Tacho Lycos
2020 NASA Student Launch
Proposal

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

September 18, 2019

Common Abbreviations & Nomenclature

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

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1. General Information

1.1 General Requirements

In Table 1--1, below, the general project requirements for the 2020 NASA Student Launch are addressed.

Table 1--1 General Requirement Verification Table

Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation	Results
NASA1.1	Students on the team SHALL do 100% of the project, including design, construction, written reports, presentations, and flight preparation apart from assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Teams SHALL submit new work. Excessive use of pas work will merit penalties.	The students of the High-Powered Rocketry Club at NC State design and implement a solution to the requirements listed in sections 1.1, 3.1, 4.1.1, 4.2.1, and 4.3.1.	Inspection	Project Management	TBD
NASA1.2	The team SHALL provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	The project management team, consisting of the team lead, vice president, treasurer, coordination lead, safety officer, outreach lead, web administrator, and social media lead will manage the project planning tasks listed in this requirement.	Inspection	Project Management	TBD
NASA1.3	Foreign National (FN) team members SHALL be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during	The team lead will identify and report Foreign National (FN) team members by November	Inspection	Project Management	TBD

	launch week due to security restrictions. In addition, FN's may be separated from their team during certain activities on site at Marshall Space Flight Center.	1, 2019 with the submission of the PDR milestone document.			
NASA1.4	The team SHALL identify all team members attending launch week activities by the Critical Design Review (CDR).	The team lead will identify and report team members attending launch week activities by January 10, 2020 with the submission of the CDR milestone document.	Inspection	Project Management	TBD
NASA1.4.1	Team members attending competition SHALL include students actively engaged in the project throughout the entire year.	The project management team will identify actively engaged team members to attend launch week activities.	Inspection	Project Management	TBD
NASA1.4.2	Team members SHALL include one mentor (see requirement 1.13).	The team lead will invite the mentors listed in section 1.2 to attend launch week activities.	Inspection	Project Management	TBD
NASA1.4.3	Team members SHALL include no more than two adult educators.	The team lead will invite the adult educator listed in section 1.2 to attend launch week activities.	Inspection	Project Management	TBD
NASA1.5	The team SHALL engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the STEM Engagement Activity Report, by FRR.	The outreach lead will identify K-12 student groups to implement STEM engagement plans with throughout the project lifecycle.	Inspection	Project Management	TBD
NASA1.6	The team SHALL establish a social media presence to inform the public about team activities.	The web administrator and social media lead will cooperate to develop an engaging and educational social media presence on various platforms including,	Inspection	Project Management	TBD

		but not limited to: club website, Facebook, Instagram, and Twitter.			
NASA1.7	The team SHALL email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient.	The team lead will send all completed documents to the NASA project management team prior to each deadline. In the event that the deliverable is too large, the web administrator will post the document on the team's website and the team lead will send the NASA project management team a link to the document.	Inspection	Project Management	TBD
NASA1.8	All deliverables SHALL be in PDF format.	The team lead will convert all deliverables to PDF format prior to submission.	Inspection	Project Management	This report is submitted in PDF format.
NASA1.9	In every report, the team SHALL provide a table of contents including major sections and their respective sub-sections.	The team lead will manage the Table of Contents in each milestone report.	Inspection	Project Management	See the Table of Contents at the start of this document.
NASA1.10	In every report, the team SHALL include the page number at the bottom of the page.	The team lead will identify the page numbers in each milestone report.	Inspection	Project Management	TBD
NASA1.11	The team SHALL provide any computer equipment necessary to perform a video teleconference with the review panel.	The team lead will acquire the necessary equipment to communicate with the NASA project management team through teleconference.	Inspection	Project Management	TBD

NASA1.12	The team SHALL use the launch pads provided by Student Launch's launch services provider.	The aerodynamics lead will design a launch vehicle to be launched from either an 8-foot 1010 rail or a 12-foot 1515 rail. The Structures lead will fabricate said launch vehicle.	Inspection	Aerodynamics; Structures	TBD
NASA1.13	The team SHALL identify a "mentor."	The team lead will identify community members qualified to mentor team members through the design process.	Inspection	Project Management	See section 1.2 for mentor listing and contact information.

1.2 Team Advisors and Mentors

i. **Name: Dr. Felix Ewere**
ii. Email: feewere@ncsu.edu
iii. Phone: (919) 515-8381
iv. Biography: Dr. Ewere is a teaching professor in the Mechanical and Aerospace Engineering Department at North Carolina State University. He holds a PhD in Mechanical Engineering and a Masters in Aerospace Engineering both from the University of Alabama in Huntsville. He has taught several MAE courses namely; Fundamentals of Aerodynamics, Numerical Methods, Engineering Mechanics (Dynamics and Statics), Engineering graphics and computing in Mechanical Engineering. Dr. Ewere's research interests are in the science and technology at the intersection of aerodynamics, structural mechanics, energy and smart materials. Recent works have focused on exploiting aeroelastic instabilities on piezoelectric structures for engineering applications. He recently received a patent for an airflow sensor that mimics protuberances on a humpback whale flipper. He is an AIAA senior member and ASME member.

i. **Name: Alan Whitmore**
ii. Email: acwhit@nc.rr.com
iii. Phone: (919) 929-5552
iv. TRA Certification: 05945
v. Biography: Alan became involved in High Power Rocketry in 1997 and has since earned his Level 3 certification for both TRA and NAR. Since 2002, Alan has served as the prefect of the Eastern North Carolina branch of TRA. In 2006, he was accepted onto the TRA Technical Advisory Panel (TAP) to advise the TRA board of directors on technical aspects of propellants, construction material, and recovery techniques. Alan is also a current member of the NAR Level 3 Certification Committee (L3CC), allowing him to supervise individual members during the process of designing, manufacturing, and flying rockets used for Level 3 certification for both NAR and TRA. Alan was recently selected as the Chairman of the Tripoli Motor Testing Committee, which is responsible for testing and certifying all new commercially manufactured hobby rocket motors manufactured in the United States.

i. **Name: James (Jim) Livingston**
ii. Email: livingston@ec.rr.com
iii. Phone: (910) 612-5858
iv. TRA Certification: 02204
v. Biography: Jim joined the TRA in 1993 and achieved his Level 3 certification in 1997. As of 1998, Jim has served as a member of the TRA TAP and has supervised over twenty Tripoli members in their own Level 3 certifications. He has also been involved in Tripoli research since 1997 and manufactures all the motors he uses (sizes I through N).

1.3 High-Powered Rocketry Club

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

1.4 Safety Officer

i. **Name: Frances McBride**
ii. Email: fcmcbrid@ncsu.edu
iii. Responsibilities: Frances McBride will act as the safety officer for the 2019-2020 year. Frances is responsible for ensuring the safe operation among lab members of lab tools and materials, including and not limited to drill presses, hand tools, bandsaws, power tools, flammable items, and hazardous materials. Frances is required to attend all launches and be present at all times during the construction of the launch vehicle and associated parts and payloads. She is additionally responsible for maintaining all lab space and equipment up to and above NASA, MAE, and EHS safety and health standards. This includes displaying proper safety information and documentation, maintaining safe operation of a flame and hazardous materials cabinet, and availability and stocking of a first aid kit. In the event that Frances is not present in the lab, an appropriately trained separate team member will be appointed to perform Frances' in-lab tasks which include and are not limited to ensuring team members are using correct PPE, educating members on proper equipment operation, and fostering a lab and launch safety culture.

1.5 Student Team Leader

i. **Name: Ashby Scruggs**
ii. Email: alscrug2@ncsu.edu
iii. Phone: (910) 986-0180
iv. Responsibilities: Ashby will act as the NC State University Student Team Leader for the 2019-20 NASA Student Launch competition. Ashby is also serving as HPRC president and Team Lead for the Senior Design team which consists of other aerospace engineering seniors: Gabe, Erik, David, Ethan, Michael, and Sean. She will be responsible for managing each of the subsystem teams and integration at the systems level.

1.5.1 Senior Design Team

Figure 1--1, below, shows the 2019-2020 competition Senior Design Team. Senior Design members and their respective roles are described in further detail below.

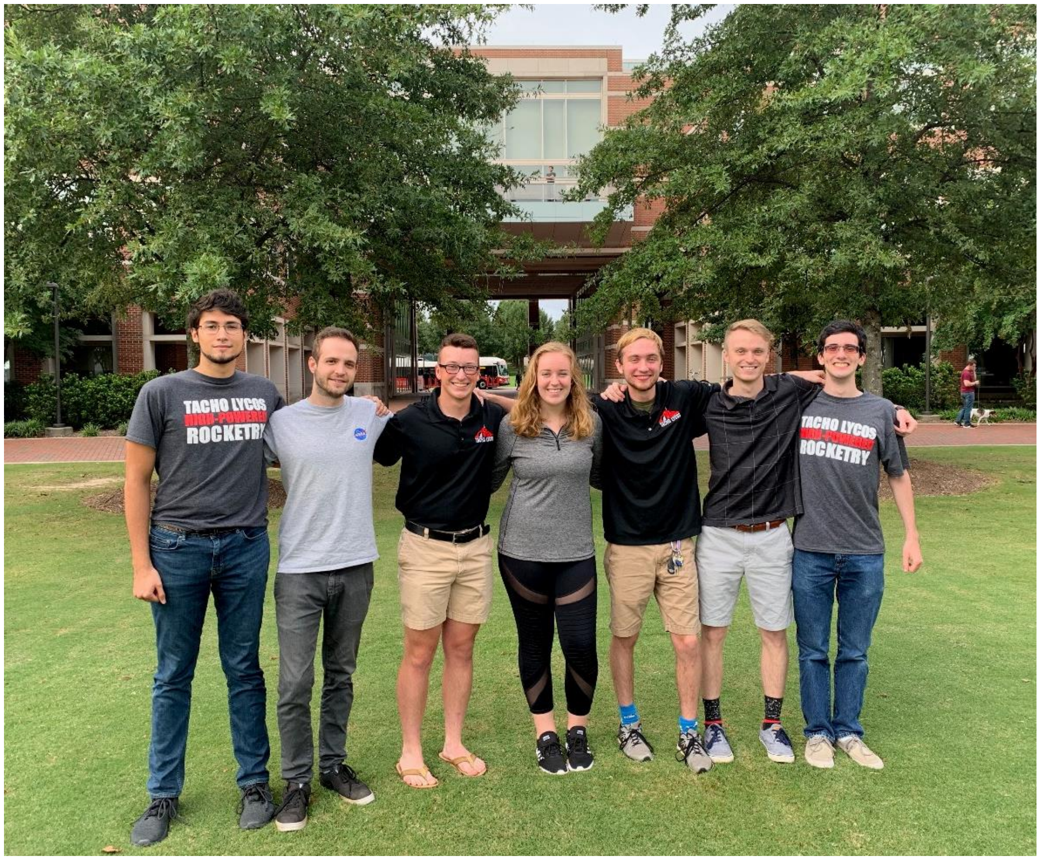

Figure 1--1 2019-2020 Senior Design Team

i. Name: Gabe
ii. Subsystem: Recovery
iii. Biography: Gabe is a senior in Aerospace Engineering, and the Recovery subsystem lead for this year's competition. As recovery subsystem lead, his duties include parachute and shock cord sizing and selection, development of the avionics bay, and adherence of the team to all recovery requirements for the competition. This is his fourth year with the club. His professional interests lie in the fields of V/STOL vehicles and CFD.

i. Name: Erik
ii. Subsystem: Sample Collection
iii. Biography: Erik Benson is a senior pursuing a Bachelor’s in Aerospace Engineering with a minor in Military Science. He is the Operations Officer at the local Army ROTC Battalion and intends to commission as a Second Lieutenant in the Infantry upon graduation with aspirations to apply to medical school. He is the team lead for Sample Collection under the Payload Subsystem. He will be responsible for the systems that contribute to the collection and storage of the

simulated ice. He will also work in conjunction with Michael and Sean, the other two team leads under the Payload Subsystem, to ensure a smooth and effective system is created as well as maintained.

i. Name: David
ii. Subsystem: Structures
iii. Biography: David is a senior completing a B.S. in Aerospace Engineering. He is also a member of NCSU SEDS and has previously worked with the Carbonell Research group performing research in protein isolation. In his free time, he enjoys painting miniatures and playing board games. David will be responsible for the design of the structure of the team's high-powered rocket. He will run FEA analysis and perform hand calculations to ensure that the launch vehicle is structurally sound. Once designs are finalized, he will lead team members in the construction of the subscale and full-scale rocket.

i. Name: Ethan
ii. Subsystem: Aerodynamics
iv. Biography: Ethan is passionate about the aerodynamic performance of vehicles. This passion has led him to a research position at NC State studying unstart physics with ramjet and scramjet engines where he experimentally examines shockwave boundary layer interactions of inlet models in supersonic flow. This interest has also allowed him the opportunity to lead the aerodynamic simulations and propulsions team of the High-Powered Rocketry Team. Ethan responsible for creating computer models to design a launch vehicle that will be stable in its flight path and selecting a motor that will bring the team to their target apogee (maximum height). Ethan will be working closely with the other teams in order to understand their requirements and make the simulations as accurate as possible.

i. Name: Michael
ii. Subsystem: Payload Vehicle
iii. Biography: Michael is an Aerospace Engineering senior who recently returned from an internship at SpaceWorks/Generation Orbit. Michael hopes to apply his experiences there to the Payload Team position, where he will be responsible for designing the rover component of HPRC's approach to the NASA Student Launch competition.

i. Name: Sean
ii. Subsystem: Payload Integration
iii. Biography: Sean is a 4th year senior pursuing an Aerospace Engineering degree as well as a minor in physics. He is also working with the NC State's Physics department on galaxy evolution research. Outside of his career as a student, he practices amateur astronomy and astrophotography. Sean hopes to use his experience with electronics, from an internship with the FREEDM Systems Center, to integrate autonomy into the payload deployment system.

1.6 Leadership Team Organization

For the 2019-20 school year, the team leadership consists of two major parties: Senior Design and Club Officers. While the two parties interact with each other regularly, they are both responsible for different aspects of the team's operation for the SL competition. These two groups are responsible for guiding around forty undergraduate students through the NASA Student Launch project. Figure 1--2, below, shows the leadership team for the 2019-2020 competition.

Figure 1--2 2019-2020 Leadership Team

The members of the Senior Design team as well as their respective responsibilities are listed in section 1.5. The Club Officers and their respective responsibilities are listed below:

i. **Position: President**
ii. Name: Ashby
iii. Years in Club: 4
iv. Prior Experience: Treasurer 2017-2019
v. Biography & Responsibilities: Ashby will act as the NC State University Student Team Leader for the 2019-20 NASA Student Launch competition. Ashby is also serving as HPRC president and Team Lead for the Senior Design team. Her role as the president primarily focuses on club activities and involvement in the NASA SL competition.

i. **Position: Vice President**

ii. Name: Evan Waldron
iii. Years in Club: 3
iv. Prior Experience: Safety Officer
v. Biography & Responsibilities: As vice president, Evan is responsible for ensuring the smooth proceedings of club operations, managing special club projects, and providing general support to other officers in the execution of their projects. One of the special projects managed by Evan is the club's interest launch, a project to get new members working hands-on with a launch vehicle during the period before subscale construction. The interest launch involves repairing and launching one of the club's previously flown launch vehicles, which familiarizes new members with construction, assembly, and safety procedures.

i. Position: Treasurer
ii. Name: Meredith Patterson
iii. Years in Club: 1
iv. Prior Experience: N/A
v. Biography & Responsibilities: Meredith Patterson is a sophomore in Aerospace Engineering. As Treasurer, her responsibility is to acquire and organize all club funds. This includes reaching out to sponsors and funders, creation of a new sponsorship packet for this year, and interviews/applications to our university organizations for club funding. She also has the responsibility of ordering, shipping, and obtaining all materials for construction of the team's rockets. She hopes to grow new company connections throughout the year to further develop the club's sponsorship network, as well as, put more funding towards outreach and underclassmen involvement.

i. Position: Coordination Officer
ii. Name: Ashlee Bracewell
iii. Years in Club: 4
iv. Prior Experience: Treasurer, Vice President
v. Biography & Responsibilities: Ashlee is a structural engineering student with a deep passion for rocketry and space exploration. She is the Coordination Lead of the High-Powered Rocketry Club. Her responsibilities in this role include sending weekly emails, collaborating with external and internal entities to organize events for the club, and communicating with contacts who reach out to the club.

i. Position: Web Administrator
ii. Name: Abhi Kondagunta
iii. Years in Club: 1
iv. Prior Experience: N/A
v. Biography & Responsibilities: Abhiram is the Website Administrator for the club. He is majoring in Materials Science and Engineering with a minor in Chemical Engineering. As the Web Administrator, Abhiram remade the club website and continues to update it. He works in conjunction with the Outreach Officer (to help spread information about the outreach program), the Treasurer (to get information about the club to sponsors), and the Social Media Officer (to help make club updates more accessible to everyone)

i. **Position: Social Media Officer**
ii. Name: Joseph Taylor
iii. Years in Club: 5
iv. Prior Experience: Social Media Officer
v. Biography & Responsibilities: The team's media officer shall keep all social media accounts held by the club up to date and active throughout the year. This includes but is not limited to: Facebook, Instagram, and Twitter. The media officer will maintain a positive presence on social media, fostering engagement with the community, educating followers about STEM, and be receptive to any comments or questions directed at any of the accounts.

i. **Position: Outreach Coordinator**
ii. Name: Annette Gray
iii. Years in Club: 3
iv. Prior Experience: N/A
v. Biography & Responsibilities: Annette is a senior in Mechanical Engineering with minors in mathematics, physics, and German studies. As the Outreach Chair, she will run this team's outreach program. This year the team has goals to expand our impact, such that more members are going to be involved in reaching out to schools and organizations. Annette will be guiding members on how to do this and ensuring attendance for each event. She will also lead most outreach events but will delegate that responsibility to another member when it is not possible for me to attend.

1.7 Subsystem Definition

To better manage the workload associated with the Student Launch project, the team has divided into several different subsystem teams. Each team will be responsible for a set of requirements as noted in the "Subsystem Allocation" column in each Requirement Verification matrix. The team has decided to divide the project into the following subsystems:

- Project Management
- Safety
- Aerodynamics
- Structures
- Recovery
- Payload

The project management team will be responsible for maintaining the schedule and mitigating any conflicts between the other subsystems. This team will be led by team lead, Ashby Scruggs. The safety team will be responsible for monitor lab and field safety as well as maintaining safety documentation. This team will be led by student safety officer, Frances McBride. The aerodynamics team is responsible for flight simulations and stability management of the launch vehicle. This team is led by senior design member, Ethan Johnson. The structures team is responsible for material selection and analysis as well as construction of the launch vehicle. This team is led by senior design member, David Torres. The recovery team is responsible for the entirety of the recovery system, from altimeters to parachutes. This team is led by senior design member, Gabriel Buss. The payload subsystem is responsible for the lunar ice collection mechanism and meeting all payload specific requirements. This team is led by senior design members, Michael Barton, Erik Benson, and Sean Clark.

1.8 Weekly Club Briefings

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

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

The club strives to provide an atmosphere that fosters learning and facilitates the flow of knowledge from veteran members to newcomers. Beyond the weekly meetings, the rocketry lab space is open for members to work on reports, rocket construction, and/or classwork, as well as for general fraternization amongst members.

The Senior Design and student leadership teams also conduct regular meetings amongst the subsystem teams to discuss document and project progress, as well as to resolve any outstanding issues. The team is divided into subsystems as described in section 1.7.

1.9 Local TRA/NAR Chapter Information

Alan Whitmore, whose qualifications are described in section 1.2, is the current prefect of Tripoli East NC (TRA Prefecture 65) and is responsible for the purchase and storage of all motors used for vehicle launches during the competition. These motors are only purchased after his approval and are stored according to his safety requirements. At launches, the motors are assembled and installed under his supervision. Jim Livingston is also Level 3 certified with the TRA, and are equally capable of supervising the storage, assembly, and installation of rocket motors.

2. Facilities and Equipment

2.1 Description

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

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

2.2 Hours of Accessibility

Monday – Friday: All day for undergraduate student leader and senior design access

6am – 12am for undergraduate student access

Saturday – Sunday: All day for undergraduate student leader and senior design access

2.3 Necessary Personnel

The club safety officer, identified in section 1.4, must be present in the Rocketry Lab for any construction or testing. Dr. Jaideep Pandit, MAE Lab Director, must approve any testing conducted using the mechanical engineering lab equipment. Dr. Shreyas Narsipur must approve any testing conducted in the subsonic or supersonic wind tunnels located at NC State.

2.4 Available Equipment

The team has access to a wide variety of tools and supplies available for use throughout the design and construction process. The team has access to a multiple speed drill press with 12" of travel as well as a scroll saw, bandsaw and belt sander. These are all low power tabletop models and are equipped with lock-out keys to prevent unauthorized use. Regarding powered hand tools, the team has access to a DeWalt 18V drill, DeWalt Jigsaw, Dremel 4300 rotary tool, Rigid Oscillating cutting tool, and Wagner Heat gun. These tools are used throughout the manufacturing process and are stored in a locking storage cabinet to regulate their use. The team's manufacturing space is equipped with compressed air lines which are used for vacuum bagging composite layups. The team also has an array of hand tools including, saws, files, wrenches, and screwdrivers. The team also has a SeeMeCNC Rostock Max V2 3D printer in the lab which is used for prototyping and small custom parts in non-load bearing applications. Outside of the lab, the team has access to a laser cutter through the North Carolina State University Entrepreneurship Initiative Garage space. Additionally, the North Carolina State University Department of Mechanical and Aerospace Engineering has a fully equipped machine shop, available for use by MAE safety trained students. As a student group, the team can submit engineering drawings for manufacture by the machine shop.

The team has access to the MAE department's many lab facilities for testing. Among the array of instruments and measuring equipment the team has used the department's universal tension testing machine and 3-point bending test machine. Throughout the design and testing phase, the team will reach out to the departmental lab director to request the use of other pieces of testing equipment as the need arises.

2.5 Supplies Required

Materials required to design and build a rocket and payload include are described in a preliminary capacity in section 6.2. In addition to these build materials, the team requires the following pieces of safety equipment. Nitrile gloves, dust masks, and safety glasses are required when working with composites and their component parts. Hearing protection, in the form of disposable earplugs, is encouraged when using benchtop power tools. This PPE is purchased in bulk and made available to all club members when working in the lab.

The team also requires several software packages to effectively complete this competition. The team has access to the Microsoft Office suite of applications through university licenses. Similarly, the team uses SolidWorks, ANSYS, and MATLAB throughout the design process. The team has purchased licenses for RockSim to perform launch and descent simulations. Lastly, the team has acquired an educational license for Asana, a Kanban and task management application.

3. Safety

3.1 Safety Requirements

In Table 3--1, below, the safety-related project requirements for the 2020 NASA Student Launch are addressed.

Table 3--1 Safety Requirement Verification Table

Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation	Results
NASA5.1	The team SHALL use a launch and safety checklist.	The project management and safety teams write a launch and safety checklist. The launch and safety checklist is included in the CDR milestone report.	Inspection	Project Management; Safety	TBD
NASA5.2	The team SHALL identify a student safety officer.	The student safety officer is identified in each milestone report.	Inspection	Safety	See section 1.4 with safety officer information.
NASA5.3.1.1	The student safety officer SHALL, monitor team activities with an emphasis on safety during the design of vehicle and payload.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety; Structures; Payload	TBD
NASA5.3.1.2	The student safety officer SHALL, monitor team activities with an emphasis on safety during the construction of vehicle and payload components.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety; Structures; Payload	TBD
NASA5.3.1.3	The student safety officer SHALL, monitor team activities with an emphasis on safety	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Project Management; Safety	TBD

	during the assembly of vehicle and payload.				
NASA5.3.1.4	The student safety officer SHALL, monitor team activities with an emphasis on safety during the ground testing of vehicle and payload.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Project Management; Safety	TBD
NASA5.3.1.5	The student safety officer SHALL, monitor team activities with an emphasis on safety during the subscale test launch.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Project Management; Safety	TBD
NASA5.3.1.6	The student safety officer SHALL, monitor team activities with an emphasis on safety during the Full-scale test launch.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Project Management; Safety	TBD
NASA5.3.1.7	The student safety officer SHALL, monitor team activities with an emphasis on safety during the competition launch day.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Project Management; Safety	TBD
NASA5.3.1.8	The student safety officer SHALL, monitor team activities with an emphasis on safety during the recovery activities.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Safety; Recovery	TBD
NASA5.3.1.9	The student safety officer SHALL, monitor team activities with an emphasis on safety during STEM engagement activities.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Demonstration	Project Management; Safety	TBD
NASA5.3.2	The student safety officer SHALL implement procedures developed by the team for	The project management and safety teams write a launch and safety checklist that encompasses the	Demonstration	Project Management; Safety	TBD

	construction, assembly, launch and recovery activities.	assembly, launch and recovery of the launch vehicle.			
NASA5.3.3	The student safety officer SHALL manage and maintain current revisions of the team's hazard analyses, failure mode analyses, procedures, and MSDS/chemical inventory data.	The safety team manages all safety documentation for the team.	Inspection	Safety	TBD
NASA5.3.4	The student safety officer SHALL assist in the writing and development of the team's hazard analyses, failure mode analyses, and procedures.	The safety team manages all safety documentation for the team.	Inspection	Safety	TBD
NASA5.4	The team SHALL abide by the rules and guidance of the local rocketry club's RSO during test flights.	The safety team ensures all regulations from the local rocketry club are followed.	Demonstration	Safety	TBD
NASA5.5	The team SHALL abide by all rules set forth by the FAA.	The safety team ensures all rules from the FAA are followed.	Demonstration	Safety	TBD

3.2 NAR/TRA Personnel Procedures

Members are required to agree to the team's and NAR's safety codes for high-power rockets, detailed below. High-Powered Rocketry Club's safety plan is a culmination of NAR, NASA, and team-derived safety requirements to minimize personnel injury and mission failure.

3.2.1 NAR High Power Rocket Safety Code

The team will comply to the NAR safety code in the following ways, additionally summarized in the safety agreement in section 3.7:

1. Certification: Team mentors are all NAR Level 3 certified and will assist members in handling dangerous vehicle components.
2. Materials: The team shall avoid using heavy body materials unless necessary for structural safety of the system.
3. Motors: The team shall only use commercially available high-power rocket motors.
4. Ignition System: NAR/TRA personnel shall control ignition and the team shall only launch at NAR/TRA approved launches with appropriate personnel present.
5. Misfires: The team shall defer to the RSO when instructed and only essential personnel shall approach the launch pad before flight to minimize risk to personnel safety.
6. Launch Safety: The RSO shall perform a five-second countdown prior to launch. Team members are required to stop work and pay attention to any rockets in flight. The rocket shall be measured and shall have a stability margin greater than or equal to 2.0. The team additionally enforces a no smoking policy within 50 feet of launch location.
7. Launcher: The team shall use NAR/TRA-provided launch rails with blast deflectors for launch. Additionally, all rockets shall be pointed 85° from the horizontal into the wind. No titanium sponge shall be in propellants in the team's motors.
8. Size: The motor shall have an impulse rating of fewer than 5,120 N-sec, under the competition requirements and well under NAR requirements.
9. Flight safety: The team shall only launch at NAR/TRA approved launches in which skies will be confirmed clear of planes and other rockets by the RSO and one or more bystanders. In the event of wind speeds over 20 mph or low cloud level, the launch shall be scrubbed immediately.
10. Launch Site: The team shall launch at a NAR/TRA approved site in Bayboro, North Carolina with sufficient range for safe rocket landing.
11. Launcher Location: Team members shall stand behind the minimum distance table set by the RSO and only essential personnel or NAR/TRA personnel shall approach the launch pad prior to launch.
12. Recovery System: All HPRC rockets shall use a dual-deploy system with a drogue parachute deployed at apogee and will use a main parachute deployed at 500 ft AGL. Nomex cloth shall protect both parachutes from damage due to black powder and heat upon landing.
13. Recovery Safety: Team members and the RSO will ensure that bystanders shall stand upwind of the launch site. Additionally, no member may run, climb, or approach dangerous places to recover a rocket.

3.3 Safety Plan and Hazard Recognition

3.3.1 Safety Training

The NCSU MAE Department requires that before use of power tools and machining equipment, all members must complete a safety and lab information training. The team shall complete this training before fabrication of SL competition components. Team members who do not complete this required training shall be prohibited from working with hazardous power tools until training is completed. Additional training shall be made available to members seeking assistant safety officer status. These assistant safety officers shall assist the safety officer during fabrication and testing in ensuring proper procedures are followed and assisting new members in safe operation of lab equipment.

3.3.2 Prelaunch Briefings

Team members go through launch day setup process several times before launch day. Members are made aware of all procedures so that on launch day the rocket can be set up correctly, safely, and rapidly. During prelaunch briefings, the rocket is assembled as if it were going to be launched. The steps are recovery assembly, including properly folding and packing parachutes, payload assembly and loading, altimeter setup, and launch vehicle assembly. Motor installation and recovery charges are discussed but not included in assembly to prevent an unwanted charge indoors. Once the vehicle is assembled, the altimeter is armed, and team members recheck that it has the proper settings. Once assembly is complete, the rocket is disassembled and prepared for safe transportation. Team members are made aware of all parts of the launch setup to ensure proper communication on launch day.

3.3.3 Hazardous Materials

Various hazardous materials are used in fabrication of the launch vehicle. Team members are alerted of the inherent hazards of working with these materials and are instructed to wear proper PPE to minimize and eliminate personnel injury. These hazards are well-documented in an inventory sheet on the flammable storage cabinet in which the materials are kept. Table 3--2 below shows the hazardous materials and their type and storage instruction.

Table 3--2 Hazardous Materials

Material	Manufacturer	Hazard Type	Storage Instruction
Black Powder	GOEX Powder Inc.	Extremely flammable	Store in cool, dry place. Keep away from open flame/ excessive heat and avoid impact.
206 Hardener	West System	Hazardous, toxic if swallowed, corrosive, skin irritant, carcinogenic	Store in cool, dry, and well-ventilated place, away from heat.
105 Epoxy Resin	West System	Hazardous, toxic if swallowed, corrosive, skin irritant, carcinogenic	Store in cool, dry, and well-ventilated place, away from heat.
406 Colloidal Silica	West System	Hazardous, skin irritant toxic if swallowed, carcinogenic	Store in cool, dry, well ventilated place, away from heat.
Methyl Ethyl Ketone (MEK)	Klean Strip	Extremely flammable, toxic if swallowed, skin irritant	Store in cool, dry, well-ventilated place, away from open flame/ heat.

3.4 Safety in Documentation

3.4.1 Fault Tree Analysis

The team will be using fault tree analysis of the entire system, including launch vehicle and payload. This analysis method will enable the team to model the different critical components of the project and see which subsystems are lacking redundant systems. Additionally, it will provide a visual guide to the different systems of the project and how a potential failure will interact with other systems. This top-down approach will enable the team to design safer systems and have a clearer understanding of interactions between systems to help ensure mission success for the overall project. An example of FTA is shown in Figure 3--1, below, with rectangles representing launch vehicle components and hexagons representing failures. In the future, once the team creates more low-level trees, trapezoids will represent failure causes.

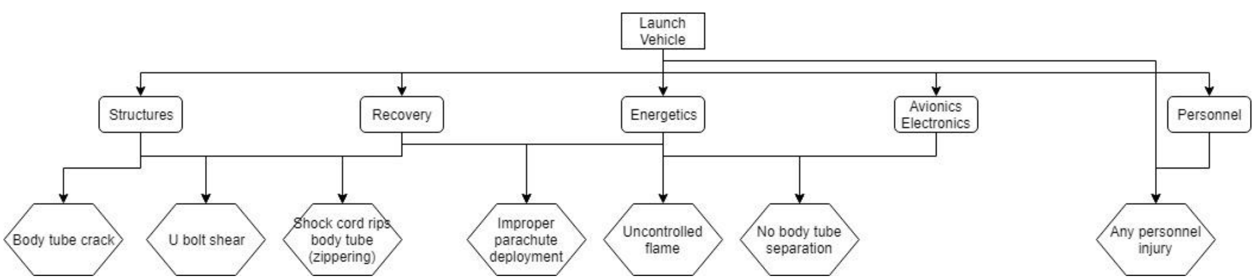

Figure 3--1 Preliminary Fault Tree

3.4.2 Checklist Amendments

The team uses checklists on launch days to organize and manage tasks between individuals. These checklists indicate what PPE is to be used and when, and lists members responsible for completing checklist tasks. The safety officer and another checklist official are responsible for delegating tasks and ensuring members complete tasks to which they were assigned.

Amendments shall be made to the checklists for clarity, including pictorial representations of PPE and clear labels of warnings and cautions. Additional checklists shall be added for everyday lab activities such as filleting bulkheads and to assist new members in.

3.4.2.1 Hazard Labels

Hazard labels shall be used to indicate varying levels of risk if a checklist step is not completed properly.

Cautions, seen below in Figure 3--2, indicate low risk; a non-critical failure will occur if the step is completed improperly. The maximum amount of personnel injury will be treatable with an on-sight first aid kit and basic first aid knowledge.

Figure 3--2 Checklist Caution Statement

Yellow warnings, seen below in Figure 3--3, indicate a moderate risk; a non-critical but major failure will occur if the step is completed improperly. The maximum amount of personnel injury will be treatable with advanced first aid.

Figure 3--3 Checklist Warning Statement

Red warnings, seen below in Figure 3--4, indicate a high risk; a critical failure will occur if the step is completed improperly. The maximum amount of personnel injury will be hospitalization or death. Officers, Tripoli officials, and members with a high amount of experience (2+ years) shall be solely responsible for completing red-warning tasks.

Figure 3--4 Checklist Severe Warning Statement

3.4.2.2 PPE Labels

Additional labels shall be applied to the checklist to indicate the proper time and type of PPE in use. These labels will assist in clarity and serve as an additional reminder to team members to wear PPE at all necessary times. Examples of these labels are shown in Figure 3--5, Figure 3--6, and Figure 3--7 below:

Figure 3--5 Particulate Mask

Figure 3--6 Nitrile Gloves

Figure 3--7 Safety Glasses

3.5 Regulation Compliance

The team shall comply with all federal, state, and local laws concerning the design, construction, and operation of high-powered rockets. Specifically, the Federal Aviation Regulations listed in 14 CFR, Subchapter F, Part 101, Subpart C; and the National Fire Protection Association (NFPA) Code for High Power Rocketry. As there is no UAV component in the team's mission design this year, federal regulations concerning the operation of UAV's do not apply.

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

The subpart of the Federal Aviation Regulations concerning the launch of high-powered rockets details where and when high-powered rocket launches can take place, and how they should be operated. The team will comply with all FAA regulations listed in this document, and will not operate a high-powered rocket:

a) At any altitude where clouds or obscuring phenomena of more than five-tenths coverage prevails;
b) At any altitude where the horizontal visibility is less than five miles;
c) Into any cloud;
d) Between sunset and sunrise without prior authorization from the FAA;

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

3.5.2 NFPA 1127 Code for High Power Rocketry

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

3.6 NRA/TRA Mentor Purchase of Energetic Devices

3.6.1 Motor and Energetics Purchase Plan

All commercially produced rocket motors shall be bought from certified distributors and manufacturers under the team's mentors' supervision. Mentors shall transport and store all motors in accordance with the manufacturer and university Environmental, Health, and Public Safety (EHPS) guidelines. The motor shall never be stored in the rocket, and the insertion of the motor is always the final step of rocket assembly at the launch site. This shall be closely supervised by the RSO and team mentor.

Black powder shall remain in the sealed container provided by the manufacturer for both transportation and storage. When not in use, black powder shall be stored with a team mentor or in the rocketry lab flame cabinet. When ejection charges are required for testing or launch, the proper amount of black powder will be calculated using Equation 1, below:

$$[CD^2L=m_{BP}] \quad (1)$$

Where C is a pressure-dependent constant, D is the diameter of the compartment, L is the length of the compartment, and m_{BP} is the mass of black powder necessary (in grams). Any person handling exposed black powder shall do so under the supervision of a team mentor or the Safety Officer. They must wear the proper personal protective equipment in accordance with the established safety plan, being safety glasses, gloves, and a mask. Any surface with which black powder comes in contact must be cleaned before and after handling.

3.7 Team Member Safety Compliance

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

3.7.1 Range Safety Inspection

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

3.7.1.1 Launch Systems

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

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

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

3.7.1.2 Emergency

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

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

3.7.1.3 Flight Operations

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

3.7.1.4 Flight Safety Review – Safety First

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

3.7.1.5 Flyer

By asking to see a current membership card: verify that the individual flying the rocket is a current member in good standing of Tripoli Rocketry Association or the National Association or Rocketry; verify the certification level of the individual and that they are flying within their certification level or attempting a new certification level; observe that the individual does not appear impaired by the use of drugs or alcohol. Under no circumstances should someone who has participated in the consumption of alcoholic beverages be allowed to enter the range or launch a rocket.

3.7.1.6 Flight Card

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

3.7.1.7 History

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

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

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

3.7.1.8 Propulsion

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

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

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

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

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

3.7.1.9 Construction

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

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

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

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

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

3.7.1.10 Stability

Verify that the rocket is of a stable design.

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

3.7.1.11 Recovery

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

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

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

3.7.2 Range Safety Officer Clearance Policy

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

3.7.2.1 Range Operations

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

3.7.2.2 Site

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

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

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

3.7.2.3 Airspace

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

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

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

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

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

3.7.2.4 Weather

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

1. Do not launch if ground level winds exceed 20 mph.
2. Do not launch if the planned flight path will carry the vehicle through any clouds.
3. Do not launch if any type of lightning is detected within 10 miles of the launch site.

Time Interval Determination Method:

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

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

3.7.3 Links to Material Safety Data Sheets (MSDS)

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

3.7.4 Team Member Safety Agreement

Mission and personnel safety are HPRC's top priority, and as such, the team invests heavily in ensuring that team members are adequately informed of their responsibilities and commitment to safety. Before beginning fabrication, all members of the team are required to read and agree to the following:
"I understand that the safety of the club, its members, and the launch vehicle is dependent on my compliance with the following safety rules/procedures:
Members shall...

- Properly use personal protective equipment at all necessary times
- Use power tools only when informed how to do so
- Have an understanding of risk and risk mitigation during design, fabrication, and launch
- Mitigate risk whenever possible and to the fullest extent
- Know the impact of personal behavior on mission success and system and human safety
- Uphold and encourage safe behavior at all times as a part of NASA Student Launch
- Recognize that the Range Safety Officer has the final say on the status of launches.

Additionally, members shall only begin fabrication when the safety officer or other properly trained individual is present and must prepare the launch vehicle for launches only when a Tripoli official and the safety officer are present."
This safety agreement ensures all members know the responsibility and impact of individuals on the team.

3.7.5 Demonstrated Team Compliance

The safety guidelines, regulations, and plans listed in Section 3.7 were presented to all HPRC members who then signed the following forms to indicate compliance.

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

1. Print Name: Ashlay Scruggs
   Signature & Date: [signature] 9/5/19
2. Print Name: Ashlee Bracewell
   Signature & Date: [signature] 9/5/19
3. Print Name: Ethan Johnson
   Signature & Date: [signature] 09/05/19
4. Print Name: Harvey Hooper IV
   Signature & Date: [signature] 9/5/19
5. Print Name: Frances McBride
   Signature & Date: [signature] 9/5/19
6. Print Name: Gabriel Buss
   Signature & Date: [signature] 9/5/19
7. Print Name: Sean Clark
   Signature & Date: [signature] 9/5/19
8. Print Name: Michael Barton
   Signature & Date: [signature] 09/05/2019
9. Print Name: Erik Benson
   Signature & Date: [signature] 05SEP2019
10. Print Name: John Inness
    Signature & Date: [signature] 9/5/19
11. Print Name: Alex Thomas 9/5/19
    Signature & Date: [signature]
12. Print Name: Annette Gray
    Signature & Date: [signature] 9/5/19
13. Print Name: Robert Kemein 9/5/19
    Signature & Date: [signature]
14. Print Name: Amit Bharde
    Signature & Date: [signature] 9.5.19
15. Print Name: Abhiram Kondagunta
    Signature & Date: [signature] 09/05/2019
16. Print Name: Meredith Patterson 9/5/2019
    Signature & Date: [signature]
17. Print Name: Evan Waldron
    Signature & Date: [signature] 9/5/19
18. Print Name: Daniel E. Jaramillo
    Signature & Date: [signature] 9/5/19
19. Print Name: Walter Buckley
    Signature & Date: [signature] 9/5/19

Alex Boyer 9/13/19 [signature]

Emma Jaynes [signature] 9/10/19

Jacob Daye [signature] 9/12/19

James Cowley [signature]

Dam Lamberton [signature] 9/12/19

Connor Knox [signature]

Chase Jenquin
[signature] 9-10-19

20. Print Name: Joseph Taylor
Signature & Date: [signature] 9/5/19
21. Print Name: David Torres
Signature & Date: [signature] 9/5/19
22. Print Name: Haydn Spurrell
Signature & Date: [signature] 9/5/19
23. Print Name: Myers Harbinson
Signature & Date: [signature] 9/5/19
24. Print Name: Jiovanni Ortiz 9/5/19
Signature & Date: [signature]
25. Print Name: David E Horne
Signature & Date: [signature] 9/5/19
26. Print Name: Benjamin Leach
Signature & Date: [signature] 9/5/19
27. Print Name: Christopher Luzzi
Signature & Date: [signature] 9/5/19
28. Print Name: Mike Pudlo
Signature & Date: [signature]
29. Print Name: Michael Casper
Signature & Date: [signature] 9/5/19
30. Print Name: Jim Li
Signature & Date: [signature] 9/5/2019
31. Print Name: Rafael Macabebat
Signature & Date: [signature] 9/5/2019
32. Print Name: Jon Calabretta
Signature & Date: [signature] 9/5/2019
33. Print Name: Shawn Stephen
Signature & Date: [signature] 9/5/2019
34. Print Name: Sanoj Nagaranthal
Signature & Date: [signature] 9/5/19
35. Print Name: Matt Lundell
Signature & Date: [signature] 9/5/19
36. Print Name: Baylen Lucas
Signature & Date: [signature] 9/5/19
37. Print Name: Becky Papania
Signature & Date: [signature] 9/5/19
38. Print Name: John Mason
Signature & Date: [signature] 9/5/19
39. Print Name: Tommy Sailor Koeplinger
Signature & Date: [signature] 9/6/19

Jacob Myers
[signature] 9/6/19

William Donaldson
[signature] 9/10/19

Jennifer Wolfe [signature] 9/11/19

Joshua Daniels
[signature] 9/11/19

Yosaira Esquivel [signature] 9/12/19

4. Technical Design

4.1 Launch Vehicle Specifications

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

4.1.1 Launch Vehicle Requirements

In Table 4--1, below, the launch vehicle-related project requirements for the 2020 NASA Student Launch are addressed.

Table 4--1 Launch Vehicle Requirement Verification Table

Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation	Results
NASA2.1	The launch vehicle SHALL deliver the payload to an apogee altitude between 3,500 and 5,500 feet above ground level (AGL).	The aerodynamics subsystem team designs a launch vehicle to launch between 3,500 and 5,500 feet AGL. The team then constructs the vehicle as designed and the launch vehicle flies between 3,500 and 5,500 feet AGL.	Analysis; Demonstration	Aerodynamics	TBD
NASA2.2	The team SHALL identify the target altitude goal at the PDR milestone.	The aerodynamics subsystem team reports the altitude goal in the PDR milestone report and is sent to the NASA project management team by November 1, 2019.	Inspection	Aerodynamics	TBD
NASA2.3	The launch vehicle SHALL carry one commercially available, barometric altimeter for recording the official altitude.	The recovery subsystem team chooses a commercially available, barometric altimeter to be used in the launch vehicle.	Inspection	Recovery	See Section 4.2.4 with the leading design choice for altimeter.
NASA2.4	The launch vehicle SHALL be designed to be recoverable and reusable.	The recovery subsystem team designs a recovery harness system that will allow the launch vehicle to be recovered upon ground impact with minimal damage.	Demonstration	Recovery	See Section 4.2 with the leading recovery

					device design.
NASA2.5	The launch vehicle SHALL have a maximum of four (4) independent sections.	The aerodynamics and recovery subsystem teams design a launch vehicle that has fewer than four (4) independent sections.	Inspection	Aerodynamics; Recovery	See Section 4.2 with the leading recovery device design.
NASA2.5.1	Couplers which are located at in-flight separation points SHALL be at least one (1) body diameter in length.	The aerodynamics subsystem team designs a launch vehicle with couplers at in-flight separation points at least one body diameter in length. The structures subsystem team construct the couplers in the correct lengths.	Inspection	Aerodynamics; Structures	See Section 4.1.2 with the leading launch vehicle dimensions.
NASA2.5.2	Nosecone shoulders which are located at in-flight separation points SHALL be at least 1/2 body diameter in length.	The aerodynamics subsystem team designs a launch vehicle with nosecone shoulders at in-flight separation points at least 1/2 body diameter in length. The structures subsystem team construct the couplers in the correct lengths.	Inspection	Aerodynamics; Structures	See Section 4.1.2 with the leading launch vehicle dimensions.
NASA2.6	The launch vehicle SHALL be capable of being prepared for flight at the launch site within two (2) hours of the time the Federal Aviation Administration flight waiver opens.	The project management and safety teams develop launch day checklists that can be executed in under two (2) hours.	Demonstration	Project Management; Safety	TBD
NASA2.7	The launch vehicle and payload SHALL be capable of remaining in launch-ready configuration on the pad for a minimum of two (2)	The project management and safety teams monitor the selected power supplies for each on-board component and test to verify functionality after over two (2) hours.	Demonstration	Project Management; Safety	TBD

	hours without losing the functionality of any critical on-board components.				
NASA2.8	The launch vehicle SHALL be capable of being launched by a standard 12-volt direct current firing system.	The project management and safety teams choose the motor ignitor that can be ignited from a 12-volt direct current firing system.	Demonstration	Project Management; Safety	TBD
NASA2.9	The launch vehicle SHALL require no external circuitry or special ground support equipment to initiate launch.	The project management and safety teams limit the launch vehicle such that it has no external circuitry or ground support equipment.	Demonstration	Project Management; Safety	TBD
NASA2.10	The launch vehicle SHALL use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	The aerodynamics team selects a solid motor propulsion system.	Inspection	Aerodynamics	See Section 4.1.5 with the leading motor selection.
NASA2.10.1	Final motor choices SHALL be declared by the Critical Design Review (CDR).	The aerodynamics team selects and reports the final motor choice by January 10, 2020.	Inspection	Aerodynamics	TBD

NASA2.10.2	Any motor change after CDR SHALL be approved by the NASA Range Safety Officer (RSO) and SHALL only be approved if the change is for the sole purpose of increasing the safety margin.	The aerodynamics team selects and reports the final motor choice by January 10, 2020.	Demonstration	Aerodynamics	TBD
NASA2.11	The launch vehicle SHALL be limited to a single stage.	The aerodynamics team designs a launch vehicle with a single stage.	Inspection	Aerodynamics	TBD
NASA2.12	The total impulse provided by a College or University launch vehicle SHALL not exceed 5,120 Newton-seconds (L-class).	The aerodynamics team chooses an L-class motor for the full-scale launch vehicle.	Inspection	Aerodynamics	TBD
NASA2.13	Pressure vessels on the vehicle SHALL be approved by the RSO.	The structures lead provides the necessary information on any on-board pressure vessels to the NASA RSO and home field RSO.	Inspection	Structures	TBD
NASA2.13.1	Pressure vessels on the vehicle SHALL have a minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) of 4:1 with supporting design documentation included in all milestone reviews.	The structures lead provides the necessary information on any on-board pressure vessels to the NASA RSO and home field RSO.	Analysis	Structures	TBD
NASA2.13.2	Pressure vessels on the vehicle SHALL include a	The structures lead provides the necessary information on any on-board pressure	Analysis	Structures	TBD

	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.	vessels to the NASA RSO and home field RSO.			
NASA2.13.3	Pressure vessels on the vehicle SHALL be described, including the application for which the tank was designed and the history of the tank.	The structures lead provides the necessary information on any on-board pressure vessels to the NASA RSO and home field RSO.	Inspection	Structures	TBD
NASA2.14	The launch vehicle SHALL have a minimum static stability margin of 2.0 at the point of rail exit.	The aerodynamics team designs a launch vehicle with a minimum static stability margin of 2.0.	Analysis; Inspection	Aerodynamics	See section 4.1.2 for current launch vehicle design.
NASA2.15	Any structural protuberance on the launch vehicle SHALL be located aft of the burnout center of gravity.	The aerodynamics team designs a launch vehicle with all structural protuberances aft of the burnout center of gravity. The structures team verifies that all structural protuberances are aft of the burnout center of gravity upon construction.	Analysis; Inspection	Aerodynamics; Structures	See section 4.1.2 for current launch vehicle design.
NASA2.16	The launch vehicle SHALL accelerate to a minimum velocity of 52 fps at rail exit.	The aerodynamics team designs a launch vehicle with a minimum velocity of 52 fps at rail exit.	Analysis	Aerodynamics	See section 4.1.2 for current launch vehicle design.
NASA2.17	The team SHALL successfully launch and recover a subscale model	The structures team leads the construction of the subscale model of the launch vehicle. The project management and safety teams lead the launch of the	Demonstration	Project Management; Safety; Structures	TBD

	of the launch vehicle prior to CDR.	subscale model of the launch vehicle before January 10, 2020.			
NASA2.17.1	A full-scale model SHALL not be used as the subscale model.	The project management team verifies the subscale model is a different size than the full-scale launch vehicle.	Inspection	Project Management; Safety	TBD
NASA2.17.2	The subscale model SHALL carry an altimeter capable of recording the model's apogee altitude.	The recovery team chooses an altimeter to record the subscale model's altitude.	Demonstration	Recovery	TBD
NASA2.17.3	The subscale model SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The project management team acquires the materials necessary to construct a new launch vehicle for this year's project.	Inspection	Project Management	TBD
NASA2.17.4	Proof of a successful flight SHALL be supplied in the CDR report.	The recovery team provides altimeter data from the subscale launch in the CDR by January 10, 2020.	Inspection	Recovery	TBD
NASA2.18	The team SHALL execute demonstration flights of the launch vehicle and payload.	The project management team holds to the schedule for the team to be able to launch demonstrations flights for both the vehicle and payload.	Demonstration	Project Management	TBD
NASA2.18.1	The team SHALL successfully launch and recover their full-scale launch vehicle prior to FRR in its final flight configuration.	The project management team holds to the schedule for the team to be able to launch demonstrations flights for both the vehicle and payload.	Demonstration	Project Management	TBD
NASA2.18.1.1	During the Vehicle Demonstration Flight (VDF) the vehicle and recovery system SHALL function as designed.	The launch vehicle specific subsystem teams design and construct the launch vehicle as written and the systems function as designed.	Demonstration	Project Management; Safety; Recovery; Structures; Aerodynamics	TBD

NASA2.18.1.2	The full-scale launch vehicle SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The project management team acquires the materials necessary to construct a new launch vehicle for this year's project.	Inspection	Project Management	TBD
NASA2.18.1.3.1	If the payload is not flown during the VDF, mass simulators SHALL be used to simulate the payload mass.	The payload team chooses mass simulators to fly in the vehicle demonstration flight if the payload is not ready for launch.	Inspection	Payload	TBD
NASA2.18.1.3.2	If the payload is not flown during the VDF, mass simulators SHALL be located in the same approximate location on the rocket as the missing payload mass.	The payload team attaches mass simulators in the same approximate location on the launch vehicle as the missing payload mass.	Inspection	Payload	TBD
NASA2.18.1.4	If the payload affects the external surfaces of the rocket or manages the total energy of the vehicle, those systems SHALL be active during the full-scale VDF.	The payload team has external components of the payload prepared for the vehicle demonstration flight.	Inspection	Payload; Aerodynamics	TBD
NASA2.18.1.5	The team SHALL fly the launch day motor during the VDF.	The safety and aerodynamics team work alongside the team's mentors to acquire and use the motor on launch day.	Inspection	Safety; Aerodynamics	TBD
NASA2.18.1.6	The vehicle SHALL be flown in its fully ballasted configuration during the full-scale test flight.	The aerodynamics team decides on the final ballasting configuration. The structures team constructs the designed ballasting configuration.	Inspection	Aerodynamics; Structures	TBD
NASA2.18.1.7	The launch vehicle or any of its components SHALL	If any modifications are necessary after the demonstration flights, the safety and	Inspection	Safety; Structures	TBD

	not be modified without the concurrence of the NASA RSO.	structures team communicate with the NASA RSO prior to making modifications.			
NASA2.18.1.8	The team SHALL provide proof of a successful flight in the FRR report.	The recovery team reports the altimeter data from the demonstration flights in the FRR by March 02, 2020.	Inspection	Recovery	TBD
NASA2.18.1.9	The team SHALL complete the VDF before March 02, 2020.	The project management team holds to the team's schedule and turns in the FRR milestone report by March 02, 2020.	Inspection	Project Management	TBD
NASA2.18.2	The team SHALL successfully launch and recovery the full-scale rocket containing the completed payload prior to March 23, 2020.	The project management team holds to the team's schedule and launches the payload demonstration flight prior to March 23, 2020.	Inspection	Project Management	TBD
NASA2.18.2.1	During the Payload Demonstration Flight (PDF), the payload SHALL be fully retained until the intended point of deployment.	The payload and safety teams design a fail-safe retention system and demonstrate its performance prior to flight.	Demonstration	Safety; Payload	TBD
NASA2.18.2.2	The payload flown during the PDF SHALL be the final, active version.	The payload team completes the construction of all payload systems prior to the payload demonstration flight.	Inspection	Payload	TBD
NASA2.18.2.4	The PDF SHALL be completed by March 23, 2020.	The project management team manages the schedule such that the payload demonstration flight is complete prior to March 23, 2020.	Inspection	Project Management	TBD
NASA2.19	If a re-flight is necessary, the FRR Addendum SHALL be submitted by March 23, 2020.	The project management team manages the schedule such that any re-flight is complete prior to March 23, 2020.	Inspection	Project Management	TBD

NASA2.19.1	If a re-flight is necessary, the FRR Addendum SHALL be submitted by March 23, 2020.	The project management team manages the schedule such that the FRR Addendum is complete prior to March 23, 2020.	Inspection	Project Management	TBD
NASA2.19.2	The team SHALL successfully execute a PDF to be allowed to fly the payload at competition.	The project management team manages the schedule such that the payload demonstration flight is complete prior to March 23, 2020.	Demonstration	Project Management	TBD
NASA2.19.3	The team SHALL not fly the payload at competition if the PDF was unsuccessful.	The project management team manages the schedule such that the payload demonstration flight is complete prior to March 23, 2020.	Demonstration	Project Management	TBD
NASA2.20	The team SHALL mark each independent launch vehicle component with the team's launch day contact information.	The project management team marks each independent section of the rocket with the team's contact information.	Inspection	Project Management	TBD
NASA2.21	The team SHALL sufficiently protect all Lithium Polymer (LiPo) batteries from ground impact. The team SHALL mark all Lithium Polymer batteries with brightly colored, clearly marked.	The payload team designs a retention system for all LiPo batteries in the payload that protects the battery from impact. The safety team will inspect and test the aforementioned design.	Analysis; Inspection	Safety; Payload	TBD
NASA2.22.1	The launch vehicle SHALL not utilize forward canards.	The aerodynamics team designs a launch vehicle that does not utilize forward canards.	Inspection	Aerodynamics; Structures	See section 4.1.2 for current launch vehicle design.

NASA2.22.2	The launch vehicle SHALL not utilize forward firing motors.	The aerodynamics team designs a launch vehicle that does not utilize forward firing motors.	Inspection	Aerodynamics	See section 4.1.5 for current launch vehicle design.
NASA2.22.3	The launch vehicle SHALL not utilize motors that expel titanium sponges.	The aerodynamics team designs a launch vehicle that does not utilize motors that expel titanium sponges.	Inspection	Aerodynamics	See section 4.1.5 for current launch vehicle design.
NASA2.22.4	The launch vehicle SHALL not utilize hybrid motors.	The aerodynamics team designs a launch vehicle that does not utilize hybrid motors.	Inspection	Aerodynamics	See section 4.1.5 for current launch vehicle design.
NASA2.22.5	The launch vehicle SHALL not utilize a cluster of motors.	The aerodynamics team designs a launch vehicle that does not utilize clustered motors.	Inspection	Aerodynamics	See section 4.1.5 for current launch vehicle design.
NASA2.22.6	The launch vehicle SHALL not utilize friction fitting for motors.	The aerodynamics team designs a launch vehicle that does not utilize friction fitted motors.	Inspection	Aerodynamics	See section 4.1.5 for current launch vehicle design.
NASA2.22.7	The launch vehicle SHALL not exceed Mach 1 at any point during flight.	The aerodynamics team designs a launch vehicle that does not exceed Mach 1 during flight.	Analysis	Aerodynamics	See section 4.1.2 for current launch

					vehicle design.
NASA2.22.8	Vehicle ballast SHALL not exceed 10% of the total unballasted weight of the launch vehicle.	The aerodynamics team designs the final ballasting configuration. The structures team implements the designed ballast configuration.	Analysis; Inspection	Aerodynamics; Structures	See section 4.1.2 for current launch vehicle design.
NASA2.22.9	Transmissions from onboard transmitters SHALL not exceed 250 mW of power per transmitter.	The recovery and payload teams choose transmitters that do not exceed 250 mW of power per transmitter.	Analysis	Recovery; Payload	TBD
NASA2.22.10	Transmitters SHALL not create excessive interference.	The recovery and payload teams choose transmitters with minimal interference.	Analysis	Recovery; Payload	TBD
NASA2.22.11	The team SHALL not use excessive and/or dense metal in the construction of the launch vehicle.	The structures and payload teams choose materials that use minimal amounts of dense metal.	Inspection	Structures; Payload	TBD

4.1.2 Launch Vehicle Dimensions

The launch vehicle was designed using RockSim. The team has previously used OpenRocket but has opted to switch to RockSim last year as it was discovered that the data from it tended to be more reliable. The current proposed rocket is 101-inches long with a constant body diameter of 6-inches. The rocket is designed to have 3 separate body sections: nose-section, mid-section, and fin can. At launch, the sections will be securely fastened together using couplers of length that meet NASA's requirements for separable components along with shear pins. These measures are taken to ensure that the rocket will not separate prematurely but they are also simple enough that the rocket should be able to easily separate when it needs to. Figure 4--1, below, shows the OpenRocket 3D schematic with body sections labelled accordingly. OpenRocket was used to provide figures because the software is able to show 3D model of the rocket's geometry and internals.

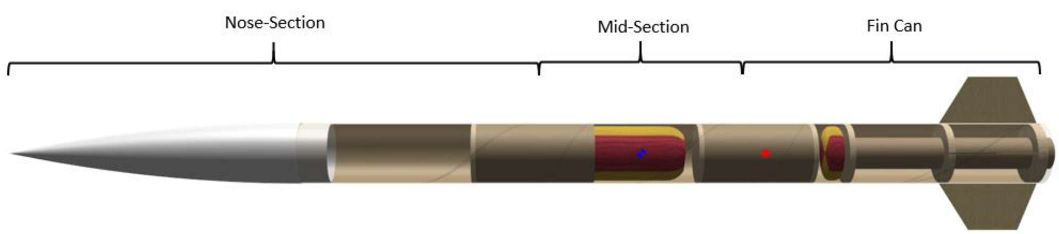

Figure 4--1 OpenRocket 3D Schematic of Launch Vehicle

Measurements of the centers are measured from the tip of the nosecone. In this current design the loaded rocket center of gravity (CG) is located at 68.4-inches and the center of pressure (CP) is located at 80.8-inches thus giving the rocket a static stability margin of 2.07 at full launch weight. At launch the rocket is designed to weigh 40.8 pounds and 36.6 pounds after engine burnout. These measurements meet the competitions requirements of having a static stability margin of at least 2.0 at the rail exit.

4.1.2.1 Nosecone Design

The nosecone for the proposed rocket is a 5:1 ogive shape with a metal tip, a 6-inch outer diameter and length from tip to shoulder of 30-inches. This geometry of the nosecone was primarily selected due to its commercial availability and the length was selected to help achieve our desired stability margin.

In previous years the club has used nose ballast in order to achieve a static stability margin of at least 2.0. The proposed launch vehicle currently does not use ballasts in its design. This design incorporates a simulated payload weight of 8.0 pounds that is housed just aft of the nosecone. Once the payload and deployment device for it have been finalized the total mass and location of the center of mass will be reevaluated in order to determine if ballast are necessary in order to achieve our required stability margin.

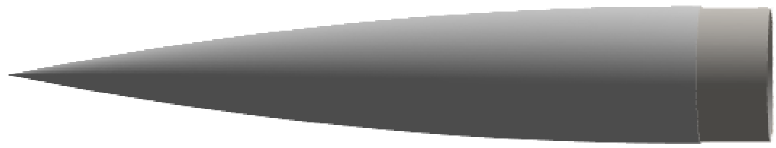

Figure 4--2 Image of Proposed Nosecone

4.1.2.2 Avionics Bay Design

The avionics (AV) bay will be contained within an 11-inch coupler with a 2-inch band of body tube. The section of body tube will serve as a mounting point for the avionics activation switches. This section will be placed 3-inches behind the forward edge of the coupler. This rocket is designed to separate aft of the 2-inch body tube portion and stay connected in front this section. This current design allows for 3-inches before the body tube section and 6-inches after it. An image of the proposed design can be seen below in Figure 4--3. These coupler lengths meet NASA's requirements for separate parts of the rocket that are designed to stay together as well as in-flight separation points.

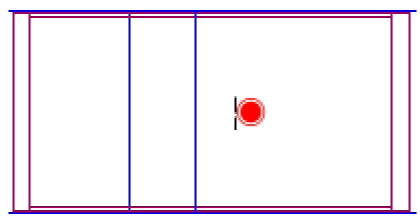

Figure 4--3 Image of Proposed Avionics Bay

This containment design is chosen so that the entire AV bay is removable from the rocket while it is on the ground. This will allow for easy access to any of the electronics if needed as well as total access to the blast caps. This access to the blast caps is crucial for installing black powder charges before launch. Historically the club has used an internally mounted AV bay and has had trouble when attempting to load the black powder charges. Last year the club decided to design a removable AV bay and they saw great success from this design. This year our team has decided to again design a removable AV bay.

4.1.2.3 Fin Can Design

The fin can will house a drogue parachute as well as the fin-motor tube assembly. Swept tapered fins have been selected based on flight data from previous years as they have shown to be effective and durable. A large leading-edge sweep is incorporated to help shift the local center of pressure further aft and a trailing-edge sweep of over 90° is used in order mitigate damage to the fin in the event the rocket lands aft-end first. In addition to the large trailing-edge sweep, the fins are also designed to be placed 0.5-inches above the aft end of the rocket to help prevent damage to them. A total of 4 fins are used in the proposed rocket design. The number of fins was selected based on ease of manufacturing as well as using the fins to shift the center of pressure to our desired location in order to obtain a static margin of at least 2.0.

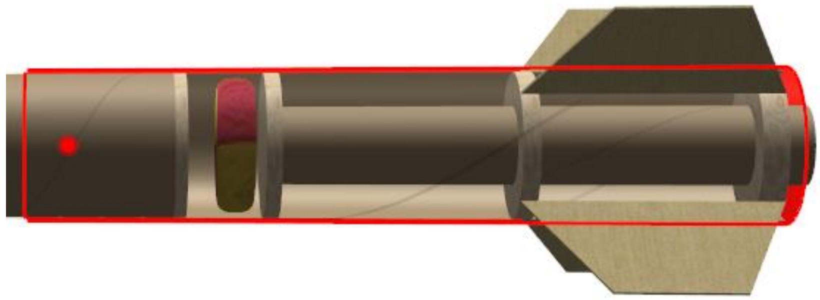

Figure 4--4 Image of Proposed Fin Can

For simplicity, the fins on the proposed rocket are not designed with measuring angles of sweeps in mind. Instead the fin was designed such that the leading-edge of the chord-tip is placed 3-inches behind the leading-edge of the chord-root. The chord-tip is designed to run parallel to the chord-root and they will be separated by 4.75-inches. This way of measurement is being implemented solely to make the manufacturing of the fin easier to do. Figure 4--5 shows a sketch of the proposed fin planform area.

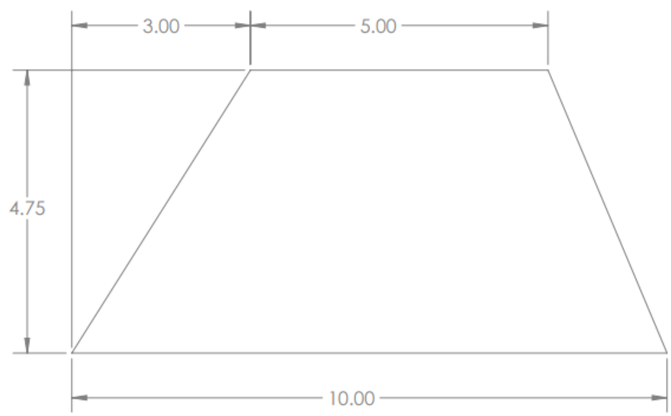

Figure 4--5 Image of Proposed Fin Planform Area

The fin tabs are designed to extend into the body of the rocket which will allow the fins the be securely attached to the motor tube by using epoxy resin. In addition to this, epoxy fillets will be used where the fins intersect with the inner and outer diameter of the fin can body tube. These fillets are used in order to reduce localized stress concentrations and to create a smooth interface between the fin and body tube in an attempt to minimize aerodynamic drag. On either side of the fin tabs will be centering rings to help reduce unwanted movement of the fins. This is a popular design choice among hobby rocketeers as it is a simple, yet effective assembly of the fin can.

4.1.2.4 Bulkhead Design

All bulkhead material will consist of 1/8-inch sheets of aircraft grade plywood. This is a proven material for this application and has shown to be reliable. ANSYS FEA has shown that a bulkhead size of ½ inch in total thickness is sufficient enough to support loads during flight. Non-specialized bulkheads will assume this dimension.

4.1.2.4(a) Avionics Bay Bulkheads

The avionics bay will feature a set of bulkheads on both ends. Each set will consist of two bulkheads, one of which matches the outer diameter of the av bay, and one of which matches the inner diameter. Each bulkhead will be 1/2" thick. This serves to create a plug on either side of the AV bay that will protect against black powder charges.

4.1.2.4(b) Nose Cone/Fin Can Bulkheads

The nose cone bulkhead and forward most motor tube bulkhead will be attached to a shock cord via a U-bolt. These bulkheads will experience greater forces than others during recovery. Initial FEA, pictured in Figure 4--6, shows that that ½" bulkheads will still suffice for this application. However, to ensure that these bulkheads are well secured their thickness will be increased to ¾ inch.

4.1.2.4(c) Aft Most Centering Ring

The aft most fin can's centering ring will support most of the force produced by the motor. Due to this, the ring uses more layers than other centering rings. As an estimate, this centering will be 1" thick, using eight layers of aircraft grade plywood.

4.1.2.4(d) U-Bolts vs eye-Bolts

When creating a contact point of for shock cords, U-bolts will be used. U-bolts are used in place of eye-bolts because they provide two points of contact to the bulkhead as opposed to the one provided by the eye-bolt. The stress on each point is halved as the contact points are doubled. This reduces the chance of the bolts shearing out of the bulkhead.

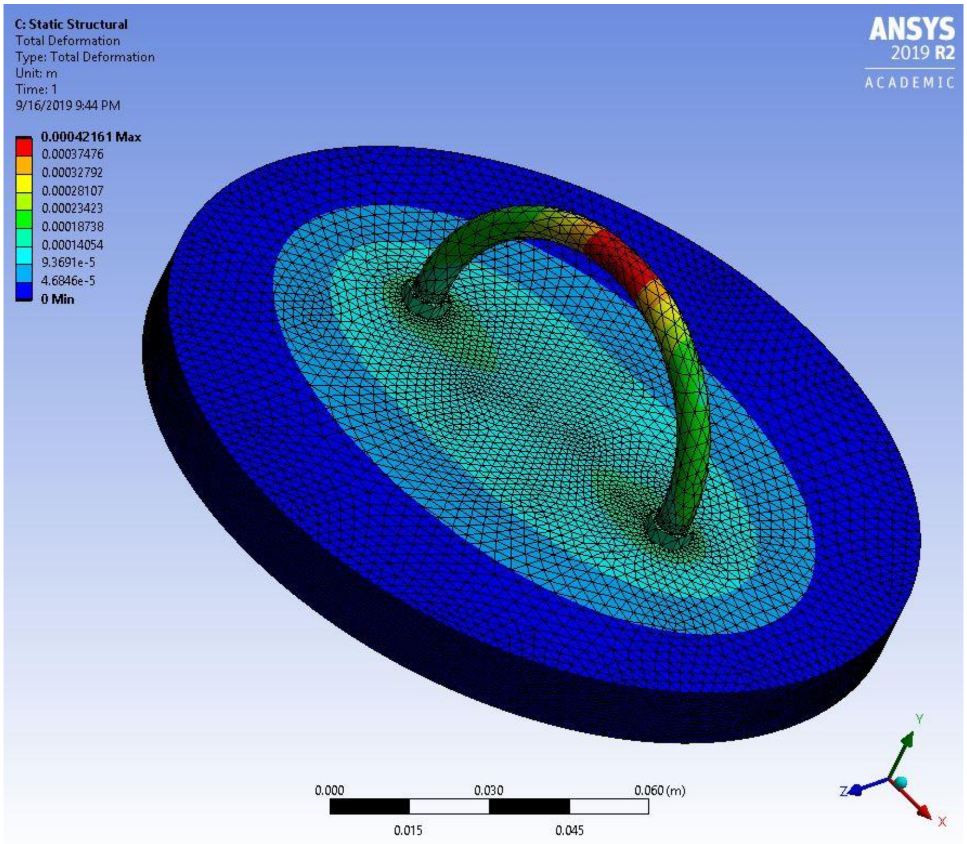

Figure 4--6 Bulkhead Deformation with 4000 N of Force Applied on the U-bolt

4.1.3 Material Selection

Good material selection is a vital part of the design process. The goal is to create a reusable rocket, without over expenditure on material costs. Based on RockSim analysis, the rocket will experience an estimated maximum Mach number of 0.56, thus the rocket will stay well below the transonic and supersonic regimes. This allows the team access to a lot of possible material choices for the body tubes of the rocket.

4.1.3.1 Phenolic Tubing

Phenolic tubing is a stronger alternative to a cardboard tubing. It is resin impregnated and heat cured which leads to its ability to endure larger amounts of compressive forces than cardboard alone. Additionally, it is inexpensive as costs run at $10/foot for a 6-inch body tube. However, phenolic tubing is susceptible to impact and puncture damage, which compromises NASA’s requirement of rocket reusability.

4.1.3.2 Blue Tube

Blue Tube is a better alternative to phenolic tubing. It provides the impact and abrasion resistance that phenolic tubing lacks. Additionally, it maintains a relatively low cost, as it runs about $18/foot for a 6-inch tube. The downside of its increased durability is its increased weight, with 48-inch tube weighing 41.61oz. However, this additional weight is proved to be insignificant with high-powered motors. The primary reason to avoid Blue Tube is that it is not water resistant. Under perfect conditions, the rocket should not encounter water, however water damage is still a possibility.

4.1.3.3 G12 Fiberglass

G12 Fiberglass is a durable composite that would ensure the reusability of the rocket. G12 Fiberglass can take blunt impacts without showing damage. Additionally, the material is water resistant which minimizes the risk of water damage to the rocket. Past club experience with this material have been very positive, so there is more inclination to use fiberglass for the upcoming competition. G12 fiberglass is also commercially available for 6-inch body tubes. The pressing negative aspects of fiberglass are its weight and its cost. G12 fiberglass weights 96oz for a 48-inch-long 6-inch diameter tube and costs $54/foot. This is twice the weight and three times the cost of Blue Tube.

4.1.3.4 Carbon Fiber

Carbon fiber is a more durable and lighter composite alternative to fiberglass. Carbon fiber features a very high strength-to-weight ratio and a high stiffness. It is an ideal material for most components of the rocket. However, it is extremely costly as it runs around $96/foot.

All factors considered, G12 fiberglass will be the material used for the body tube of the rocket. The material is significantly more durable than Blue Tube and is water resistant. G12 Fiberglass has the ability to undergo blunt impacts without failure, which is a critical property when meeting NASA's rocket reusability requirement. The downsides of weight and cost are overcome by the benefits of the material. RockSim simulations shown in Figure 4--7 have predicted that the rocket will be able to fly in between the NASA required altitude with a full G12 fiberglass body, so weight is presently a non-issue. As for costs, the teams budget can handle the extra expense of a fiber glass body tube. The team cannot handle the additional costs of carbon fiber, so this puts carbon fiber out of consideration.

The nose cone of the rocket will be made from molded fiberglass due to commercial availability. While molded fiberglass has weaker physical properties than G12 fiberglass, it has proven to be more than sufficient in previous club rockets.

4.1.4 Construction Methods

4.1.4.1 Bulkhead Fabrication

Fabrication of the bulkhead begins with a CAD model. These models are then used to laser cut bulkhead layers from 1/8-inch-thick aircraft grade birch plywood. A number of preselected layers will be cut. Once all layers have been cut, the fabrication of the final bulkhead begins. Two small holes are cut in each layer to make room for the insertion of dowel rods. After the dowels are inserted, West Systems two-part epoxy is applied to both sides of each layer, except for the top and bottom layers, where epoxy is applied to one side. The layers are then stacked, using the wooden dowels to keep the layers aligned. Once all layers are placed together, the bulkhead is placed under plastic sheeting and a vacuum is pulled. Weights are placed on top of the bulkhead to promote adhesion. This is left for 24 hours for the epoxy to cure. After this, any additions to the bulkhead, such as U-bolts, blast caps, or terminal blocks are installed. The bulkhead is now ready to be installed inside the launch vehicle. A thin layer of epoxy is added around the edge of the bulkhead. The bulkhead is then slid into the fuselage, with which it has a friction fit. If the bulkhead is unable to fit, then it must be sanded to fit. Once the bulkhead is in position, an epoxy fillet is added to both sides of the bulkhead. These fillets are made with the standard two-part epoxy plus colloidal silica to thicken the epoxy. The bulkhead is then left undisturbed for 24 hours for the epoxy to cure.

4.1.4.1(a) Safety Standards

During bulkhead fabrication, team members will follow all safety procedures put in place by the team's safety officer. This includes:

a) Necessary training for the operation of select power tools, including the laser cutter and drill press
b) Use of proper PPE during the operation of power tools, and the handling of epoxy. This includes latex gloves, safety glasses, and disposable respirators when necessary
c) Proper usage and storage of epoxy, which is classified as a hazardous material.

These standards are elaborated on in more detail in Section 3.

4.1.4.2 Cutting Body Tubes

The selected body tube is marked at length where it needs to be cut. Masking tape is then applied over the marking and then remarked over the tape. This is done in order to reduce splintering from cutting. A hose clamp, which will serve as a guide for cutting, is then placed around the tube and tightened at the cutting mark. From here, a utility knife is used to cut around the body tube. A Dremel can also be used to make these cuts, but in this case a hose clamp would not be used as a guiding edge as there is risk of the Dremel coming into contact with the hose clamp.

If the team has access to a drop saw, then this will be used in place of the above method. In this case, the tube will be pre-marked and then handed off to a machine shop on campus. The personnel here will make the cuts instead of club members.

4.1.4.2(a) Safety Standards

When body tubes are being cut, team members will follow all safety procedures put in place by the team's safety officer. This includes:

a) Necessary training for the operation of select power tools, including the drop saw and Dremel.
b) Use of proper PPE during the operation of power tools. This includes safety glasses and disposable respirators.

These standards are elaborated on in more detail in Section 3

4.1.4.3 Adhering Couplers to Body Tubes

Once the couplers are cut to length and marked, they are attached to the body tubes using two-part epoxy. The epoxy is left to cure for 24 hours before moving.

4.1.4.4 Securing Motor Tubes

The motor tube will be secured with a combination of two centering rings and a forward bulkhead inside the fin can, as shown in Figure 4--4. The forward bulkhead is installed first and secured with two-part epoxy. After the resin is set, the motor tube is placed in tandem with the middle centering ring. The forward side of the motor tube is epoxied to the forward bulkhead and middle centering ring. This system is then let to cure for twenty-four hours. Fins are inserted through slots previously created in the fin can. Immediately after, the aftermost bulkhead is put into place, being help to the motor tube and fin can with epoxy. After this is set, the motor tube is secured.

4.1.4.4(a) Safety Standards

During the motor tube installation, team members will follow all safety procedures put in place by the team's safety officer. This includes:

a) Use of proper PPE when handling epoxy. This includes latex gloves and safety glasses.
b) Proper usage and storage of epoxy, which is classified as a hazardous material.

These standards are elaborated on in more detail in Section 3.

4.1.4.5 Ballast Installation

If needed for stability, a ballast will be added to the nose cone of the rocket. The ballast will consist of lead blocks. These will be inserted before the nose cone ballast is installed as the blocks will be epoxied to the forward side of the bulkhead. Light filler material will also be added in with the ballast to occupy the empty space in the nose cone, in order to prevent the ballast from coming loose.

4.1.5 Motor Selection

The motor for this rocket was selected based on the apogee requirement as well as historical data within the club. An optimum choice would be the L-1150R, however this motor has been used in the club before and has been historically inconsistent with its performance. Since a large part of the competition is accurately predicting the apogee of the launch vehicle, we have decided to not use this motor.

The L-850W was also considered as a possible option in the early design phase. This motor is different than other options as it offers a lower average thrust with a longer burn time. It also appeared to be a good option to bring this rocket to its target apogee due to its total impulse. However, this motor was eventually decided against as it was determined that the motors lower average thrust would result in the rocket taking longer to reach maximum velocity. This would cause the rocket to spend more time in lower velocities, and thus spend more time with a lower stability margin.

Taking these things in consideration, the club has opted to use the Aerotech L1390G to bring our rocket to its intended apogee. Table 4--2 lists the specifications of this motor.

Table 4--2 Rocket Motor Specifications

Motor	L1390G
Propellant	1,973 g (4.3 lbs.)
Total Weight	3,876 g (8.5 lbs.)
Total Impulse	3,946.5 N·s (888 lbs.·s)
Burn Time	2.9 s

4.1.6 Projected Altitude

Simulations were run on RockSim as well as OpenRocket. These programs estimate that the rocket will reach an apogee of 4550 feet above ground level (AGL) with mild wind conditions. These simulations assume standard sea-level conditions, an 8 ft launch rail, and a launch orientation of 5° from vertical. Figure 4--7 shows altitude versus time from one of our simulations. Note that the total flight time is 55 seconds which meet the requirement of a total flight time of less than 90 seconds.

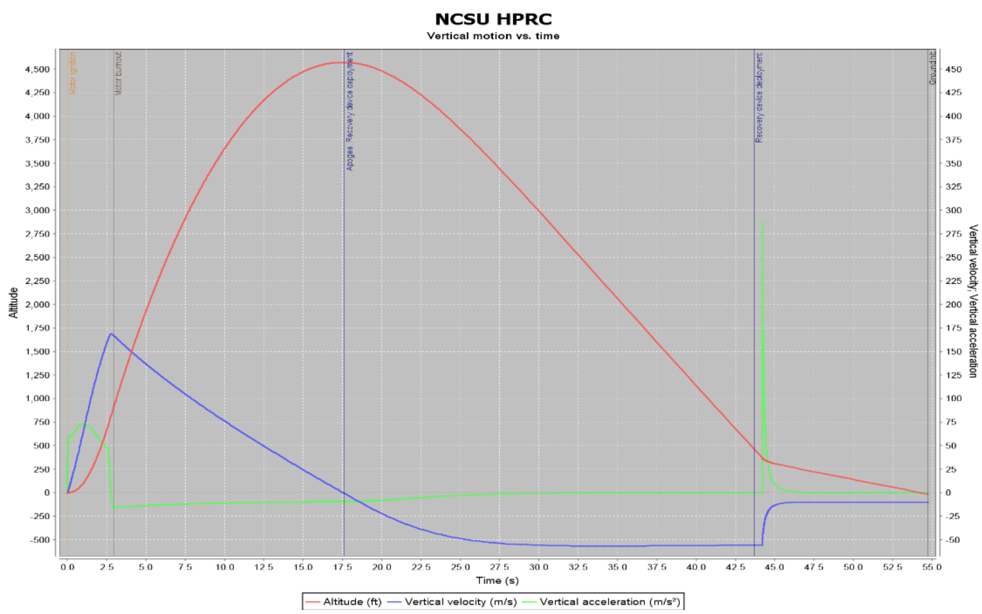

Figure 4--7 Altitude Plot of Launch Vehicle Flight

4.2 Launch Vehicle Recovery Specifications

The rocket will utilize a standard dual deploy parachute system to meet recovery requirements. The altimeter bay housing all required recovery computers will contain two fully independent altimeter systems to ensure redundancy and reliability. The altimeters will be programmed and wired to detonate pyrotechnic charges which will cause the separation of body sections and deployment of parachutes. Two events will be marked by said pyrotechnic charges: drogue deployment at apogee and main deployment at a lower altitude, as seen in Figure 4--8, below.

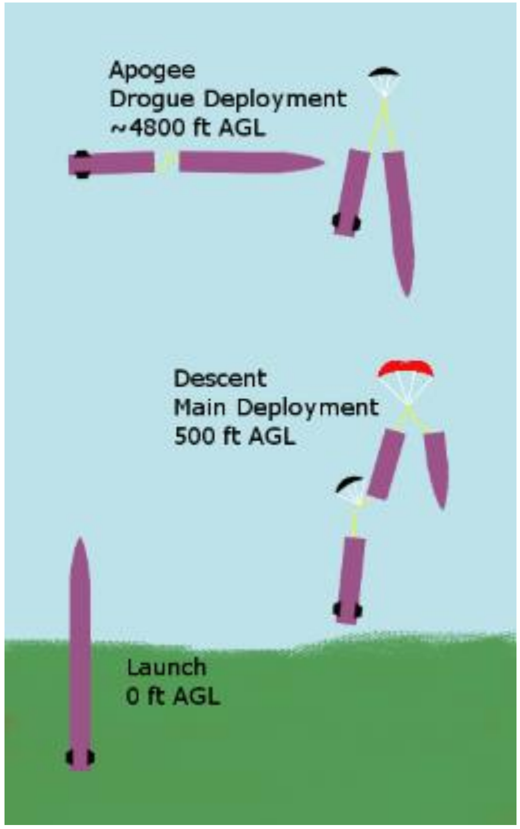

Figure 4--8 Recovery Events

4.2.1 Recovery System Requirements

In Table 4--3, below, the recovery-related project requirements for the 2020 NASA Student Launch are addressed.

Table 4--3 Recovery System Requirement Verification Table

Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation	Results
NASA3.1	The launch vehicle SHALL stage the deployment of its recovery devices.	The recovery team designs a dual deployment recovery system.	Demonstration	Recovery	See Section 4.2 for recovery system design.
NASA3.1.1	The main parachute SHALL be deployed no lower than 500 feet.	The recovery team designs a main parachute deployment event no lower than 500 feet.	Demonstration	Recovery	See Section 4.2 for recovery system design.
NASA3.1.2	The apogee event SHALL not have a delay longer than 2 seconds.	The recovery team designs a drogue parachute deployment event with an apogee delay of no more than 2 seconds.	Demonstration	Recovery	See Section 4.2 for recovery system design.
NASA3.1.3	The launch vehicle SHALL not utilize motor ejection.	The recovery and aerodynamics teams design an ejection system that does not use motor ejection.	Demonstration	Aerodynamics; Recovery	See Section 4.2 for recovery system design.
NASA3.2	The team SHALL perform a successful ground ejection test for both the drogue and main parachutes before both the subscale and full-scale launches.	The recovery and safety teams demonstrate the performance of the launch vehicle's ejection system prior to each launch.	Demonstration	Safety; Recovery	TBD
NASA3.3	Each independent section of the launch vehicle SHALL not exceed a maximum kinetic energy of 75 ft-lbf at landing.	The recovery team designs a launch vehicle that does not exceed a kinetic energy of 75 ft-lbf.	Analysis	Recovery	See Table 4--5 for current kinetic energy calculations.
NASA3.4	The recovery system SHALL contain redundant, commercially available altimeters.	The recovery team designs a redundant recovery electronic system that utilizes commercially available altimeters.	Inspection	Safety; Recovery	See Figure 4--9 for electrical recovery system design.

NASA3.5	Each altimeter SHALL have a dedicated power supply, and all recovery electronics SHALL be powered by commercially available batteries.	The recovery team designs a redundant recovery electronic system such that both the primary and redundant altimeters are powered by different commercially available batteries.	Inspection	Recovery	See Section 4.2.4 for recovery system design.
NASA3.6	Each altimeter SHALL be armed by a dedicated mechanical arming switch that is accessible from the exterior of the launch vehicle airframe when the rocket is in the launch configuration on the launch pad.	The recovery team designs a redundant recovery electronic system such that both the primary and redundant altimeters are turned on by a mechanical arming switch.	Demonstration	Safety; Recovery	See Section 4.2.4 for recovery system design.
NASA3.7	Each arming switch SHALL be capable of being locked in the ON position for launch.	The recovery team designs a redundant recovery electronic system such that both the arming switches can be locked in the ON position during launch.	Demonstration	Safety; Recovery	See Section 4.2.4 for recovery system design.
NASA3.8	The electronic components of the recovery system SHALL be completely independent of any payload electrical circuits.	The recovery team designs a redundant recovery electronic system such that all recovery electronics are independent of other on-board electronics.	Demonstration	Safety; Recovery; Payload	See Section 4.2.4 for recovery system design.
NASA3.9	Removable shear pins SHALL be used for both the main parachute compartment and the drogue parachute compartment.	The recovery team uses removable shear pins at in-flight separation points.	Inspection	Recovery	See Section 4.2 for recovery system design.
NASA3.10	The launch vehicle SHALL not drift more than 2,500 feet radius from the launch pad.	The recovery team designs a recovery system that results in a drift of no more than 2,500 feet from the launch pad. The vehicle demonstration flight results in a drift radius of no more than 2,500 feet.	Analysis; Demonstration	Recovery	See Section 4.2.2 for recovery system design.

NASA3.11	The launch vehicle SHALL make ground impact within 90 seconds after apogee.	The recovery team designs a recovery system that results in ground impact within 90 seconds of apogee.	Analysis; Demonstration	Recovery	See Section 4.2.2 for recovery system design.
NASA3.12	The team SHALL use an electronic tracking device to transmit the position of the tethered vehicle or any independent section to a ground receiver.	The recovery team chooses an electronic tracking device to transmit the position of the launch vehicle.	Demonstration	Recovery	See Section 4.2.5 for recovery system design.
NASA3.12.1	Each untethered section of the rocket SHALL have its own electronic tracking device.	The recovery team chooses an electronic tracking device to transmit the position of the launch vehicle.	Demonstration	Recovery	See Section 4.2.5 for recovery system design.
NASA3.12.2	The electronic tracking device SHALL be fully functional during the official flight on launch day.	The recovery team chooses an electronic tracking device to transmit the position of the launch vehicle.	Demonstration	Recovery	See Section 4.2.5 for recovery system design.
NASA3.13	The recovery system electronics SHALL not be adversely affected by other on-board electronic devices.	The recovery team designs a redundant recovery electronic system such that all recovery electronics are independent of other on-board electronics.	Demonstration	Safety; Recovery; Payload	See Section 4.2 for recovery system design.
NASA3.13.1	The recovery altimeters SHALL be located in a separate compartment with the vehicle from any other radio frequency transmitting and/or magnetic wave producing device.	The recovery team designs an avionics bay that is separate from other on-board, transmitting electronics.	Demonstration	Safety; Recovery	See Section 4.2 for recovery system design.
NASA3.13.2	The recovery system electronics SHALL be shielded from all onboard transmitting devices.	The recovery team designs an avionics bay that is separate from other on-board, transmitting electronics.	Demonstration	Safety; Recovery	See Section 4.2 for recovery system design.

NASA3.13.3	The recovery system electronics SHALL be shielded from all onboard devices which may generate magnetic waves.	The recovery team designs an avionics bay that is separate from other on-board, transmitting electronics.	Demonstration	Safety; Recovery	See Section 4.2 for recovery system design.
NASA3.13.4	The recovery system electronics SHALL be shielded from any other onboard electronic devices which may adversely affect the proper operation of the recovery system electronics.	The recovery team designs an avionics bay that is separate from other on-board, transmitting electronics.	Demonstration	Safety; Recovery	See Section 4.2 for recovery system design.

4.2.2 Descent Calculations

When the rocket reaches its apogee, projected to be 4809 ft AGL, the primary competition altimeter will detonate the pyrotechnic charge between the fin can and midsection. This charge will separate the two sections as well as deploying the drogue parachute. A second charge will detonate one second later by the redundant altimeter system to ensure separation, with the delay being implemented to prevent over pressurizing the chamber or burning any susceptible materials on the way out of the body tube. The drogue selected for the system is a Fruity Chutes 24 Inch Classic Elliptical Parachute, under which the rocket will descend at a rate of 81.5 ft/s as calculated by Equation 2

$$v = \sqrt{\frac{2\,g\,m}{A\,C_D\,\rho}} \tag{2}$$

Here v is the descent velocity, g is the acceleration of gravity, m is the mass of the rocket under parachute, A is the area of the parachute, C_D is the drag coefficient of the parachute, and ρ is density of air. The empty mass of the rocket, based on estimations given by Rocksim and weighing available materials, was determined to be 36.6 lb. Parachute parameters of area and drag coefficient were derived from manufacturer specs on the Fruity Chutes website to be A = 3.14 ft^2 and C_D = 1.47. Gravity and air density assumed standard sea-level conditions. The drogue parachute will be attached to both body sections with a 30 ft length of shock cord, being attached closer to the midsection than the fin can. This arrangement ensures the body sections do not impact and damage each other during descent, as well as ensuring the fin can does not collapse the main chute once it is deployed. Attached at the same point will be a Nomex cloth which will be wrapped around the drogue to protect it from the pyrotechnic charges.

When the programmed altitude of 500 ft AGL is reached by the vehicle, the altimeters will trigger another pyrotechnic charge, separating the midsection from the nosecone and payload bay as well as deploying the main parachute. The redundant altimeter system will again fire on a one second delay for the same reasons as the drogue charge. The main parachute is a Fruity Chutes 96-inch Iris UltraCompact parachute. Under this chute, descent rate was calculated to be 17.1 ft/s using A = 50.3 ft^2 and C_D = 2.09, again retrieved from the Fruity Chutes website. Main deployment shall be performed using a Nomex deployment bag to protect the parachute from pyrotechnic charges and to allow for clean parachute deployment.

Descent time has been calculated using the descent rates derived above, and the drift distance has been calculated for wind speeds up to 20 mph and tabulated in Table 4--4, below, assuming the vehicle moves at wind speed in a single direction for its whole descent time. The whole descent takes 82 seconds, satisfying the maximum time of 90 seconds set forth by requirement NASA3.11. The maximum drift distance as calculated is 2407 ft in 20 mph winds, which satisfies the maximum wind drift requirement NASA3.10 of no greater than 2500 ft. Actual launch day conditions should be well within the calculated distance due to the rocket being launched into the wind.

Table 4--4 Wind Drift Distance Calculations

Wind Speed	Descent Time	Drift Distance
0 mph	84 s	0 ft
5 mph	84 s	619 ft
10 mph	84 s	1237 ft
15 mph	84 s	1856 ft
20 mph	84 s	2474 ft

The mass of each body section has been estimated as established above in the descent rate calculations. Using the descent rate of 17.1 ft/s under main parachute, the landing kinetic energy for each independent section has been calculated and is listed in Table 4--5, below. The highest kinetic energy of any section is the nosecone section, with a kinetic energy of 73.5 ft-lbf, satisfying the maximum of 75 ft-lbf per requirement NASA3.3.

Table 4--5 Landing Kinetic Energy Calculations

Section	Mass	Kinetic Energy at Landing
Nosecone	.5011 slugs	73.5 ft-lbs.
Midsection	.3363 slugs	49.3 ft-lbs.
Fin can	.2994 slugs	43.9 ft-lbs.

4.2.3 Recovery Materials and Construction

All body sections and recovery equipment will be tethered together with 5/8-inch tubular Kevlar shock cord and steel quick links. The team has used these often in the past and being rated upwards of 1000 lbs. should withstand all recovery forces. Connections to body sections will be made utilizing a U-bolt in a permanently affixed bulkhead to ensure proper force distribution during recovery events.

Each separation point on the rocket will be held together using four nylon shear pins in accordance with recovery requirement NASA3.9. Sizing of black powder charges will be calculated using Chuck Pierce's Ejection Charge Calculator and verified through ground tests per requirement NASA3.2. Ejection tests will be conducted to ensure body sections separate with adequate force to properly deploy parachutes without causing damage to any part of the rocket or its systems.

The AV sled will be constructed from aircraft-grade birch plywood. These sheets shall be laser cut into shape and the AV sled assembled from sections that are sanded and bonded together using wood glue. The altimeters shall be secured to the sled inside Faraday cages designed to protect altimeters using standard M3 machine screws and plastic standoffs. A compartment will be laser cut and built into the AV sled to house the two 9V batteries snugly. Plastic zip ties and wire organizers will be used to ensure that all wires are neat, organized, and secure during flight for ease of maintenance and to prevent damage to recovery circuits during flight. To ensure proper assembly of the avionics bay on launch day all wires shall be color coded and labeled to prevent any wiring errors.

In prior years, the club has noticed spikes in altimeter altitude readings just following the indicated firing of the main and drogue black powder charges on the altimeter data log. This has been determined to likely be from the pressure increase caused by the pyrotechnic detonation and the less than airtight sealing of the AV bay bulkhead to the coupler section. To rectify this issue and get more accurate altimeter readings designs will be developed to determine a method of sealing the AV bay. Potential design solutions involve possibly changing construction material to a high density, machinable plastic like UHMW or to a ductile metal such as aluminum as permitted by the NAR safety code and requirement NASA2.22.11. These materials may be easily machined, and additional centering rings added to allow for O-ring, press-fit, or other sealing methods to be used to form an airtight seal between the AV bay and the black powder charges.

4.2.4 Avionics Bay Design

The AV bay sled will house two PerfectFlite StratoLogger CF altimeters, screw switches, and 9V batteries on separate circuits along with a BigRedBee BeeLine Transmitter and single cell LiPo. The StratoLogger has been chosen due to issues the team has had using other altimeter manufacturers in the past, with very few problems arising with the StratoLoggers. Two altimeters will be used for redundancy per requirement NASA3.4, with the backup altimeter set to fire its drogue charge one second after the primary altimeter and main charge 50 ft lower. In addition to the delay, the charges fired by the backup altimeter will contain 0.5 g more black powder to ensure proper separation in the event a primary charge fired but did not cause separation. Both altimeters will be connected to a fresh 9V battery of their own, making each altimeter an independent system and ensuring a long enough charge. Before each flight, the 9V battery will be voltage checked to ensure battery voltage is above 9V. Figure 4--9, below provides an electrical schematic of the AV bay sled.

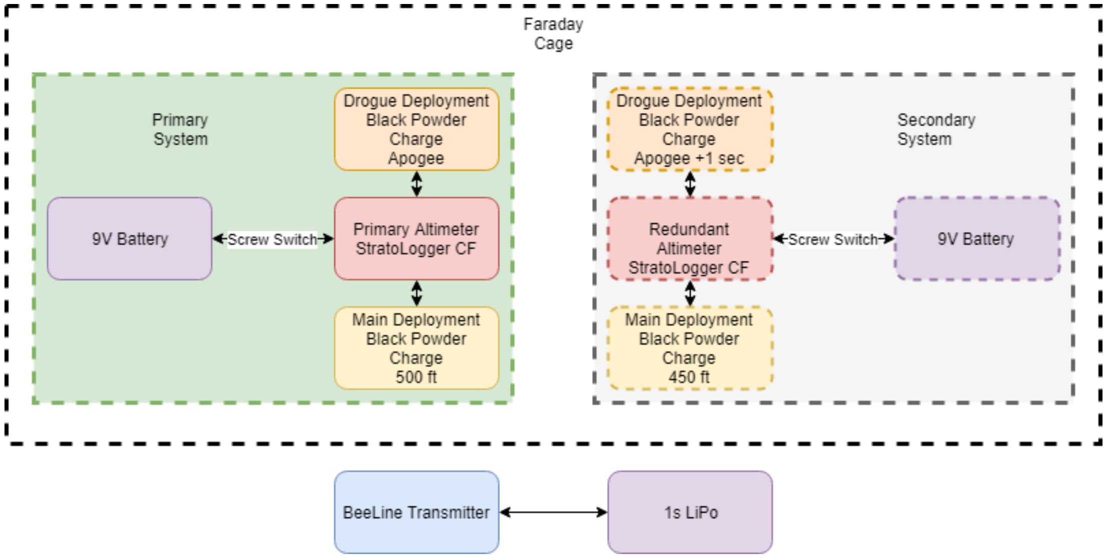

Figure 4--9 Avionics Bay Design

Two screw switches will be housed on the AV bay sled and connected to the altimeters. These screw switches allow for turning on the altimeters on the launch pad via holes in the airframe that allow access with a screwdriver per requirement NASA3.6, and due to their rotary nature will remain in the ON position throughout launch despite flight forces, per requirement NASA3.7. These screw switches require that the sled be precisely located to match the holes in the airframe, which will be achieved with threaded rods and nuts. Screw switches allow the AV bay sled to be fully removable from the body without requiring rewiring the switches. Each altimeter will have a separate, dedicated switch.

For proper altimeter functionality, static ports will be drilled into the body tube to ensure proper pressure sampling. Static port placement and sizing will be done in accordance with manufacturer recommendations by PerfectFlite. Four static ports will be drilled at 90° to each other at the same axial location. The holes will be sized according to Equation 3 below from the StratoLogger CF user's manual, where P is the port diameter in inches, L is the length of the AV Bay in inches, and D is the diameter of the AV Bay in inches:

$$P = .0008 * L * D^2 \tag{3}$$

To verify proper altimeter function before launch, both altimeters will undergo vacuum tests. Altimeters will be connected to a power source and two LED's, one connected to the drogue terminal and another to the main terminal. The altimeter setup will be placed in a viewable vacuum chamber, and a suitable vacuum to simulate flight conditions will be pulled on it. The vacuum will be released, and LED's will be monitored for drogue and main deployment. Detailed flight data will then be reviewed to ensure no unusual functionality or readings occurred during the test.

4.2.5 Rocket Tracking Device

The rocket will be equipped with a UHF tracker, with considered options being the BigRedBee BeeLine, the XFM1 Tracking Transmitter, the Merlin Systems Standard RMV Rocketry Transmitter, or the Marshall Scout UHF Transmitter. All the above options transmit on amateur radio bands thus requiring at least one member of the recovery team to have a current HAM radio license. This method was selected over a BigRedBee GPS tracker or similar for ease of communication and reliability issues with the 900 MHz band radios and GPS transponders that are sold with the tracker unit. Further, accurate GPS tracking of the rocket requires some method of turning the transmitted coordinates into a physical location such as a map or laptop/smartphone with a map application. Using a RF tracker allows for simple, compact, single person tracking of the rocket with a more robust system architecture. The transmitter will typically transmit a sequence of information in Morse code including the operator's call sign and battery voltage, followed by a series of homing beeps. Transmissions can be modified to suit operator needs and to aid in recovery of the rocket. A directional antenna of the 'Yagi' type coupled with a handheld amateur radio transponder and compass will be used to determine the straight-line direction and bearing to the rocket. This antenna provides optimal reception when pointed directly at the transmitter, and thus can be followed directly to the rocket upon landing. The ground recovery team carrying the transceiver shall be the HAM licensed individual per FCC regulations.

The BigRedBee BeeLine is the most desirable transmitter for use in this rocket. It is capable of being tuned to 315/433/869/915 MHz bands in addition to the 70cm band thus allowing for mitigation of interference per NASA2.22.10. Maximum transmitter power is 16 mW, well under the limit of 250 mW laid out in requirement NASA2.22.9. Potential issues arise from prior experience with trackers from the same manufacturer that have had reliability issues. Should those occur, a back transmitter shall be installed to protect against the possibility of not having a transmitter flight ready at competition. This radio tracker shall be powered by a 3.7 V, 1000 mAh Lithium Polymer (LiPo) battery. The LiPo battery will solely be powering the radio tracker. This is enough to meet the required 2-hour pad time, flight time, and post-landing time needed to locate and recover the rocket. Tracker power shall be switched on during launch day assembly of the AV sled and just prior to closure of the AV coupler to maximize battery lifetime. Prior to taking the rocket to the launch pad connection shall be established with the transmitter by the HAM licensed club member to ensure proper transmitter and receiver operation.

A second tracking device is not provided because the failure of the tracking device would not result in any safety risks or failure to meet the mission success criterial. Thus, it is not considered a flight-critical or mission-critical component. Use of a tracker whether it be GPS, radio, or otherwise is considered a backup means to the primary method of locating the rocket during descent and landing, that is visual tracking of the rocket during descent. The presence of an electronic tracker functions as a backup in the eventuality of any abnormal flight events render visual tracking unsuccessful.

Due to weight and access concerns, the transmitter will be housed in the midsection of the rocket along with the altimeters. In order to comply with requirement NASA3.13, the AV bay will be separated into two sections by a removable bulkhead. The altimeters will be in one section inside a Faraday cage to negate any interference from the RF transmitter, which will be in the other section.

4.3 Experimental Payload Specifications

4.3.1 Experimental Payload Requirements

To complete the payload requirements for this year's competition, the team must design a rover capable of being stowed in the launch vehicle until landing. Upon landing, the rover must drive to one of five simulated lunar ice recovery sites, obtain 10 mL of simulated lunar ice, and transport the ice 10 linear feet away from the recovery site. In Table 4--6, below, the payload-related project requirements for the 2020 NASA Student Launch are addressed.

Table 4--6 Experimental Payload Requirement Verification Table

Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation	Results
NASA4.2	The team SHALL design a system capable of being launched in a high-power rocket, landing safely, and recovering simulated lunar ice.	The project management team organizes each of the subsystem teams and works to integrate each subsystem with each other.	Demonstration	Project Management	TBD
NASA4.3.1	The launch vehicle SHALL be launched from the NASA-designated launch area using the provided Launch pad.	The aerodynamics team will design a launch vehicle to be launched from either an 8-foot 1010 rail or a 12-foot 1515 rail. The structures team will fabricate said launch vehicle.	Inspection	Aerodynamics; Structures	TBD
NASA4.3.2	The team SHALL recover a lunar ice sample from one of five recovery areas.	The payload team designs a lunar ice recovery vehicle that will collect an ice sample from one of the recovery areas.	Demonstration	Payload	TBD
NASA4.3.3	The payload SHALL recover a lunar ice sample of a minimum of 10 milliliters.	The payload team designs a lunar ice recovery vehicle that is capable of storing 10 milliliters of simulated lunar ice.	Demonstration	Payload	TBD
NASA4.3.4	The payload SHALL transport the stored sample 10 linear feet from the recovery site.	The payload team designs a lunar ice recovery vehicle that can travel 10 linear feet after collecting the sample of lunar ice.	Demonstration	Payload	TBD
NASA4.3.5	The team SHALL abide by all FAA and NAR rules and regulations.	The payload team designs a lunar ice recovery vehicle alongside the safety	Demonstration	Safety; Payload	TBD

		team that abides by all FAA and NAR rules.			
NASA4.3.6	The team SHALL not deploy the payload via black powder charges after ground impact.	The payload team designs a deployment system that does not utilize black powder charges after ground impact.	Inspection	Safety; Payload	TBD
NASA4.3.7	The payload SHALL be fully retained until it is deployed as designed.	The payload team designs a payload retention system that functions as designed.	Demonstration	Safety; Payload	TBD
NASA4.3.7.1	The team SHALL design a mechanical retention system.	The payload team designs a mechanical payload retention system.	Inspection	Safety; Payload	TBD
NASA4.3.7.2	The retention system SHALL be designed to successfully endure flight forces.	The payload team designs a payload retention system designed to withstand flight forces.	Analysis	Safety; Payload	TBD
NASA4.3.7.3	The retention system SHALL be a fail-safe design.	The payload team designs a fail-safe payload retention system.	Demonstration	Safety; Payload	TBD
NASA4.3.7.4	The retention system SHALL not exclusively use shear pins as a method of retention.	The payload team designs a payload retention system that does not use shear pins exclusively.	Inspection	Payload	TBD
NASA4.4.1	If jettisoned during the recovery phase, the payload SHALL receive real-time RSO permission prior to initiating the jettison event.	The safety team does not jettison the payload until real-time RSO permission is granted.	Demonstration	Safety; Payload	TBD
NASA4.4.2	If jettisoned during the recovery phase and if the payload is a UAV, the payload SHALL be tethered to the launch vehicle until the RSO has given permission to release the UAV.	The safety team does not jettison the payload until real-time RSO permission is granted.	Demonstration	Safety; Payload	TBD
NASA4.4.3	If a UAV is chosen as the payload vehicle, the team SHALL abide by all FAA regulations for model aircraft.	The safety team holds the payload design accountable for all FAA rules and regulations if the payload is a UAV.	Inspection	Safety; Payload	TBD
NASA4.4.4	If a UAV is chosen as the payload vehicle and weighs more than 0.55	The safety team holds the payload design accountable for all FAA rules and regulations if the payload is a UAV.	Inspection	Safety; Payload	TBD

	pounds, the UAV SHALL be registered with the FAA.				

4.3.2 Payload Bay Design

The payload bay design will accomplish three main objectives: stabilization of the rover through the duration of the flight, payload deployment upon landing and, through sensor feedback, autonomously conducting said deployment. This section will address the following aspects of the payload bay: overall design, orientation and stabilization, and autonomy.

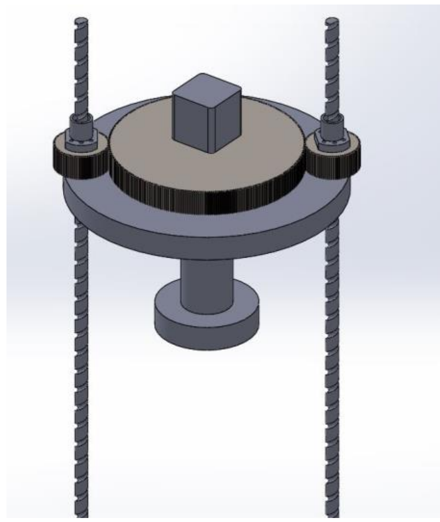

Figure 4--10 Dynamic Plate Assembly

The main deployment assembly, shown in Figure 4--10, is constructed from two lead screws, a gear system, a dynamic pushing plate, an electronic latch, a DC motor, and a power supply. The two lead screws will be fixed into the forward bulkhead and into the aft centering ring. They are each fed through a split nut that is attached to a gear. The gear system is comprised of a driving gear and two smaller gears that hold the lead screws. When the driving gear is turned, the entire pushing plate will move axially through the payload bay. To clear the distance from the last centering ring to the edge of payload bay (which once held space for the coupler), a 6.25-inch extrusion will rest on the opposite side of the plate holding the gear system. This extrusion is what will effectively push the payload out of the body tube. Finally, a solenoid latch will be embedded into the extrusion and will connect directly onto the wheel of the rover. Once the pusher plate has reached the aft centering ring, the latch will disconnect to complete the deployment process.

To adhere to the payload retention requirement by securing the payload during flight, the rover will be situated with one of its wheels locked to the deployment mechanism. The specific solenoid latch will be selected based on a load analysis to withstand the acceleration changes as well as the payload weight. Additionally, the aft-facing wheel is positioned into a well that extrudes from the aft centering ring, shown in Figure 4--11, below.

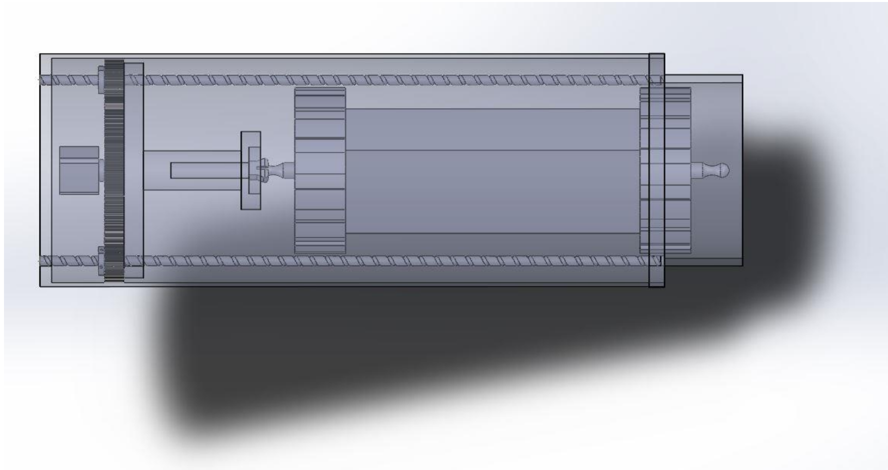

Figure 4--11 Rover and Deployment System Orientation During Flight

The pusher plate will not be able to freely move along the lead screws as the deployment motor will be idle during flight. The combination of the latch and extruding well will prevent the payload from moving in any direction parallel or perpendicular to the rocket's central axis during the flight or deployment phases. These securing mechanisms will ensure that movement is restricted in three degrees of freedom.

The payload deployment will be created with the capability of operating autonomously. However, it was decided that the system should interact with the mission control for confirmation before initiating the deployment sequence. The dynamic plate will also house a feather board micro-controller, accelerometer, and altimeter. The accelerometer and altimeter will provide the feedback for the autonomous process. There will be four major changes in acceleration from launch to landing and the fourth would signify that the payload has landed. To prevent premature deployment and to ensure payload retention during flight, an altimeter will be used in conjunction with the accelerometers feedback. The deployment procedure will only initiate if both accelerometer and altimeter agree. The feather board includes a transmitter and allows the system to request deployment permission from control, providing the third mechanism to prevent premature deployment. Once the sequence begins, the accelerometer will be the only source of feedback. As the dynamic plate reaches the aft centering ring, the motor and latch will disengage, effectively deploying the rover.

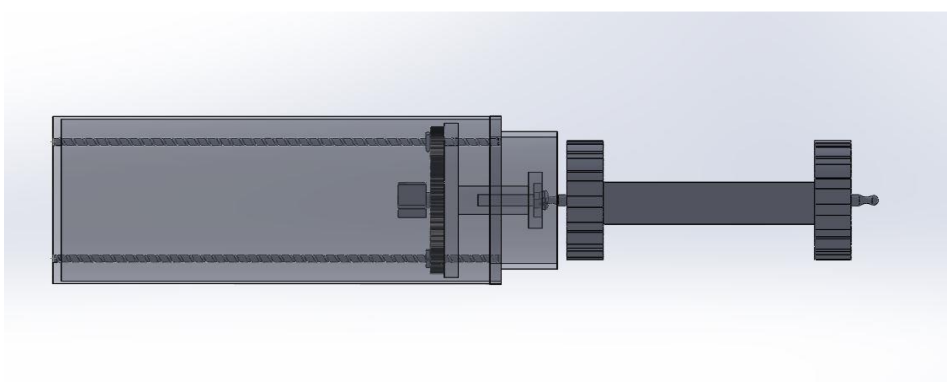

Figure 4--12 Rover Deployed from Payload Bay

4.3.2.1 Design Alternatives

4.3.2.1(a) Alternative *Dynamic Plate* Design

It should be noted that in the current design, there is no need for a separate pod to encase the payload. However, upon force analysis of the payload bay, it may prove that further protection is required. If that is the case, the leading alternate design is to replace the gear system with a series of wheels and a belt. This pulley system would require less space, allowing for the main dynamic plate to take on an oval shape. With this geometry, radial supports would extend from the inner body tube, along the minor axis of the oval plate. The minor axis of the plate would be equivalent to the diameter of the payload pod, allowing for the payload to be adequately supported and protected if necessary. The pulley system is not being considered as the main design due to complications that would arise if the belt slipped or broke during flight

4.3.2.1(b) Alternative Limit Switch Disengagement Design

If the complete autonomy within the deployment system will provide too many potentials for failure, the latch disengagement and motor could be controlled by a limit switch that breaks the circuit. Once the dynamic plate reaches the end of the payload bay, the limit switches would be pushed, current to the motor would be cut, and the electronic latch would disengage.

4.3.3 Rover Design

To complete the payload objectives of the 2020 competition, students could choose between land vehicles (rovers) and air vehicles (rotorcraft). The team compared the characteristics of the two concepts and concluded that a rover would perform the best; greater vehicle weight would make for easier digging, and the risks of crashing a flying vehicle would not be present. The leading design will use a configuration with two wheels placed coaxially on either end of the vehicle to maximize usable payload volume. The wheels used will be of a large diameter of 4.25 inches, suitable for overcoming uneven terrain. The weight will be distributed such that the rover can self-right if deployed upside down by driving forward. This eliminates the complexity of having a moving payload bay, as the rover can self-right without an external mechanism.

Inherently, a two-wheeled vehicle is unstable. Rather than actively stabilizing the rover chassis, it was decided that a third, smaller wheel would be deployed at the back of the rover to provide a third support point. The wheel will be mounted on a spring-loaded arm that will serve as both the deployment mechanism and a suspension system. After deployment from the payload bay, the third wheel will automatically unfold from its stowed configuration. To drive forward, the rover will turn both of its wheels in the same direction; changing the relative speed of the two wheels would allow the rover to steer. Each of the two drive wheels will have an independent motor. See Figure 4--13 and Figure 4--14 for a depiction of the folded and unfolded states of the rover.

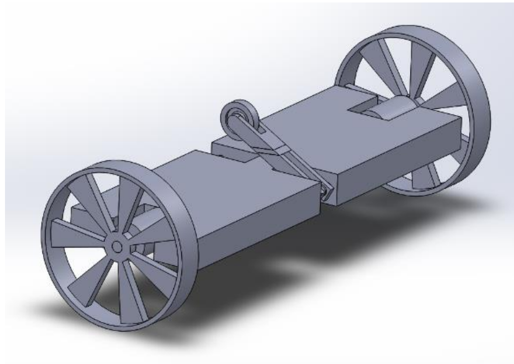

Figure 4--13 Third Wheel Stowed

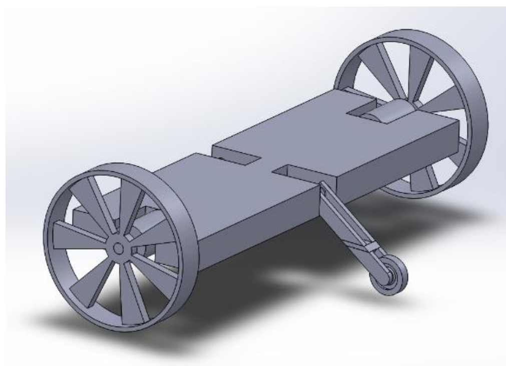

Figure 4--14 Third Wheel Deployed

Once deployed, the rover will be driven by remote control to the recovery site. After simulated ice collection is complete, the rover will be driven at least 10 linear feet away from the recovery site. To reach a target speed of 4 mph, the wheels will need to spin at an estimated average rate of 300 rpm; this would allow the rover to move at human walking speed, allowing the rover to reach the recovery site in time for the next volley of rockets at the competition.

4.3.3.1 Manufacturing Techniques

Most of the rover's components will be commercial off-the-shelf (COTS) parts. The wheels, motors, servos, controllers, and other electronics can be readily found from existing suppliers for robotics competitions, such as VEX Robotics and AndyMark. Certain components, such as structural supports for electronic components, might benefit from 3D printing. If it is needed, the team has a SeeMeCNC Rostock MAX V2 3D printer; it prints in a cylindrical space 10.5 inches in diameter and 15 inches tall, using ABS plastic. A soldering iron and soldering flux will be needed to attach wires to controller boards and motors. The structural parts of the rover will likely only require common tools such as screwdrivers and wrenches for assembly. The only advanced construction skills required should be 3D printing and soldering knowledge. A team member with software expertise, most likely in Python, will be needed to program the controllers on the rover.

4.3.3.2 Design Alternatives

4.3.3.2(a) Alternative *Tank Treads* Design

Tank-style treads were considered for rover design. These treads would provide the advantage of high traction and large surface area, meaning that they would have no issues moving out of the payload bay and navigating unexpectedly rough terrain. The tread design could take advantage of a passively stabilized payload bay; the bay could be mounted on bearings and weighted such that the "tank" rover would always be upright once the payload section of the rocket landed. The rover itself could be built such that its center of mass was conducive to this passive stabilization design. Another possibility was to forgo stabilization altogether, to simply allow the rover to drive out of the tube. The rover could land on either of its two sides, and the sampling tool could be flipped to either side. The two variations of this design are pictured in Figure 4--15.

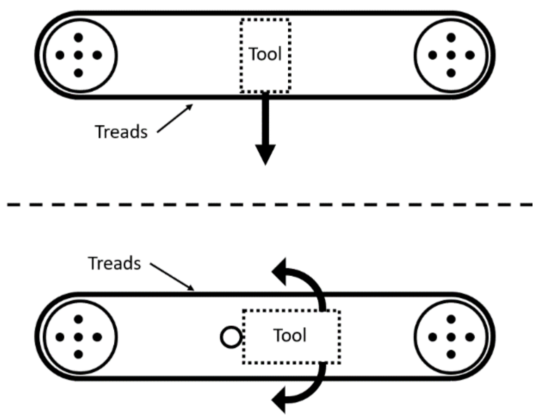

Figure 4--15 Tank Inspired Design

There are two primary issues with the tank design. There was concern on the team that a tread-fitted rover would move too slow; it was proposed that the rover move at least at human walking speed. During the competition, subsequent volleys would have to be delayed in the event the rover landed far off target; the treaded rover could be very slow in its drive to the recovery site.

4.3.3.2(b) Alternative *Foldaway Wheels* Design

Another rover drivetrain design using four wheels was considered. With the goal of maximizing wheel diameter in mind, a design with foldable wheels to be stored during flight was considered. To deploy, the rover would start driving forward, wheels still folded underneath it. A central rail would allow for better traction and guidance for the rover as it drove. Once the first pair of wheels emerged from the payload tube, they would unfold to prevent the rover from tipping over while it pulled its second set of wheels out of the payload bay. When the second set emerged, they would also unfold so that the rover would have a stable, four-wheel drive train. This method of stowage was estimated to allow for wheel diameters up to 3.5 inches. If fenders were in place to prevent the top of the wheels from contacting the payload tube interior, the rover had a good chance of fully deploying from the payload bay. A front view of this rover design can be seen in Figure 4--16.

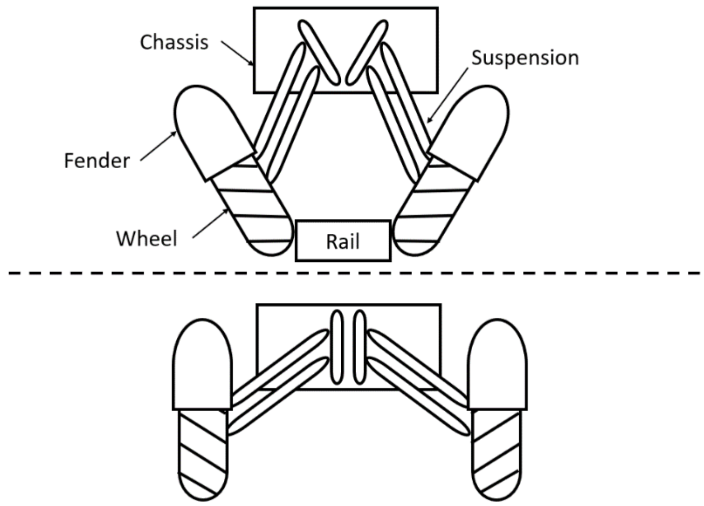

Figure 4--16 Foldaway Vehicle Design

Two issues with this design were noted: the deployment mechanisms for the wheels could be complex and prone to failure, and the design inherently placed the rover's center of mass above the payload bay's central axis, meaning that active stabilization would be needed to right the rover before deployment.

4.3.3.2(c) Alternative Variable Chassis Height Design

Once the two-wheeled rover design was selected, one method of allowing the ice collection tool to reach ground level was proposed as part of the rover's design. The wheels could be angled upward such that the chassis of the rover would sink to ground level, allowing the Sample Ice Collection and Containment Unit (SICCU) to contact simulated ice at the recovery site. Once the simulated ice was collected, the wheels would return to their original angle to drive away from the recovery site. A flexible tail, a precursor to the third wheel, would provide stability regardless of the drive wheels' orientation. An illustration of this design can be seen in Figure 4--17 and Figure 4--18.

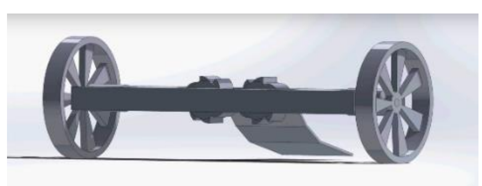

Figure 4--17 Driving Configuration

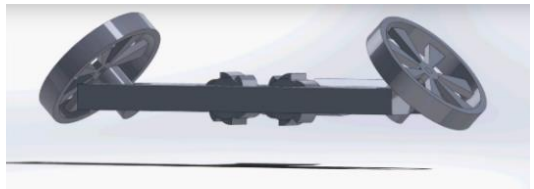

Figure 4--18 Collection Configuration

The team pointed out that this design posed considerable risk to the ice collection process; the angling wheels would have to fight friction when lowering and raising the chassis.

4.3.3.2(d) Alternative Deployable Micro-Vehicle Design

One enhancement to the current two-wheeled design could come in the form of a smaller vehicle deployed from the main rover. There are a few possible uses for a secondary vehicle, and they could be accomplished without hampering the main rover's functionality, even in the event of failure. One potential micro-vehicle could be a UAV equipped with a camera to provide video feed of upcoming terrain, informing the rover drivers of potential hazards. Alternatively, this small UAV might be flown to the recovery site and serve as a beacon that the main rover could follow autonomously; in the event of a flight or beacon failure, the rover could still be driven manually. Another micro-vehicle design could be a "dump-truck" that deploys from underneath the main rover's chassis; once the simulated ice was collected by the main rover at the recovery site, the sample could be put into the smaller rover to be driven 10 linear feet away. In the event of the micro-vehicle's failure, the main rover could perform the transportation itself. These enhancements would provide unique challenges to overcome in stowing, controlling, and powering these small vehicles, as well as in designing them to prevent interference with the main rover's functionality.

4.3.4 Sample Ice Collection and Containment Unit (SICCU)

Once the rover arrives to an appropriate recovery site the Sample Ice Collection and Containment Unit (SICCU) will be deployed. Deployment will be accomplished by a pair of motorized deployment arms that have two segments each. These arms are mounted to the underside of the rover chassis. The SICCU, when fully deployed, will rest on top of the ground. The motor system will be activated and the SICCU will begin rotating. The SICCU is comprised of two mirrored cylindrical drums. Each drum has small scoops extending from it. When the drums are rotating, the scoops will contact the ground and collect material. As each drum continues to rotate the material will accumulate into the interior of the drum. Figure 4--19 and Figure 4--20, below, show the proposed design for the SICCU.

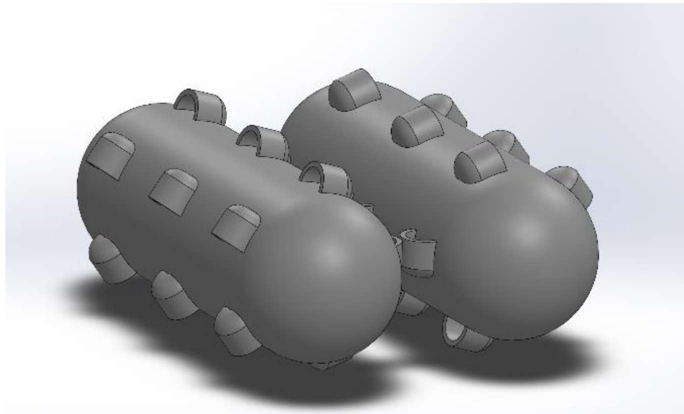

Figure 4--19 Isometric View of SICCU

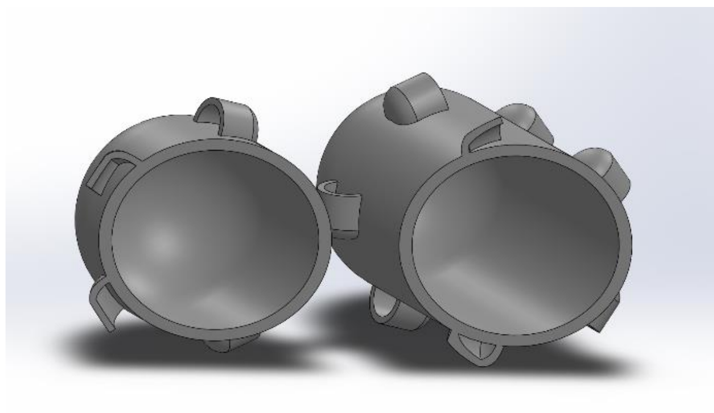

Figure 4--20 Section View of SICCU

Once enough sample ice is collected the rotation of the SICCU will be ceased by the remote operator. The arms will then retract the SICCU up from the ground and reassume the mobile orientation. Once fully in the stowed position the rover will navigate 10 feet away from the recovery site. As the rover reaches its final location the remote operator will await further instructions.

4.3.4.1 Manufacturing Techniques

To manufacture a part with this amount of geometric complexity an initial solution would be to 3D print the part. The benefit of 3D printing would be that the exact size and shape could be produced with a high level of detail. A serious drawback to this method would be the risk of delamination under load experienced while digging. 3D Printing also would be difficult because each of the drums need to be hollow, therefore this method would require significant finishing to remove excess material on the interior. The leading manufacturing method is to use PVC parts. PVC parts while being off the shelf, and therefore requiring some modification, can be found in very usable sizes and geometries. PVC offers an affordable and strong material that can withstand outdoor elements including water, making it an attractive choice. Furthermore, the affordability of the material allows for multiple iterations of design implementation as the project progresses. Using PVC shaping and cutting will be necessary to fashion the SICCU which may be challenging to mate scoops to the central drum body. Paying attention to the joint between the drum body and the scoops, the bond strength must be high to withstand the forces experienced while digging. The leading solution would be using a two-part PVC cement coupled with appropriate surface preparation such as sanding.

4.3.4.2 Design Alternatives

4.3.4.2(a) Alternative *Lengthwise Scoops* Design

Making each scoop the width of the axis of the drum such that there were only five unique scoops total, would increase the amount of surface area that can capture sample ice. This would create a larger profile for ice to collected into the interior of the drum. With longer scoop-length and therefore longer edges there are more places for the SICCU to get caught or lodged on the environment which would create new challenges. Additionally, when digging through the sample ice, a larger surface area would necessitate more torque to dig. This would be less desirable as reducing the magnitude of forces required would allow smaller and more efficient electronics to meet the design specifications.

4.3.4.2(b) Alternative *Single Drum* Design

A single drum design would not appropriately account for the forces due to the rotating drum being balanced. Without other hardware or parts acting to cancel those forces, the rover would be relying on reaction forces. Should those reaction forces be insufficient, the rover could change orientation during sample collection which would jeopardize mission success. Furthermore, the mirrored nature of the drums allows the equal and opposite moments to nullify each other's effect while also creating a pincer-like effect with the simulated ice. The leading edges of the scoops rotate together to collocate the ice. This ensures the best possible chance of sample retrieval.

4.3.4.2(c) Alternative Clasping Sample Collector Design

This design forfeits some of the complexity of a rotating sample collection device but introducing new problems as well. While necessitating less electronics and moving parts this method does not have as much systemic reliability. With the scoop alignment being the major factor determining the efficacy of retaining sand after acquisition, the reliability of clasping is questionable at best. Additionally, the downward collection and scooping would be more heavily dependent on the orientation and locomotion of the rover than that of a rotating scoop design solution. Because the clasping solution relies on translational motion and not rotational the reaction forces from digging would have a higher chance of changing the rover's orientation during operation in comparison to a rotational solution. If the clasping scoops articulated the model would likely be that of a cantilevered beam, the result would be that at the scale an insufficient amount of force could be transferred such that scoops could glide through the ice to get an appropriate scoop.

4.4 Technical Challenges

4.4.1 Launch Vehicle Challenges

An important challenge to recognize is the issue of communication within the senior design team. In the past, communication issues between sub-system leads have led to roadblocks and conflicts, which unnecessarily slow vital processes. It is a challenge keeping information flowing between all team leads during busy times and it requires deliberate effort to keep the information moving. Even though it is difficult, our senior design team is going to put efforts into effective communication and conflict resolution.

The first avenue of communication is through a task organization program called Asana. Here, all tasks are organized by to-do, in-progress, blocked, and completed. This allows for leads to see tasks being led by other sub-system leaders. All leads will have a better grasp of what their counter parts are working on.

In person communication skills will also be refined to allow for effective personal communication, even during stressful periods. Stressful periods tend to promote poor behavior, especially if things are not going well. Aggression caused by stress needs to be avoided as this is detrimental to team morale and benefits no one. To avoid this, we will make a commitment to resolve issues when they arise, rather than choosing to not bring them up to avoid confrontation. Additionally, communication skills that can be used during stressful period will be researched and taught to the senior design team. The hope of these efforts is to mitigate unnecessary conflict and production delays.

4.4.2 Recovery System Challenges

Due to the altitude, rail exit speed, stability and motor selection requirements, the team has decided on an L1390G motor. This motor is rather powerful compared to the size and weight of the launch vehicle, making the apogee higher than would be preferred. The aerodynamics of the rocket were modified to try to balance stability while bringing down the apogee, but eventually the only solution was to increase the weight of the rocket. By increasing the weight of the launch vehicle, the apogee and descent time decreased, but kinetic energy for the body sections increased. Body weights had to be carefully tweaked to make any parachutes viable options. After carefully modifying the weights the drogue and main parachutes were selected, but both the kinetic energy and drift are very close to their limits, making the solution very sensitive to modifications.

4.4.3 Experimental Payload Challenges

4.4.3.1 Payload Bay Technical Challenges

The nose section is made up of the nose cone (33in) and payload bay (24in long), with a center of gravity (CoG) 38in from the aft end of the payload bay. During the deployment process, the CoG will shift towards the aft end. However, this shift will not necessarily compensate for the final effective length of payload bay. Just before the latch is disengaged, the payload section will have an effective length equivalent to the length of the payload plus the length of the rover (Fig X-X3). This long moment arm may cause the nose section to break static equilibrium and drive the rover into the ground, preventing successful deployment. This concern may be amplified depending on the orientation of the nose section upon landing. The ground at the launch sight is tilled and if the nose section lands with its aft end, or the opening to the payload bay, in a trough then the only way deployment would be possible is if the motor is strong enough to overcome the weight of the entire section. A potential solution to keep the section parallel with the ground, if the landing orientation is favorable, is to place a ballast in the nosecone. However, this will not help to mitigate a worst-case scenario of the payload opening facing a trough.

To prevent the deployment mechanism from getting hung up and causing the motor to stall, all potentials for resistance need to be identified and mitigated if possible. One such contributor will be the friction from the wheels. To avoid this, either the material that extrudes from the aft centering ring must allow the wheels to easily slip over the surface or the wheels will need to be wrapped in a material to reduce this friction. However, other factors need to compare including the difference in the friction coefficient between lead screw and ball screw designs.

The payload deployment sequence will only initiate if feedback from both accelerometer and altimeter register as true. One challenge will be filtering the noise in these devices to ensure that there are no false positives (or negatives) and the integration of the sensors into the deployment system provides no potentials to fail outside of a malfunctioning sensor.

4.4.3.2 Rover Technical Challenges

In general, past student launch teams have had trouble operating rovers; the terrain can be unpredictable at the competition's field. Especially difficult are the ruts created by tilling of the field; small or low-lying rovers can get stuck on the "humps" of these ruts. Due to the team's use of a two-wheeled rover, these humps will be of most concern when driving in the direction of the tilling. The chassis could get stuck on the highest point, while one or both drive wheels lose contact with the ground and lose traction.

Another possible scenario involves the sample collection system. If the collection device becomes stuck in place due to a servo malfunction, the rover may be unable to drive forward. A possible fallback plan may be to drive backwards, with the third wheel leading the rest of the rover; however, the spring-deployed arm holding the wheel was not originally intended to fight the torque induced by rotating the chassis backwards.

Since the rover will be in contact with the ground throughout its segment of the mission, there is a chance for contact with water. If launch day is preceded by rain or dew that wets the ground, water droplets could interact with electronic components and cause them to malfunction. In a worst-case scenario, the rover could drive into a puddle initially unseen by the operators, and severely damage itself. A possible solution would be to place waterproofing materials or casings around exposed connections and control boards; this comes at a cost of weight, however, which is already limited due to the heavy battery and drive motors.

Due to the rover's limited weight requirements, maintaining the weight of the rover may prove challenging. The payload bay was estimated to weigh 2 lbs., leaving 6 lbs. available to the rover itself. Currently, around 3 lbs. of the rover will be dedicated to the drive train and batteries alone, leaving 3 lbs. for all other components including the chassis structure and the sample collection mechanism. During prototyping, it may happen that the motor or battery requirements become greater than the initial estimates and force weight cuts on the other components of the rover.

4.4.3.3 Sample Collector Technical Challenges

A potential challenge is that collector size and ground clearance are opposing design criteria. While a larger collector would increase the amount of ice that could be collected, however this would compete with the larger ground clearance ensuring higher mobility. Moving forward team leads will work to the solution to ensure both criteria can be satisfied.

A potential scenario that could be difficult is that particulate matter could interfere with the drive system and prevent movement. As a contingency the system should be designed such that each drum could rotate independently. This may add complexity to the system depending on the complexity of the gearing.

5. Educational Engagement

5.1 Description of Outreach

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

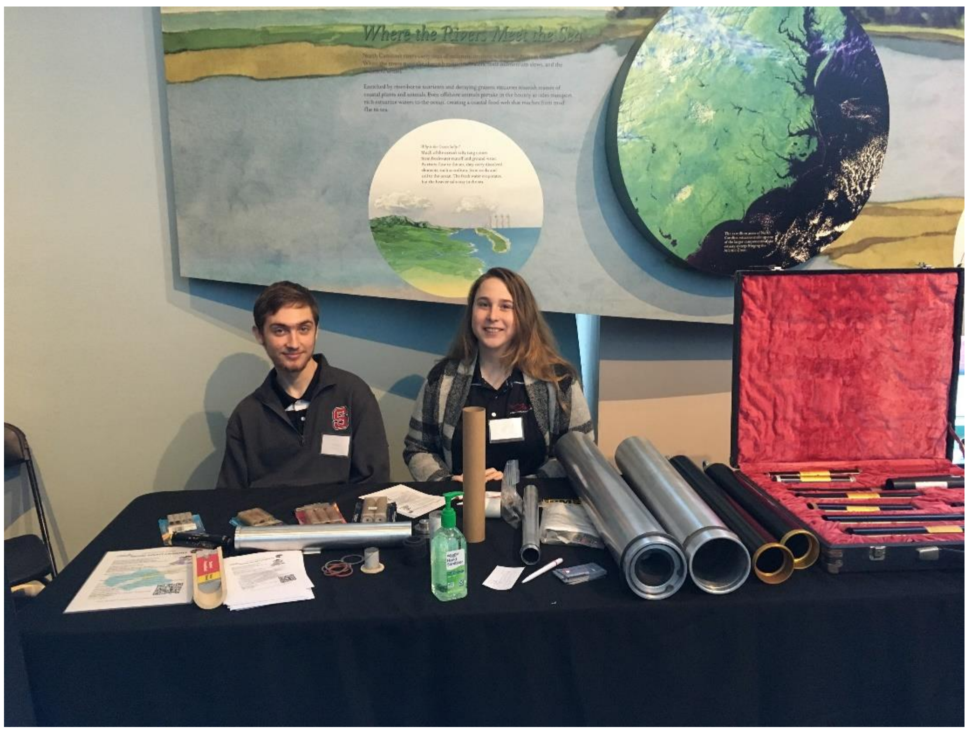

Figure 5--1 Team Members Prepared to Teach Students about Solid Propellant

The team will attend local STEM events and visit local K-12 classrooms, with the possibility of adding non-local teleconference visits, to engage students in STEM and rocketry activities. The team wants to show these students the rewarding and unique challenges provided by STEM. It brings members a great deal of satisfaction knowing that they have helped inspire future scientists, engineers, and others pursuing STEM careers. Events will include information sessions regarding HPRC and NASA Student Launch and an interactive rocket building experiment or demonstration for the students.

The High-Powered Rocketry Club plans reach a significant number of students with its outreach program. The planned activities, in section 5.2, already exceed NASA's minimum outreach participant requirements with more events still being arranged. Last year, the team reached out to 3,850 students and is working to engage more students this year. To meet this goal, the team is researching local events to engage more of the community. In past years, most of the outreach has been to elementary and middle school students, but the team is developing lesson plans and contacting local high schools for outreach opportunities.

Figure 5--2 Team Member Cleaning 2 Liter Bottles for Outreach Experiment

5.2 Planned Outreach

JY Joyner Science Go Round

Members of HPRC will travel to Joyner Elementary School to take part in the school's yearly Science Go Round. Members will have a short presentation to introduce the students to the team and NASA Student Launch. After the presentation, members will help students design, construct, and launch their own water bottle rockets. Students will then be asked to think about their design and evaluate its performance. The team has participated in this outreach event for the last several years and looks forward to another successful year. This event will take place in early November, and it is expected to reach around 100 participants.

Weatherstone Elementary STEM Expo

Weatherstone Elementary School hosts a STEM Expo every spring. HPRC sets up a classroom to engage attending students about rocket science. Members will run a short presentation introducing the team and NASA Student Launch and then demonstrate rocketry concepts by showcasing medium sized rockets and rocket motor casings. Additionally, members will conduct a quick assembly of the rocket. Members will finally assist students in designing, building, and launching water bottle rockets. This is another event that the team has participated in for the last several years and has enjoyed attending. This event will take place in early February and is expected to reach around 500 participants.

Astronomy Days

Astronomy Days is a weekend long event hosted by the North Carolina Museum of Natural Science and the Raleigh Astronomy Club. This event hosts displays, talks, and demonstrations about astronomy. HPRC helps host an amateur rocketry booth with Tripoli Rocketry Association. The team walks students through the construction of a rocket motor and allows them to put one together. Members also talk about NASA Student Launch, the team, and how visitors can get involved in local rocket launches. The event will take place in late January, and while attendance and level of engagement vary, the team expects to reach over 3000 students.

6. Project Plan

6.1 Development Schedule

Table 6--1, below, shows the development schedule for this year's project.

Table 6--1 2019-2020 NASA Student Launch Schedule

Event/Task	Start Date	End Date/Submission
Request for Proposal Released	Aug. 22, 2019	
Proposal	Aug. 22, 2019	Sep. 18, 2019 3:00 pm CDT
Preliminary Design Review (PDR) Q&A	Oct. 09, 2019	
PDR	Oct. 09, 2019	Nov. 01, 2019 8:00 am CDT
PDR Team Teleconference	Nov. 04-20, 2019	
Subscale Launch Opportunity		Nov. 16, 2019
Critical Design Review (CDR) Q&A	Nov. 25, 2019	
CDR	Nov. 25, 2019	Jan. 10, 2020 8:00 am CST
CDR Team Teleconference	Jan. 13-28, 2020	
Flight Readiness Review (FRR) Q&A	Jan. 31, 2020	
Full-Scale Launch Opportunity	Feb. 22, 2020	
FRR	Jan. 31, 2020	Mar. 02, 2020 8:00 am CST
FRR Team Teleconference	Mar. 06-19, 2020	
Launch Week Q&A	Mar. 26, 2020	
Team Travel to Huntsville, AL	Apr. 01, 2020	
Launch Readiness Review (LRR)	Apr. 01, 2020	Apr. 02, 2020
Launch Week Activities	Apr. 02, 2020	Apr. 03, 2020
Launch Day	Apr. 04, 2020	
Backup Launch Day	Apr. 05, 2020	
Post-Launch Assessment Review (PLAR)	Apr. 06, 2020	Apr. 27, 2020 8:00 am CDT

ID	Task Mode	Task Name	Duration	Start	Finish
1		Proposal	20 days	Thu 8/22/19	Wed 9/18/19
2		PDR Milestone Report	22 days	Thu 10/3/19	Fri 11/1/19
3		Subscale Construction	26 days	Mon 10/14/19	Sat 11/16/19
4		CDR Milestone Report	35 days	Mon 11/25/19	Fri 1/10/20
9		Testing	51 days	Sun 12/1/19	Fri 2/7/20
5		Fullscale Construction	30 days	Mon 1/13/20	Fri 2/21/20
6		FRR Milestone Report	22 days	Fri 1/31/20	Mon 3/2/20
8		NASA SL Competition	4 days	Wed 4/1/20	Sun 4/5/20
7		PLAR Milestone Report	16 days	Mon 4/6/20	Mon 4/27/20

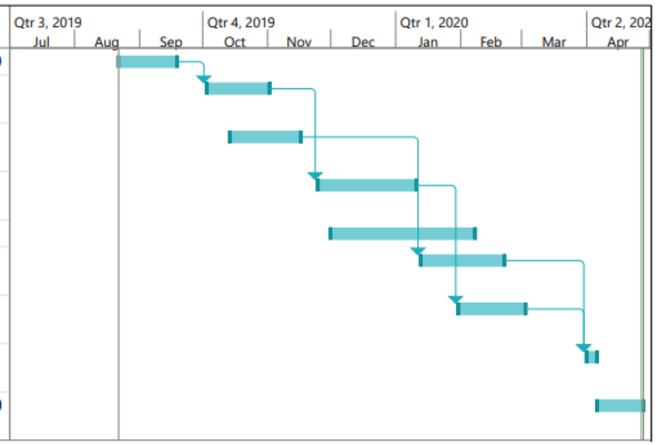

Figure 6--1 2019-2020 NASA Student Launch Schedule

6.2 Project Budget

In Table 6--2, below, the year-long budget for the 2020 NASA SL competition is listed.

Table 6--2 2020 NASA Student Launch Budget

	Item	Quantity	Price per Unit	Item Total
Subscale Structure	Aerotech I435T-14A	2	$56.00	$112.00
	Aero Pack 38mm Retainer	1	$27.00	$27.00
	Motor Casing	1	$340.00	$340.00
	38mm G12 Airframe, Motor Tube	1	$64.00	$64.00
	4" Phenolic Airframe, 3 Slots	1	$33.50	$33.50
	4" Phenolic Airframe	2	$26.00	$52.00
	4" Phenolic Coupler	4	$21.00	$84.00
	Plastic 4" 4:1 Ogive Nosecone	1	$23.00	$23.00
	Domestic Birch Plywood 1/8"x2x2	6	$14.82	$88.92
	Rail Buttons	4	$2.50	$10.00
	U-Bolts	4	$1.00	$4.00
	Blast Caps	4	$2.50	$10.00
	Terminal Blocks	3	$7.00	$21.00
	Paint	1	$100.00	$100.00
	Key Switches	2	$12.00	$24.00
	Subtotal:			**$993.42**
Full-Scale Structure	6" G12 Airframe, Half Length (30"), 3 Slots	1	$80.00	$80.00
	6" G12 Airframe, Full Length (60")	1	$228.00	$228.00
	3" G12 Airframe, Half Length (30"), Motor Tube	1	$50.00	$50.00
	6" G12 Coupler 12" Length	2	$60.00	$120.00
	6" Fiberglass 5:1 Ogive Fiberglass Nosecone	1	$94.95	$94.95
	Domestic Birch Plywood 1/8"x2x2	8	$14.82	$118.56
	Aerotech 75/3840 Motor Case	1	$360.00	$360.00
	75 mm Motor Retainer	1	$72.00	$72.00
	Rail Buttons	4	$2.50	$10.00
	U-Bolts	4	$1.00	$4.00
	Hardware	N/A	$20.00	$20.00
	Aerotech L1390G-PS	2	$161.00	$322.00
	Aerotech 75mm Forward Seal Disk	1	$37.50	$37.50
	Blast Caps	4	$2.50	$10.00
	Terminal Blocks	3	$7.00	$21.00
	Paint	1	$150.00	$150.00
	Key Switches	2	$12.00	$24.00
	Poster Printing (feet)	4	$10.00	$40.00
	Subtotal:			**$1,762.01**

Payload	1-inch PVC Pipe	1	$5.98	$5.98
	1 /2-inch PVC pipe	40	$0.49	$19.60
	1-inch PVC cap	8	$0.83	$6.64
	PVC cement	1	$8.98	$8.98
	Drum Motor	2	$19.99	$39.98
	Encoder Connector	2	$0.99	$1.98
	Bore Gear	2	$9.99	$19.98
	StratoLogger CF altimeter	1	$61.06	$61.06
	ADXL 354 multi axis Accelerometer	1	$47.39	$47.39
	Limit Switches	1	$7.99	$7.99
	77 oz-in DC Motor	1	$24.99	$24.99
	ESP32 Feather Board	1	$19.95	$19.95
	3.75 in Aluminum Spur	1	$39.72	$39.72
	1.25 in Aluminum Spur	2	$18.49	$36.98
	400mmx8mm Lead Screw	2	$21.55	$ 43.10
	6V Solenoid Lock Latch	1	$12.80	$12.80
	Drive Motor	2	$39.99	$79.98
	LiPo Battery	1	$33.99	$33.99
	4’’ Traction Wheel	2	$15.99	$31.98
	Wheel Hub	2	$2.99	$5.98
	Master Controller	1	$19.95	$19.95
	Motor Controller	1	$99.99	$99.99
	Arm Servo	1	$69.99	$69.99
	Rover Structure	1	$74.29	$74.29
	Caster Wheel	1	$4.36	$4.36
	Deployment/Suspension Spring	1	$11.27	$11.27
	Radio Receiver	1	$33.99	$33.99
	Servo Controller	1	$19.99	$19.99
	Radio Antenna	1	$54.99	$54.99
	Subtotal:			**$998.23**
Recovery and Avionics	Iris Ultra 96" Compact Parachute	1	$433.89	$433.89
	18" Elliptical Parachute	1	$57.17	$57.17
	Stainless Steel Quick Links	14	$1.97	$27.58
	5/8” Kevlar Shock Chord (yard)	20	$4.34	$86.80
	1 /4” Kevlar Shock Chord (yard)	15	$3.69	$54.75
	Black Powder	1	$17.95	$17.95
	E-Matches	1	$80.25	$80.25
	Shear Pins	1	$1.00	$1.00
	StratoLogger CF Altimeter	4	$49.46	$197.84
	6" Deployment Bag	1	$49.45	$49.45
	18" Nomex Cloth	1	$24.00	$24.00

	BeeLine Radio Transmitter	1	$59.00	$59.00
	4" Deployment Bag	1	$43.00	$43.00
	13" Nomex Cloth	1	$16.00	$16.00
	Iris Ultra Elliptical 24" Compact Parachute	1	$64.00	$64.00
	Iris Ultra Compact Elliptical 60" Parachute	1	$241.88	$241.88
	Subtotal:			**$1,454.56**
Miscellaneous	Epoxy Resin	2	$86.71	$173.42
	Epoxy Hardener	2	$45.91	$91.82
	Nuts (box)	1	$5.50	$5.50
	Screws (box)	1	$5.00	$5.00
	Washers	1	$5.00	$5.00
	Wire	1	$13.00	$13.00
	Zip Ties	1	$11.00	$11.00
	3M Electrical Tape	4	$8.00	$32.00
	9V Batteries	2	$14.00	$28.00
	Wood Glue	2	$3.00	$6.00
	Rubber Bands	1	$5.00	$5.00
	Paper Towels	1	$25.00	$25.00
	Battery Connectors	3	$5.00	$15.00
	Shipping			$1,200.00
	Incidentals (replacement tools, hardware, safety equipment)			$1,500.00
	Subtotal:			**$3,115.74**
Travel	Student Hotel Rooms (# rooms)	4	$791.70	$3,166.80
	Mentor Hotel Rooms (# rooms)	3	$1,178.10	$3,534.30
	Van Rentals (# cars)	2	$198.00	$396.00
	Gas (Miles)	1144	$0.60	$686.40
	Subtotal:			**$7,783.50**
Promotion	T-Shirts	40	$14.00	$560.00
	Polos	30	$25.00	$750.00
	Stickers	500	$0.37	$185.00
	Banner	1	$250.00	$250.00
	Subtotal:			**$1,745.00**
Total Expenses:				**$17,852.40**

6.3 Funding Plan

HPRC gets all its funding from multiple NC State University organizations, North Carolina Space Grant (NCSG), as well as potential sponsorships.

The NC State University Student Government Association's Appropriations Committee is responsible for distributing university funds to campus organizations. The application process includes a proposal, presentation, and an in-person interview. In the 2018-2019 academic year, HPRC received a total of $2,160: $640 in the fall semester and $1,520 in the spring semester. A request for $2,000 has been placed for the current fall semester and the same amount will be requested in the spring semester, assuming that the Appropriations Committee budget will remain the same.

Engineering and Technology Fee is an NC State University fund that allocates funding for academic enhancement through student organizations. Their funding will primarily pay for our faculty advisor's travel costs.

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

In addition to funding through NC State organizations, the North Carolina Space Grant will provide a large amount of monetary support to the club. NCSG accepts funding proposals during the fall semester and teams can request up to $5,000 for participation in NASA competitions. NCSG will review the proposal and inform the club on the amount awarded, which will likely be the full amount requested. These funds will be available for use starting November 2019.

In the past, HPRC has held sponsorships with Collins Aerospace, Jolly Logic, and more. We are currently seeking out new sponsorships and reaching out to our past sponsors. We hope to get at least $4,500 more in funding from various companies.

These totals are listed in Table 6-3, below, which compares the projected costs and incoming grants for the 2019-2020 school year.

Table 6--3 Projected Costs for 2019-2020 Competition

Organization	Fall Semester Amount	Spring Amount	School Year Total
Engineering Technology Fee	-	-	$1,500.00
SGA Appropriations	$900.00	$900.00	$1,800.00
Sponsorships	-	-	$3,600.00
NC Space Grant	-	-	$5,000.00
College of Engineering	-	-	$6,000.00
Total Funding:			**$17,900.00**
Total Expenses:			**$17,832.40**
Difference:			**$68.00**

6.4 Plan for Sustainability

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

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

HPRC recruits new members in both the spring and fall semesters when the university holds several club exposure events. Current members advertise the club by explaining the competition and rocketry in general, focusing on this year's project. In addition to these in person events, the club is also advertised on all of our social media outlets. Using these resources, the club usually brings in over 100 new members per year but has struggled with member retention in the past. In the 2019-2020 competition year, the club is introducing more enrichment opportunities early in the semester to engage and mentor our underclassmen. This includes lab safety training, weekly lessons during our general body meetings, and an underclassmen-led interest launch in late September. These events will provide hands-on training to new members during the report intensive parts of our project while also developing the skills of our existing members.

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

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