor case. Post-flight inspection of the motor components will be performed by the mentor to ensure the proper functionality of the motor. In the unfortunate event of a motor-related catastrophic event, the mentor will report all findings, photographs, and video of the event to the vendor as well as file a Malfunction Engine Statistical Survey (MESS) Report.

4.8 Safety Officer Responsibilities

The safety officer is responsible for ensuring the safety of the team for the entire duration of the project. The role of safety officer has been appointed by the club, and the team members have direct contact through WhatsApp as well as group meetings. Responsibilities of the safety officer include:

1) Mitigation of potential hazards:
    a) Responsible for implementing protocols that help mitigate potential hazards.
    b) Maintaining the safety documentation for the team.
2) Attend every potentially hazardous step to ensure proper precautions are taken to mitigate risks. These responsibilities include:
    a) Making sure proper procedures are followed during build opportunities including all PPE equipment.
    b) Supervised launch vehicle and payload assembly and enforced proper procedures during all testing and launching days.
    c) Ground testing. NAR/TRA qualified mentors should be present for additional supervision and handling of all potentially explosive. flammable substances.
    d) Launch days
        i) Sub-scale launch testing: Ensure all safety measures are taken before/during/after launch and ensure all redundancy measures have been checked and are functional.
        ii) Full-scale launch testing: Ensure all safety measures are taken before/during/after launch and ensure all redundancy measures have been checked and are functional. Ensure the payload does not cause any structural strain on the rocket.
    e) Supervision of team on launch days
        i) Ensure the team follows all safety protocols for pre/post-launch
        ii) Ensure all redundancy equipment is operational
        iii) NAR/TRA certified mentor should be present and supervising the team in any step involving potential chemical/physical hazards
    f) Supervision of recovery activities
        i) Maintaining contact with the electronic recovery equipment in the rocket to track the trajectory and alert the team about any changes.
        ii) Enforce recovery safety protocols
        iii) Verify that all deployment charges are spent and electronics are disarmed before handling the rocket.
        iv) Supervise the disposal of spent propellant.
3) Hazard mitigation in STEM engagement
    a) Adult supervision while helping educate students.
    b) All members need to be accounted for at all times

4.9 Team Safety Responsibilities

The team is required to follow all safety regulations under NAR/Tripoli and other safety precautions while handling substances:

1) Physical Hazards: The team is to refer to **Table 7. Fabrication hazards:** Chemical hazards and follow the regulations.
2) Launch Hazards: The team is to refer to **Table 8. Launch hazards**: Chemical hazards and follow the regulations.

The team is required to obey the instructions of the safety officer and the mentor when handling any substance or dealing with a task that can affect the well-being of members.

1) Safety briefings: The Safety officer will conduct mandatory meetings with the team before and after working on a part of the competition. These briefings will include the discussion of:
    a) Precautions and restrictions
    b) Safety equipment
    c) Potential hazard mitigation strategies
    d) Demonstrations of all equipment used
    e) Feedback on following the restrictions
2) Testing briefings: Before conducting any type of testing, The safety officer is to conduct a Testing safety meeting with the help of an NAR/Tripoli mentor to ensure each member is informed of the risks and mitigation strategies
3) Launch briefings: The Safety officer and the NAR/Tripoli mentor will conduct an official Launch briefing before all sub-scale and scale launches, These meetings will include :
    a) Weather Brief
    b) NAR/Tripoli regulation revision
    c) Setting up restrictions
    d) Assigning workspaces
    e) Post-Launch protocols

4.10 Safety Regulation Agreements

Upon completion of the proposal, all team members will read the safety section to be aware of necessary PPE, hazards, risks, and mitigation strategies during all stages of the competition. During all sub-scale and full-scale launches, the safety officer will hold pre-launch briefings and all team members will follow RSO instructions. Team members will sign a safety agreement that declares they have read and understood the safety section, as well as the regulations from the Student Handbook. Furthermore, all club members (and thus team members) are required by the school to fill out a liability waiver to participate in club activities, to ensure that they are aware of rocketry's inherent risks.

I, ______________, am aware that:

- Range safety inspections will be conducted on each rocket before it is flown.
- We may be removed from the launch area if we do not comply with RSO's determination of safety.
- 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.
- The team mentor is ultimately responsible for the safe flight and recovery of the team's rocket. Therefore, we 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.
- Any team that does not comply with the safety requirements shall not be allowed to launch their rocket.

Signature:___________________________
Date: ____________________

5 Technical Design

The design flow follows the process shown in **Figure 29.** The overall project begins with the SLI Handbook requirements. These set the overall delivery vehicle parameters and the tone for the payload. This starts the iterative process of selecting construction methods, airframe, and payload structural design. Through simulation and testing, these steps are iterated and refined. Validation is performed through payload simulated testing, ground testing, sub-scale launches, and launching of the full-scale rocket.

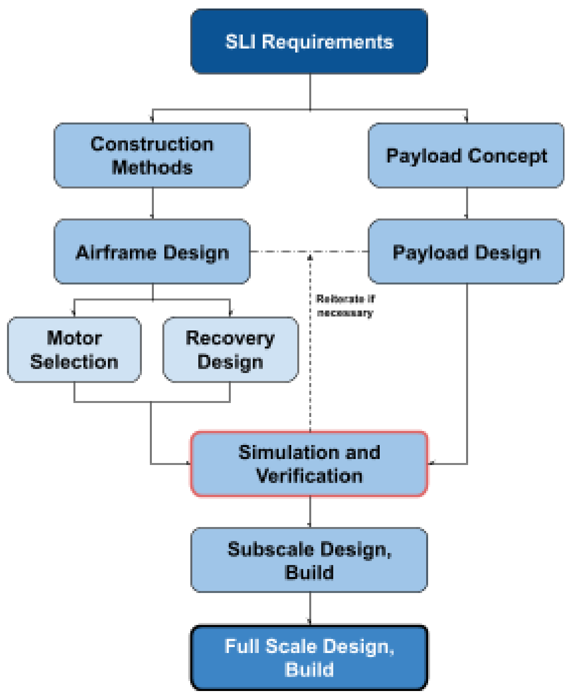


Figure 29. Proposed design process flow

5.1 Construction Methods

The proposed construction process for the SLI rocket airframe follows the basic flow for a high-performance fiberglass airframe. Unfortunately, this generally is not documented in most literature, and rocket airframe kits usually do not include instruction sets. The steps listed document the proposed methodology that we would employ for the construction, necessary safety measures, mitigation strategies, and all the necessary PPE used for the airframe at the time of writing this proposal. This section focuses primarily on techniques that will be used. Specific rocket design details will be presented in a subsequent section. The following descriptions are simplified to demonstrate how we intend to build the airframe. This is not to be confused with Standard Operating Procedures (SOPs) since they will be written before construction. We will utilize commercially available G10 fins, centering rings, and filament-wound fiberglass for body tubes, nose cones, couplers, and motor mounts. Fiberglass is a reliable material that can resist multiple instances of impact and water damage, thus helping the vehicle's reusability. Fiberglass also provides a smooth surface for a nice fit and finish with a very low drag coefficient and is aesthetically pleasing.

5.1.1 Adhesive Selection per Application

Adhesives are an important part of constructing a rocket. Here are the adhesives that we are going to be utilizing for our project

Adhesive	Application	Benefits
JB Weld	• Centering rings to motor mount tube • Fin root edge to the motor mount • Motor retainer to motor mount	• High-temperature rating (588° F) • High strength bonding • Does not flow pre-cure • Permanent and durable
West System 105/206 (no additives)	• Laminating composites • Wetting fiberglass before application of thickened epoxy	• High strength bonding • Moisture resistant • Easy to sand and paint • Compatible with fillers • 20-30 minute working time at 72° F • Slow cure (10-15 hours) • Low viscosity
West System 105/206 with High-Density Filler	• Internal fillets	• Increase bonding strength • Thicker consistency and smooth fillets • Increased viscosity
West System 105/206 with High Density Filler and Colloidal Silica	• External fillets	• High viscosity • Make epoxy thixotropic
Proline 4500Q	• Used for all fiberglass-to-fiberglass structural bonds that are not subject to very high temperatures	• Heat resistant up to temperatures as high as 450° F • Strong adhesion and durability High impact resistant

Table 13. Adhesives

Figure 30. Preferred adhesive selection for fiberglass airframe assembly

5.1.2 Fiberglass Preparation for Optimum Adhesive Bonding

Before commencing any build, the fiberglass is first completely washed. This removes residual dust from the fiberglass cutting process as well as mold compound from the fiberglass fabrication process. Washing the fiberglass consists of scrubbing all surfaces in a soap and water solution. The body tubes are scrubbed with aggressive sponges.

Preparing a fiberglass surface for epoxy involves several steps to ensure a strong chemical bond. First of all, it is important to wear gloves during the process, as any oils from your hands can interfere with the bonding process. To begin the preparation, we use 400-600 grit sandpaper to sand the area where the epoxy will be applied. This strips away the oxide layer on the fiberglass, creating open hydrogen groups that promote strong chemical bonds between the fiberglass and the epoxy. It is important to note that for an optimal bond, fresh sandpaper should be used as any grease or debris left on the sandpaper from previous projects could compromise the strength of the bond. After sanding, the surface should be wiped down with acetone using lint-free wipes to remove any residual dust and debris. This cleaning process should ideally be repeated 5-6 times, and a clean surface should have low surface tension, increasing the surface area of interaction between the epoxy and the fiberglass.

A critical aspect of surface preparation is the timing. The epoxy should be applied within 15-30 minutes of surface prep to prevent dust from settling and interfering with the bond. Additionally, bubbles in the epoxy should be avoided, as voids can weaken the bond and ruin the surface smoothness. Proper mixing of the epoxy is essential to ensure that all resin and hardener will be reacted. Any unreacted resin or hardener could reduce the strength of the epoxy. Following these steps will ensure maximum performance of the bond between the fiberglass and the epoxy.
We will be scrubbing the fiberglass tubes with warm water and a detergent. The interior and exterior will be scrubbed with a cleaning brush. All parts will then be rinsed with clean water. This helps in removing fiberglass dust, grease, and mold-release compounds.

Figure 31. Fiberglass preparation example

5.1.3 Fin Preparation

Before the fins can be inserted into the fin can, they should be beveled for the best aerodynamic performance. While there are many ways of beveling a fin, two methods are considered for this project:

- Hand Beveling the Fins -
  - Progressive grits of sandpaper are used to shape the fins.
  - Sandpaper is placed on a flat surface and beveling is done with a constant angle of attack and in a circular motion.
  - Further shaping and refinement are performed with sequentially finer grits of sandpaper.
- Beveling with a Router Table -
  - A vertical chamfer bit is used to set the angle (typically 11.25° chamfer bit).
  - The fence of the router table is set to expose the depth of the desired chamfer.
  - The router bit height is adjusted to control the amount of material that is removed per pass.
  - The fin is held vertically with various clamps and jigs to ensure stable orientation.
  - After machine beveling, the shape is further refined by manually sanding with progressively finer grits of sandpaper.

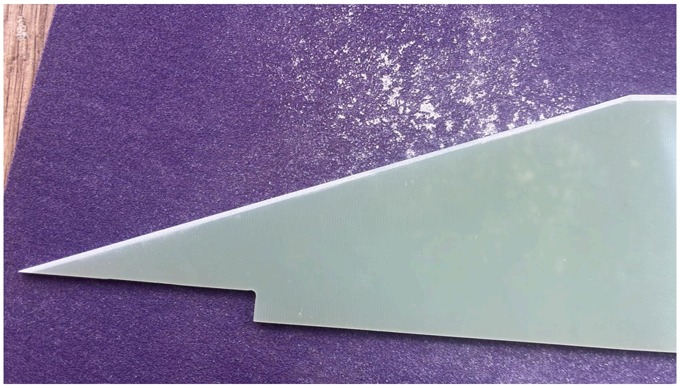


Figure 32. (Left) Hand beveled of fiberglass fins, and Figure 33. (right) Machine beveling

5.1.4 Fin Can Construction

This proposal considers two methods of assembling the fin can, namely, assembling the fin can outside of the airframe, and assembling the fin can inside of the airframe. Both have their respective advantages and disadvantages.

The first method includes assembling the motor mount and centering rings outside of the body tube, inserting it into the booster tube, and then attaching the fins to the rocket after the motor mount has been inserted into the booster tube. This has the advantage that the fins will be perfectly aligned with fin slots, the booster body tube does not require additional slotting and maintains as much structural integrity as possible, and one can apply a full set of internal fillets.

Internal Fin Can Construction	
Materials	**Purpose**
Motor mount tube	This tube will hold the solid motor which we will be utilizing.
Forward centering ring	Keeps the motor mount centered, provides mechanical coupling between the motor mount and body tube, and offers a hard attachment point for the recovery harness.
Aft centering ring	Acts as another centering ring for the motor mount, provides mechanical coupling between the motor mount and the booster tube, and acts as a thrust plate for the motor retainer.
⅜” tubular kevlar	The recovery leader is made of ⅜” tubular kevlar and has a 4600 lbs test strength. The shock cord will be attached to the front centering ring and will act as a shock absorber for parachute ejection events and will also house attachments for the Nomex blanket and the parachutes.
JB Weld epoxy	Will be used to epoxy both centering rings onto the motor mount,

	the motor retainer to the motor mount, and the fin root chord to the motor mount.
Proline 4500Q epoxy	Used to adhere motor mount to booster tube

Table 14. Fin can materials

The process of assembling the fin can internal to the airframe consists of the following steps:

- All fiberglass components are cleaned and prepared per **section 5.1.2**
- Centering ring locations are marked based on the ends of the fin slots. The position of the centering rings will sandwich the fin tabs between the rings providing additional bonding and stabilizing surfaces.
- The forward centering ring will have holes drilled to accept ¼" stainless U-bolts for attachment of the recovery harness. Two sets of U-bolts will be used to configure the recovery harness as a Y-harness ensuring mechanical redundancy.
- The forward centering ring is adhered to the motor mount with JB Weld epoxy ensuring a high-temperature bond.
- The motor mount and forward centering ring are adhered to the booster tube with ProLine 4500Q epoxy. The rear centering ring is dry fit only to provide centering of the assembly.
- The fins are attached through the fin slots to the motor mount using JB Weld high-temperature epoxy.
- Fillets are added to the forward centering ring through the top opening of the body tube.


Figure 34. (left) U-bolt attachment on forward centering ring, Figure 35. (right) attachment of Y-harness leader


Figure 36. Example of marking motor mount for centering rings(left), Figure 37. Mounted centering rings (right)

Figure 38. Inserting the motor mount

The second method to construct a fin can involves constructing the entire assembly including fins before inserting it into the booster tube. This allows for easier application of internal fillets from the fins to the motor mount. However, it is much more difficult to apply internal fillets from the fins to the body tube. This also compromises the integrity of the body tube at the aft end of the rocket by extending the fin slots.

The following process is used if the entire fin can is constructed outside of the body tube and inserted in as a completed unit:

- All fiberglass components are cleaned and prepared per **section 5.1.2**
- Centering ring locations are marked based on the ends of the fin slots. The position of the centering rings will sandwich the fin tabs between the rings providing additional bonding and stabilizing surfaces.
- The forward centering ring will have holes drilled to accept ¼” stainless U-bolts for attachment of the recovery harness. Two sets of U-bolts will be used to configure the recovery harness as a Y-harness ensuring mechanical redundancy.
- The forward ***and rear*** centering rings are adhered to the motor mount with JB Weld epoxy ensuring a high-temperature bond.
- The fin slots on the body tube are extended to the aft end of the body tube. This allows for a slot that is completely open on the aft side of the rocket.
- The motor mount is dry fit into the body tube (not glued).
- The fins are attached through the fin slots to the motor mount using JB Weld high-temperature epoxy.
- The motor mount assembly is then slid out of the rocket and internal fillets from the fins to the motor mount are applied.
- The fin can is then glued in place by applying a ring of Proline 4500Q epoxy where the forward centering ring will be, and the fin can is slid in place.
- Fillets are added to the forward centering ring through the top opening of the body tube.

Figure 39. 2023 R4S rocket fin can

While building a fin can completely outside of the rocket has its benefits such as being able to see the internal fillets. We would like to avoid cutting through the booster tube to insert the fin can. Since most, if not all, of our team, have previously built or are in the process of building an

L1 kit, we are more experienced with inserting the fin can before attaching the fins. This lets us inject epoxy into the body tube leading to a much more even spread of epoxy and a better attachment point.

5.1.5 Internal Fillets

Two methods of internal fillets can be followed to ensure the attachment of fins to the motor mount.

Method 1: Injection
Injection is a technique where we use a syringe and West System epoxy with fillers (**see section 5.1.1**) to inject epoxy into the space between the motor mount and the booster tube. This ensures an equal spread of epoxy and a solid support point for the fins inside the booster tube.
This step does involve drilling holes next to the fin slots in the booster tube which will be filled with the epoxy and covered with an external support.

Steps :

- Drill evenly spaced holes using a drill press and a 3D-printed jig
- Epoxy the rear centering ring in the correct spot to help retain the flowing epoxy
- Mix West System epoxy (105/206) in a 3:1 ratio of epoxy and hardener
- Add 3 tsp of High-density filler to one pump of epoxy
- Mix thoroughly and ensure the epoxy is thixotropic and right thickness
- Suck up the mixed epoxy into the syringe ensuring no air bubbles or foam have been taken up.
- Slowly inject an appropriate amount of epoxy into the holes ensuring no epoxy runs outside of the booster tube. It is important that the airframe is level to allow the epoxy to settle evenly.
- Tightly cover the hole with masking tape and let it cure.

This step is a three-session process for a three-fin design that requires the epoxy injected into one side to fully cure before continuing with the others.

Figure 40. Fin insertion using a 3D jig

Figure 41. Example of injecting epoxy

Method 2: **Internal fillets by hand**
Doing fillets by hand includes using an application rod with epoxy on the top to reach into the inside of the booster tube.

Steps :
- Mix West System epoxy (105/206) in a 3:1 ratio of epoxy and hardener
- Add 1.5 tsp of West system High-density filler to one pump of epoxy
- Add 3.5 Colloidal Silica for each pump of epoxy to the mixed system
- Mix thoroughly and ensure the right texture for the epoxy
- Use a rod and manually paint fillets on the inside of the rocket
    - Fin to motor mount fillets: Add sufficient epoxy to the area where the fin and the motor mount meet.
    - Fin to booster tube fillets: add sufficient epoxy to the area where the fin and the inside of the booster tube meet.
- Epoxy the centering ring into the correct place.

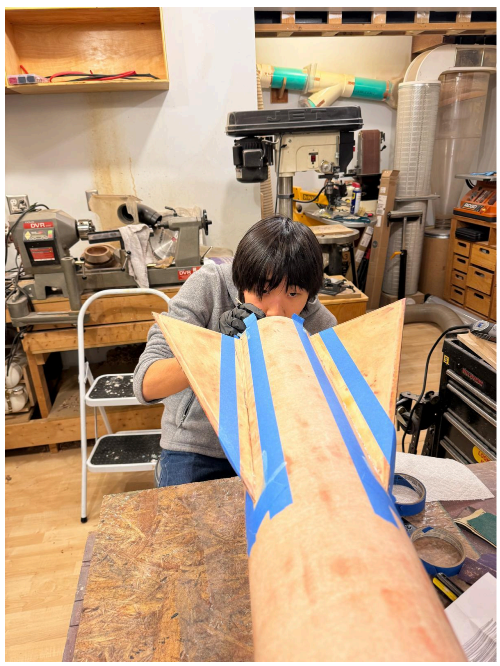


Figure 42. Internal fillets

5.1.6 External Fillets

External fillets are an important part of constructing a rocket. Not only do they provide structural support by conjoining the fins and the outer surface of the booster tube but they also provide an aesthetic look by making the transition from the fin to the booster ergonomic.
Steps :
- Sand and clean the surface where the epoxy is going to be painted for the external fillets
- Select a size for the external fillets and mark them using a round tool. The tool usually used for fillets is a fondant tool or a custom-made 3D printed tool.

- Mask up the areas outside the marked area including part of the fin
- Mix West System epoxy (105/206) in a 3:1 ratio of epoxy and hardener
- Paint a really thin layer of epoxy onto the designated area to prep it for a large batch
- Add 1.5 tsp of West System High-density filler to one pump of epoxy
- Add 3.5 tsp of Colloidal Silica per pump of epoxy to the mixed system
- Mix thoroughly and ensure the right texture for the epoxy
- Put the epoxy onto the fins ensuring no epoxy goes outside the marked area
- Use a tool to remove excess epoxy and shape the fillet and then leave it for a day to dry.

This step is a 3 session process that also requires setting the epoxy. The setting time for the West system epoxy mix with 206 Slow Hardener is recommended to be at least eight hours.

Figure 43. Rockets for schools 2023 external fillets

After all fillets have cured, we use Bondo glazing putty to fill in the low spots and sand the fillets back to make the surface level and smooth.

5.1.7 Nose Assembly

The nose cone contains a housing where we can attach the GPS tracker check **section 5.6**. The nose cone and its housing are built as below:

- The nose cone and its coupler are drilled for the screws using a 3D-printed jig. #6 PEM nuts are secured inside the coupler allowing the nose to be secured to the coupler with #6 stainless screws from the outside. This allows for the assembly to be disassembled for access to the nose cone avionics.
- The bulkhead is epoxied on the bottom of the coupler using Proline 4500Q

- The bulkhead is drilled for a 5/16” forged eye bolt and secured with a 5/16” nylon lock nut.
- The 3d printed housing for the telemetry module is fitted inside the nose cone coupler.


Figure 44. Featherweight tracker and housing (left), Figure 45. Assembled nose cone (right)

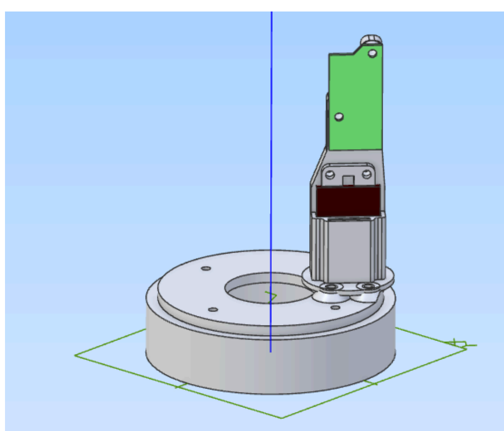


Figure 46. 3D model of tracker housing

5.1.8 Aesthetics

Priming and painting is essential for not only providing aesthetics but also helps improve the rocket's aerodynamics by providing a smooth surface for the air to flow through as the rocket ascends.

Fiberglass usually contains imperfections due to the nature of the manufacturing process. Priming the rocket helps provide a smooth layer and also a surface on which the paint can adhere better. This helps prevent the paint from flaking off during masking or from small impacts.
Steps:

- Before priming the rocket, the fiberglass surfaces need to be thoroughly cleaned using SprayWay Glass Cleaner (alcohol-based cleaner) with a lint-free microfiber cloth. This helps remove the surface dust, grease, oils, and other debris that might prevent the primer from adhering well to the surface of the rocket.
- Priming is done in 3 coats:
  - Mist Coat: This step involves a very light spray of Dupli-Color Filler Primer. This "tack" layer preps the surface for heavier coats.
  - Medium Coat: This step involves a heavier spray and is used to start filling imperfections in the body tube
  - Heavy Coat: This step is the last coat done to fill imperfections in the body tube.
  - Each coat requires at least 10 minutes of drying before another coat can be applied.
- After the first set of priming, we sand the primer and repeat these steps to achieve the desired finish, as the paint finish is determined by the smoothness of the surface underneath.
- The primer is then coated with a Dupli-Color Sandable Primer. This final layer is a thin primer that fills in final imperfections and is the final layer that the paint will adhere to.

Painting is done after a desired finish is achieved via priming. Painting the rocket offers an aesthetic look while also improving the aerodynamics of the rocket by filling any minute imperfections left out by the primer.

- Before applying coats of paint, the primed surface needs to be fully dry and needs to be cleaned using SprayWay Glass Cleaner with a lint-free microfiber cloth.
- Painting follows the same type of coating process as priming.
- The paint does not need to be sanded unless there are anomalies like overspray or a run where the paint needs to be sanded back completely and restarted.

Clear coating provides a high-gloss finish by adding an extra layer of material to the rocket. It also helps protect the primer and paint from cracking/getting damaged by moisture and other elements. Clear coating is done using Dupli-Color High Heat Engine Paint Gloss Clear Coat with Ceramic which helps provide an abrasion and chemical resistant surface. Clear coat is also used to fill any imperfections that have been left unfilled. Clear coating involves the same process of coating as priming and painting.

Wet sanding and buffing are the final steps in making the paint job look aesthetically pleasing. To remove orange peel and other surface imperfections inevitable from spray painting, wet sanding is used to remove any high spots in the paint. Wet sanding is advantageous to dry sanding as the water lubricates the surface (preventing deep scratches) and collects any sanding dust produced. Starting at 800-1000 grit and moving up to 2000-2500 grit, the rocket is sanded until as many imperfections are removed as possible. Then, after a thorough wipe down with a damp rag to remove excess water and any sanding debris, the paint is polished and buffed using a 3-stage polishing compound. The compounds are applied using a dual-action polisher rather than by hand to speed up the process. After the final, finest grit compound is used, the surface is again wiped with a clean cloth to remove excess polishing compound, and automotive wax is applied.

Figure 47. Polishing clear coat on a high-power kit

Figure 48. Finished class 2 rocket built by NHS Aerospace Club for Rockets For Schools

5.2 Payload

For our payload, we will be designing and constructing a scaled-back version of the college payload. Instead of recording and transmitting on a 2-M radio band to NASA, telemetry will be transmitted to a laptop on-site. The rocket payload was chosen through multiple whole-team brainstorming sessions and a final vote, where we concluded that being a first-year team, due to the competition's complexity compared to our team size, ensuring success in the competition was more important than attempting a grand, risky, and intricate payload. This allows us to focus more evenly on all aspects of the competition.

5.2.1 General Payload Requirement Compliance

Once the payload idea is finalized, it is important to ensure that it is engineered in a way that does not go against NASA guidelines. A table of the general requirements and our proposed compliance plan is listed in a table below:

Requirements	Proposed plan
4.4.1. 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.	We will not be utilizing black powder or similar energetics for our payload. Energetics will only be used for deployment of in-flight recovery systems
4.4.2. Teams shall abide by all FAA and NAR rules and regulations.	We will be abiding by all FAA and NAR rules and regulations. A detailed list of these requirements are in **section 4.4** (NAR) and **section 4.6.1** **(FAA)**
4.4.3. Any payload experiment element that is jettisoned during the recovery phase shall receive real-time RSO permission before initiating the jettison event unless exempted from the requirement by the RSO or NASA.	We do not plan on ejecting our payload during jettison events or deployment events. Our payload will be fully contained inside the rocket from launch to landing.
4.4.4. 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 permitted to release the UAS.	We do not plan on utilizing an Unmanned aircraft system (UAS) for our purposes in this competition.
4.4.5. 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).	We do not plan on utilizing an Unmanned aircraft system (UAS) for our purposes in this competition.
4.4.6. Any UAS weighing more than .55 lbs. shall be registered with the FAA and the registration number marked on the vehicle.	We do not plan on utilizing an Unmanned aircraft system (UAS) for our purposes in this competition.

Table 15. General payload requirements

5.2.2 Payload Description

Being a first-year team, we wanted to dip our toes into SLI fun while ensuring that our payload was realistic, considering our relatively small team size. Upon deliberation, we decided that a scaled-back USLI challenge would be a reasonable, but still interesting challenge. Similar to the college/university mission, our objective as a first-year high school team will be to launch and safely recover a STEMnaut capsule holding 4 STEMnauts while recording telemetry data, namely max Gs, max velocity, altitude, descent rate, and chute status. We will code an application that, depending on the stage of the launch, ascent, apogee, or descent, will transmit different data important to that stage. We will, however, not be separating the capsule and will not be transmitting on the 2M band specified by NASA, but keeping the capsule in the rocket nose cone and transmitting to a computer on the ground.

A critical part of the payload will be the detection of launch, apogee, descent, and ground impact. Using altimeter data and an Arduino, we will detect each of these stages and using a wireless transmitter, transmit data based on what stage of flight the rocket is in:

Ascent: max G, max velocity
Apogee: maximum altitude
Descent: decent rate, chute status based on descent rate
Throughout: STEMnaut orientation

The capsule will be contained in the nose cone along with the GPS transmitter. We concluded this would be optimal to prevent any possible problems that could occur during parachute deployment if the payload were contained in the payload tube and something were to go wrong.

5.2.3 Payload Design

To outline the general shape of the payload and determine what parts need to be created in CAD, an initial mockup was created.

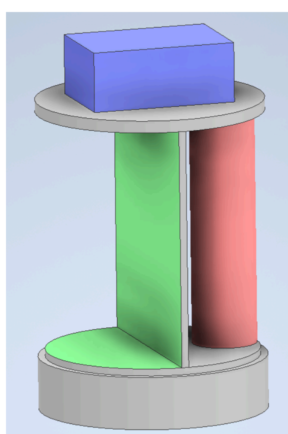


Figure 49. Payload mockup

Dimensions were set to fit the Featherweight tracker (in red), with the STEMnaut capsule in green and space for mounting electronics on a platform at the top. This gave us an initial list of parts to engineer: a tracker/STEMnaut capsule mount, an electronics mounting platform, and a part to connect the top and bottom pieces. Furthermore, upon working on airframe design, we discovered that having a way to add ballast would be optimal. The bottom tracker/capsule mount will be made to also function as a part to place ballast weight.

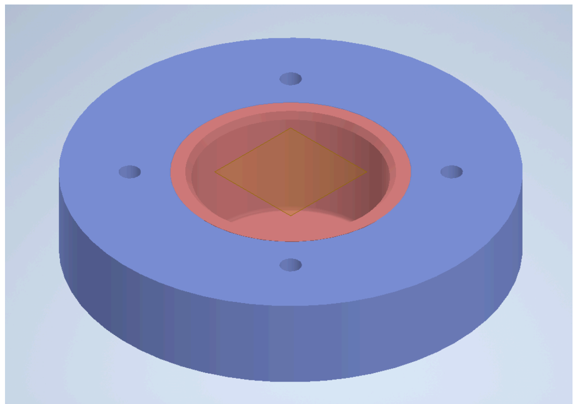


Figure 50. Initial payload mounting plate with ballast holder

We plan to scratch-build a cockpit to place our STEMnauts in and will design further electronics integration and CAD mounts for other electronic components after proposal acceptance and bill of materials finalization in PDR. This will allow optimal sensor placement rather than arbitrarily creating CAD models before we finalize purchases.

5.2.4 Payload Electronics

Based on our electronic lead's familiarity with the platform, a large community, and abundant community resources, we concluded that using an Arduino for a central hub would be optimal, specifically an Arduino Nano due to its compact size.

To transmit live data, we plan to use an Adafruit RFM95W 915 MHz LoRa module. Since the Featherweight tracker we are using is optimized for this purpose, we investigated how it was transmitting, and found it was using LoRa. The Adafruit RFM95W seemed to be a reasonable option, with existing Arduino libraries and since it, being LoRa, operates on license-free frequencies. The transmitted power levels comply with the SLI radio transmitter requirements.

For our other sensors, we also decided to use Adafruit modules as they offer high-quality libraries, making their products work together well. Furthermore, many Adafruit sensor boards use the STEMMA QT interface, making daisy-chaining easy. To detect altitude and vertical velocity, we plan to use an Adafruit BMP390, which uses the newest pressure sensor chip from Bosch. To detect STEMnaut orientation and max Gs, we plan to use an Adafruit LIS3DH accelerometer.

5.3 Airframe Design

As planned in the design process flow as shown in **Figure 29**, we have developed a preliminary design for the airframe which complies with the SLI rules and meets the necessary design criteria. This initial design has been crafted to ensure that the vehicle can withstand the demands of launch and flight while adhering to all required standards. Each design choice has been made with a focus on safety, performance, and reliability.

5.3.1 General Vehicle Requirements

Vehicle requirements	
Requirement	**Implementation Plan**
2.1. The vehicle shall deliver the payload to an apogee altitude between 3,500 and 5,500 feet above ground level (AGL). Teams flying below 3,000 feet or above 6,000 feet on their competition launch will not be eligible for the Altitude Award.	We will be constructing a vehicle that is capable of delivering a payload to an apogee in the range of 3500-5500 ft.
2.2. Teams shall declare their target altitude goal at the CDR milestone. The declared target altitude shall be used to determine the team's altitude score.	We will be declaring our target altitude by the CDR milestone and we will be using it for our final launch at Huntsville, Alabama
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 launch vehicle will be designed for multiple uses and will be recoverable. Our recovery system consists of a dual deploy avionics bay, 2 parachutes, ⅜" tubular kevlar, and more.
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.	All components will be tethered to our main vehicle via ⅜" tubular kevlar at all times.
2.4.1. Coupler/airframe shoulders which are located at in-flight separation points shall be at least two airframe diameters in length. (One body diameter of surface contact with each airframe section.)	Our coupler/airframe shoulders are 2 airframe diameters in length. The outer diameter matches the general vehicle diameter (4 in) and the inner diameter is smaller than the vehicle diameter.
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.	We do not have any coupler/airframe shoulders that are not located at non-in-flight separation points.
2.4.3. Nose cone shoulders which are located at in-flight separation points shall be at least ½ body	Our nose cone which is located at a separation point is ½ the body diameter in length.

diameter in length.	
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 launch vehicle is capable of being prepped for flight at the launch time within 2 hours of the time the FAA flight waiver opens. All energetics are loaded on-site by a NAR/TRA-qualified mentor
2.6. The launch vehicle and payload shall be capable of remaining in the launch-ready configuration on the pad for a minimum of 3 hours without losing the functionality of any critical onboard components, although the capability to withstand longer delays is highly encouraged.	The launch vehicle and payload will remain capable of being in a launch-ready configuration for a minimum of 3 hours without losing any critical functionality. Our batteries are able to stay idle for at least 4 hours.
2.7. The launch vehicle shall be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.	The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system.
2.8. The launch vehicle shall require no external circuitry or special ground support equipment to initiate the launch (other than what is provided by the launch services provider).	We will be only utilizing the launch equipment provided by the launch services provider and will be making sure that the rocket doesn't require any additional equipment
2.9. 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).	We will be utilizing a commercially available solid motor propulsion system which is made of ammonium perchlorate composite propellant. This motor is certified by NAR, TRA. Our preliminary motor choice is the K1103X
2.9.1. Final motor choice shall be declared by the Preliminary Design Review (PDR) milestone.	We will be choosing our final motor by the PDR deadline. A preliminary choice that we have made is the K1103X motor.
2.9.2. Any motor change after PDR shall be approved by the NASA management team or NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment shall not be approved. The only exception is teams switching to their secondary motor choice, provided the primary motor choice is unavailable due to a motor shortage.	Any motor change after the PDR milestone will be approved by the NASA management team or the NASA Range Safety officer.
2.10. The launch vehicle shall be limited to a single motor propulsion system.	We have designed our launch vehicle to function on only one solid motor propulsion system.
2.11. The total impulse provided by a High School or Middle School launch vehicle shall not exceed 2,560 Newton seconds (K-class).	Our selected motor has a total impulse of 1789.0 Ns which classifies it as a K-class motor.
2.12.1. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating	We will not be utilizing a pressurized container for our purposes in this competition.

Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.	
2.12.2. 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.	
2.12.3. 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.	
2.13. The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined as the point where the forward rail button loses contact with the rail.	Our vehicle is designed to have a static stability margin higher than 2.0 at the point of rail exit.
2.14. The launch vehicle shall have a minimum thrust-to-weight ratio of 5.0: 1.0.	The vehicle has a thrust-to-weight ratio of 12:1
2.15. Any structural protuberance on the rocket shall be located aft of the burnout center of gravity. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.	We will not be designing or utilizing any structural component that is a protuberance on the rocket.
2.16. The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit	The launch velocity of the vehicle is simulated in OpenRocket to be 99.8 ft/s

Table 15. General vehicle requirements

5.3.2 OpenRocket Model

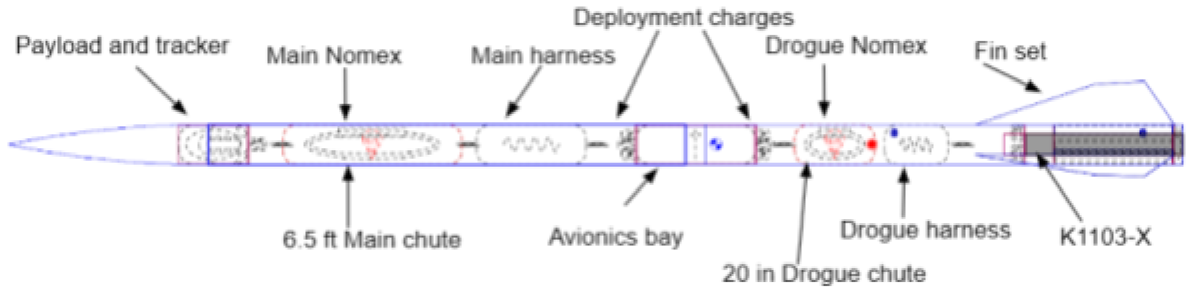


Figure 51. OpenRocket side view

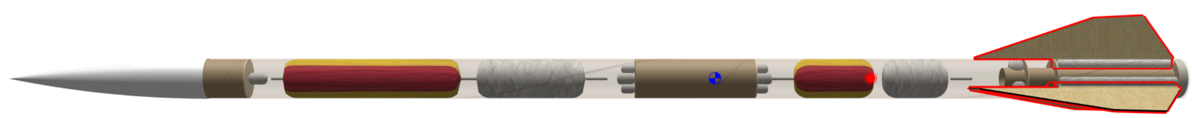


Figure 52. OpenRocket assembly view

The figures above show the OpenRocket models that we have created for the full-scale rocket. A detailed component list is written below in the proposal. The Motor used for this model is the K1103-X. The total weight of the rocket including the K1103-X motor is 20.2 Lb.

5.3.3 Static Stability

Static stability is defined as the tendency of a vehicle, after an external disturbance to return to the undisturbed condition. Static Margin or the margin of stability is used to describe the directional stability of a rocket.

$$S.M. = \frac{\overline{X}_{CP} - \overline{X}_{CG}}{Body\ diameter}$$

Variable	Definition
CP	Center of pressure (in)
CG	Center of gravity (in)

Table 17. Static stability equation variables

Understability

The CP of a rocket must be aft of the CG of a rocket. A major reason is that the rocket needs to be capable of handling aerodynamic forces without tilting. Since the aerodynamic forces act usually around the center of pressure, it might cause the rocket to tilt and change its angle of attack. This leads to the change of the flight path of the rocket from linear to rotational and eventually leads to the rocket tumbling.

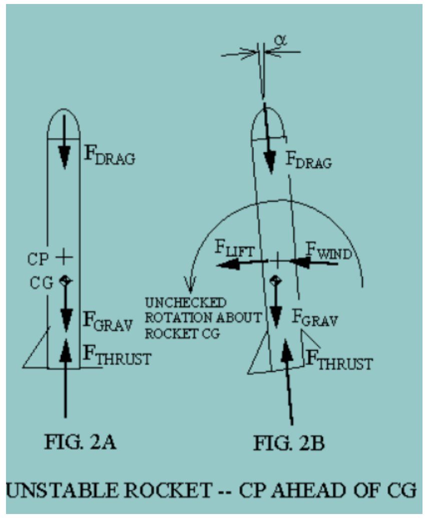


Figure 53. Diagram of an unstable rocket

Overstability is usually defined as having 2 or more body diameters worth of distance between the CG and the CP. Overstable rockets are usually "weathercock," meaning the rocket leans more into the wind. Overstable rockets tend to slightly arc into the wind which reduces its max apogee. Overstability usually occurs with a stability margin of 3.0 and above. Static stability is defined in the following equation below.

Open rocket calculates the static stability of a rocket. Our rocket design has a stability margin of 3.89**.** Although it is high and considered to be overstable, it is too early in the design process to accurately engineer our rocket towards the under 3.0 mark. We have also created a margin that allows us to simulate different-sized parachutes and allows us to try out a multitude of options before the final competition launch.

Parameters	Value
Stability	3.89 caliber
CG	71.18 in
CP	86.87 in

Table 18. Stability margin in OpenRocket.

5.3.4 Fin design

Fin design is an essential step in designing a rocket. It involves looking at different types of shapes and their impact on the aerodynamics of the rocket. For our purposes, we will be researching the effect on aerodynamics of multiple shapes and formations of the fin.

Design Choice	Effect	Suitability (y/n)
Elliptical	• Lowest induced drag due to smooth, rounded shape at subsonic speeds • Construction: More complex to design and build with fiberglass. • Impact resistance: Low risk of structural failure due to high-speed impact	Yes
Trapezoidal	• Moderate induced drag • Construction: is made of simple shapes and can be analyzed accurately • Impact resistance: low risk of structural failure due to high-speed impact	Yes
Square	• High-induced drag especially at high subsonic speeds • Not optimal for performance • Construction: Easiest to design and build due to simple shape • Impact resistance: Low risk of structural failure due to high-speed impact	No
Swept delta	• Low induced drag • High stability at supersonic speeds and usually utilized with high-speed rockets • Construction: more complex to design • Impact resistance: since these types of fins protrude out from the bottom of the booster tube, they are not suitable for high-speed landing at velocities up to 20 ft/s and have a high risk of structural failure.	No
Split fins	• Typically used to control roll and improve stability • More intricate to design and install • Impact resistance: moderate risk of structural failure due to high-speed impact	No

Table 19. Fin shapes

Improving the aerodynamics of a rocket involves optimizing design aspects to help reduce drag and enhance stability. Some techniques that we will be utilizing to help improve the aerodynamics of our rocket are as follows:

- Tapered Fins :
  - Airfoil shape:
    - Aerodynamic effect: Shaping fins into airfoils reduces drag and increases lift. Airfoiled fins are more efficient in maintaining laminar flow therefore minimizing turbulence.
    - Construction method: Use a router table or sandpaper to sand and shape the edges of the fins while also changing to finer grits of sandpaper to ensure the edge is smooth.
  - Bevelled edges:
    - Aerodynamic effect: Beveling the leading and trailing edges of the fin can reduce drag by smoothing airflow transitions over the fin surface.
    - Construction: Use a router table or sandpaper to shape the fins.
- Smooth fillets :
    - fillets provide a smooth surface through which air can travel as it goes down the rocket and interact with fins. Adding fillets to the rocket helps not only improve the structural integrity of the fins but also improves the aesthetics and aerodynamics of the rocket.
- Painting and Clear-Coated Surfaces:
  - Smooth Surface:
    - Aerodynamic effect: Painting and applying a clear coat to the fin's surface can significantly reduce friction caused by the impact of turbulent air onto the surface of the fins.
    - Construction: Proper surface preparation, including sanding and priming the fins is essential to achieve a smooth finish. Multiple layers of paint and a clear coat will be required to ensure a smooth and level surface.

The fin design was performed using the OpenRocket FreeForm Fin option. The fin shape that was selected is based on a slightly modified trapezoidal fin (the surface opposite to the root edge is not parallel, but slanted in slightly).

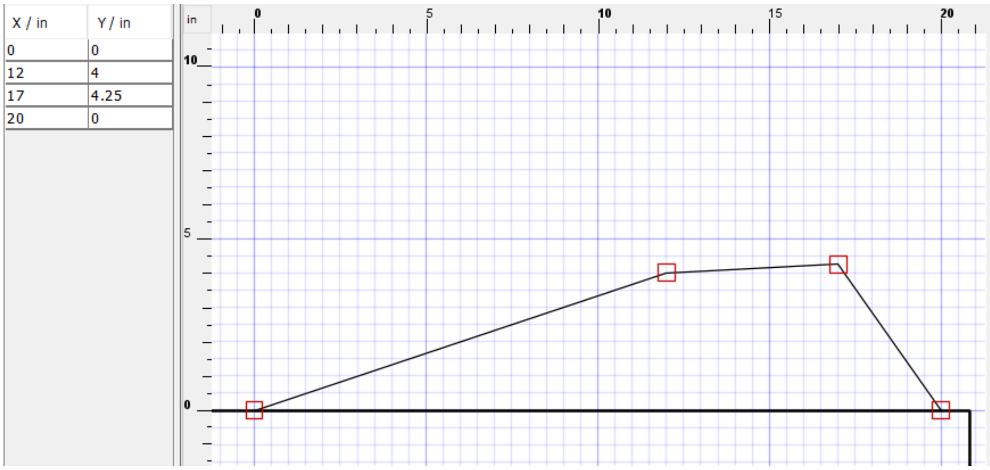


Figure 54. Proposed freeform fin shape

Considerations that went into this fin design include:

- Tapering on the rear of the fin to minimize fin damage from hard impacts.
- Long root cord to maximize bonding surface, root bonding from through the wall tabs, internal fillets, and external fillets.
- Ease of shape for fin beveling with a router table.
- Low fin height to fin length ratio leading to lower Cd.
- Overall aerodynamic efficiency for sub-Mach flight.
- Aesthetically pleasing design.

Note that a more detailed list of design justifications will be presented at PDR.

5.4 Recovery System Design

Designing an effective recovery system for a rocket is crucial to ensuring the safe return of the launch vehicle. The primary goal of the recovery system is to minimize impact forces upon landing and ensure that the rocket and the payload are reusable. This involves research and the analysis of our preliminary design for the recovery system of the rocket.

5.4.1 General Recovery requirements

Requirement	Implementation plan
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.	Both our sub-scale and full-scale launch vehicles have a staged deployment where the drogue parachute is deployed at apogee and the main parachute is deployed closer to the ground. We are not utilizing tumble or streamer recovery for our design.
3.1.1. The main parachute shall be deployed no lower than 500 feet.	The main parachute is programmed to deploy at or above 500ft.
3.1.2. The apogee event shall contain a delay of no more than 2 seconds	The apogee event will contain a delay of less than or at 2 seconds.
3.1.3. Motor ejection is not a permissible form of primary or secondary deployment	Our motor will be contained within the rocket from launch to recovery and will not be utilized as a method of primary or secondary deployment.
3.2. Each team shall perform a successful ground ejection test for all electronically initiated recovery events before the initial flights of the sub-scale and full-scale vehicles.	We will be performing a successful ground ejection test for all electronic recovery events before any flight. This includes both the sub-scale and full-scale vehicles.
3.3. Each independent section of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf at landing	We have calculated the impact kinetic energy of each independent section of the rocket and the highest impact energy calculated is 42.6 Ft-lbf.
3.4. The recovery system shall contain redundant, commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	Our recovery systems use 2 different altimeters with barometric functions and are designed specifically for the initiation of recovery events. We are utilizing an Eggtimer quantum and a Stratologger CF as our recovery altimeters. A detailed reason why these altimeters have been chosen is included in **Section 5.4.5**
3.5. Each altimeter shall have a dedicated power supply, and all recovery electronics shall be powered by commercially available batteries.	Each altimeter will have a dedicated power supply and all power supplies are commercially available batteries.
3.6. Each altimeter shall be armed by a dedicated	We will be using dedicated mechanical arming

mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	switches for the altimeters. The switches will be made of screw switches and armed after the rocket is loaded on the launch pad.
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).	Our arming switches are designed to withstand forces caused by flight.
3.8. The recovery system, GPS and altimeters, and electrical circuits shall be completely independent of any payload electrical circuits.	All recovery and GPS systems circuits are independent and include dedicated power supplies.
3.9. Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.	We will be utilizing removable shear pins for both the main and drogue parachute compartments. We are going to be calculating shear pin sizes and present our calculations in the Preliminary Design Review
3.10. Bent eye bolts shall not be permitted in the recovery subsystem	We are going to be utilizing stainless steel, closed, forged eyebolts, and U-bolts for our recovery systems. No bent eye bolts will be included in the rocket
3.11. The recovery area shall be limited to a 2,500 ft. radius from the launch pads.	The recovery area is going to be limited to a 2500 ft radius from the launch pads and if the parachute drifts any further, permission from the RSO will be required before recovery
3.12. Descent time of the launch vehicle shall be limited to 90 seconds (apogee to touch down)	We have optimized our recovery systems to be able to land the vehicle in 90 seconds from apogee to touch down. A detailed version of our descent characteristics is in **Section 5.7.4**
3.13. An electronic tracking device shall be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	We are utilizing one featherweight GPS tracker to track and transmit the position of the vehicle. We are not going to be having any independent sections.
3.13.1. Any rocket section or payload component, which lands untethered to the launch vehicle, shall contain an active electronic tracking device.	We are not going to have any independent sections that are going to land untethered to the launch vehicle.
3.13.2. The electronic tracking device(s) shall be fully functional during the official competition launch.	We will be ensuring that a fully functional electronic tracking device is being utilized for the official competition launch.
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 system electronics will be safely contained within the rocket to minimize any risk of damage during flight or landing.
3.14.1. The recovery system altimeters shall be physically located in a separate compartment within the vehicle from any other radio frequency	The recovery system altimeters are contained in the altimeter bay and are located separate from any radio frequency or magnetic wave-producing

transmitting device and/or magnetic wave-producing device.	device.
3.14.2. The recovery system electronics shall be shielded from all on-board transmitting devices to avoid inadvertent excitation of the recovery system electronics.	The recovery system is contained in a separate bay area known as the avionics bay to avoid inadvertent excitation of recovery electronics
3.14.3. The recovery system electronics shall be shielded from all on-board devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	We are not utilizing generators, solenoid valves, and tesla coils for our purposes in this competition
3.14.4. The recovery system electronics shall be shielded from any other on-board devices which may adversely affect the proper operation of the recovery system electronics.	We have separated the onboard tracker and any payload electronics from the recovery system to avoid early deployment.

Table 20. General recovery requirements

5.4.2 Dual Deploy Recovery Systems

The goal of the recovery system is to safely transition the rocket from apogee to ground. This can occur in many ways. The least efficient method is using a single deployment where the main parachute opens at apogee and allows the rocket to descend at a constant rate the entire way down where that rate is set by the ground impact speed. While it does provide a gentle impact, the rate is slow enough from apogee to low altitude that the rocket drifts away. Dual deployment uses two deployment events to more efficiently bring the rocket from apogee to landing. A two event deployment uses a small drogue parachute at apogee to allow the rocket to descend at a safe, non-ballistic rate down to a predetermined altitude (usually 500-700 ft) where a main parachute will be deployed. The main parachute slows the vehicle down to a safe landing velocity. This process minimizes drift while maintaining a safe recovery of the airframe. **Figure 55** below depicts the stages of a typical dual deployment flight and recovery.

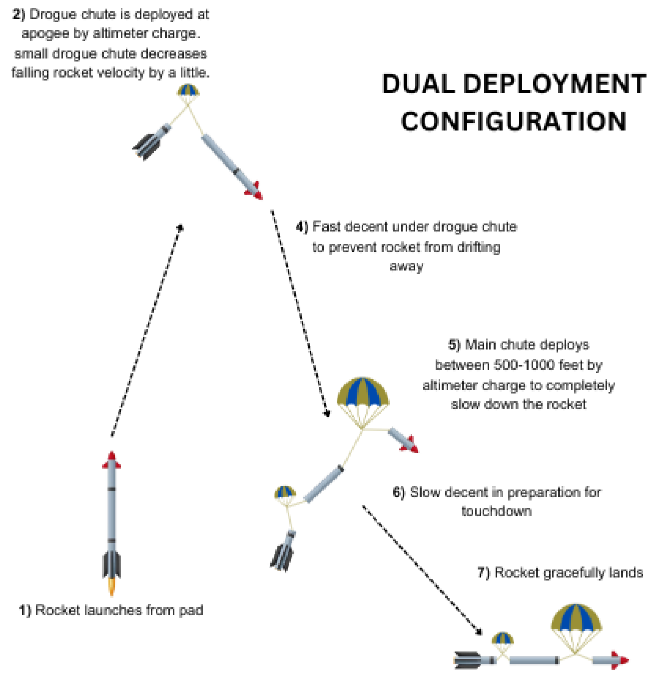


Figure 55. Stages of a dual deploy recovery sequence

Figure 56 compares the simulated recovery profile of a single deploy at apogee compared with a dual deploy implementation, with a 10 mph average wind speed and identical rates of descent. This demonstrates the necessity of dual deployment in maintaining a reasonable recovery distance.

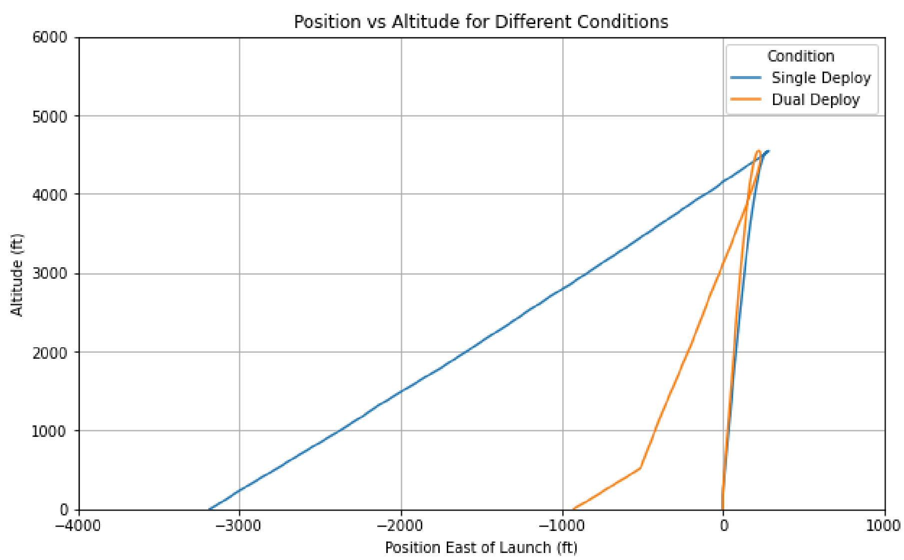


Figure 56. Drift profile comparing single deployment vs dual deployment

Dual deploy relies on the concept of electronic deployment. The most basic form of deployment is known as motor deployment. This relies on a timing element within the motor to trigger a deployment charge based primarily on an amount of time from motor ignition. A delay element within a motor that burns at a specific rate is used to set this time. This is an open loop system that does not take into account the actual flight conditions. Electronic deployment is a closed loop system that senses the altitude and flight characteristics to determine when to fire the deployment charges.

Dual deploy recovery uses the algorithm within the flight computer to fire two different recovery charges. This enables one to set one deployment charge at apogee for the drogue parachute, and sets one deployment charge at a predetermined altitude for the main parachute. Commercially available flight computers have been optimized over thousands of flights to provide consistent, reliable algorithms that have a proven track record of performance. Some algorithms include added safety features such as a failsafe mode which will fire the main parachute if it detects a failure or unsafe condition of the drogue parachute.

For added reliability, dual deploy methods allow for the possibility of full redundancy. Full electronic redundancy means having a completely parallel, redundant system. This includes the power source, wiring, arming switch, flight computer, electronic match, and deployment charge. The primary system would be set for nominal conditions, and the redundant system would be configured to actuate a second or two after the primary system. In general, the backup deployment charges would be larger. If the primary charges were insufficient to cause separation, the larger backup charges would give a much higher probability of forcing the separation. By configuring the backup charges to fire later than the primary, the larger charges would simply fire into an open body tube if the primary system worked as planned.

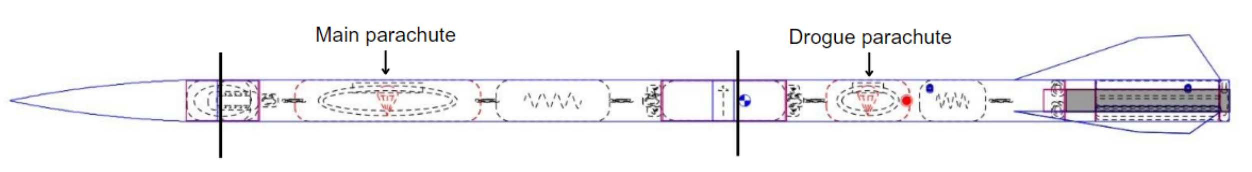


Figure 57. Dual deploy diagram with separation points

In **Figure 57**, the separation points and parachute locations of the rocket are shown. The main chute is stored in the payload tube and the drogue chute is stored in the booster tube of the rocket.

5.4.3 System-Level Calculations

According to section 3 of the handbook, the requirements for rocket descent are 90 s from apogee to touchdown, electronically controlled deployment charges, main chute deployment greater than 500 ft above ground level, and an impact kinetic energy of less than 75 ft-lbs. At this stage of the design, we will be aiming for an altitude of 4500 ft. This is halfway between the limits of 3500 ft and 5500 ft allowing for the most design flexibility between proposal and PDR.

The maximum landing velocity can be calculated from the maximum allowed impact KE. The heaviest separate section of the rocket is 8.66 lbs, and converting 75 ft-lbs to Joules, 8.66 lbs to kg, and substituting:

$$KE = \frac{1}{2}mv^2$$

$$101.7\,J = \frac{1}{2}(3.93)(v^2).$$

Solving for v:

$$v = \sqrt{\frac{2(101.7)}{3.93}} = 7.19\,m/s \approx 23.6\,ft/s.$$

Allowing a 100 ft margin to main parachute deployment and a 17.9 ft/s main parachute descent velocity (aiming for 85s descent time), we can calculate the time for and velocity of drogue descent:

- Main chute descent: 600 ft/17.9 ft/s = 33.5s
- Drogue descent time: 90s-33.5s = 56.5s
- Drogue descent velocity: v = d/t = (4500-600) ft/56.5s = 55.9ft/s.

To organize: in order to descend within the 90s, meet impact kinetic energy requirements from an apogee of 4500 ft, and have a margin for ideal main chute velocity, we need:
- 55.9 ft/s drogue descent velocity
- 600 ft main chute deploy
- 17.9 ft/s main chute descent velocity.

5.4.4 Parachute Selection

Parachute selection is an important part of successful recovery. It requires selecting between different types of parachutes and determining the size of the said parachute

$$D = \frac{1}{2}\rho V^2 S C_d$$

Variable	Definition
D	Drag produced (lbs)
ρ	Air pressure/ density (slug/ft^3)
S	Total reference area (ft^2)
C_d	Drag Coefficient

Table 21. Parachute drag equation variables

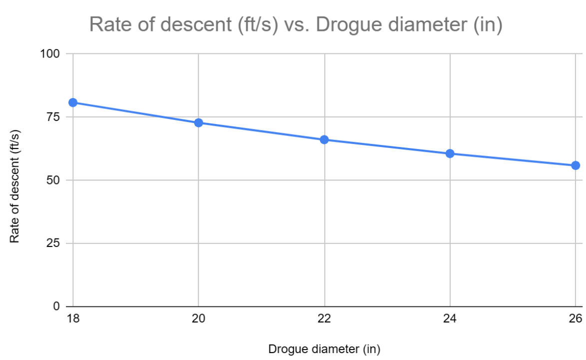
This equation is used to calculate the total drag produced by the parachute. The drag is dependent on the air pressure, the surface area of the parachute, and the coefficient of drag. Since air pressure is a variable that we cannot control, the best way to pick an efficient parachute is by choosing one with a high coefficient of drag and then refining the reference area to get optimum simulations. The table below shows the types of parachutes we researched and their advantages/disadvantages.

Parachute type	Advantages	Disadvantages
Parasheet	● Low cost ● Simple to fold	● Inefficient, Cd of approximately 0.7 ● Poor stability and usually oscillates
Classic elliptical	● Good stability at lower speeds ● Good efficiency, Cd of about 1.5-1.6 ● Packs into a smaller volume	● Wobbles at high speeds ● Expensive ● Packing an irregular shape is more difficult than a flat parachute.
Cupped parabolic	● Only 4 shroud lines ● Very robust to accidental high-speed deployment	● Low Cd of 0.8. ● Much larger packing size compared to equivalent parachutes.
Cruciform	● Good high-speed stability ● Simple design ● Good for a high-speed drogue parachute	● Inefficient, CD of approximately 0.4. ● Inaccurate models for OpenRocket.

Table 22. Parachute types

The classic elliptical parachute has a high Cd of 1.5-1.6 which achieves ideal drag, with less parachute material and smaller packed volume; however, an elliptical parachute's asymmetrical shape causes an imbalance in the aerodynamic forces acting on the parachute, which in turn causes high-speed instability. It also causes airflow instabilities which can cause the parachute to pitch, roll, or yaw leading to unpredictable descent behavior.

High-speed instability can be fixed by incorporating a spill hole which is 15-20% of the diameter of the parachute. This reduces the pressure difference caused by the uneven air pressure on different parts of the canopy with a minimum impact on the effective parachute area. A spill hole allows some of the turbulent air under the canopy to escape and helps equalize the forces acting on the parachute, decreasing the oscillatory motion and resulting in a controlled descent. The plots below show the rate of descents for varying diameters for both the drogue and main parachutes.



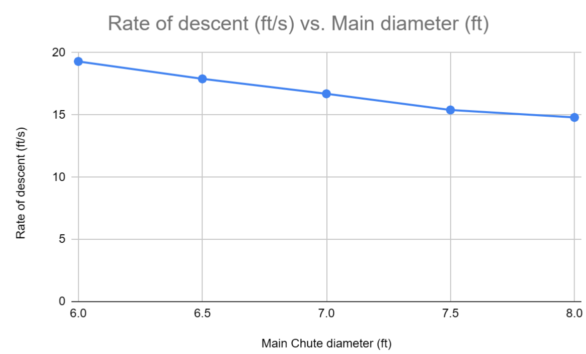


Figure 58. Drogue diameter vs rate of descent (right), Figure 59. Main diameter Vs rate of descent (left)

The drogue parachute is selected to minimize the time the rocket spends in the air while slowing the descent rate enough for the main chute to safely deploy. The main chute is selected to reduce the rate of descent to a velocity that will not cause significant damage on landing while also meeting the 90s limit. Our simulations through an open rocket have helped us determine that a 20 in drogue chute and a 6.5 ft main chute slow down the rocket enough while also letting the rocket land in under 90s (from apogee to touchdown).

5.4.5 Avionics Bay

The avionics bay for our rocket will be utilizing two retailed altimeters. To choose between a variety of altimeters, we have conducted our research to decide which altimeters will be best for our purposes.

The following table only contains the extra features that the altimeters have to offer while also comparing prices. Common features like output channels and data recording capabilities have been omitted.

Manufacturer	Altimeters	Cost	Extra features
Eggtimer Rocketry	Quantum	$40	• Arming/disarming safety feature: 4 4-digit safety code is required to arm/disarm the altimeter. • Failsafe feature: If free fall is detected after drogue deployment, a failsafe feature is implemented where the main parachute will be deployed to attempt to save the rocket • Remote ground testing from 100 feet away.
	Proton	$85	• Arming/disarming can be done from over 100 ft away. • 40 sample per second data collection
Missile works	RRC2+	$54.95	• Audible altimeter readings via a beeper
	RRC3+	$79.95	• Impervious to Lithium battery discharge
Featherweight Altimeters	Blue raven	$175	• Dedicated software for altimeter • Contains an Accelerometer and gyroscope
Perfect Flite	StratoLoggerCF	$69.95	• Audle reporting of data through a beeper • 20 samples per second data connections • Resistant to false triggers from wind gusts
Altus Metrum	Easy Mini	$80	• Small and compact
Silicdyne	Fluctus	$339	• Dedicated flight analysis software • On-Board GPS • Contains Accelerometers, Barometers, and GyroMeter for tilt measurement

Table 23. Types of altimeters

Our goals in this competition do not require high-end altimeters with multi-staging capabilities. Rather, we require an altimeter that is capable of very simple dual deployment and data logging while also cutting down costs and reducing complexity. All the altimeters listed above have some capabilities in common ie. dual deployment, data recording, etc. Some systems like the Fluctus and the Blue Raven are good altimeters but have features that are beyond the overall requirements. We have decided to use a combination of the Eggtimer Quantum and the StratologgerCF altimeters. Doing so will ensure redundancy via 2 different altimeter brands, pressure sensors, and algorithms. This option not only cuts down on costs but gives us an additional layer of safety.

The Stratologger CF has extremely limited availability because Perfectflite, the company that manufactures the altimeter, makes only 10 per year. Since there is limited availability and we already have one Stratologger CF, we are not going to be buying a new altimeter. If the altimeter gets damaged, we will purchase the RRC2+ as a last resort. The RRC2+ has the same essential functions as the Stratologger CF.

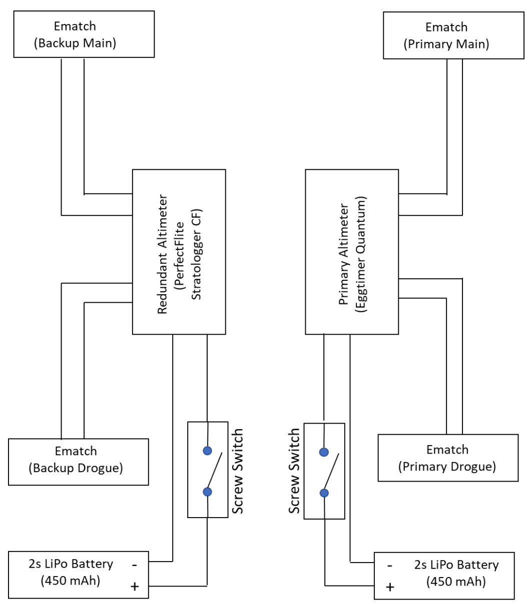


Figure 60. Schematic of avionic bay

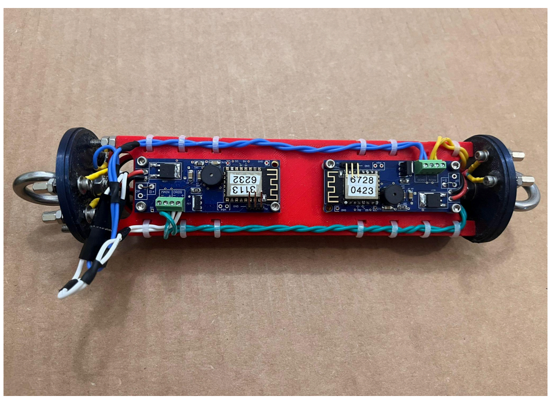
The figure above shows the proposed avionics bay electrical schematic: It includes the components as follows

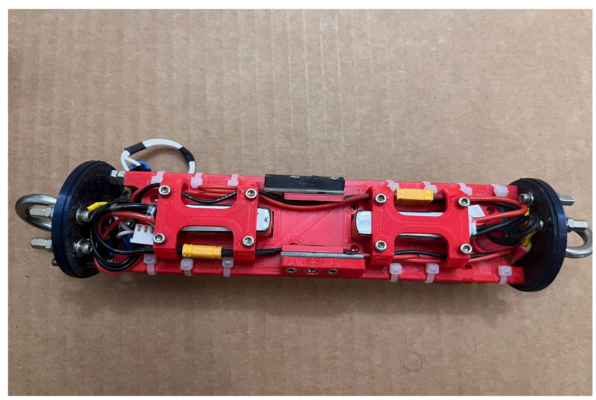
- Commercially available barometric altimeters that are designed specifically for high-power rocketry.
- Fully redundant, parallel systems which utilize different brands of flight computers. Each has an independent power source and mechanical switch.
- The altimeters are armed via a screw switch which is capable of being armed through the airframe and remains in a locked, vibration-resistant state.
- Each battery is sufficient for at least 4 hours of operation

Below is an example of an avionics sled built by one of the students on the team for a 2" airframe. Many of the design and construction aspects of this example will be utilized in the SLI avionics bay design. Note that this employs many small, but important details aimed for high reliability. These include:

- All wire connections to bulkheads utilize high-reliability crimp connectors.
- All wire terminations have proper strain relief either by design or extended with heat shrink. Wires are well secured at all points.
- Wires are implemented as twisted pairs to greatly reduce the possibility of electromagnetic interference.
- Lithium polymer batteries that are reusable to prevent wear and tear of the altimeter bay from removal after every flight. These can be recharged in place using a charger that continuously monitors the health of the cells during charging.
- High reliability, positive connect power switch.
- Full system redundancy.

A similar design will be utilized for the sub-scale rocket (likely the same diameter as the example altimeter). For the full scale, we plan to use very similar methods but will have considerably more space available in a 4” airframe.





Figures 61, 62. Avionics bay using 2 egg timer altimeters

5.4.6 Deployment Charge Calculations

Ematches controlled by the altimeters will be used to ignite the black powder deployment charges. To ensure separation while minimizing stress to airframe components, the type and amount of black powder used will need to be optimized through calculation and ground testing.

We will be using FFFFG, or 4FG, black powder for our deployment charges. Black “powder,” is granular, and its grade is determined by the size of the grains; the more F’s there are, the smaller the grain size. The speed at which the black powder burns is determined by the surface area to volume ratio, essentially the grain size. 4FG will be used as it combusts quickly enough that separation is not affected by vent holes in our airframe. It also burns quickly converting from solid to gas, reducing the risk of flaming particles flying about.

Basic physics and chemistry equations can be used to approximate the needed black powder amount. Using F=PA, the predefined cross-sectional area of our airframe will allow us to isolate and determine P. Using ideal gas law and the chemical equation for the combustion of black powder, we can back-calculate the moles (and thus the mass) of black powder needed.

The nose will be coupled together using three 4-40 nylon shear pins, and the booster coupled using three 2-56 shear pins. Assuming the maximum value of tolerance, the nose will require 163.53 lbs of force to separate and the booster 101.64 lbs. To ensure separation, we will add 20%: 196.24 lbs, and 121.97 lbs, respectively.

On our 4 in the airframe, $A \approx 4\pi$ in^2, Thus, using F=PA, the pressure needed to separate the nose will be 15.62 psi and the booster 9.71 psi. Converting that to atmospheres and substituting into PV=nRT, we get for the nose:
$1.06V = n(0.08206)T$

And for the booster:
$0.66V = n(0.08206)T$

We are solving for *n*, moles of gas, thus:
$n_{nose} = \frac{1.06V}{0.08206T}$ and $n_{booster} = \frac{0.66V}{0.08206T}$

The volume of our payload section is approximately 7.93 L and the volume of our booster is 6.62 L. Depending on its composition, black powder burns at ~1200°-1350° Celsius. Taking a middle of 1250°C for T, we get the payload:
$n_{nose} = \frac{1.06(7.93)}{(0.08206)(1523.15)}$

And for the booster:
$n_{booster} = \frac{0.66(6.62)}{(0.08206)(1523.15)}$

These calculations give us the moles of gas needed to create our specified pressure:
$n_{nose} = 0.0673\ moles$ and $n_{booster} = 0.0350\ moles$.

A simplified chemical equation for the combustion of black powder is:
$2KNO_3 + 3C + S \rightarrow K_2S_{(s)} + 3CO_{2\,(g)} + N_{2\,(g)}$ †.

Using stoichiometry, we can calculate the mass of black powder needed; the ratio of moles of gas to moles of reactants is 5:6:

For the nose:
5:6=0.0673:x
x=(0.101 moles black powder)*45.0g/mol = 4.55 g

For the booster:
5:6=0.0350:y
y=(0.0524 moles black powder)*45.0g/mol = 2.36 g

While in theory, our calculations are relatively accurate for the minimum force to separate a static rocket, these calculations are merely a starting point. Additional margins will be added to ensure separation at altitude and in the presence of other forces acting on the separation points. After optimizing as much as possible using calculations and online resources, we will conduct ground testing to verify our calculations and ensure successful parachute deployment.

There are various online resources also available to calculate the amount of black powder needed. In addition to our calculations, using these resources will help us verify and ensure better success before performing any ground tests.

For the backup altimeter, an additional 20% margin will be applied to ensure separation if the primary charge fails. If the primary charge is successful, then the backup charge will fire into an open tube with no detrimental effect.

† : The reaction for the combustion of black powder is complex with many products, said products change based on the reaction environment. However, this seems to be an accepted simplification of the reaction, which should be good enough for our uses.

5.5 Motor Selection

For our full-scale rocket, we propose to use an Aerotech K1103X or an Aerotech K2050ST motor, leaning heavily towards the K1103X. NASA requires a minimum thrust-to-weight ratio of 5.0:1.0, a minimum static stability margin of 2.0 caliber at the rail exit, and a 52 ft/s rail exit velocity. To meet these requirements, we compared several K-impulse motors to determine the optimal one. Namely, the K1103X, K2050ST, K805G, and the K550W. We organized the information we deemed vital for our decision into a table:

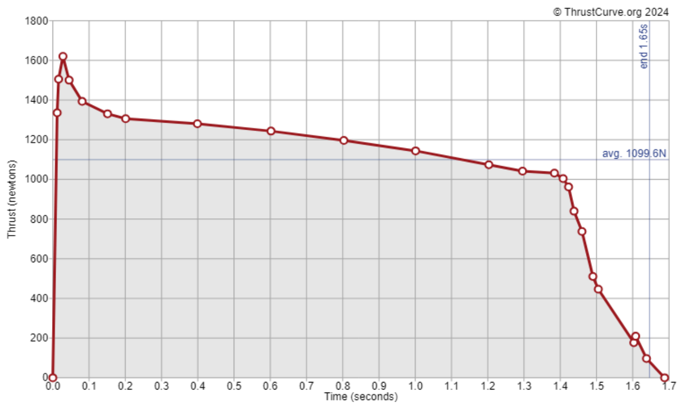
Variables	Motor			
Motor Name	K1103X	K2050ST	K805G	K550W
Total Impulse (Ns)	1789	1384	1762	1539
Thrust-to-weight	12:1	23:1	9:1	6:1
Rail exit velocity (ft/s)	99.8	122.7	77.8	64
Rail exit stability (caliber)	2.97	3.21	2.52	1.82
Comments:	Easy to ignite, large flame, low amount of smoke.	Very fast burn, blue/purple flame, very energetic	Green flame, very difficult to ignite	A large amount of smoke, loud

Table 24. Motor choices

We concluded that the K1103X would be optimal: a commercially available, Tripoli-certified reload for an Aerotech 54/1706 motor casing. Upon simulation in OpenRocket, this motor allowed us to reliably reach our target altitude of 4500 ft and also met all of the minimum requirements for thrust-to-weight ratio, stability, and rail exit velocity; however, it requires the fuel grains to be glued to the liner, which will be done by the mentor.

As every NASA requirement was met, we are considering the K2050ST as our second option.. Its burn time, however, is almost half of the K1103X: approximately 0.8s compared to 1.7s. While a fast-burning motor helps against weathercocking, this gives us an almost unreasonably high rail exit velocity and causes high stress to the STEMnauts. Thus, we are considering this while heavily leaning towards the K1103X.

Another option, a K805G, has Mojave Green propellant that can be difficult to ignite, with toxic barium chloride exhaust and a lower rail exit velocity. Our last considered option, a K550W, does not meet the requirement for minimum rail exit stability, has a slow rail exit of 64 ft/s, and a thrust-to-weight ratio of 6:1, uncomfortably close to the minimum of 5:1. Thus, we concluded that the K1103X is the best motor for our use, as it is best balanced in terms of thrust-to-weight ratio, stability upon rail exit, and rail exit velocity.



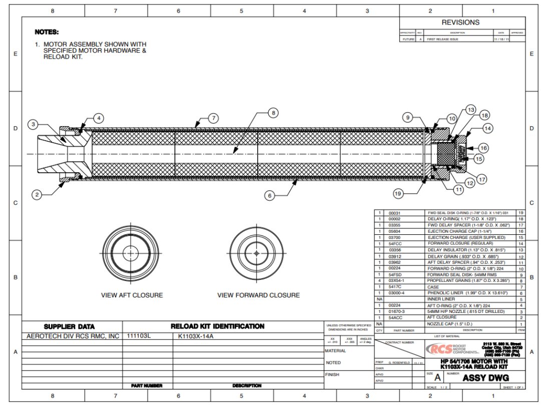


Figure 63. Thrust curve for the Aerotech K1103X (left), Figure 64. motor cross section (right).

Note: despite the motor shipping with a deployment charge, we will omit use as motor ejection is not permitted.

For a sub-scale motor, we plan to use an I impulse motor, as it is a 50% scale-down from a K impulse. A specific motor will be chosen for our sub-scale airframe as the design is worked on between proposal submission and PDR.

5.6 Rocket Tracking and Telemetry

We researched a multitude of options for GPS tracking units, The table below includes all the options we considered while deciding.

Tracking Unit	Cost	Features
Featherweight GPS	$165	• 10 GPS solutions per second • Vertical and horizontal velocity tracking • Reports positions up to 262,467 feet altitude and up to Mach 1.45 • Easy integration with an app • Live tracking
Eggtimer Mini GPS Tracker	$100	• 1 GPS solution per second • Vertical and horizontal tracking • Reports position up to 31,680 feet • Live tracking • Kit that requires assembly • No cell phone integration required
Apogee Simple GPS Tracker	$475.84	• Live tracking • Stand-alone system (no cell phone integration) • Reports positions up to 31,680 feet
Fluctus	$339.00	• Vertical and horizontal tracking • Up to ±200G for accurate speed measurement • Measures altitudes up to 65,000 feet • The gyrometer measures the rotation of the rocket • Weighs 23 grams • Live tracking • Easy integration with the app
Multitronix Kate-3	$1525	• 5 GPS solutions per second • 50G accelerometer is recorded at 100 readings/sec • 3-axis gyroscope recorded at 100 readings/sec at up to 2000 degrees/sec • Live tracking
Marco Polo	$265	• Tracking up to 10,560 feet away • No live tracking • Can only be used as a backup tracker

Table 25. Types of GPS trackers

To track the position and altitude of our rocket during flight, we will be using the Featherweight GPS tracker. After researching a variety of GPS units, we found that the Featherweight GPS tracker would most accurately provide us with our rocket's telemetry due to its tracking frequency of 10 GPS solutions per second and extensive range. It also effortlessly integrates with an app, allowing us to track our rocket in real-time and review its data immediately.

5.7 Simulated Performance

The accurate simulation of a rocket's performance is critical to understanding its behavior under various conditions and ensuring mission success. Simulating a rocket provides valuable insights into factors such as trajectory, altitude, velocity, acceleration and aerodynamic forces before any physical launch takes place. By incorporating parameters like wind conditions, and drag we can predict and optimize a rocket's flight path. The simulated results serve as essential tools in the design and refinement process enabling safer, more efficient launches and allowing the team to identify any potential issues before they arise. The following sets of simulations represent an initial analysis for the proposed design. As the design evolves through the engineering process, these simulations will be used as a benchmark for improvements. Additional simulations will be performed to both fulfill the requirements as well as compliment required simulations to ensure success of the project.

5.7.1 Altitude

Simulating the projected flight path of the rocket in OpenRocket gives us an approximate apogee of 4565 ft, including 700 g of optional ballast weight. Previously, we have found OpenRocket to slightly overestimate altitude. The probable altitude of the rocket in its current state should be approximately 4000-4400 ft in this flight configuration. Being centered between the NASA SLI requirements for altitude (3500 - 5500 ft), this design gives us the most flexibility for minor adjustments between now and selecting our final altitude at the PDR deadline. The figure below is a simulation of the rocket's flight path detailing the rocket's important events. The time from apogee-to-ground hit is approximately 85 seconds which is under the 90-second limit set for the competition with a little margin.

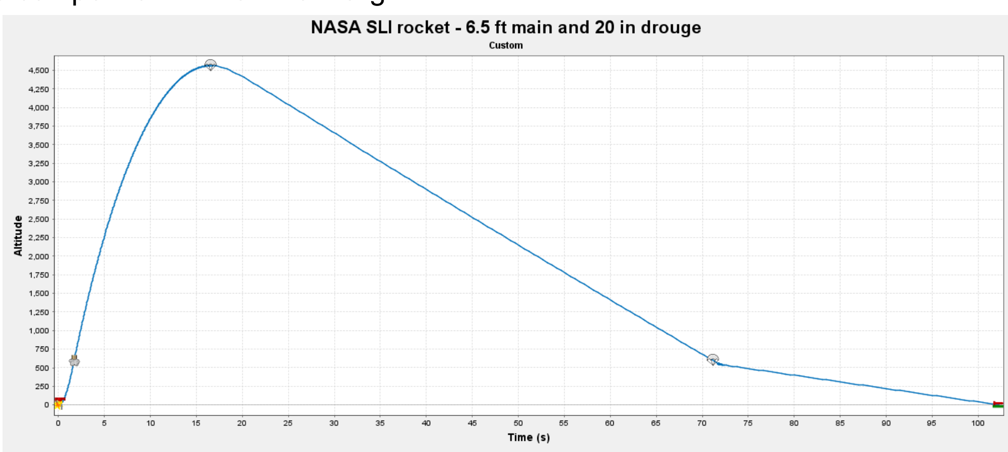


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Figure 65. Simulated flight altitude vs time

The plot above graphs the altitude when the ballast mass is at its maximum (700 g), representing a worst case scenario, knowing that additional mass will probably be added to the rocket design through construction and potential design changes. This ballast can always be reduced or removed as necessary to allow for flexibility in the design. The figure below contains a plot that shows the altitude that the rocket achieves by varying ballast mass. Note that the design is flexible within the target range for the SLI requirements.

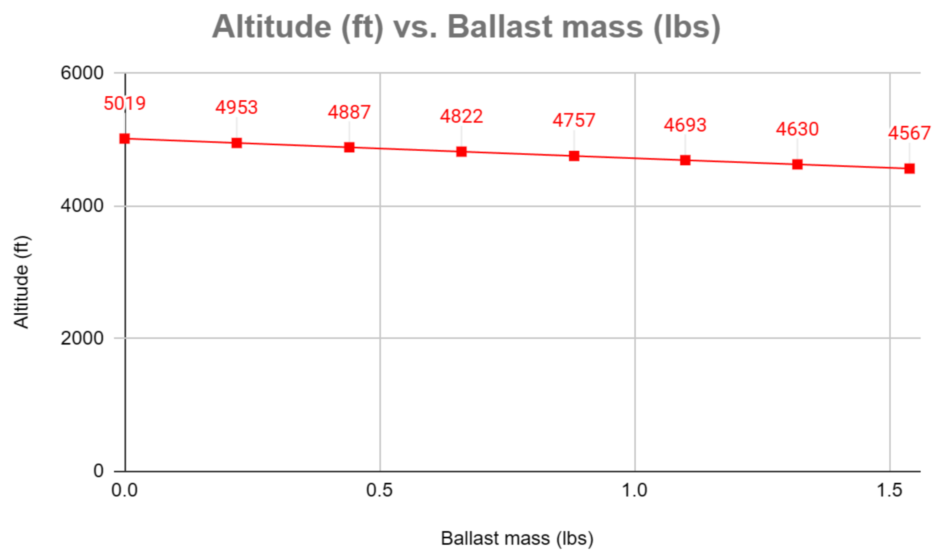


Figure 66. Altitude vs ballast mass

This plot gives the simulated estimate of altitude with different ballast masses and allows us to predict how the rocket is going to behave as weight is increased/added. This allows us to have almost 500 ft of adjustability in the target altitude.

5.7.2 Velocity and Acceleration

OpenRocket is capable of simulating the maximum velocity of the rocket. OpenRocket simulated the maximum velocity of the rocket to be approximately 603 ft/s or Mach 0.542

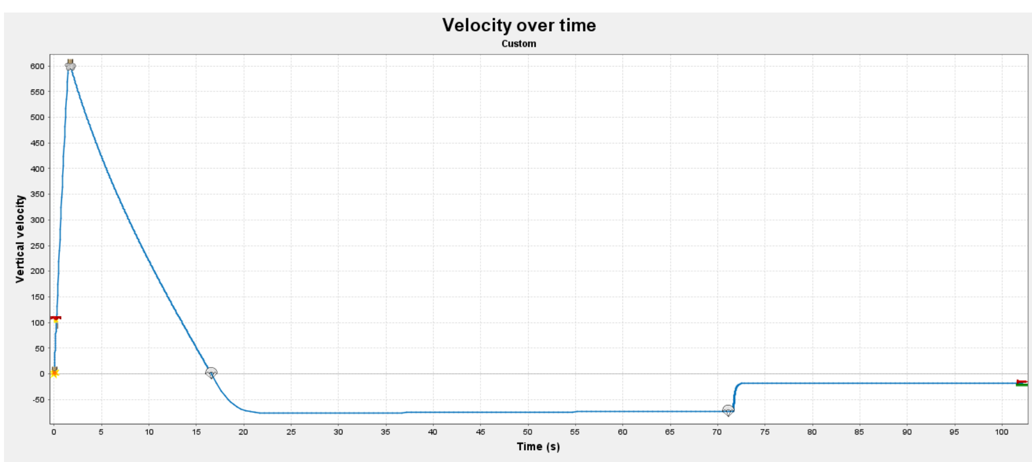


Figure 67. Simulated velocity vs time

Maximum acceleration is defined as the highest rate at which an object can increase its speed in response to a force acting upon it. The force acting upon our rocket is the K1103X motor exhaust output. OpenRocket simulated the maximum acceleration experienced by the rocket due to the K1103-X motor as 536 ft/s^2

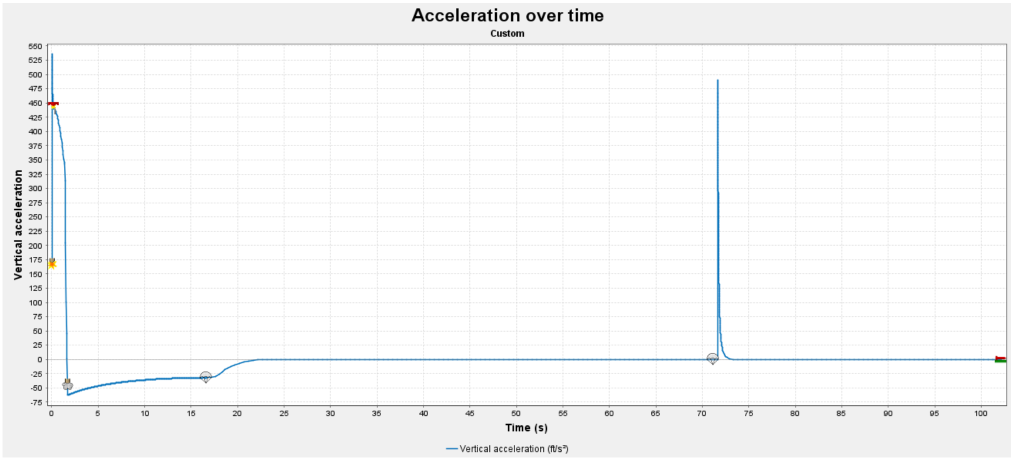


Figure 68. Simulated acceleration vs. time

Maximum acceleration occurs after motor burnout. The rocket experiences some acceleration after apogee and the drogue deployment but it is lower than the maximum acceleration faced by the rocket. The second spike in the graph is the acceleration after the main chute deployment.

5.7.3 Dynamic Stability

Dynamic stability is defined as a system's ability to maintain operational stability during disturbances caused by aerodynamic forces. We modeled the dynamic stability of the rocket in OpenRocket, initially using ideal conditions of vertical rock in nominal winds. The stability vs time plot shows stability as viewed by an observer, and the stability vs altitude plot demonstrates the stability at rail exit (10 ft 1515 rail).

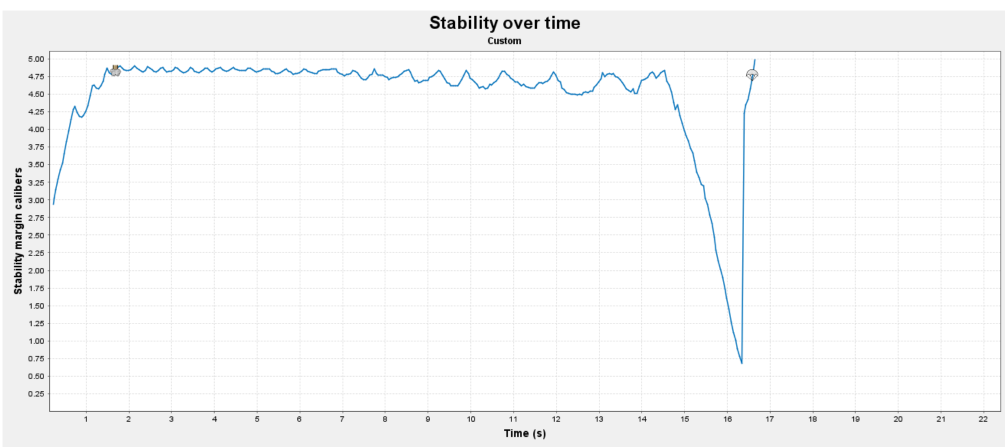


Figure 69. Simulated dynamic stability vs time

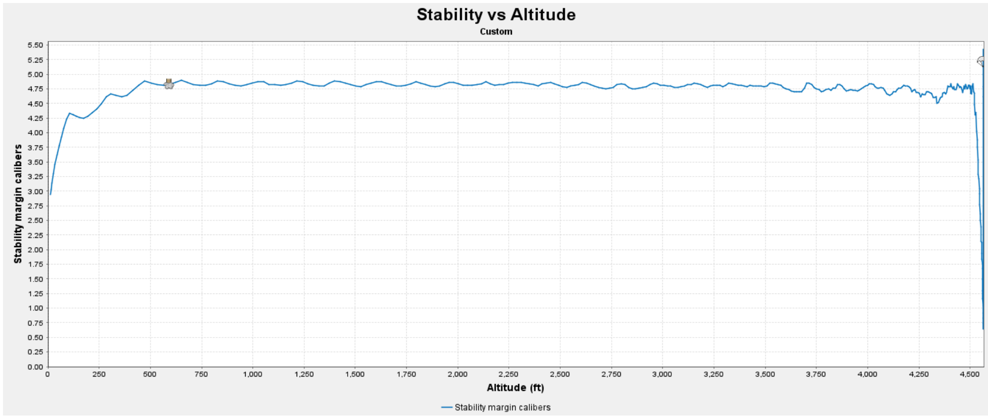


Figure 70. Simulated stability vs altitude

The rail exit dynamic stability is the first data point of the graph above showing the dynamic stability at a respectable 2.94 caliber. Both graphs show an upward trend in stability up to the deployment charges. The increase in stability is due to increasing velocity and depletion of mass at the aft end of the rocket from the reduced mass of propellant burning. The depletion of propellant shifts the center of gravity forward leading to an increase in stability. The graphs show that the stability maxes out at around 4.7 to 4.8 caliber after all of the propellant has been consumed.

5.7.4 Descent Characteristics

There are many decent characteristics worth noting. At the time of the proposal, we will present some of the most important aspects. Further details will be written in later reviews.

Descent velocity between drogue deployment and main deployment:
The drogue parachute deploys at apogee and slows the launch vehicle down to approximately 60.6 ft/s. The SLI requirement for deployment of the main parachute is 500 ft minimum. To have some margin for the main parachute to deploy and properly inflate, the primary charge on the main parachute is currently modeled at 600 ft. This slows the landing velocity of the launch vehicle to 17.9 ft/s. 17.9 ft/s is an important velocity since it allows us to safely land the rocket with acceptable kinetic energy while conforming to the SLI limit of a 90-second descent from apogee to touch down.

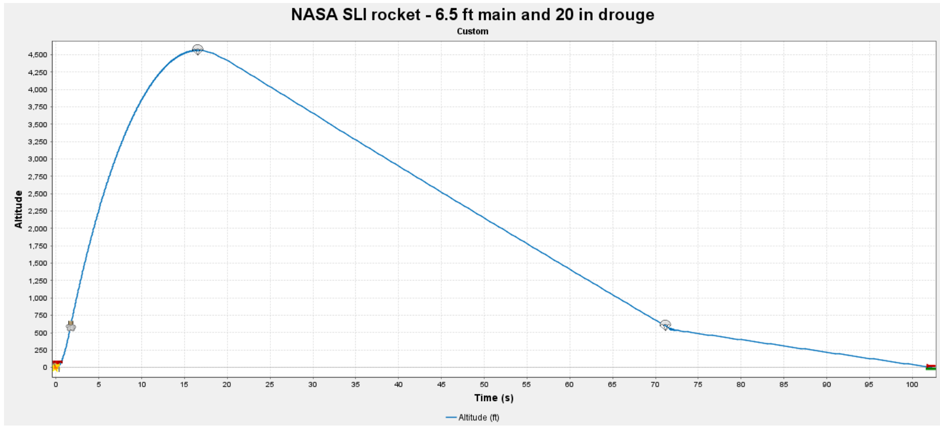


Figure 71. Simulated altitude vs time

The simulated descent time is approximately 85 seconds, which is a good simulated range we want to have for further adjustments after the proposal.

5.7.5 Impact Kinetic Energy

The SLI requirements state that the maximum impact kinetic energy is limited to 75 ft-lbf for any portion of the airframe. To achieve an impact velocity of 75 ft- lbf with the given weight of the heaviest section of the rocket (the booster), we calculated that the landing velocity needs to be around 23.6 ft/s. Note that this is a very fast rate of descent for a rocket of this mass.

The design space allows us to reduce the rate of descent considerably while still achieving the 90 s apogee-to-landing time with some margin. The proposed design has sized the parachutes to allow for a simulated landing velocity of 17.9 ft/s to minimize impact kinetic energy while still achieving the 90 s apogee-to-landing time requirement. The rates of descent will continue to be optimized during the design and test cycles.

The impact force for each section is listed below Impact kinetic energy is defined by the equation below. The velocity is kept constant at 17.9ft/s

$$KE = \frac{1}{2}mv^2$$

Section Name	Weight (lbs) after burnout	Total impact force (ft-lbf)
Nose cone assembly	2.26	11.2
Payload tube	4.67	22.9
Avionics bay	1.28	6.3
Booster tube	8.66	42.6

Table 26. Impact kinetic energy of each section

5.7.6 Drift Calculations

Drift is an important topic that determines if we can land the rocket fast enough and in a safe area. SLI rules state that the maximum range of a rocket for landing is a 2500 ft radius from the launch pad. Understanding the drift performance also enables us to safely determine which field and weather conditions are sufficient for the recovery of test launches.

We utilized OpenRocket's feature of simulating position in different wind speeds. The data was then consolidated and plotted using a Python script. For this proposal, a 10' rail with a 0° tilt based on 1515 rail buttons.

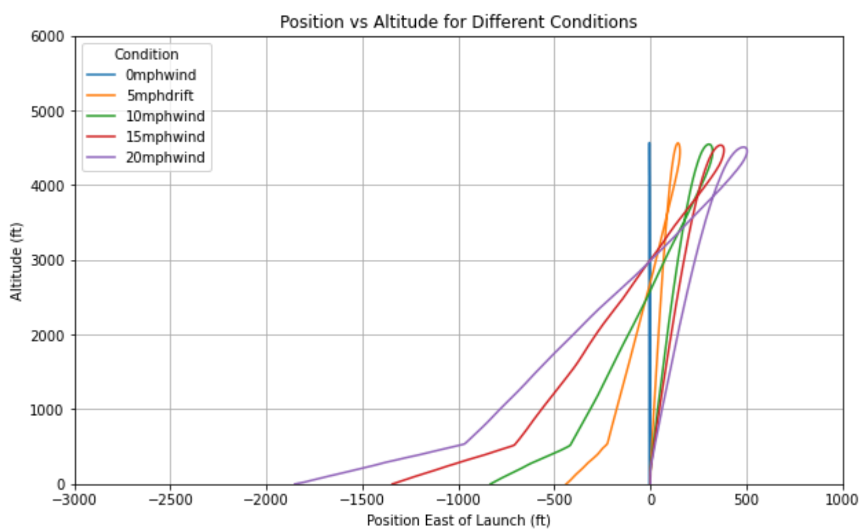


Figure 72. Drift of proposed launch vehicle vs wind speed

All simulations show that the rocket is under the 2500 ft retrieval radius specification. The worst-case recovery radius was 1800 ft with 20 mph winds. We kept the launch rail in its vertical position and the wind flowed from the west. It is understood that the RSO may require that the rail be tilted into the wind depending on wind conditions to prevent rockets from flying over spectators. A more detailed analysis will be performed by sweeping rail angle as the design phase progresses.

5.7.7 Fin Flutter

Fin flutter can be a catastrophic event if not recognized and mitigated properly. While fin flutter analysis is not a requirement for this proposal, we felt it was prudent to perform some initial calculations to ensure that the airframe design is viable. Fin flutter is an effect where the fins of a rocket experience rapid oscillatory motion. This usually occurs at high speeds where the airflow over the find creates fluctuating pressure distributions. Fin flutter can occur due to the following circumstances:

- **<u>Aerodynamic Forces:</u>** During ascent, the fins generate lift to stabilize and control the rocket, However at certain speeds and angles of attack, the aerodynamic forces can cause the fins to vibrate rapidly leading to disassembly or trajectory change.
- **<u>Resonance:</u>** If the frequency of such aerodynamic forces matches the natural frequency of the fin structure, resonance can occur. Usually depends on the material composition and thickness. Resonance can lead to a potential structural failure and rapid disassembly.
- **<u>Structural properties:</u>** The thickness and material of the fins play a critical role in their vulnerability to flutter. More flexible fins are prone to flutter whereas stiff and thicker fins are less susceptible to flutter.

Fin flutter can be mitigated/controlled using different strategies which are important to consider:

- Material selection: Using materials with high stiffness-to-weight ratios, such as fiberglass can reduce the susceptibility of fins to flutter. Thickness is also a big factor since a thicker fin composed of the same material will be less susceptible to fin flutter. It is important to find a balance between material strength, thickness, and the impact of thickness on the aerodynamics of the rocket.
- Fin flutter approximation equation code: Fin flutter can be approximated using an equation

$$V_f = a \times \sqrt{\frac{G_E}{\frac{39.3 \times A^3}{\left(\frac{t}{c}\right)^3 \times (A+2)} \times \left(\frac{\lambda+1}{2}\right) \times \left(\frac{p}{p_0}\right)}}$$

$$a_{ft/sec} = 49.03 \times \sqrt{459.7 + T_F}$$

Variable	Definition
V_f	Calculated fin flutter velocity (ft/s)
a	Speed of sound at launch altitude (ft/s^2)
G_E	Shear modulus of the fin material (lbs/in^2)
A	Fin aspect ratio = $(\text{Fin Height})^2$/ (Fin Area)
t/c	Thickness ratio = Fin thickness /Root chord length
λ (lambda)	Fin taper ratio : (tip chord length)/(root chord length)
a	Speed of sound (ft/s)
T_F	Temperature (°F)

Table 27. Fin flutter velocity and speed of sound equation variables

To mitigate fin flutter in rockets, the flutter velocity, or V_f, should be higher than the maximum velocity of the intended flight plus additional margin. This helps ensure that no structural damage is done to the rocket in flight by fin flutter.

For our purposes, we will be utilizing a Python script written by John Bennet (**https://github.com/jkb-git/Fin-Flutter-Velocity-Calculator**). This code allows the user to input their specific fin design and launch conditions. The code will then calculate the approximate fin flutter velocity of the design.

Utilizing this code and our fin design, We calculated our fin flutter velocity as 1022.6 ft/s which is double the maximum velocity the rocket faces 603 ft/s. This gives us a good margin for safety and helps us ensure that even if fin flutter occurs, the fins will be able to handle it without causing damage to the airframe.

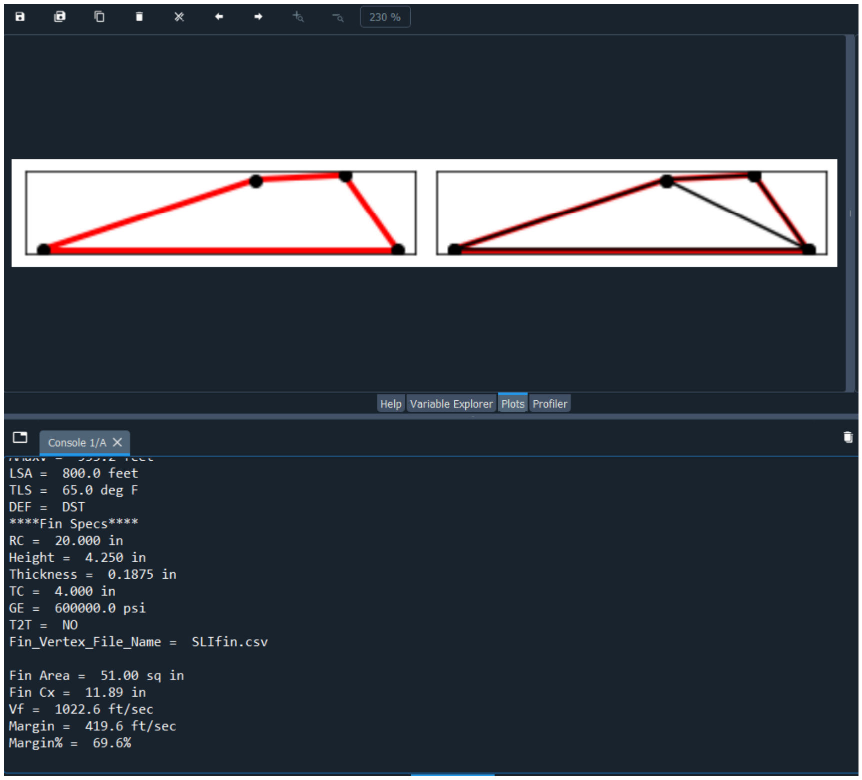


Figure 73. Output results for the proposed fin design

5.8 Project Goal and Safety Requirements

General Requirements	
Requirement	**Implementation Plan**
1.1 Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Student team members shall only be a part of one team in any capacity. Teams will submit new work. Excessive use of past work will merit penalties.	Students will conduct all of the project design, construction, report writing, presentation preparation, and flight preparation within the legal limit (excludes motor and ejection charge preparation). We are a first-year team, so there will be no recycling of material.
1.2 The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	Students will divide the required reports writing according to lead roles and understanding of sections. The team will review and revise drafts, updating the project plan as the competition progresses.
1.3 Team members who will travel to the Huntsville Launch shall have fully completed registration in the NASAGateway system before the roster deadline.	Team leads will establish an internal registration deadline for traveling members and provide support if issues arise while attempting to complete

Team members shall include: ● 1.3.1 Students actively engaged in the project throughout the entire year ● One mentor (see requirement 1.13) ● No more than two adult educators	registration. Students will attend mandatory meetings about the project and complete all assigned tasks accordingly.
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 EngagementActivity Report can be found on pages 86 – 89	Student members will organize, run, and document engagement STEM activities with the community, including the event plans and participants to ensure minimum engagement requirements are met satisfactorily.
1.5 The team shall establish and maintain a social media presence to inform the public about team activities.	Student members will post weekly to various social media websites/software such as Instagram and Facebook, as well as district newspapers to inform the public about team activities.
1.6 Teams shall email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. If a deliverable is too large to attach to an email, the inclusion of a link to download the file will be sufficient. Late submissions of PDR, CDR, or FRR milestone documents will be accepted up to 72 hours after the submission deadline. Late submissions will incur an overall penalty. No PDR, CDR, or FRR milestone documents will be accepted beyond the 72-hour window. Teams that fail to submit the PDR, CDR, or FRR milestone documents will be eliminated from the project.	The team will ensure all deliverables are submitted by each milestone deadline by establishing internal time frames and completing each item accordingly. The team understands the overall consequences of failing to achieve a milestone punctually.
1.7 Teams who do not satisfactorily complete each milestone review (PDR, CDR, FRR) shall be provided action items needed to be completed following their review and shall be required to address action items in a delta review session. After the delta session, the NASA management panel shall meet to determine the teams' status in the program and the team shall be notified shortly thereafter	If required to attend a delta review session, the team will establish internal deadlines to review criticism and revise action items satisfactorily and accordingly.
1.8. All deliverables shall be in PDF format.	The team will export all finished documents in Portable Document Format using built-in tools software Google Docs and Slides, as well as Microsoft Word and Excel.
1.9. In every report, teams shall provide a table of contents including major sections and their respective subsections.	Following the title page, each report will include a table of contents outlining all major sections and respective subsections as well as their locations within the document.
1.10. In every report, the team shall include the page number at the bottom of the page	Each page within every report will include a footnote that details the page number of the document in the

	bottom right corner.
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.	When preparing for a review panel teleconference, team members will ensure the chosen location has adequate internet connection. The team will also set up multiple computer systems capable of transmitting video and audio to ensure the performance.
1.12. All teams attending Launch Week shall be required to use the launch pads provided by Student Launch's launch services provider. No custom pads shall be permitted at the NASA Launch Complex. At launch, 8-foot 1010 rails and 12-foot 1515 rails will be provided. The launch rails will be canted 5 – 10 degrees away from the crowd on Launch Day. The exact cant will depend on Launch Day wind conditions.	The team will use the Student Launch's launch services provided launch pads without customization. The team will ensure launch rails are canted away from the crowd according to on-day wind conditions.
1.13. Each team shall identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year and may or may not be affiliated with the school, institution, or organization. The team mentor shall not be a student team member The mentor shall maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of two flights in this or a higher impulse class, before PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to Launch Week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attend Launch Week in April.	The team identifies Mr. Andrew Brown as the supporting mentor throughout the project year. He maintains the current certification of TRA L3, and has flown and successfully recovered the minimum two higher impulse flights before the PDR.
1.14. Teams will track and report the number of hours spent working on each milestone.	Members will add hours into a tracking spreadsheet to detail the number of hours spent on each milestone, project items, individual hours, and overall team hours. The total will then be continuously updated and reported.

Table 28. General requirements

Safety requirements	
Requirement	**Implementation Plan**
3A. Provide a written safety plan addressing the safety of the materials used, facilities involved, and student responsible, (i.e., Safety Officer) for ensuring that the plan is followed. A risk assessment should be done for all these aspects in addition to proposed mitigations. Identification of risks to the successful completion of the project should be included.	The team's Safety Officer (Naoki Matsumoto) and lead will write a safety plan identifying and assessing risk as well as proposing mitigation strategies for all materials, tools, and facilities involved in the project. Each team member will follow the plan outlined and the SO will ensure regulation is followed.
3B Provide a description of the procedures for NAR/TRA personnel to perform. Ensure the following: ● Compliance with **NAR High Power Safety Code requirements** ● Performance of all hazardous materials handling and hazardous operations	The team will provide procedural descriptions including for compliance with NAR High Power Safety requirements and for handling hazardous materials and operations for NAR/TRA personnel to perform.
3C. Describe the plan for briefing students on hazard recognition and accident avoidance, as well as for conducting pre-launch briefings.	The team's Safety Officer will ensure all team members follow safety regulations through mandatory pre-build and pre-launch meetings dedicated to briefing students on safety, including hazard recognition, accident avoidance, caution warnings, and PPE.
3D. Describe methods to include necessary caution statements in plans, procedures, and other working documents, including the use of proper Personal Protective Equipment (PPE).	In each report, descriptions of proper plans, procedures, and PPE use will be outlined and included in necessary caution statements.
3E. Each team shall provide a plan for complying with federal, state, and local laws regarding unmanned rocket launches and motor handling. Specifically, regarding the use of airspace, Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; Amateur Rockets, Code of Federal Regulation 27 Part 55: Commerce in Explosives; and fire prevention, NFPA 1127 "Code for High Power Rocketry."	The team will outline all federal, state, and local laws and describe the team's actions to meet and comply with all laws regarding unmanned rocket launches and motor handling.
3F Provide a plan for NAR/TRA mentor purchase, storage, transportation, and use of rocket motors and energetic devices.	The team will ensure our mentor complies with guidelines for the purchase, storage, transportation, and use of rocket motors and energetic devices through manufacturer instructions.
3G. Include a written statement that all team members understand and will abide by the following safety regulations: ● 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. ● The Range Safety Officer has the final say on all	The team's Safety Officer will write and review a written statement signed by each team member to indicate understanding and agreement to abide by all required safety regulations.

rocket safety issues. Therefore, the Range Safety Officer has the right to deny the launch of any rocket for safety reasons. • The team mentor is ultimately responsible for the safe flight and recovery of the team's rocket. Therefore, a team shall 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. • Any team that does not comply with the safety requirements shall not be allowed to launch their rocket.	

Table 29 General safety requirements

5.9 Technical Challenges and Solutions

Problem	Solution
Work schedule	
As the college application season approaches, the majority of our team, composed of graduating seniors, will face scheduling conflicts. Balancing the rigors of their current responsibilities with the intricate demands of application deadlines, interviews, and personal statements will create challenges in coordinating team schedules.	To mitigate the impact of such scheduling conflicts. All tasks must be assigned well in advance. By distributing responsibilities across the team and leveraging the strengths and skills of each member. We can ensure that progress continues even as individual members juggle their commitments. Starting early helps alleviate the pressure during the application season but also provides the ability to adapt to unforeseen challenges.
Balancing the workload equally across team members presents a significant challenge. It means to make sure the workload is not carried by one member but equally divided based on strengths.	To address the challenge of balancing the workload and avoid potential issues, we have created a solid team plan supported by detailed assignments which have been outlined in spreadsheets and a GANTT chart. This solution provides a clear view of each member's responsibilities, deadlines, and progress which allows us to allocate tasks efficiently.
Payload	
Choosing a payload. Being a first-year team, choosing a reasonable payload that is interesting to all team members, but isn't an unrealistic amount of work was a challenge.	Whole team in-person and online discussions were used to ensure all members had a say and the team reached a realistic conclusion that is possible for a high school team.
Ensuring proper progress of the writing aspects while working on payload engineering. Balancing payload creation along with assigned documentation	As progress and time estimations are made, reassignment of duties will be considered. Communication between team members is critical to

presents a challenge of workload balancing.	this solution and will be ensured by the various collaboration softwares we use.
Rocket design and simulation	
As per SLI rules, the standard units are to be presented in imperial units. Since the team is well versed in metrics, the team needs to change their work habits and utilize Imperial which usually leads to miscommunications and delays.	We proposed to continue work primarily in the metric system which has proven to be more reliable for calculations. By maintaining our workflow in metric, we can leverage accuracy and consistency and minimize the risk of errors during critical steps like analysis and data processing. Once calculations have been completed and reviewed we can convert the final results into imperial units. This approach allows us to maintain the precision of our work while ensuring that the final outputs meet the required specifications.
The rocket design process has been heavily dependent on the development and refinement of the payload. It led to numerous iterations of the airframe and each adjustment prolonged the design phase. Additionally, the parachute simulation which is critical for ensuring the safe recovery of the rocket requires extensive time and fine tuning. Which changed with the addition of weight and the movement of components during the design phase.	To overcome the delays and complexities caused by the dependence of the rocket and recovery design on the payload. We proposed a more integrated approach. Working in tandem with the payload development team, we incorporated all other components of the rocket that were not dependent on the payload to minimize the number of components we needed to edit/ move around. Parachute simulation was done after the payload design had been finalized to minimize issues later on.
Launch related issues	
The weather in Southeast Michigan during the winter months presents a significant challenge for our launch schedule. The conditions are unpredictable, with frequent fluctuations that make it difficult to plan. Launch opportunities are sparse, and even when scheduled, they are often canceled due to adverse weather or poor field conditions. This disrupts testing and data collection, which delays the project timeline.	To address the challenges posed by unpredictable winter weather in Southeast Michigan, we proposed to start our launch preparations well in advance. By initiating the process early, we can be ready to launch as soon as the weather conditions permit. Building early helps us in this process a lot. Collaboration with all local rocketry clubs and organizations provides us with more launch opportunities and helps mitigate the impact of adverse weather, ensuring that we make the most of every launch window.

Table 30. Technical challenges and solutions

6 STEM Engagement

6.1 Plans for STEM Engagement Activities

Below are the four requirements of STEM Engagement activities and the plans for each. For the definitions of the STEM Engagement sections, see **section 8.5**.

As first year participants in SLI, we will leverage existing NASA and American Institute of Aeronautics and Aeronautics (AIAA) lesson resources to provide a solid basis for our lesson planning structures and a successful initial experience for our student participants while we ramp up our ability to teach STEM content at various grade levels. It is our intention to then build on this content to develop lessons of our own over time.

6.1.1 Education — Direct Engagements

Direct Engagement Activity	Target Audience	Methodology	Instructional Goal
Rocket Activity - 3…2…1… Puff! ~ 1 hour This lesson is from the NASA Educator Guide	Northville High School students in PLTW Introduction to Engineering Students - 100+ People	1. Students construct straw rockets through multiple iterations. 2. Students complete testing following launch safety protocols. 3. Students track their data in a report throughout the process.	Students will learn about rocket stability as they construct and fly small paper rockets using the engineering design process
Paper Airplanes ~1 hour	Northville Schools middle school students in the Academic Resources Program - includes the Project Lead the Way (PLTW) Flight and Space Gateway program - 90 People	1. Students initially construct a paper airplane without guidance as a baseline. 2. Students apply general guidance provided by instructional presentation from the team relating to lift and drag forces to help them build version 2. 3. Students apply additional physics from and construction forces for “optimal” paper airplane flight for version 3	Students will apply Newton’s Laws of Motion, particularly the third law of action and reaction through the engineering design process.
Paper Airplanes + Straw Rockets	Girl Scouts of Southeastern	This event will be the culmination of both events above, including	Students will learn about Newton’s Laws of Motion

~ 1.5 hours	Michigan Elementary Age Brownie and Junior Girl Scouts - 50 to 100 students	an iterative version of the evaluation reports for each activity. The similarity in concepts will allow a streamlined lesson on Newton's Laws, aerodynamics and the engineering process for our youngest audiences.	and basic aerodynamics through modeling airplane and rocket flight motion.

Table 31. Education - direct engagements

6.1.2 Education — Indirect Engagements

Indirect Engagement Activity	Target Audience	Methodology	Instructional Goal(s)
In-Class Presentations	Northville High School students in on-level and honors physics class	As we are a first year SLI participant, we plan to hone our teaching skills by presenting content related to advanced rocketry-concepts such as fin flutter, shear pins, and payloads to current physics students. Presentation and concept discussions are underway with the district physics teachers and will be updated once complete.	Students will learn about a rocketry-related STEM concept through a presentation.
Demo/Test Launches	Individuals interested in rocket launches	We plan to use our Facebook and Instagram accounts to advertise a "live rocketry demonstration" utilizing a prior TARC rocket in a demo launch. This live demo launch will adhere to all safety protocols for our team and for all participants who are present for the launch. During this launch session, we will overview important preliminary concepts, such as basic rocket components, parachute folding, motor components, and the usage of altimeters.	Individuals will witness a demo or test-launch and understand some of the precautions and STEM-related concepts like wind drift compensation while following all required safety protocols.

Table 32. Education - indirect engagements

6.1.3 Outreach — Direct Engagements

Outreach - Direct Engagement Activity	Target Audience	Hands-on Exposure to STEM-related hardware
Club Fair	Northville High School students interested in rocketry	At the club fair, Aerospace Club members will present model rocketry, like last year's rocket from Rockets For Schools, for high school students looking for new clubs to join. This pairs with sustainability as well, as it will attract new students to carry on the club after the seniors have graduated.
Freshman Orientation Night	Northville High School incoming students interested in rocketry	At Freshmen Orientation Night, club members will present model rocketry with the same goal of interacting with the team and its hardware, but this will be a much more personal meeting with the students and their parents. This interaction may also help to build better alignment with the PLTW Flight and Space Gateway program already present in our district middle schools.

Table 33. Outreach - direct engagements

6.1.4 Outreach — Indirect Engagements

Outreach - Indirect Engagement Activity	Target Audience	Methodology
Social media live streams and videos	Youth interested in engineering, rocketry, and aerospace.	We will use the social media account to post our progress with the SLI program, continue our CATO Mondays, Tech Tuesdays and Friday Fun-Fact posts, and show mini-films or clips of what we do as a club. To make this more interactive, we will regularly reply to viewer comments and consider requests and questions from viewers as we make new content. Furthermore, we plan to livestream key test launches with video and a live chat, replying in real-time to enhance the interaction.
After-school club meetings	Northville High School students interested in rocketry	We host weekly meetings on Mondays after-school. Our club has an open door policy, meaning anyone from the building can sit in if they'd like. Local students and staff would be able to interact with the team informally and

		regularly to keep apprised of the rocketry hardware and progress of our SLI project and aerospace activities.

Table 34. Outreach - indirect engagements

6.2 Evaluation Criteria for STEM Engagement

Every activity report corresponds to one activity and will detail the events that unfolded during the outreach. The activity report contains several questions, and below will go through each one and explain how we will evaluate the effectiveness of the engagement.

6.2.1 Learning Target for the Activity

The learning targets have been listed in the STEM Engagement tables in **section 6.1**. The targets will be aligned with Next Generation Science Standards (NGSS), Project Lead the Way (PLTW) curriculum standards, or other STEM standards wherever possible.

6.2.2 Activity Description

In this portion of the activity report, we will outline specifically what methods we will be using. Any materials we will be bringing, whether it be a rocket for outreach or a presentation for education will be shown as an attachment here, as well. Any other documentation or waivers we might have to send out to middle school students for consent in the program will also be shown here, but we will also include any photos of the activity in progress. Our response detailing what methods we will undergo for the engagement will be elaborated on in detail before the activity is completed; however, any last-minute changes or logistical errors that cause a change in plans will be mentioned in the report as well.

6.2.3 Evaluation of Learning Targets and Results

For each learning objective, we will have success criteria. These are the benchmarks that we will use to examine whether the activity and event were successful. An example of a success criteria could be the ability of middle school students to correctly differentiate certain scientific terms and concepts. These success criteria will typically be “I can…” statements, dictating the new knowledge or skills that students should be able to know or exercise during and after our activities.

Furthermore, in this evaluation, we will examine what we wanted to happen compared to what did, and reflect on whether this was a result of execution or overestimating what we could do. The reflection regarding the quality of execution will contain a critical evaluation of each step or activity detailed in the previous question (see **section 6.2.2**), and reflect what steps should be taken to improve future activities.

6.2.4 Feedback from Participants

In this section, we will evaluate the feedback received from student participants and the adults who were present as we learned ways to engage students with STEM concepts and activities at the elementary, middle school and high school levels.

We will collect written feedback from all participants directly in an age appropriate manner. For instance,we plan to use “Three Roses and A Thorn” for elementary and middle school students and a Google Form with criteria based ranking questions for high schoolers. Finally, we plan to gather written feedback through a Google Form from the instructors and adult chaperones present for each activity to help us improve our skills as instructors to convey the STEM concepts in future activities. The feedback collection forms are currently in progress.

7 Project Plan

7.1 Schedule/Work Breakdown Structure (WBS)

In order to break down the project and have deadlines for important milestones, the team created a GANTT chart to ensure all work that needs to be completed is getting completed. This will be used in conjunction with a work assignment spreadsheet to delegate appropriate tasks to appropriate people. A preliminary chart showing roles and responsibilities are detailed in **<u>Figure 13</u>**.

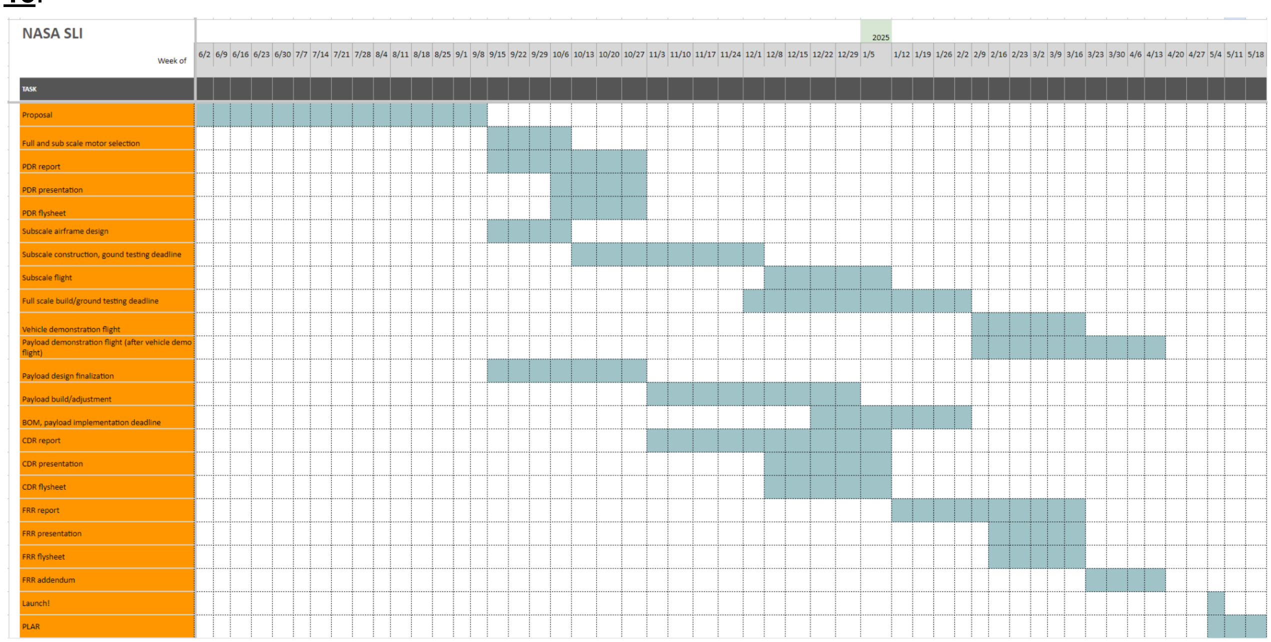


Figure 75. GANTT Chart

7.2 Budget

The budgets provided cover all aspects necessary to complete the project successfully, including Bill of Materials (BOM) for both full-scale and sub-scale, STEM engagement costs, and travel expenses to the launch. Currently, we are planning to fund only our adult educator's costs to participate in launch week. Each budget includes the individual item, quantity demanded, unit price, final cost, and total gross expenditures. We have received a Michigan Tax Exemption as a Non-Profit School. The total expenses thus does not include taxes as we do not expect to factor it in. The budget is still preliminary and will be updated as incidentals and funding increase. A summarized table of total expenditures is below:

TOTAL EXPENSES		
Category		**Final Cost**
Consumables		$62.58
Full-scale		$1,033.89
Sub-scale		$228.99
PPE		$76.88
Travel		$8,490.00
Shipping		$200.00
Launch fees		$30.00
	Total:	$10,122.34

Table 35. Total expenditures

7.2.1 Bill of Materials (BOM)

The BOM is categorized into full-scale and sub-scale line item budgets including individual components, quantity of units, and material vendors. Each BOM also includes the preliminary gross cost for each rocket. As the project continues, we will update the budget with any additional incidental costs. For many of the common, reusable items, they will be loaned by the NAR/TRA mentor to the team. These include items like Kevlar recovery harnesses, parachutes, and expensive tracker modules that can be moved from airframe-to-airframe. This greatly reduces our first year cost. Other items, such as screws, which are best purchased in quantities far larger than needed for this project, will be donated by the team mentor.

Full Scale Bill of Materials

System	Component	Vendor	Qty	Unit Cost	Final Cost	Status	Team Cost
Booster	54 mm Screw On Motor Retainer	Mach1Rocketry	1	$31.00	$31.00	15% Discount	$26.35
	54 mm FWFG Motor Mount, price per inch	Mach1Rocketry	18	$1.50	$27.00	15% Discount	$22.95
	54 mm to 98 mm G10 Fiberglass Centering Rings	Mach1Rocketry	3	$6.75	$20.25	15% Discount	$17.21
	3/16" G10 Fiberglass Custom Fin Set	Mach1Rocketry	1	$50.00	$50.00	Estimated Price pending Final Quote	$50.00
	U-bolt, Stainless, 1/4-20, 1-1/4" (8896T94)	McMaster-Carr	2	$5.47	$10.94		$10.94
	1515 Rail Buttons	Railbuttons.com	2	$0.75	$1.50	Donated by Mentor	$0.00
	PEM nuts, Stainless, #10-24 (96439A450)	McMaster-Carr	2	$0.50	$0.99	Donated by Mentor	$0.00
	98 mm FWFG Body Tube, Price per foot.	Mach1Rocketry	4	$30.00	$120.00	15% Discount	$102.00
	Custom Fin Slotting	Mach1Rocketry	3	$2.00	$6.00	15% Discount	$5.10
Avionics Bay	98 mm FWFG Coupler, 12" length	Mach1Rocketry	12	$3.00	$36.00	15% Discount	$30.60
	98 mm G10 Stepped Bulkhead	Mach1Rocketry	2	$14.00	$28.00	15% Discount	$23.80
	98 mm FWFG Switch Band, 1" length	Mach1Rocketry	1	$3.50	$3.50		$3.50
	Threaded Rod, 1/4-20, Stainless, 13" (98804A107)	McMaster-Carr	2	$4.66	$9.32	15% Discount	$7.92
	Nylon Lock Nut, 1/4-20, Stainless (91831A029)	McMaster-Carr	2	$0.13	$0.25	Donated by Mentor	$0.00
	Knurled Nut, 1/4-20 (92741A160)	McMaster-Carr	2	$1.00	$2.00	Donated by Mentor	$0.00
	Eggtimer Quantum	Eggtimer Rocketry	1	$40.00	$40.00	Loaned by Mentor	$0.00
	Perfectflite Stratologger CF	Perfectflite	1	$64.95	$64.95	Loaned by Mentor	$0.00
	Screw Switch	Missileworks	2	$3.00	$6.00		$6.00
	#8-32 Stainless PEM Nuts (96439A360)	McMaster-Carr	3	$0.37	$1.10		$1.10
	U-bolt, Stainless, 1/4-20, 1-1/4" (8896T94)	McMaster-Carr	2	$5.47	$10.94		$10.94
	2S 450 mAh LiPo Battery	Amazon	2	$10.00	$20.00	Loaned by Mentor	$0.00
Payload Assembly (Rocket, not experiment)	98 mm FWFG Body Tube, Price per foot.	Mach1Rocketry	4	$30.00	$120.00	15% Discount	$102.00
	#8-32 Stainless Truss Head Screws	McMaster-Carr	3	$0.07	$0.22		$0.22
Nose Assembly with Experimental Payload	98 mm Nose Cone, FWFG, 5:1 cone, coupler, bulkhead	Mach1Rocketry	1	$90.00	$90.00	15% Discount	$76.50
	#8-32 Stainless PEM Nuts (96439A360)	McMaster-Carr	3	$0.37	$1.10	Donated by Mentor	$0.00
	#8-32 Stainless Truss Head Screws	McMaster-Carr	3	$0.07	$0.22	Donated by Mentor	$0.00
	U-bolt, Stainless, 1/4-20, 1-1/4" (8896T94)	McMaster-Carr	2	$5.47	$10.94		$10.94
	Featherweight GPS Tracker Module	Featherweight	1	$165.00	$165.00	Loaned by Mentor	$0.00
	Arduino Nano	Amazon	1	$5.67	$5.67	Re-use from previous project	$0.00
	ADXL343 3-Axis Accelerometer Board	Adafruit	1	$5.95	$5.95		$5.95
	LIS3DH 3-Axis Accelerometer Board	Adafruit	1	$4.95	$4.95		$4.95
	BMP390 Barometric Sensor Board	Adafruit	1	$10.95	$10.95		$10.95
Recovery	Quicklinks, Stainless, 5/16". (8947T27)	McMaster-Carr	5	$5.00	$25.00	Loan from Mentor	$0.00
	Quicklink, Stainless, 1/4"	McMaster-Carr	1	$2.00	$2.00	Loan from Mentor	$0.00
	Drogue Harness, 3/8" Tubular Kevlar, Stitched Loop, 30 ft	Custom	1	$46.00	$46.00	Loan from Mentor	$0.00
	Main Harness, 3/8" Tubular Kevlar, Stitched Loop, 25 ft	Custom	1	$33.00	$33.00	Loan from Mentor	$0.00
	Drogue Parachute (add specs)	Custom	1	$79.23	$79.23	Loan from Mentor	$0.00
	Main Parachute (add specs)	Custom	1	$200.00	$200.00	Loan from Mentor	$0.00
	Drogue Nomex Blanket	Custom	1	$9.00	$9.00	Donated by Mentor	$0.00
	Main Nomex Blanket	Custom	1	$19.00	$19.00	Donated by Mentor	$0.00
Energetics	Aerotech K1103X-P Reload Kit	buyrocketmotors.com	3	$167.99	$503.97	On Order	$503.97
	Aerotech 54/1706 Motor Case	Wildman Hobbies	1	$186.29	$186.29	Loan from Mentor	$0.00
	Goex ffffG Black Powder, per gram	Chris' Rocket Supplies	100	$0.07	$6.61	Donated from Mentor	$0.00
	Firewire Electronic Match	MJG Technologies	20	$0.71	$14.20	Donated from Mentor	$0.00
				Total:	***$2,029.03***		***$1,033.89***

Table 36. Full scale Bill of Materials

Sub-Scale Bill of Materials

System	Component	Vendor	Qty	Unit Cost	Final Cost	Status	Team Cost
Booster	38 mm Screw On Motor Retainer	Mach1Rocketry	1	$27.00	$27.00	15% Discount	$22.95
	38 mm FWFG Motor Mount, price per inch	Mach1Rocketry	12	$1.25	$15.00	15% Discount	$12.75
	38 mm to 54 mm G10 Fiberglass Centering Rings	Mach1Rocketry	2	$4.50	$9.00	15% Discount	$7.65
	3/16" G10 Fiberglass Custom Fin Set	Mach1Rocketry	1	$30.00	$30.00	Estimated Price pending Final Quote	$30.00
	1010 Rail Buttons	Railbuttons.com	2	$0.75	$1.50		$1.50
	PEM nuts, Stainless, #10-24 (96439A450)	McMaster-Carr	2	$0.50	$0.99		$0.99
	54 mm FWFG Body Tube, Price per foot.	Mach1Rocketry	2	$16.00	$32.00	15% Discount	$27.20
	Custom Fin Slotting	Mach1Rocketry	3	$2.00	$6.00	15% Discount	$5.10
Avionics Bay	54 mm FWFG Coupler, 7" length	Mach1Rocketry	7	$1.50	$10.50	15% Discount	$8.93
	54 mm G10 Stepped Bulkhead	Mach1Rocketry	2	$9.50	$19.00	15% Discount	$16.15
	54 mm FWFG Switch Band, 1" length	Mach1Rocketry	1	$2.00	$2.00	15% Discount	$1.70
	Threaded Rod, M4, Stainless, 8" Length (90024A222)	McMaster-Carr	1	$3.37	$3.37	One piece, cut.	$3.37
	Nylon Lock Nut, M4, Stainless (93625A150)	McMaster-Carr	2	$0.08	$0.16	Donated by Mentor	$0.00
	Knurled Nut, M4, Stainless	Amazon	2	$0.92	$1.84	Donated by Mentor	$0.00
	Eggtimer Quantum	Eggtimer Rocketry	2	$40.00	$80.00	Loaned by Mentor	$0.00
	Screw Switch	Missileworks	2	$3.00	$6.00	Loaned by Mentor	$0.00
	#6-32 Stainless PEM Nuts (96439A230)	McMaster-Carr	3	$0.23	$0.69	Donated by Mentor	$0.00
	Forged Eye Bolt, M4, Stainless	Amazon	2	$1.14	$2.27	Donated by Mentor	$0.00
Payload Assembly	54 mm FWFG Body Tube, Price per foot.	Mach1Rocketry	2	$16.00	$32.00	15% Discount	$27.20
	#6-32 Stainless Truss Head Screws	McMaster-Carr	3	$0.07		Donated by Mentor	$0.00
Nose Assembly	54 mm Nose Cone, FWFG, 5:1 cone, coupler, bulkhea	Mach1Rocketry	1	$63.50	$63.50	15% Discount	$63.50
	Forged Eye Bolt, M4, Stainless	Amazon	1	$1.14	$1.14	Donated by Mentor	$0.00
	Featherweight GPS Tracker Module	Featherweight	1	$165.00	$165.00	Loaned by Mentor	$0.00
	3D Printed Tracker Mount	Custom	1			Donated by Mentor	$0.00
	4-40 3/8" Stainless Screws	McMaster-Carr	4	$0.06		Donated by Mentor	$0.00
Recovery	Quicklink, Stainless, 1/4"	Amazon	4	$2.40	$9.60	Loan from Mentor	$0.00
	Quicklink, Stainless, M3	Amazon	1	$0.64	$0.64	Loan from Mentor	$0.00
	Drogue Harness, 1/4" Tubular Kevlar, Stitched Loop, 2	Custom	1			Loan from Mentor	$0.00
	Main Harness, 1/4" Tubular Kevlar, Stitched Loop, 15	Custom	1			Loan from Mentor	$0.00
	Drogue Parachute (15" 0.707 Elliptical)	Custom	1	$59.26	$59.26	Loan from Mentor	$0.00
	Main Parachute (32" 0.707 Elliptical)	Custom	1	$105.18	$105.18	Loan from Mentor	$0.00
	Drogue Nomex Blanket	Custom	1			Loan from Mentor	$0.00
	Main Nomex Blanket	Custom	1			Loan from Mentor	$0.00
Energetics	Aerotech I (really big flame) Reload Kit		1	$65.00	$65.00	Donated from Mentor	$0.00
	Aerotech 38/XXX Motor Case	Wildman Hobbies	1		$0.00	Loan from Mentor	$0.00
	Goex ffffG Black Powder, per gram	Chris' Rocket Supplies	15	$0.07	$0.99	Donated from Mentor	$0.00
	Firewire Electronic Match	MJG Technologies	8	$0.71	$5.68	Donated from Mentor	$0.00
				Totals:	***$755.31***		***$228.99***

Table 37. Sub-scale Bill of Materials

SLI Sub-Scale and Full-Scale Consumables

Component	Vendor	Qty	Unit Cost	Final Cost	Status	Team Cost
Proline 4500Q (pint) *	Wildman Hobbies	1	$39.00	$39.00	Donated by Mentor	$0.00
JB Weld (10 oz) *	Amazon	1	$17.98	$17.98	Donated by Mentor	$0.00
West System 105/206 (32 oz) *	Amazon	1	$105.86	$105.86	Donated by Mentor	$0.00
West System 404, High Density Filler *	Amazon	1	$51.26	$51.26	Donated by Mentor	$0.00
West System 406, Colloidal Silica *	Amazon	1	$19.21	$19.21	Donated by Mentor	$0.00
Dupli-Color Filler Primer	JB Tools	1	$7.74	$7.74		$7.74
Dupli-Color Sandable Primer	JB Tools	2	$6.81	$13.62		$13.62
Dupli-Color Base Coat Paint	JB Tools	3	$6.87	$20.61		$20.61
Dupli-Color High Temperature Gloss Clear Coat	JB Tools	3	$6.87	$20.61		$20.61
			Total:	$295.89		$62.58

* Minimum package size available. This is far more than required for the builds.

Table 38. Consumables expenses

7.2.2 Travel Costs

We currently plan to fund our educator's (Mrs. Krebs') travel expenses for the launch week in Huntsville, AL. Once additional funding is acquired, the team plans to subsidize student members (and families)' expenses to ensure everyone can attend the launch events.

Travel Expenses			
Item	**Qty**	**Unit Cost**	**Final Cost**
Round Trip Flight (DTW->HSV)	1	$415.00	$415.00
Car Rental (Standard @ Enterprise)	5	$55.00	$275.00
Lodging (WaterWalk Extended Stay by Wyndham Huntsville)	5	$120.00	$600.00
Team Member Travel	9	$800.00	$7,200.00
		Gross Total	$8,490.00
		Total With Tax	$8,999.40

Table 39. Travel expenses

7.2.3 STEM Engagement

If the team's STEM engagement activities require the acquisition of material goods, we will include a line item budget including components, vendors, fees, taxes, and gross cost.

7.3 Funding

7.3.1 Funding Pathways

During the project timeline, the team will strive towards several approaches to generate funding for the necessary expenditures.

Team Fund: The team currently has approximately $2,000 allocated for buying rocket components and funding the club's sustainability plans for future members. We also collect membership fees of $35 and plan to receive at least $500 from current and new members in the coming school year.

Fundraising Events: Organize bake sales and coordinate with local businesses (ie. Chipotle or Panera) to raise money for the build.

School Funding: Approach the school board and request a grant covering travel expenses for the launch week in Alabama. The district often gives out grants to help supply projects otherwise difficult to produce in a school setting, which are newly open to student proposals this year.

Sponsorships: Approach local businesses or branches and request grants to fund the project. In return, we offer to promote the companies on our website, social media, team events, and on the rockets themselves.

7.3.2 Allocation of Funds

Project Materials: Materials and components needed to build the two rockets, including tools, PPE, prototyping materials, and electronics. Currently, most of our funding is allocated towards project materials.

Travel Expenses: We will cover all travel costs for our adult educator to attend Launch Week in Huntsville, AL. Each team member will receive a set subsidy of $800 for their expenses. If we are unsuccessful in raising complete travel funding, each team member will self-fund the remaining balance of travel costs.

Promotional Materials: Any funds necessary to showcase the project and the team, including banners, brochures, and presentation materials. We currently have no promotional materials that require funding, thus allocating zero percent of our total assets.

Contingency Fund: Establish a contingency fund to cover unexpected expenses that may arise during the competition. For the upcoming school year, we have already established a large emergency fund that can cover any unforeseen incidentals.

7.4 Sustainability Plan

The Northville High School Aerospace team is participating in SLI for the first time this year. For past rocketry competitions like TARC/ARC and Rockets for Schools, the team has been primarily funded by grants, club dues, and individual contributors to cover materials, launches, and travel expenses in the regional area. We have commitments from individual contributors and participants to cover all SLI team expenses for this initial year while ramping up more sustainable and supplemental funding sources for the program.

7.4.1 Partnerships and Funding

The team has begun the process of contacting corporate sponsors, applying for additional grants through the Northville Education Foundation, and developing partnerships with local businesses in Michigan. We are actively seeking partnerships with members of the non-profit organization Aerospace Industries Association of Michigan (AIAM). So far, we have successfully obtained a new $1,500 sponsorship from Microchip Technologies. We hope to continue this and other future sponsorship opportunities for the future years to help fund our aerospace missions.

7.4.2 Recruitment and Sustainability

The team actively recruits new members through in-person events like the club fair, school district, and team social media that showcases previous work in Rockets for Schools and TARC. We are in the process of creating direct STEM engagement opportunities with the two middle schools in our district that offer Project Lead the Way (PLTW) Flight and Space programs as well as at the high school level with both Physics and PLTW Engineering classes to aid in recruiting and sustainability.

Our school also posts a weekly newsletter called the Mustang Trail which features dedicated segments for clubs and their progress. Our goal is to have recurring segments in this newsletter regarding our progress with Project Rooni.

7.4.3 STEM Engagement

See section 6.1.1-2 for direct and indirect STEM engagement.

As a first year SLI team, our activities for STEM Engagement are intended to be pipelines for elementary and middle school students in the district to join the Aerospace Club when they attend Northville High School. Cultivating a genuine interest in rocketry through STEM engagement activities will be imperative to sustain the Aerospace Club and help us compete in additional NASA SLI competitions. Our goal is to retain fifteen or more new members per year and to help them earn their L1 licenses as well.

Furthermore, we will maintain contact with the high school participants from our activities through email lists to generate continued interest in the club and aid in word-of-mouth marketing.

8 Project Deliverables

8.1 Sub-Scale Model of Rocket

We will be building and launching a sub-scale model of our competition rocket to simulate how the full-scale rocket will perform in flight.

Requirements	Proposed Plan
The sub-scale rocket should resemble and perform similarly to the full-scale rocket but will be a separately built vehicle.	We propose to build a 50% scale rocket using components scaled as close to 50% as possible.
The sub-scale model will carry an aviation bay which will be capable of recording necessary flight data.	A fully redundant dual-deploy avionics bay will be utilized. The flight computers will be either the same or equivalent to the full scale with data logging capability.
The sub-scale model will utilize a motor that has a minimum total impulse of 20.01 -40.0 Ns which is classified as an E motor.	We propose to use an I-impulse motor. The exact motor will be determined at a later date. The selection of the motor will be based on achieving flight characteristics as close as possible to the simulated full scale.
The sub-scale model will not exceed 75% of the dimensions of the full-scale rocket. This includes length and diameter	We plan to build the sub-scale airframe as a 50% scale replica of the proposed full scale, well below the limit of 75%.
The CDR should include an Altimeter flight profile graph or a quality video showing a successful launch, recovery events, and landing. The data or the video will include the whole flight (liftoff through landing).	We will provide a profile graph of the Altimeter flight data and will also provide a .csv or a .xlsx file of raw altimeter data in the CDR. We will also provide a video of take-off through landing.
Quality pictures of all sections of the model including the nose cone, recovery system, airframe, and booster.	We will be taking pictures of the fully landed configuration of the sub-scale rocket which includes all parts.
The sub-scale flight should be conducted at any time between the proposal award and the CDR submission deadline. The Sub-scale flight data will be reported in the CDR report and the presentation at the CDR milestone. This deadline is on the 8th of January 2025 - 8:00 a.m. CST.	The sub-scale flight will be scheduled at an appropriate launch with a target date of early December. All flight data will be included in the CDR report and presented at the CDR milestone.

Table 40. Sub-scale deliverables

8.2 Full-Scale Vehicle and Payload Demonstration

We will demonstrate our full-scale rocket capabilities during the full-scale Vehicle Demonstration Flight and Payload Demonstration Flight.

Requirements	Proposed plan
The full-scale rocket will be a newly constructed rocket, designed and built specifically for the 2024-2025 project. The vehicle and recovery system will function as designed.	We will be designing and building a new full-scale rocket with a specific purpose to follow the rules for the 2024-25 competition. All aspects of the design will function properly.
Payload does not have to be flown during the full-scale Vehicle demonstration launch but can be supplemented with Mass simulators	Since the payload does not have to be flown during the full-scale Vehicle Demonstration Flight, we are going to be supplementing the missing weight by utilizing mass simulators. Mass simulators will be placed in the approximate location of the payload.
Any changes to the external surfaces of the rocket such as camera housings or external probes will be active during the full-scale Vehicle demonstration flight.	We are not going to be utilizing any external surfaces for our purposes in the 2024-2025 competition.
The Full-scale model is to be launched on the competition motor selected beforehand. If the home launch field cannot support the full impulse of the competition launch motor, we will request a waiver for the use of an alternate motor in advance.	The full-scale rocket will be launched with the motor that we have selected for the final launch at Huntsville, Alabama. Our launch fields and ground equipment can support the motor we have selected. If any special circumstances occur, we will notify the NASA panel and act accordingly.
The vehicle should be flown in its full ballast configuration. This means that the vehicle will be flown with the maximum amount of ballast that will be utilized during the competition launch flight. Additional ballast will not be added without a re-flight of the full-scale launch vehicle.	The vehicle will be launched in its final and active configuration, which includes the ballast. If additional ballast is to be added we are going to notify the NASA panel and conduct a re-flight of the full-scale launch vehicle.
The launch vehicle or any of its components shall not be modified without the approval of the NASA management team or the Range Safety Officer (RSO) after the successful completion of the full-scale demonstration flight.	The launch vehicle or its components will not be modified without notifying and gaining the approval of the team mentor, the Range Safety Officer after the Vehicle demonstration flight. Any changes that have been approved will be documented and presented to the NASA panel.
Altimeter flight profile data with altitude and velocity versus time plots. The plots will include the whole flight data (liftoff through landing).	We will provide a profile graph of the Altimeter flight data and will also provide a .csv or a .xlsx file of raw altimeter data in the CDR.

Quality pictures of the landed configuration of all sections of the launch vehicle which includes the nose cone, recovery system, airframe, and booster.	We will be taking pictures of the fully landed configuration of the sub-scale rocket which includes all parts.
Deadline: The Vehicle demonstration flights will be completed by the FRR submission deadline which is on the 17th of March 2025 - 8:00 a.m. CDT.	We have a target date of early February for the launch vehicle demonstration, pending weather and uncertainty of launch dates. This provides some margin for weather-related cancellations as well as scheduling conflicts.
The full-scale Vehicle Demonstration flight will be completed before the Payload Demonstration Flight deadline.	We will complete all necessary parts of the full-scale Vehicle Demonstration flight before doing the payload demonstration flight.
The competition rocket will be launched for the payload demonstration flight.	We will be utilizing the final configuration of the Full-scale rocket including all external additions and ballasts.
The payload will be fully retained until the point of deployment (if applicable). All retention mechanisms shall function as designed and recovered. They should also not sustain any damage that requires repair. The payload should be flown in its final and active version	The payload will be secure inside the rocket and any retention mechanisms that will be utilized to contain the payload will be checked after recovery to make sure no damage has been sustained in the process of flight. The payload will be flown in the final competition version.
Deadline: The Payload demonstration flight will be completed by the FRR Addendum deadline which is the 14th of April 2025- 8:00 a.m. CDT	We have a target date of early March for the launch vehicle demonstration, pending weather and uncertainty of launch dates. This provides some margin for weather-related cancellations as well as scheduling conflicts.

Table 41. Full-scale and payload demonstration deliverables

8.3 Full-Scale Launch Vehicle and Payload, Huntsville

Requirements	Proposed plan
Before Launching in the final launch week at the NASA Launch Complex teams are expected to pass the Launch Readiness Review	We will have passed the Launch Readiness Review and are going to be prepared for the final launch during launch week in Huntsville Alabama.
The team mentor will be present to oversee the rocket preparation and launch activities	During the final launch week, our team mentor will be present and monitor all activities performed by us making sure all safety regulations are followed and the rocket is prepped correctly.
The rocket and payload should be submitted to the launch site Range Safety Officer (RSO) before flying the rocket.	We will be submitting the rocket after final checks and preparations to the RSO and receive a Go - No Go.
We will launch the rocket at a NAR or TRA-sanctioned and insured launch.	We will be launching the rocket at the official NASA launch site and ensuring that the launch site is insured.
Both the team mentor and the Launch Control Officer will be observing the flight and report any abnormal events during ascent or recovery on the Launch Certification and Observations report.	Both the team mentor and the Launch Control Officer will observe the flight and report all events during ascent, descent, and landing on the Launch Certification and Observations report.
The scoring altimeter will be presented to both the team mentor and the RSO.	After a successful launch and recovery, We will be providing the scoring altimeter to the RSO and the team mentor for final data verification and scoring.

Table 42. Full-scale launch Huntsville deliverables

8.4 Social Media

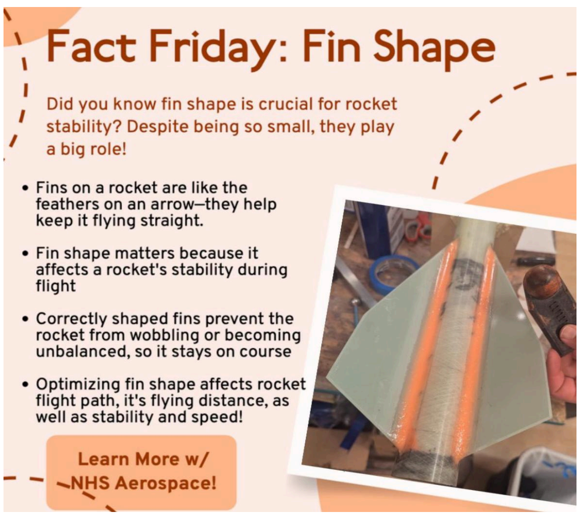
To reach individuals through social media, we primarily plan on utilizing Instagram and Facebook. Our rationale for choosing these platforms is to meet the target demographic for our outreach efforts, which are youth interested in aerospace engineering/rocketry.

We currently have 127 followers on Instagram. Our goal is to reach 500 followers by the end of the competition. To provide consistent, informational posts, we have adopted the following weekly content schedule:

- Monday: CATO Mondays (Catastrophe at Take Off)
- Thursdays: Tech Thursdays (Technical aspects of rocketry; heavy engineering and physics related)
- Friday: Fact Friday (Fun facts about aerospace and rocketry)

Listed below are the official club accounts on Instagram and Facebook.

- Instagram: @officialnhsaerospace
- Facebook: @Northville High School Aerospace Club
- Twitter : @NHSAerospace



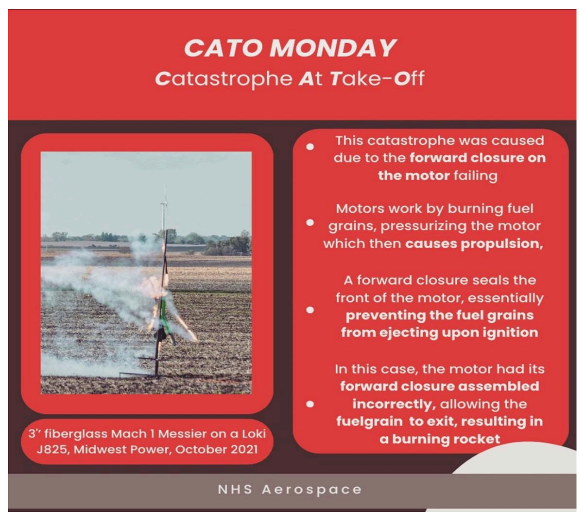


Figure 76. Fact Friday (left), Figure 77. CATO Monday (right)

Additionally, we plan to branch out our outreach efforts with video creation by creating short videos ranging from 1 minute to 30 seconds. We plan to use Adobe Premiere Pro for the editing and our goal is to capture critical aspects of our rocket construction. Our goal is to reach 10,000 impressions by the end of the competition.

8.5 STEM Engagement

Requirements	Proposed Plan
Direct Engagements: Reach a minimum of 250 participants by having instructional, hands-on activities where participants engage in learning STEM-related concepts.	We will be engaging in activities with a minimum of 250 students and a detailed plan for this engagement is written in **sections 6.1.1**
Indirect Engagements: Participants are engaged in learning a STEM concept through instructor-led facilitation or presentation	We will be teaching people about concepts related to steps throughout the competition and a detailed plan for this engagement is proposed in **section 6.1.2**
Outreach- Direct Engagements: Participants can get hands-on exposure to STEM-related hardware	We will be holding outreach events where participants will be able to gain experience and exposure to STEM-related hardware. A detailed plan for this is proposed in **section 6.1.3**
Outreach-Indirect Engagements: Participants can interact with the team in an informal setting	We will be setting up areas where participants can come and get informed about the team and learn about what we do as a club and what our goals are for this project. A detailed plan for this is proposed in **section 6.1.4.**
Each activity report submitted should represent one activity. There may be multiple events listed for the same activity.	We will ensure that each activity report represents only one activity and all the events that we conducted to represent that activity
The activity report shall be fully completed and list all the event dates and information for an activity. The STEM engagement Activity type shall be correctly identified for the activity.	We will ensure that the activity report is fully completed before completion and ensure that all dates and information are recorded. We will ensure that the STEM engagement Activity type is correctly identified from the four categories: direct engagements, indirect engagements, direct outreach, and indirect outreach.
Activity descriptions and learning targets should be clear and specific. Include all documents, evaluations, surveys, questionnaires, handouts, videos, or presentations used in the activity	We will make sure that all activity descriptions and learning targets are defined correctly and are specific. All documentation related to the activity will be present in the STEM engagement Activity report.

Table 43. STEM engagement requirements

8.6 Deliverable Milestones

Documentation plays a critical role in this program. The deliverable milestones include:

Date	Deliverables
October 28, 2024	☐ Preliminary Design Review Report ☐ Preliminary Design Review Presentation ☐ Flysheet as of PDR
November 4-26, 2024	☐ PDR Video Conference Live Presentation and Feedback
November 29, 2024	☐ Gateway Registration Deadline
December 8, 2024	☐ Critical Design Review Q&A
December 16, 2024	☐ Deliver Huntsville Event Roster
January 8, 2025	☐ Sub-scale Flight deadline ☐ Critical Design Review Report ☐ Critical Design Review Presentation ☐ Flysheet as of CDR ☐ Transmitter datasheet
January 15 - Feb. 6, 2025	☐ CDR Video Conferences Live Presentation and Feedback
February 10, 2024	☐ Team photos due
February 11, 2024	☐ Flight Readiness Review Q&A
March 17, 2025	☐ Vehicle Demonstration Flight deadline ☐ Flight Readiness Review Report ☐ Flight Readiness Review Presentation ☐ Flysheet as of FRR ☐ List of radio-transmitted data ☐ Transmitter datasheet
March 24 - Apr. 11, 2025	☐ FRR Video Conference Live Presentation and Feedback
April 14, 2025	☐ Payload Demonstration Flight and vehicle Demonstration Re-flight deadline ☐ FRR Addendum (if necessary)
May 19, 2025	☐ Post-Launch Assessment Review

Table 44. Milestones