Stony Brook University

NASA Student Launch Initiative

2019 - 2020 Proposal

September 18, 2019

Stony Brook AIAA Chapter
113 Light Engineering Building
Stony Brook, New York 11794-2300

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1 General Information

1.1 School and Project Information

School Name: University of Stony Brook

Supporting Organizations:

- AIAA, Stony Brook University Chapter (AIAA-SBU)
- Metropolitan Rocketry Association (METRA)
- Stony Brook Department of Mechanical Engineering

Location:
American Institute of Aeronautics and Astronautics
College of Engineering and Applied Sciences
231 Engineering Building
Stony Brook, NY 11794-2200

Project Title: Stony Brook NASA Student Launch Initiative

1.2 Faculty and Mentor

Advisor Name: Dr. Sotirios Mamalis

Phone: (631) 632-8077

Email: Sotirios.Mamalis@stonybrook.edu

Dr. Sotirios Mamalis' research interests lie in the area of power generation and propulsion systems with an emphasis on internal combustion engines. His research focuses on the modeling of advanced combustion modes in engines, such as Homogeneous Charge Compression Ignition (HCCI), using conventional and alternative fuels, and development of physical models appropriate for powertrain simulation and analysis. Another of his interest areas is the thermodynamic analysis of propulsion systems using exergy concepts for identifying processes that promote efficient energy conversion.

Advisor Name: Dr. Nilanjan Chakraborty

Phone: (631) 632-9327

Email: Nilanjan.Chakraborty@stonybrook.edu

Dr. Nilanjan Chakraborty's research interests are in robotics, artificial intelligence, dynamical systems, and applied optimization. He is interested in developing capabilities for robots that will allow them to work robustly and reliably with or without human teammates and enable long-term autonomy in robotic systems. He specializes in developing contact dynamics-based algorithms for manipulation planning, robot motion planning, and distributed planning for multi-robot systems. He is a member of the IEEE Robotics and Automation Society and ACM.

Mentor Name: George N. George

Phone: (201) 893-0105

Email: georgesquared@yahoo.com

Level 2 Certification:
TRA Member #129
NAR Member #24025

1.3 Team Leadership

Name: Alisher Khodjaniyazov
Position: Team Lead
Email: alisher.khodjaniyazov@stonybrook.edu

Name: Le Si Qu
Position: Deputy Team Lead
Email: lesi.qu@stonybrook.edu

Name: Gerard Miles
Position: Navigation and Recovery Lead (NNR)
Email: gerard.miles@stonybrook.edu

Name: Ishmam Yousuf
Position: Structures, Aerodynamics and Propulsion Lead (SAP)
Email: ishmam.yousuf@stonybrook.edu

Name: Dhruv Patel
Position: Payload Lead (PAY)
Email: dhruv.patel@stonybrook.edu

1.4 Organizational Structure

The Student Launch team at Stony Brook University is comprised of 13 undergraduate students, three faculty advisors, and one professional mentor. The project is divided into three technical subsystems as follows:

- Navigation and Recovery (NNR)
- Structures, Aerodynamics, and Propulsion (SAP)
- Payload (PAY)

Each subsystem is assigned a senior design team of four to five members. In addition, AIAA-SBU will be hosting the social media content, website and STEM engagement initiatives with input from the following positions on the team:

- Social Media Lead
- STEM Engagement Lead

The breakdown of the organizational structure is shown in Figure 1 – 1 below.

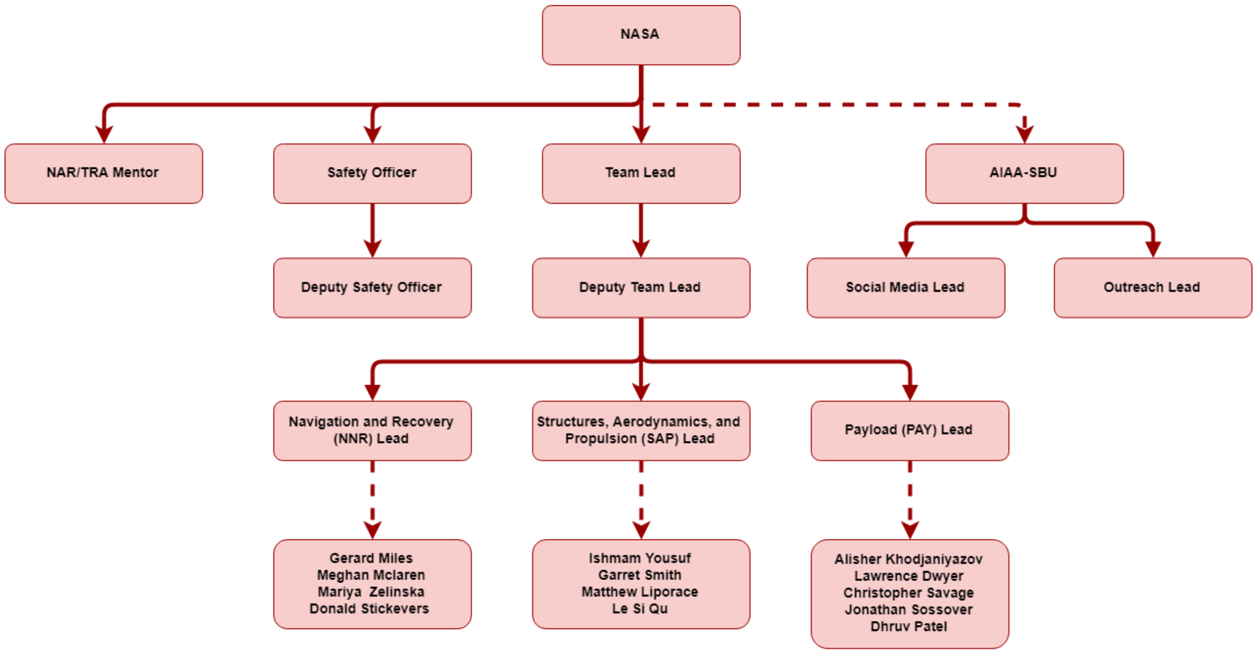


Figure 1 – 1: Organizational Structure Flowchart.

1.5 Safety Officer

Name: Jonathan Sossover
Position: Safety Officer
Email: jonathan.sossover@stonybrook.edu

Name: Donald Stickevers
Position: Deputy Safety Officer
Email: donald.stickevers@stonybrook.edu

1.6 NAR/TRA Section

The Student Launch team will work with the following NAR/TRA section for launch support:

Metropolitan Rocketry Association (METRA) in Pine Island, NY

Tripoli Prefecture #094

2 Facilities and Equipment

2.1 Engineering CAD Labs

There are two separate CAD labs located in the Engineering building at Stonybrook University and operated by the College of Engineering and Applied Sciences. One lab contains 40 computers while the other contains 24 computers. Each computer has software installed to aid in design and analysis, such as the SolidWorks CAD program, and multiphysics software such as COMSOL.

Hours of Operation:
Monday - Thursday 9:00 am - 8:00 pm
Friday 12:00 pm to 8:00 pm

2.2 SBU iCreate Innovation Lab

The Innovation lab at Stonybrook University provides students with a facility to prototype their designs. The equipment in this lab offered includes soldering irons, electrical components, paints, chemicals, various hand tools, and wiring for computers; all of which can be used free of charge. In addition, there are a variety of 3D printers that aid in rapid prototyping: a LulzBot Taz 5, a Flashforge Creator Pro, a Printrbot Simple Metal, and a few UP Mini printers.

Hours of Operation:
Monday 10:00 am - 7:00 pm
Tuesday 10:00 am - 4:00 pm
Wednesday 10:00 am - 7:00 pm
Thursday 10:00 am - 4:00 pm
Friday 10:00 am - 4:00 pm

2.3 Student Machine Shop

The machine shop housed in the basement of the Engineering building at Stonybrook University provides certified students with power tools and machining equipment, which can be used to fabricate custom parts. Any student that utilizes this facility must have a partner and a supervisor in the room with them while they work. The equipment provided includes lathes, milling machines, drill presses, bandsaws, CNC machines, welding equipment, and various power tools. There are also several skilled machinists available during business hours to assist students with their projects.

Hours of Operation:
All weekdays excluding Wednesday 10:00 am - 3:00 pm

2.4 Senior Design Lab

The senior design lab located in the basement of the Engineering building at Stonybrook University is a dedicated space for engineering students to work on and store their senior design projects. The equipment provided consists of workspaces, hand tools, and testing equipment. No work that requires protective equipment may be conducted in this area.

Hours of Operation:
Accessible at all times to senior students as long as they work with at least one other person.

2.5 Research and Development Park

A dedicated region on the Stony Brook University campus used for scientific research by researchers and corporations. Located on this site are the Advanced Energy Research & Technology Center (AERTC), the Center of Excellence in Wireless and Information Technology (CEWIT), and the Rehabilitation Research and Movement Performance (RRAMP) laboratory. The area is about 1.5 km long and 0.5 km wide and includes the testing track for the motorsports team in addition to the cross-country course.

3 Safety

3.1 Safety Requirements

As per the NASA 2020 Student Launch Handbook and Request for Proposal, there are various safety requirements, which may be found in section 5 of the handbook, to be met during rocket construction and rocket launch procedures. They are listed as follows:

- Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.
- Each team must identify a student safety officer who will be responsible for all items in requirement 3.
- The role and responsibilities of the safety officer will include, but are not limited to:
    - Monitor team activities with an emphasis on safety during:
        - Design of vehicle and payload
        - Construction of vehicle and payload components
        - Assembly of vehicle and payload
        - Ground testing of vehicle and payload
        - Subscale launch test(s)
        - Full-scale launch test(s)
        - Launch day
        - Recovery activities
        - STEM Engagement Activities
    - Implement procedures developed by the team for construction, assembly, launch, and recovery activities.
    - Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.
    - Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.
- During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.
- Teams will abide by all rules set forth by the FAA.

3.2 Safety Officer

Safety Officer Jonathan Sossover and Deputy Safety Officer Donald Stickevers will be responsible for working with each team to ensure safety is a top priority through all stages of development, testing and launch. The Safety Officer responsibilities are:

- Work with team leaders and address safety concerns at each bi-weekly meeting.
- Create, update and maintain a safety folder which will include:
  - Hazard checklist
  - Ground safety checklist
  - Flight safety checklist
  - Launch procedures
  - FAA/Local/University safety laws
  - NAR/TRA safety laws
  - Safety agreements signed by team members
  - MSDS of chemicals
  - Safety violations history
  - Hazard analysis
  - FMEA (Failure Modes and Effects Analysis)
  - Any additional documents needed to explain, guide and document scenarios related to safety
- Assist in writing ground safety checklists, flight safety checklists, and launch procedures with NAR mentors and team leaders.
- Conduct pre-launch briefings to review flight safety checklists and launch procedures.
- Work with NAR mentors to create a plan to purchase, transport, and store hazardous materials such as motors and black powder ejection charges in compliance with NAR/FAA regulations.
- Establish a hazard analysis matrix for possible hazardous events in order to mitigate the severity and frequency of such events.
- Formulate an FMEA document with the assistance of team leads to recognize and abate failure modes.
- Ensure all team members review the items in the safety folder and sign the safety agreement.
- Confirm that all involved team members are outfitted with the appropriate protective gear during construction, assembly, and launch of the vehicle.
- Enforce the appropriate procedures when safety violations occur.

3.3 Safety Laws and Compliance

The Safety Officers will have in depth knowledge of NAR/TRA code for high power rocketry, NASA SL 2019 Safety Regulations, NFPA 1127 "Code for High Power Rocket Motors", Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; "The handling and use of low explosives (Ammonium Perchlorate Solid Rocket Motors - APCP)”, and the Code of Federal Regulation 27 Part 55: Commerce in Explosives; Fire Prevention. The Safety Officers must review the Material Safety Data Sheets (MSDS) to make sure local laws and safety procedures are followed when ordering, handling, and storing all hazardous materials and chemicals. The NAR Safety Code may be found below.

Table 3 – 1: NAR Safety Code Compliance

Item	NAR Code	Compliance
1	**Certification.** I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing	Only the NAR mentor, George N. George, is permitted to purchase, store, and handle rocket motors.
2	**Materials.** I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary, ductile metal, for the construction of my rocket.	The SAP, R&N, and PAY teams are responsible for using suitable and appropriate materials on the rocketry system, to satisfy this requirement.
3	**Motors.** I will use only certified, commercially made rocket motors and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.	Only personnel with NAR/TRA level 2 certification will be allowed to purchase, store, and handle high-powered rocket motors.
4	**Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor, only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch and will use a launch switch that returns to the “off” position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.	The Range Safety Officer (RSO) will have the final say in determining all safety issues. The NAR mentor, team Safety Officers, and the Propulsion team will ensure that the motor igniters are properly installed and that all procedures are followed in compliance with the NAR Safety C.

5	**Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	All team members will be responsible for meeting this requirement and any further instructions given by the Range Safety Office during misfires. RSO will have the final say on all misfires.
6	**Launch Safety.** I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.	The team will not fly the rocket until the NAR mentor has reviewed the design, examined the build, and is satisfied with regards to established amateur rocketry design and safety guidelines. Members will also be responsible for meeting this requirement and any further instructions given by the Range Safety Officer during launch. The team leaders will be accountable for determining the stability during launch.
7	**Launcher.** I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight and that is pointed to within 20 degrees from vertical. If the wind speed exceeds 5 miles per hour, I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.	All team members will be responsible for meeting this requirement and any further instructions given by the Range Safety Officer during launch. Rockets motors are not allowed to expel titanium sponges for the 2019 NASA Student Launch Competition.

8	**Size.** My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.	SAP is responsible for meeting this requirement
9	**Flight Safety.** I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying and will ensure that my rocket will not exceed any applicable altitude limit in effect at the launch site.	All team members will be responsible for complying with this requirement. The Range Safety Officer will have the final say on wind speed and direction and rocket launch direction.
10	**Launch Site.** I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).	Location of launch sites for flight testing will be determined in association with LIARS, in compliance with FAA/NAR/Local laws for test launches. The Range Safety Officer will have the final say in determining whether it is safe for launching. No other launch sites will be allowed
11	**Launcher Location.** My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.	Location of Launch sites for flight testing will be determined in association with LIARS, in compliance with FAA/NAR/Local laws for test launches. The Range Safety Officer will have the final say in determining

		whether it is safe for launching. No other launch sites will be allowed.
12	**Recovery System.** I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.	The NAR mentor, with the help of the R&N team, will be responsible for the safe flight and recovery of the launch vehicle. Safety checklists will be used by the R&N team during the integration of the recovery system to ensure compliance of safety code during launch day. The Range Safety Officer will have the final say.
13	**Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.	All team members will be responsible for meeting this requirement and any further instructions given by the Range Safety Officer during launch.

The Stony Brook University team will only conduct approved launches, in locations and in conditions that comply with local, state, and FAA regulations. Safety Officers are required to review, understand and brief the team on all regulations regarding unmanned rocket launches and motor handling, including Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C, Amateur Rockets, Code of Federal Regulation 27 Part 55: Commerce in Explosives; and fire prevention, and NFPA 1127 “Code for High Power Rocket Motors.” Before launching or testing in an approved location both Safety Officers must approve of the weather conditions including but not limited to wind, visibility, humidity, lightning. An airbrake system with redundant avionics will be utilized to ensure the rocket does not surpass the maximum apogee altitude as agreed upon with NASA or any launch site host.

3.4 Hazard Recognition and Avoidance

During all stages of design, development, and testing, Safety Officers will determine what is required from all members of the team to ensure that hazards, their risk level, and the safety procedures required by those hazards are known, implemented and followed. Safety officers will conduct a safety briefing at each bi-weekly meeting. When any hazardous material is being used, the team member ordering, handling, or storing the material must review and follow the safe protocol outlined in the MSDS. Stony Brook University has several courses to train students on the correct procedures and safety in various labs on campus, shown in detail in section 3.7. No member of the team may conduct work in any facilities on campus if they have not completed the required safety courses. Proper safety equipment will be required for certain manufacturing and testing tasks, including but not limited to personal respirators, eye goggles, gloves, face shields, and proper footwear.

Risk analysis using the Risk Assessment Code (RAC) developed by Industrial Safety Bastion Technologies will allow us to identify and mitigate risks. The RAC tables is shown below.

Table 3 – 2: Risk Assessment Code

Probability	**Severity**			
	1 – Catastrophic	**2 – Critical**	**3 – Marginal**	**4 – Negligible**
A – Frequent	1A	2A	3A	4A
B – Probable	1B	2B	3B	4B
C – Occasional	1C	2C	3C	4C
D – Remote	1D	2D	3D	4D
E – Improbable	1E	2E	3E	4E

Table 3 – 3: Risk Level Color Code Scheme

High Risk
Moderate Risk
Low risk
Minimal Risk

Table 3 – 4: Definitions of Severity

Description	Personal Safety and Health	Facility/Equipment	Environmental
1- Catastrophic	Loss of life or a permanent disabling injury	Loss of facility, systems of associated hardware.	Irreversible severe environmental damage that violates law and regulation.
2- Critical	Severe injury of occupational related illness.	Major damage to facilities, systems, or equipment.	Reversible environmental damage causing a violation of law or regulation.
3- Marginal	Minor injury or occupational related illness.	Minor damage to facilities, systems, or equipment.	Mitigable environmental damage without violation of law or regulation where restoration activities can be accomplished.
4-Negligible	First aid injury or related occupational related illness.	Minimal damage to facilities, systems, or equipment.	Minimal environmental damage not violating law or regulation.

Table 3 – 5: Definitions of Probability

Description	Qualitative Definition	Quantitative Definition
A-Frequent	High likelihood to occur immediately or expected to be continuously experienced.	Probability > 0.1
B-Probable	Likely to occur to expected to occur frequently within time	0.1 ≥ Probability > 0.01
C-Occasional	Expected to occur several times or occasionally within time.	0.01 ≥ Probability> 0.001
D-Remote	Unlikely to occur but can be reasonably expected to occur at some point within time.	0.001 ≥ Probability> 0.000001

E-Improbable	Very unlikely to occur and an occurrence is not expected to be experienced within time.	0.000001 $\geq$ Probability

Table 3 – 6: Example of Hazard Risk Analysis Matrix

Hazard	Cause	Effect	Pre-RAC	Mitigation	Post-RAC
Injury from high power machinery	Lack of experience, knowledge of utilizing machinery, tiredness, etc.	Death or severe personal injury	**1C**	Training all personnel through completion of EOS 029-Machine Shop Safety. Not overworking members. Allowing frequent breaks. Abiding safety agreement.	**1E**
Injury from chemical	Chemical Spills, Contact with eyes, Fume inhalation, etc.	Severe personal injury	**1B**	Reading and understanding MSDS. Abiding safety agreement.	**1E**
Injury during handling motor and black powder	Lack of experience, knowledge of handling motors and preparing black powder ejection charges, etc.	Death or severe personal injury	**1C**	Allowing only NAR certified personnel to handle motor and black powder. Abiding safety agreement	**1D**
Injury from during launch	Failing to appropriately utilize flight checklists. Bystanders unaware of safety procedures.	Mission failure. Severe personal injury.	**1A**	Attending and abiding by instructions during pre-launch briefings. Attention to detail while following flight checklists and launch procedures	**1E**
Injury during ground testing	Failing to appropriately utilize ground checklists. Bystanders unaware of safety procedures	Mission failure. Severe personal injury.	**2A**	Attention to detail while following flight checklists. Performing FMEA for mission critical systems.	**2E**

3.5 Subsystem safety

Each system and subsystem will be required to use the RAM matrix and complete Failure Mode and Effects Analysis (FMEA) document that will be reviewed by both Safety Officers and the team leaders. The format is based on "Standard for Performing a Failure Modes and Effects Analysis" by NASA Goddard Space Flight Center. This format will be changed and improved as the design process continues. The first iteration can be seen below:

Table 3 – 7: Example of FMEA Format

Team Name: ___________________								
System Description: ____								
System Type: ____								
FMEA Date: _______								
Process Step:	**Potential Failure Modes:**	**Potential Failure Causes:**	**Occurrence**	**Potential Failure Effects:**	**Responsible Individuals:**	**Actions Taken:**	**Occurrence**	**Severity**

3.6 Team Safety Procedures and Checklists

Safety Officers will produce detailed safety checklists that will be continually updated as more materials are used, and systems are developed. These checklists will have detailed procedures regarding the process of transporting the rocket and materials, preparing for launch, deployment, troubleshooting, recovery, and the like.

3.6.1 Project Safety Agreement

We will utilize SBU's American Institute of Aeronautics and Astronautics (AIAA) safety agreement. All team members must read, understand, abide, and agree to all the requirements stated below:

I agree to read, understand and abide by following regulations:

- NAR/TRA code for high power rocketry

- NASA SL 2020 Safety Regulations
- NFPA 1127 "Code for High Power Rocket Motors"
- Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; "The handling and use of low explosives (Ammonium Perchlorate Solid Rocket Motors-APCP)," Code of Federal Regulation 27 Part 55: Commerce in Explosives; Fire Prevention.
- University Facility Laws (EDS 029 – Machine Shop Safety, ENV 001 – Hazardous Waste Training, ELS 002 – Lab Chemical Safety)

I agree to attend, contribute, read, understand, and abide by all ground safety checklists (during ground testing and assembly) and flight safety checklists (during pre-launch assembly)

I agree to read, understand, and follow MSDS of any chemicals I will be using.

I agree to attend, understand, and follow the requirements highlighted during safety briefings.

I agree to notify the safety officers of any concerns over any safety issues.

I agree to abide by the following requirements as highlighted in the NASA SL 2020 document:

- Range Safety Inspection of each rocket before it is flown. Each team shall comply with the determination of the safety inspection.
- The Range Safety Officer has the final say on all rocket safety issues. Therefore, the Range Safety Officer has the right to deny the launch of any rocket for safety reasons.
- Any team that does not comply with the safety requirement will not be allowed to launch their rocket.

I understand that violation of any of the mentioned requirements will result in disciplinary action. I understand it is my responsibility to read, understand, and abide by all of the requirements put forth by this agreement.

3.6.2 Plan for the Purchase/Storage/Handling of Hazardous Devices

Devices such as motors and black powder ejection charges will be purchased, stored, and handled by George N. George, who is both NAR and TRA level 2 certified. Motors and black powder canisters will not be stored in crowded areas, near igniters, or in high temperatures ranging from 45 to 100 degrees Celsius. LIARS have the facilities and resources required to store and transport such material according to the above criteria which is outlined in order to ensure the safety of all individuals involved. To this end, all motors that the team plans to utilize will first be simulated in computer software such as OpenRocket or Rockism. Since the safety officers are not certified, they will read all necessary documents regarding safety relating to such devices, complete safety checklists detailing the steps associated with handling them, and work with NAR mentors to prepare them during test flights and on the day of launch. The safety officers will also emphasize safety concerns with the Structure and Propulsion as well as Navigation and Recovery teams during safety briefings as they are the groups that will be utilizing the devices in question.

3.7 Laboratory and Machine Shop Safety Rules

In order to gain access to Facilities and Equipment on Stony Brook University Campus, the completion of certain safety courses is required. All university policies must be followed and no student will work in any laboratory if they have not had the proper training/certification/permission. The following rules apply in all Laboratories and when using any manufacturing equipment at Stony Brook University.

1. Observe the "Buddy System." No student is permitted to work alone in a laboratory.
2. Students are responsible for the cleanliness of the laboratory. Students must clean work areas. Equipment issued for laboratory use must be returned at the close of the laboratory period.
3. Students will be held financially responsible for any breakage or damage due to their own negligence or abuse. Do not modify or change any of the laboratory equipment without the permission of the Lab Manager as the student shall be held financially responsible.
4. Smoking, eating/drinking, or unruly behavior is prohibited in all laboratory areas. Unruly behavior is defined as acting in a manner that might produce unsafe conditions.
5. Stay aware of everyone in lab. Students must observe general safety precautions. Safety hazards should be reported to the Lab Manager as soon as possible.
6. Proper attire is required at all times in the laboratory. This includes but is not limited to:
    a. Only closed-toed shoes.
    b. No loose fitting clothing.
    c. No exposed jewelry of any kind.
    d. No exposed skin below the waist.
    e. No clothing below the elbow on the arms.
    f. Long hair (shoulder length or longer) must be tied up
7. Students must have taken and passed the EH&S safety courses EOS 029, ELS 002, and ENV 001. Students must provide a printed record to the Manager. This must all be done by each and every member of a lab group before the commencement of work.
8. Only work on assigned workstations. Do not tamper with the materials or project of another group.
9. Report any accidents or injuries to the Lab Manager immediately. In the event of an emergency see "For an Emergency" poster.
10. No power tools of any kind can be used in this laboratory.
11. Laboratory access may be revoked at any time due to inappropriate conduct at the sole discretion of the Lab Manager. Access revocation may be individual or group based, at the Lab Manager's discretion.

3.8 Emergency Services on Campus

For an on-campus emergency, dial (631) 632-3333 on any cell phone or 2-3333 from a university phone. If needed, there are university telephones inside the laboratories, fire extinguishers in the hallways, and first aid kits in the Labs.

4 Technical Design: Launch Vehicle

4.1 Vehicle Requirements

1. The vehicle will deliver the payload to an apogee altitude between 3,500 and 5,500 feet above ground level (AGL). Teams flying below 3,000 feet or above 6,000 feet on Launch Day will be disqualified and receive zero altitude points towards their overall project score.
2. Teams shall identify their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team's altitude score during Launch Week.
3. Teams shall identify their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team's altitude score during Launch Week.
4. The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.
5. The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.
    - Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length.
    - Nosecone shoulders which are located at in-flight separation points will be at least 1⁄2 body diameter in length.
6. The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.
7. The launch vehicle and payload will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged.
8. The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.
9. The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.
10. The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR)
    - Final motor choices will be declared by the Critical Design Review (CDR) milestone.
    - Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO) and will only be approved if the change is for the sole purpose of increasing

the safety margin. A penalty against the team's overall score will be incurred when a motor change is made after the CDR milestone, regardless of the reason.

11. The launch vehicle will be limited to a single stage.
12. The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class). The total impulse provided by a High School or Middle School launch vehicle will not exceed 2,560 Newton-seconds (K-class).
13. Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria:
    - The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.
    - Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.
    - The full pedigree of the tank will be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.
14. The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.
15. Any structural protuberance on the rocket will be located aft of the burnout center of gravity.
16. The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.
17. All teams will successfully launch and recover a subscale model of their rocket prior to CDR. Subscales are not required to be high power rockets.
    - The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale will not be used as the subscale model.
    - The subscale model will carry an altimeter capable of recording the model's apogee altitude.
    - The subscale rocket must be a newly constructed rocket, designed and built specifically for this year's project.
    - Proof of a successful flight shall be supplied in the CDR report. Altimeter data output may be used to meet this requirement.
18. All teams will complete demonstration flights as outlined below.
    - Vehicle Demonstration Flight - All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown must be the same rocket to be flown on launch day. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity,

recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full-scale demonstration flight:

- The vehicle and recovery system will have functioned as designed.
- The full-scale rocket must be a newly constructed rocket, designed and built specifically for this year's project.
- The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply:
    - If the payload is not flown, mass simulators will be used to simulate the payload mass.
    - The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.
- If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale Vehicle Demonstration Flight.
- Teams shall fly the launch day motor for the Vehicle Demonstration Flight. The team may request a waiver for the use of an alternative motor in advance if the home launch field cannot support the full impulse of the launch day motor or in other extenuating circumstances (such as weather).
- The vehicle must be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the launch day flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.
- After successfully completing the full-scale demonstration flight, the launch vehicle
  or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).
- Proof of a successful flight shall be supplied in the FRR report. Altimeter data output is required to meet this requirement.
- Vehicle Demonstration flights must be completed by the FRR submission deadline. No exceptions will be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. THIS EXTENSION IS ONLY VALID FOR RE-FLIGHTS, NOT FIRST TIME FLIGHTS. Teams completing a required re-flight must submit an FRR Addendum by the FRR Addendum deadline.

- Payload Demonstration Flight - All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown must be the same rocket to be flown on launch day. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed pay- load during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. The following criteria must be met during the Payload Demonstration Flight:
    - The payload must be fully retained until the intended point of deployment (if applicable), all retention mechanisms must function as designed, and the retention mechanism must not sustain damage requiring repair.
    - The payload flown must be the final, active version.
    - If the above criteria are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required.
    - If the above criteria are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required.

19. An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA- required Vehicle Demonstration Re-flight after the submission of the FRR Report.
    - Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline will not be permitted to fly the vehicle at launch week.
    - Teams who successfully complete a Vehicle Demonstration Flight but fail to qualify the payload by satisfactorily completing the Payload Demonstration Flight requirement will not be permitted to fly the payload at launch week.
    - Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload at launch week. Permission will not be granted if the RSO or the Review Panel have any safety concerns.
20. The team's name and launch day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.

21. All Lithium Polymer batteries will be sufficiently protected from impact with the ground and will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.
22. Vehicle Prohibitions
    - The launch vehicle will not utilize forward canards. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.
    - The launch vehicle will not utilize forward firing motors.
    - The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, Metal- Storm, etc.)
    - The launch vehicle will not utilize hybrid motors.
    - The launch vehicle will not utilize a cluster of motors.
    - The launch vehicle will not utilize friction fitting for motors.
    - The launch vehicle will not exceed Mach 1 at any point during flight.
    - Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad (i.e. a rocket with an unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast).
    - Transmissions from onboard transmitters will not exceed 250 mW of power (per transmitter).
    - Transmitters will not create excessive interference. Teams will utilize unique frequencies, hand- shake/passcode systems, or other means to mitigate interference caused to or received from other teams.
    - Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of light- weight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.

4.2 Structures, Aerodynamics & Propulsion

Figure 4 – 1: Complete Rocket Assembly & Liftoff

The purpose of the structure, propulsion & aerodynamics team is to construct a fully functioning & safe rocket consisting of the airframe, couplers, variable drag system, fins & propulsion system. The vehicle is divided into 4 separable compartments each housing different subsystems: nose cone, payload bay, avionics bay and propulsion bay. The spherically blunted ogive nose cone has a diameter of 6 inches and a length of 24 inches. The nose cone connects to the payload bay with the use of a 6-inch-long shoulder, which meets the shoulder length requirements set by the competition. It also houses a GPS tracking system which will allow the team to retrieve the rocket after launch.

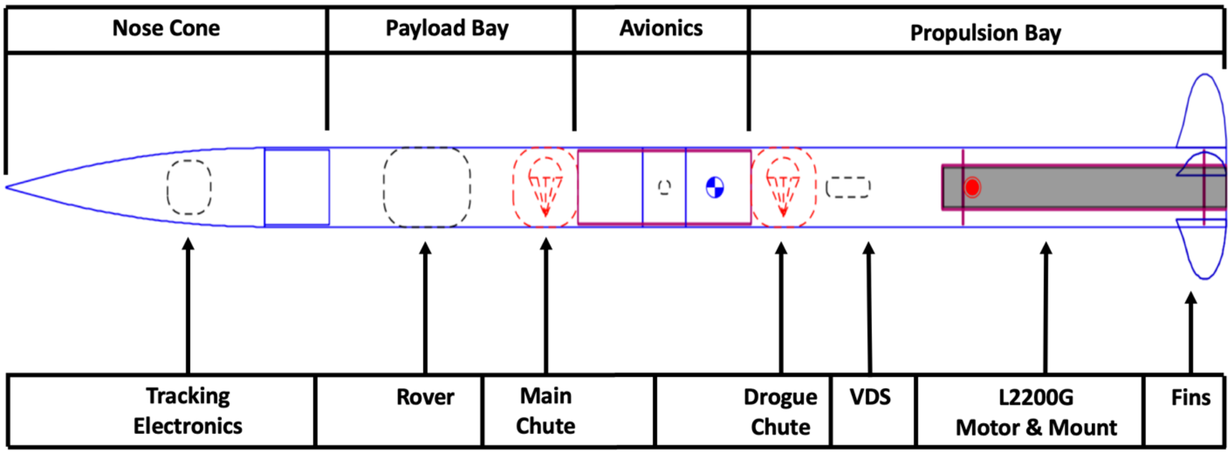


Figure 4 – 2: Rocket Compartments & Respective Positions

The payload bay houses the rover with a separation mechanism that contains lead screws which push the nose cone out of the way after a safe landing. The payload bay also houses the fore recovery system containing a shock cord attachment for the main chute. The main chute connects to the avionics bay which houses altimeters & various electronics for navigation & deployment. The avionics bay will be used as a coupler for the rocket connecting the payload bay to the propulsion bay.

The propulsion bay also acts as the aft recovery bay which houses the drogue chute and shock cord attachments. The top of the propulsion bay houses the VDS (variable drag system) and the midsection houses the L2200G motor with its motor mount & retaining rings. The propulsion bay is also slotted for the fins which attach directly to the motor mount through the booster frame.

Table 4 – 1: Overall Vehicle Specifications

Total Length	Mass	Diameter	Stability	Apogee
113 inches	54.1 lbm	6 inches	3.97 cal	5218 feet

4.2.1 Nose Cone

Figure 4 – 3: The Nose Cone & Payload Assembly

The spherically blunted ogive tangent nose cone design with chosen for the rocket due to its characteristics in reducing drag and optimizing manufacturing costs. While conical nose cones are far simpler to construct, their use primarily lies in supersonic flights. Similarly, elliptical nose cones are best suited for subsonic files. Ogive tangent nose cones are optimized for transonic flights and have widespread use in professional rocketry. The goal of the nose cone design was to find ways to reduce pressure drag & friction drag. In the subsonic region, pressure drag is more negligible than friction drag however the effects of pressure drag is seen to increase for the transonic region.

The Bluffness Ratio & the Fineness Ratio are the two parameters that affect the pressure drag. The ogive tangent nose cone design was spherically blunted, meaning that the tip was capped off with a segment of a sphere. This allows for the presence of the bluffness ratio (BR), which is essentially the tip diameter divided by the base diameter. The optimum BR of 0.15 was chosen for the nose cone design. The Fineness Ratio is essentially the length of the nose cone divided by the base diameter. Increasing the length of the nose cone increases friction drag & adds more mass to the nose cone, which could also move the CG up towards the nose cone, thus increasing the stability margin of the rocket. Optimization was done to choose an ideal FR value of 4:1 since there is very little additional gain when the FR is increased above a value above 5:1.

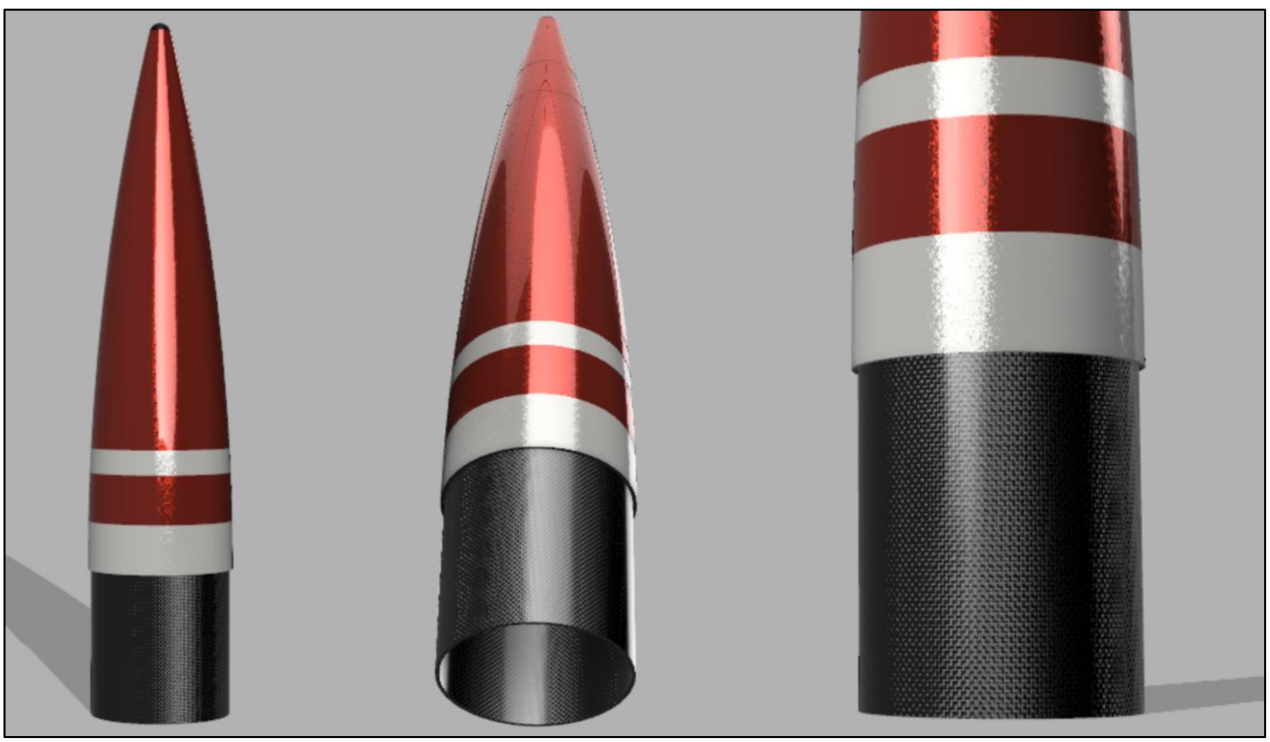


Figure 4 – 4: Nose Cone

The detailed dimensions of the nose cone can be described generally by the following equations:

$$\rho = \frac{R^2 + L^2}{2R}$$

Where ρ is the ogive radius which dictates the outer shape of the nose cone. This can be used to formulate a relationship which relates the y value at every point on the curve to the x as shown in the below:

$$y = \sqrt{\rho^2 - (L - x)^2} + R - \rho$$

However, this equation does not take the spherically blunted tip into account, which requires some additional formulations. The equation below depicts the center of the spherical nose cap where r_n is the radius of the tip, L is the length of the nose cone and R is the radius of the base. The position of the center of the spherically blunted tip can be acquired as follows:

$$x_0 = L - \sqrt{(\rho - r_n)^2 - (\rho - R)^2}$$

It is also possible to define a tangency point which mathematically formulates where the ogive tangent surface intersects the spherically blunted tip:

$$y_t = \frac{r_n(\rho - R)}{\rho - r_n}$$

$$x_t = x_0 - r_n$$

The telemetry equipment will also be located within the nose cone. Due to its strength and low density compared to other composites, carbon fiber was considered as the primary material of choice. However, carbon fiber is a conductive material and would subsequently block radio frequency signals from the GPS antenna. The nose cone will be 3D printed in three separate sections due to print bed limitations of on-campus resources. The material selected for the nose cone is polylactic acid (PLA) and the sections will be bonded together with two-part epoxy. Printing the nose cone through the Innovation Lab on campus introduces significant cost savings since university students have free access.

4.2.2 Avionics Coupler

The avionics bay will be utilized as a coupler which connects the propulsion bay to the payload bay. The 6 inch outside diameter of the coupler region matches the outside diameter of the airframe. The shoulders of the avionics bay have lengths that equal to the diameter of the air frame (6 inch). The payload side shoulder of the avionics bay fits into the payload bay while maintaining enough clearance for the fore recovery bay which houses the main chute. The propulsion side shoulder of the avionics bay fits into the propulsion bay while maintaining enough clearance for the aft recovery bay which houses the drogue chute. The total estimated length of the avionics bay is 16 inches including the shoulders & plates.

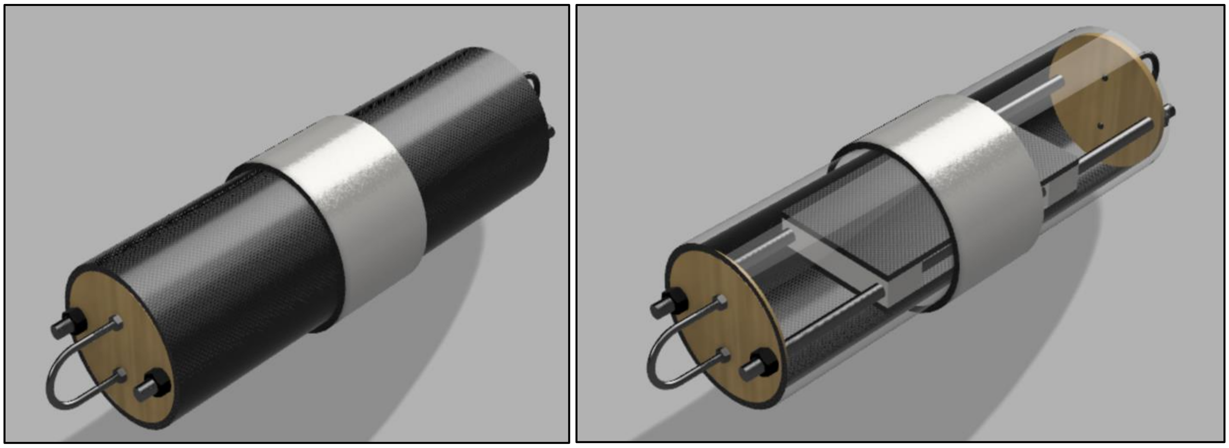


Figure 4 – 5: Avionics Bay

4.2.3 Variable Drag System

The VDS (Variable drag system) will be utilized in-flight to reach target apogee by increasing the surface area and disrupting the flow. A few methods of accomplishing this task were explored. Initially the design process included a CAM mechanism with 3 blades which is driven by a central spur gear & a DC motor. After liftoff, this VDS system would acquire readings from a redundant altimeter placed in the propulsion bay, thus directing the VDS to unfold outwards from the body of the rocket in order to increase drag. Though this system is bound to have a very fast response, there is a tradeoff between ease of use & damage to the airframe. The blade system would experience very large shear forces during the flight which would compromise structural integrity.

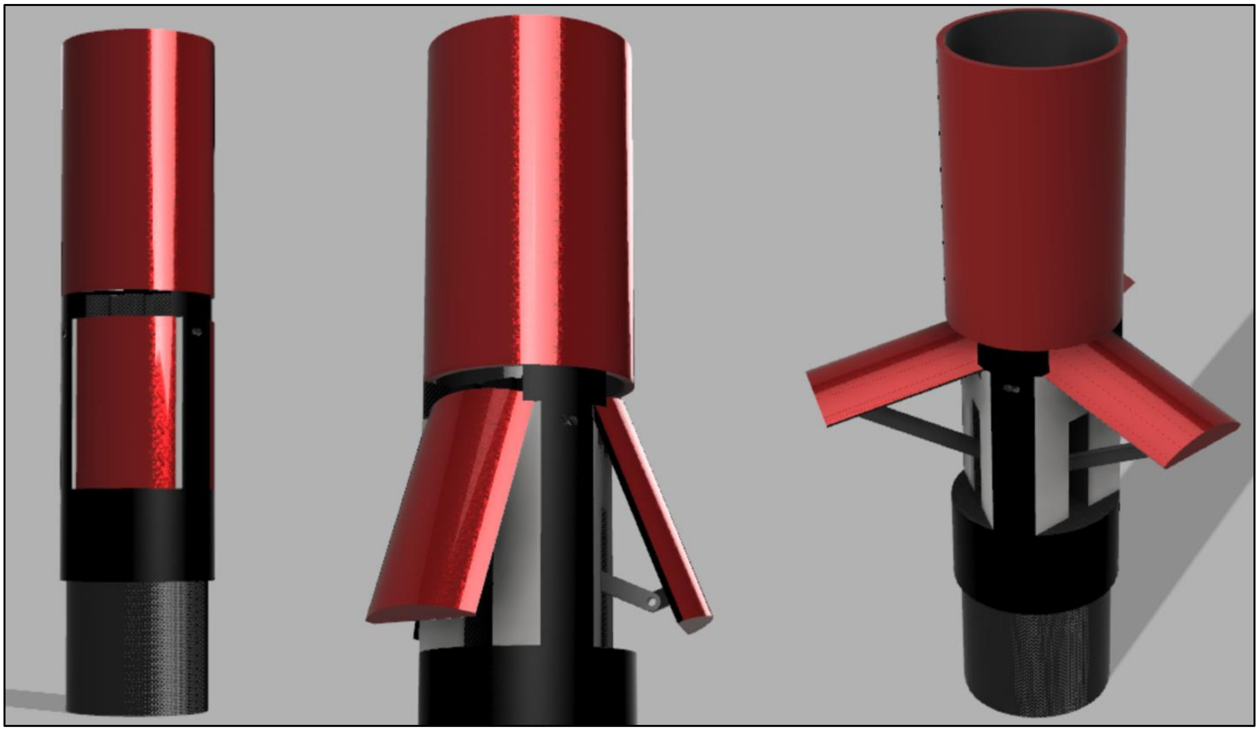


Figure 4 – 6: Variable Drag System

As a preliminary design, the VDS currently involves the use of three air brakes which is mounted on top of the propulsion bay. The total length of the air brakes & the complete VDS is designed to be 10 inches however, there is an additional 6 inches of hollow tubing which will serve as the aft recovery bay & will also provide room for the shoulder of the avionics bay. The air brakes will be hinged at the top of the VDS body which has a piston cavity. A four bar linkage system will connect the air brakes to a piston which will then be driven by a lead screw & servo motor or a linear actuator. The VDS is mounted 4 inches below the center of gravity of the rocket in order to avoid instability during liftoff. Additionally, the firing of the driving piston will be suppressed until the rocket reaches at least half of the target apogee as a safety mechanism. Readouts from a redundant altimeter in the propulsion bay will allow for the development of a closed loop control system. Although it is very difficult to simulate the behavior of the air brakes this early in the design process, extensive research and analysis will be done using FEA tools and the Flow Simulation package of SolidWorks.

4.2.4 Fins

Mounted at the bottom of the rocket are five elliptically shaped fins. Their height is 7.5 inches and base is 6.3 inches. They will be slotted through the outer tube and permanently fixed to the inner motor tube. The fins will be constructed using ¼ inch thick fiberglass with rounded edges. Once full design parameters of the competition are known, flutter analysis will be performed on the fin design.

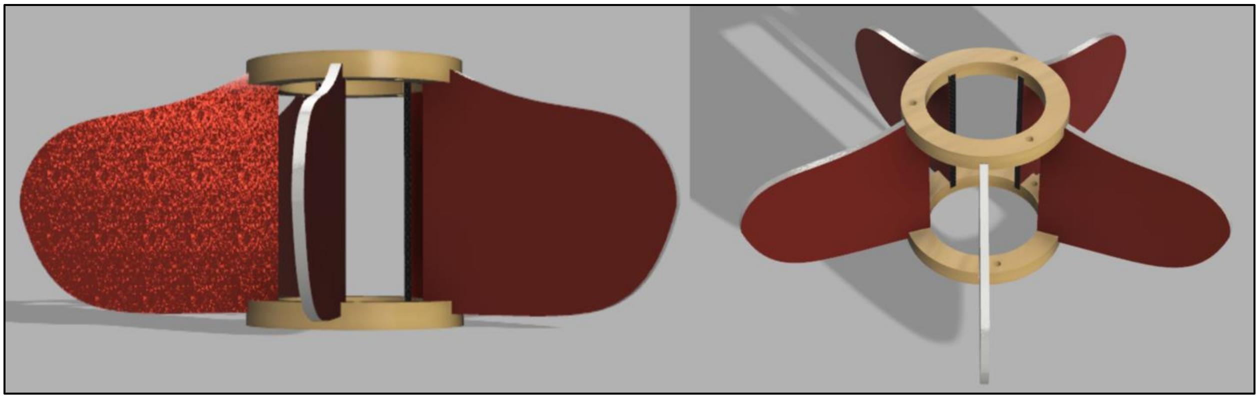


Figure 4 – 7: Elliptical Fin Assembly

Although in theory the 5 elliptical fin design produces the largest marginal stability and the highest possible apogee based on the motor choice, implementing this design will be extremely difficult. Therefore, similar simulations were also run with a simpler 3 fin cropped delta design which have root chord length of 10 inches, height of 8 inches and tip chord length of 2 inches. Further performance analysis will be performed to weigh the benefits of using the easier to implement 3 cropped delta fin design vs. the theoretically superior 5 elliptical fin design.

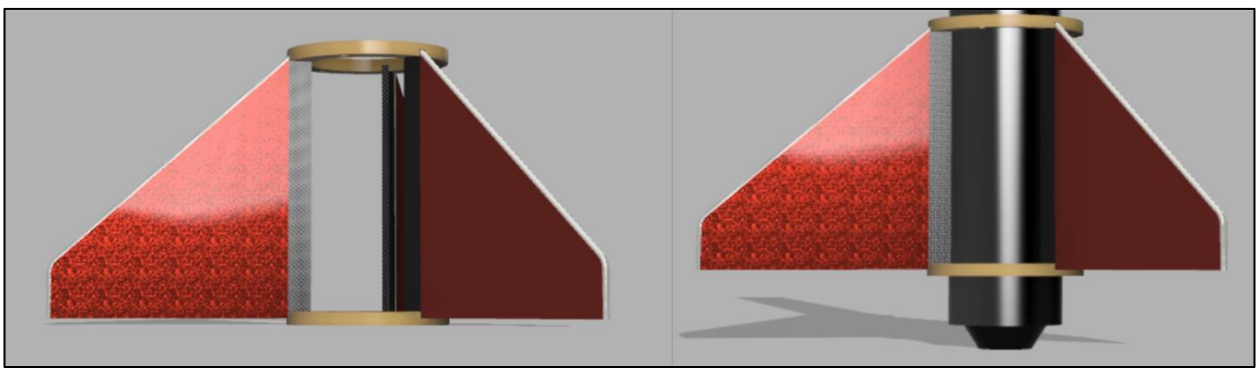


Figure 4 – 8: Cropped Delta Fin Assembly

4.2.5 Booster Bay & Propulsion

Much like any other projectile, rockets obey the basic laws of physics and rely specifically on Newton's second law to determine how high and how fast it will go. The most basic form of this equation is:

$$F = ma$$

By accounting for changes in mass during flight which will affect momentum, and the difference in pressure caused by the gasses exiting the rocket's motor nozzle, the improved equation becomes:

$$Thrust = \dot{m}u_e + A_e(P_2 - P_3)$$

Once thrust is known, the total impulse can be calculated using the equation:

$$I = \int_0^t T dt = T_{avg} t_{burn}$$

The impulse is useful for classifying rocket motors into grades which is primarily used to differentiate between how large and strong a motor is. Specific impulse on the other hand is useful for determining how efficient the motor is and follows the equation:

$$I_{sp} = \frac{I}{mg_0} = \frac{V_{eq}}{g_0} = \frac{V_e + \frac{A_e(P_e - P_0)}{\dot{m}}}{g_0}$$

It is important to note that specific impulse is in the same units no matter the convention being used. Lastly, the Rocket Equation, or Tsiolkovsky's equation, is an equation that helps determine the overall change in velocity of the rocket by relating it to the effective exhaust velocity. This equation is used by computer simulations along with some other parameters to determine trajectory of flight and apogee.

$$\Delta V_{mod} = I_{sp} g_0 \ln\left(\frac{m_f}{m_f}\right) - \ gravity\ penalty - drag\ pentalty$$

Figure 4 – 9: Booster Bay

The launch vehicle is currently estimated to be 54.1 lbm in total with the projected motor to be used being the AeroTech L2200G. This motor will be able to accelerate a rocket of this mass to a velocity of 87.4 fps at rail exit, assuming a 12 feet rail and ideal launch conditions. With this motor, even if the rocket design exceeds the current weight estimate, there is enough impulse to accelerate the rocket to an appropriate speed by the rail exit, and enough thrust to propel the rocket to an appropriate apogee that falls within the given constraints. Figure 4 – 10 and Table 4 – 2 display the manufacturer's specifications for the L2200G motor. Originally we were contemplating the use of the AeroTech K1520T however, simulations using this motor projected and apogee that was too close to the minimum threshold for comfort.

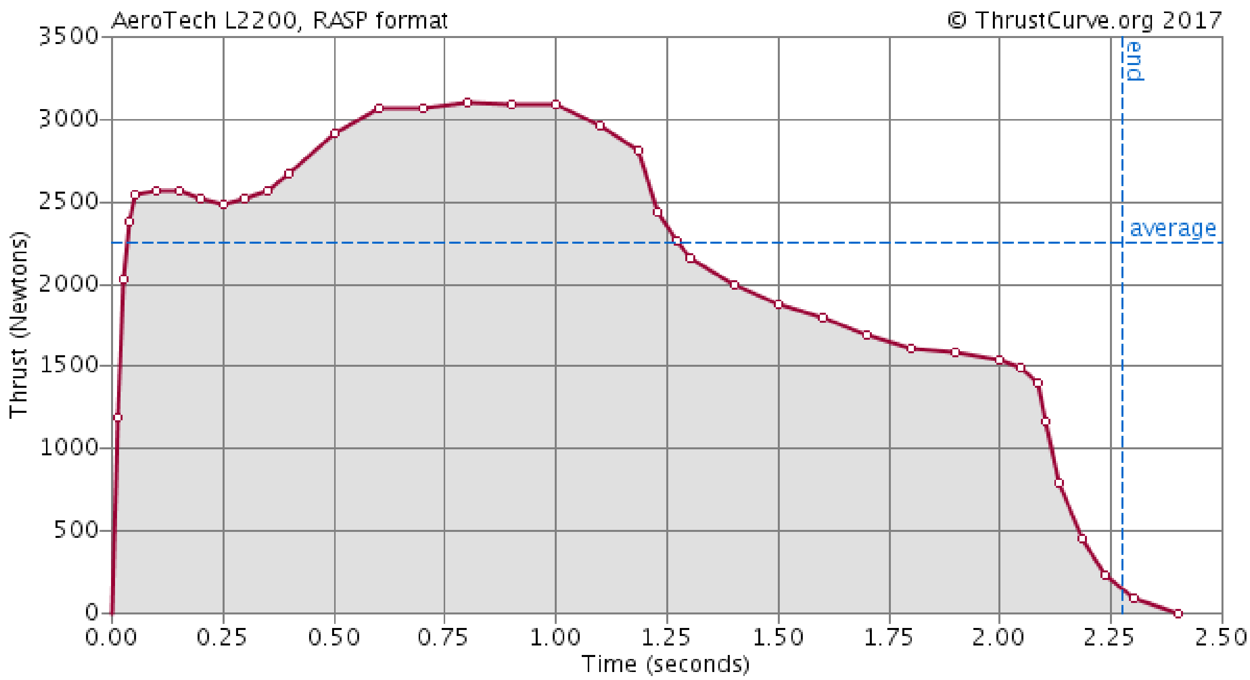


Figure 4 – 10: Thrust Curve for L2200G Motor.

Table 4 – 2: Overall Motor Specifications

Average Thrust	Total Impulse	Diameter	Burn Time
494.58 lb-s	1147.42 lb-s	75 mm	2.32 s

4.2.6 Aerodynamics & Flight Simulations

In designing the rocket, there are 3 main balancing factors: stability, cost, and apogee. Necessary equipment restricts length to 113 inches and diameter to 6 inches. While increasing the length of the rocket increases stability, material tubing cost increases too. Therefore, the rocket length and diameter were kept to a minimum.

By placing large masses near the nose cone, the center of gravity shifted higher on the rocket. Similarly, the center of pressure was shifted lower by placing the fins and drag system near the bottom. In this way, stability was increased.

Elliptical fins were chosen for their ability to minimize induced drag. In simulations, these fins maximize both stability and apogee. The elliptical shapes are slightly modified to provide greater structural stability. Furthermore, the fins hang 1 inch off the bottom of the booster, thus lowering the center of pressure. By increasing the number of fins, optimization of stability and apogee improved.

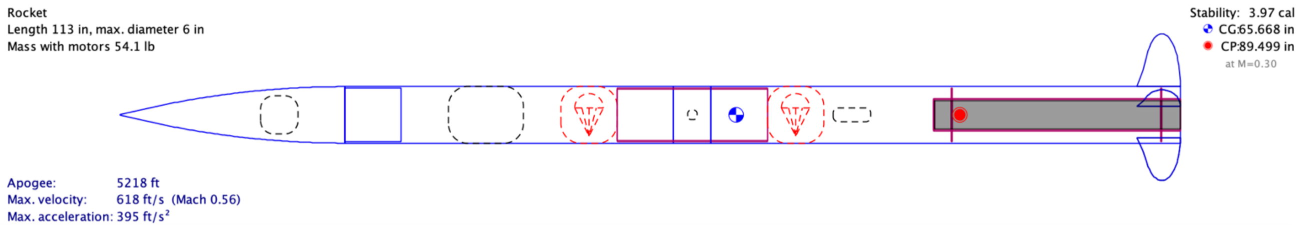


Figure 4 – 11: Listed apogee, stability & stats for 5 elliptical fin design

On the other hand, simulations were also performed by utilizing a set of 3 cropped delta fins. These fins optimized stability but not apogee since the increases to 4.42 cal and the apogee decreases to 5181 feet. However, the elliptical fins are still being considered as the primary choice since the increased apogee may lead to choosing a motor with lower average thrust which will cut down on costs massively.

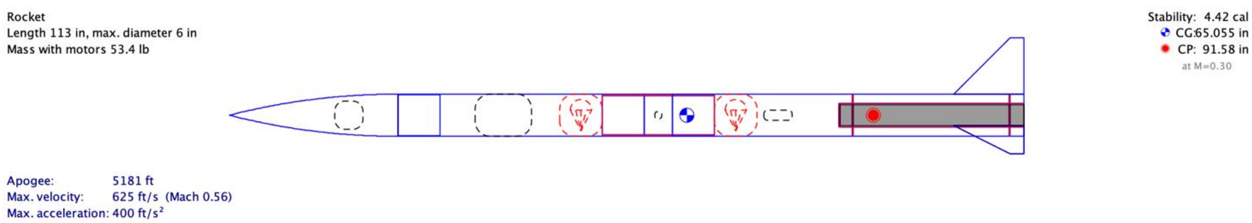


Figure 4 – 12: Listed apogee, stability & stats for 3 dropped delta fin design.

Using Open Rocket, a target apogee of 5218 feet was simulated. Upon "launch," the rocket has a 3.97 stability margin. The estimated average thrust to weight ratio is 9.14:1. As the rocket velocity increases, so does the margin of stability. Further studies upon aerodynamics will be performed using SolidWorks simulations. A stress analysis will be performed to determine issues regarding the rocket's max acceleration of 395 feet per second squared.

Table 4 – 3: Apogee Simulations

Wind Speed (mph)	Simulated Apogee (feet)
0	5223
5	5217
10	5190
15	5153

20	5125

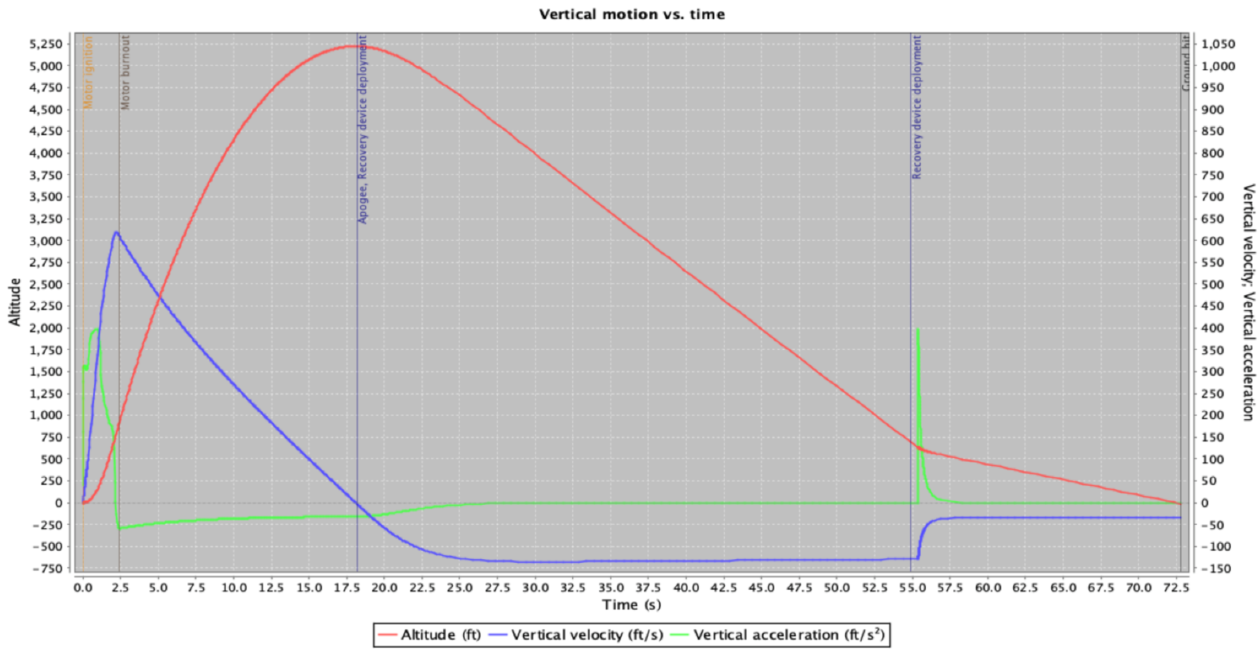


Figure 4 – 13: Altitude, Velocity & Acceleration Curves for 5 Fin Design.

4.2.7 Materials & Manufacturing Methods

The airframe houses the rocket's payload, avionics, recovery system, and propulsion. The goal for material selection is to achieve a high strength to weight ratio that can sufficiently withstand the forces of a high-powered rocket launch. The material chosen for the airframe is 6-inch fiberglass tubing which is strong and durable.

The booster bay will also contain the main parachute. Two centering rings will be used to act as the primary load path for the trust from the motor, one above the fins (forward centering ring) and one will be below (aft centering ring). The rings will be manufactured from hardwood with the use of a lathe. The forward centering ring will also have a U-bolt that will be used to attach the recovery system. An Aero Pack 75mm screw-on motor retainer will hold the engine in the rocket.

The fins will be machined from ¼ inch fiberglass sheets. Fiberglass has the appropriate strength characteristics while keeping the cost of the rocket lower. The system that will be used for the fins is through-the-wall (TTW) as opposed to surface mounting. This allows for multiple points of attachment to the airframe which increases the strength of the fins. The fins will be made from fiberglass and epoxied to the motor mount rings. There will be cutaways in the airframe to allow the fins and rings system to slide into the booster bay. Then, the fins will be bonded to the airframe with epoxy. To increase structural integrity, fillets will be added to smooth out the joint between the airframe and fin surfaces. All custom parts will be machined in the Student Machine Shop by team members using a variety of tools including the lathe, mill, band saw, and drill press.

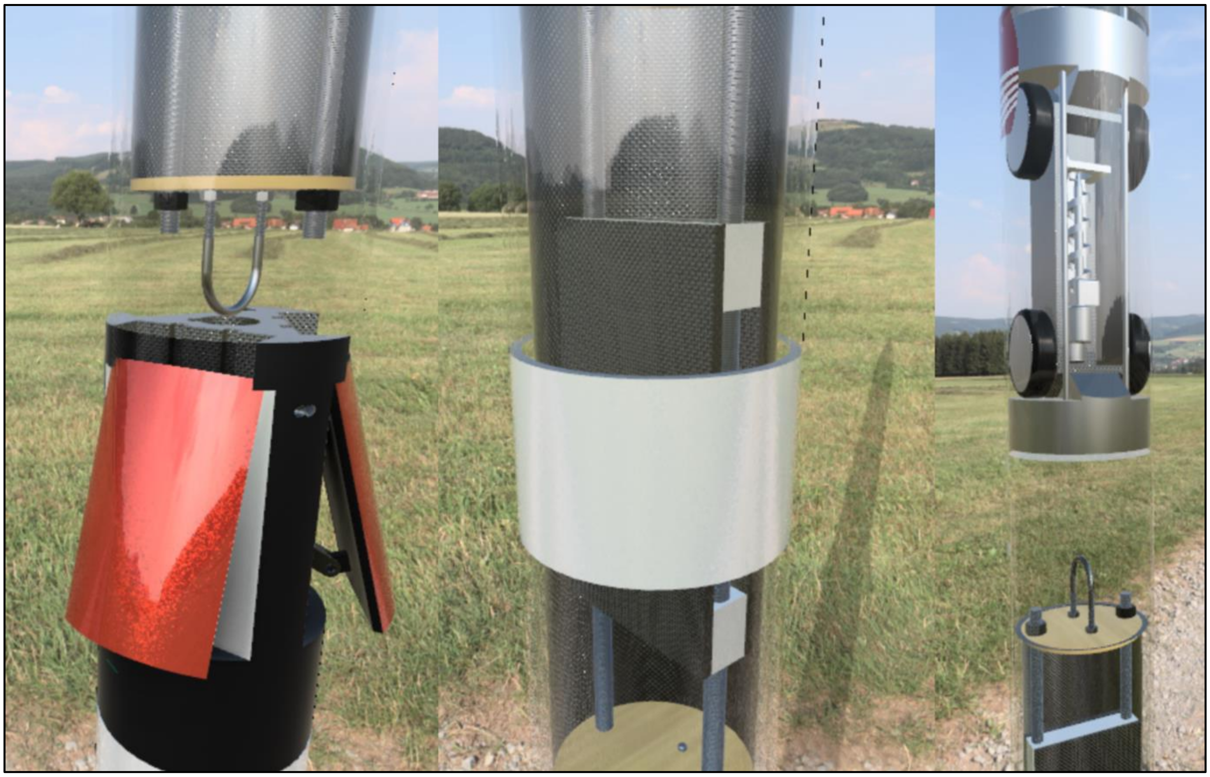


Figure 4 – 14: Transparent Assembly Displaying Payload, Avionics & VDS.

4.2.8 Technical Challenges

Table 4 – 4: Technical Challenges & Solutions

Technical Challenges	Proposed Solution
Variable Drag System (VDS)	The structural integrity of the VDS must be ensured during deployment. Additional simulations will be required to determine the drag and surface effects.
Optimizing weight against durability	Having a higher weight lowers the apogee that the rocket is able to achieve.
Implementing 5 Fin Design	Alignment of all 5 fins perfectly will be extremely difficult. However, slotted retention rings (held together by threaded rods) will allow the team to carefully align them

Interference Between Tracking Electronics & Avionics Bay	Place the tracking electronics in the nose cone & shield the hollow inside using aluminum foil. Placing the tracking system in the nose cone also spatially separates the two redundant systems.

4.3 Recovery System

The purpose of the recovery subsystem is to manage the controlled, safe descent of the vehicle from apogee to rest.

4.3.1 Parachutes

The drogue parachute of the vehicle will be deployed upon its arrival at the apogee height. In turn, this will cause the separation of the junction between the drogue bay and the avionics bay. The main parachute will then be deployed around 600 feet AGL in order to decelerate the rocket and guarantee a safe landing.

A low fidelity model was used in order to determine the parameters of the main parachutes that will play a factor in the vehicles design. This model obtained rough estimates for the parachutes nominal diameter by utilizing the basic equations used in both dynamics and fluid mechanics with the current vehicle parameters.

The terminal descent velocity necessary to fulfill the provided kinetic energy requirements is demonstrated in Equation [4.1]:

$$v_{term} = \sqrt{\frac{2KE}{m}} \qquad \text{Equation [4.1]}$$

In which,

v_{term}: Terminal Velocity

KE: Kinetic Energy

m: Mass

A kinetic energy at the landing zone of less than 75 $ft\ lbf$ is mandatory for each separate section of the vehicle.

The equation used to solve for the drag force acting on the vehicle is seen in Equation [4.2]:

$$F_{Drag} = \frac{1}{2}\rho {v_{term}}^2 C_d A_o \qquad \text{Equation [4.2]}$$

The variables are defined as

F_{Drag}: Drag force

ρ: Density of the Air

C_d: Drag Coefficient

A_o: Surface Area of Parachute Canopy

A_o is defined as Equation [4.3]:

$$A_o = \frac{\pi}{4} {D_o}^2 \quad \text{Equation [4.3]}$$

Where,

D_o: Nominal Parachute Diameter

By combining equations [4.1], [4.2], and [4.3] it is possible to solve directly for the necessary nominal parachute diameter.

$$D_o = \sqrt{\frac{4m^2 g}{KE\rho\pi C_d}} \quad \text{Equation [4.4]}$$

Many of the parameters in these equations have values which come from individual parachutes. Numerous parachute considerations, for both the drogue and main parachutes, can be seen in the following table:

Table 4 – 5: Parachute Types and Characteristics

Parachute	Measure Type	C_d	Stability	Use	Cost (approx.)
Annular or Toroidal	Frontal area is protected (circle shape)	Usually around 2.2	Good at a low speed	Main Parachute	$250+
Elliptical	Frontal area is protected (circle shape)	Usually around 1.6	Medium to good from high to low	Main or Drogue Chute	Around $200
Panel Style	Across top panels	Around 1.1	Vertical stability is very good, can rotate	Main Parachute	Around $200
Flat Sheet	Across chute	Around 0.7	Alright at lower speeds, bad at high speed	Main or Drogue Chute	Less than $200

Cruciform	Across chute	Around 0.7	Good at most speeds	Main or Drogue Chute	Around $200

Drag, stability, and cost are the main parameters being considered for different kinds of parachutes. Doing research and tests on parachutes according to these parameters will narrow down potential parachutes for the deployment of both the main and the drogue.

A sample calculation for the nominal diameter is seen below by using the low fidelity model. The following assumptions were made in order to use said model

I. Constant air density ($0.0023769 \frac{slug}{ft^3}$)

II. Streamer recovery assumed as one tethered parachute for the entire system

III. Simplification of drag forces, in which the only considered drag forces is that of the main parachute. The drag force of the body is not considered in this model.

IV. The value of the rocket mass is approximated as $50lb$.

$$D_o = \sqrt{\frac{4m^2 g}{KE\rho\pi C_d}} = \sqrt{\frac{4(1.552795\ slugs)^2(32.2ft/s^2)}{(75lb \cdot ft)(0.0023769\frac{slug}{ft^3})\pi(2.2)}} = 15.876ft$$

The below table demonstrates the above calculation for all potential designs.

Table 4 – 6: Chosen Parachute Types

Parachute	C_D	D_o(ft)	D_C(in)	Cost (USD)
Annular/Toroid	2.2	7.45	120	433
Elliptical	1.6	7.446652	84	200

Our main concern when it comes to which parachutes to buy are the cost and the weight of the chute. This was recommended to us by several alumni of the competition. The main parachute we are looking into primarily is the Iris Ultra 120'' Standard Parachute. This is an annular/toroid parachute. Primarily, our interest in this one is due to its relatively high drag coefficient resulting in a smaller diameter overall and thus less weight as compared to an elliptical parachute. A potential concern with this parachute however is its high cost. For our drogue chute, it was recommended to us to use an elliptical parachute instead of an annular/toroid for the cost and it being more stable at higher speeds. The parachute we are looking into is the 24’’ Elliptical Parachute.

In the future, a higher fidelity model will be developed in order to model the vehicles deployment system. The model will be able to take numerous factors including, but not limited to, optimal altitudes for the deployment of the main parachute, drag forces generated from the vehicle during its recovery phase, drag forces acting on the drogue and main parachutes, CFD modeling of the airflow surrounding both of the parachutes, and also the effects of variations in weather. Data from the high fidelity model will be used in order to obtain the optimal dimensions and shape for drogue and main parachutes. The use of the model will allow for a more accurate model of how the kinetic energy and drift of the vehicle are affected by key parameters during the vehicles recovery phase. When ready, physical tests done on the ground will need to be performed in order to verify all simulated parameters. The above simulations and tests of the rocket will need to be completed before the subscale and full-scale test launches.

The rocket will also require a shock cord, which will have the purpose of keeping the rocket attached during its separation during the recovery phase. Essentially, the shock cord will ensure that the rocket will, upon its descent, not have its components discarded in multiple directions. Logically, due to the use of the dual deployment recovery system, two shock cords will be required to prevent separation. It will be a necessity that both of these cords will be able to withstand the weight of the rocket in its entirety. In addition, the shock cords must be strong and durable due to the unpredictability of the descent of the rocket.

Through the requirements stated above, the only logical candidates of materials to use for the shock cord are nylon and Kevlar. Of the two, Kevlar seems to be the better option. This is because Kevlar has a much higher melting point than that of nylons. As such, the Kevlar will be able to better resist the extreme temperatures that will be reached by the ejection charges used to deploy the parachutes and separate the rocket during the recovery phase. Additionally, Kevlar has a higher tensile strength, further exemplifies why it is the material best suited to the needs of the rocket.

There will be two sets of shock cords inside of the rocket. One of them will be attached to the nosecone of the rocket, and the other will be attached to the vehicles base. The shock cord will be bundled into lengths that are separate and equal. Research and testing will need to be done in order to properly determine the required and optimal dimensions of the shock cords that will be used. It is of the utmost importance that this is done right because if done incorrectly, not only will the shock cord risk being unable to support the stress caused by the falling rocket, but the rocket will also run the serious risk of its components hitting each other during and after their separation.

For the placement of the parachutes, we intend on putting the drogue parachute down between the propulsion section and avionics bay of the rocket, and the main parachute above that by being in between the avionics bay and the payload. In addition, the configuration for the launched recovery system that we currently intend on using is Configuration #2 from the supplementary Counterparts document. This is because it allows for the nose cone to completely avoid hitting the other components of the rocket during its descent, so it can be considered rather safe.

It also will be a necessity to calculate the terminal velocity of the rocket. This can be done through the following equation:

$$v_{term} = \sqrt{\frac{2mg}{C_d \rho (\pi/4) {D_c}^2}} \qquad \text{Equation [4.5]}$$

D_c: canopy diameter

A sample calculation can be seen below using the properties of the current main annular parachute being looked into, as seen earlier.

$$v_{term} = \sqrt{\frac{2mg}{C_d \rho (\pi/4) {D_c}^2}} = \sqrt{\frac{2(1.552795\ slugs)(32.2 ft/s^2)}{(2.2)(0.0023769\ \frac{slugs}{ft^3})(\pi/4)(120/12 ft)^2}} = 15.604\ ft/s$$

4.3.2 Shear Pins and Ejection Charges

Two sets of four removable shear pins will be used to hold the main parachute and drogue parachute compartments in place until apogee is reached. Once this occurs, the rocket will be able to disconnect the shear pins and break off into segments when a specified number of ignition charges are separated. However, the shear pins must also be able to withstand the impulse that is imparted when the drogue parachute deploys and still allow the main parachute to be released further during the descent.

To determine the quantity and specifications of the shear pins, the forces acting on the rocket during flight will be considered. While the shear pins must be thin enough to break when the black powder charges ignite, they should be thick enough to not cause the rocket to separate due to the pressure difference between the inside and outside of the rocket. This pressure difference comes into play while the rocket is launched as the altitude causes a decrease in the external pressure while the internal pressure remains constant. Finite element analysis will be used to prior to ground ejection testing to ensure that the shear pins can avoid failure with the predicted forces acting on the rocket.

While other factors like drag will also have some effect, the pressure differential between the inside and outside will be the main factor that will be analyzed in selecting properly sized shear pins. To calculate the maximum pressure difference, we consider the pressure outside the rocket at maximum height and approximate temperature. Using the following equation:

$$\Delta P = \frac{F}{A} \qquad \text{Equation [4.6]}$$

In which the variables are defined as:

ΔP : the change in pressure
F: force acting on the rocket
A: cross sectional area

The force acting on the rocket can be determined by rearranging the previous equation as such:

$$F = \Delta P(\frac{\pi d}{4}) \qquad \text{Equation [4.7]}$$

d: diameter of the rocket.

As four shear pins will be used between each separable section, the formula can be rearranged to solve for the minimum shear force to break the pins.

$$F_{min} \geq \Delta P(\frac{\pi d}{4N}) \qquad \text{Equation [4.8]}$$

Where,

F_{min}: minimum shear force
N: number of pins

The maximum shear force is the force that causes the ejection charge to fail to separate the rocket, as shown in the following equation:

$$F_{req} = (K \times N \times F_{max}) \qquad \text{Equation [4.9]}$$

For which

F_{req}: required force
F_{max}: maximum shear force
K: factor of safety

As the pressure is tied to the force and cross sectional area, the previous equation can be rewritten as:

$$P_{req} = \frac{F_{max}}{F_{min}}(K \times N \times \Delta P) \qquad \text{Equation [4.10]}$$

P_{req}: required pressure

Shear pin selection will be closely tied to the process of selecting the appropriate ejection charges. The primary concerns are that the charges cause irreversible damage to a component outside the shear pins or that not enough is used to properly deploy the parachutes, resulting in failure in either case. Following the recovery system requirements, ejection tests will be conducted to confirm the amount of black powder used does not damage any of the rocket sections.

The ideal gas law is used to derive the mass of black powder needed as follows:

$$PV = mRT \qquad \text{Equation [4.11]}$$

In which the symbols are denoted as:

P: pressure of black powder gas

V: volume of black powder gas

M: mass of black powder gas

R: gas constant

T: temperature at which gas is at

The ideal gas equation can be used based on the assumptions that the rocket is pressurized quickly, the gas behaves ideally, and that there is negligible heat loss. This equation is used to determine the required pressure, P_{req}, to separate the rocket. Since the volume of a cylinder is the area of a circle multiplied by its length, the ideal gas law can be reduced to a mass per unit length form as shown below:

$$\frac{m}{L} = D^2\left(\frac{\pi P_{req}}{4RT}\right)\left(454\ \frac{g}{lbf}\right) \qquad \text{Equation [4.12]}$$

L: length of cylinder

A conversion factor is applied for dimensional consistency. An additional constant is added for simplicity as:

$$= \frac{\pi P_{req}}{4RT} \qquad \text{Equation [4.13]}$$

C: constant

The final equation used for selecting the mass of black powder is:

$$m = CD^2L \qquad \text{Equation [4.14]}$$

These equations will only be used as guidelines for initial selection of the launch components. Once the shear pin dimensions and amount of black powder are chosen, ground tests will still be performed to confirm that there are no manufacturing defects in this portion of the recovery system.

4.3.3 Avionics

The electronics required for the Dual Event Recovery System include altimeters, batteries, electric matches, switches, a GPS transmitter, and a GPS module. They are responsible for parachute ejection and signaling the location of rocket components upon touchdown. The altimeters and batteries, themselves will be mounted to a fiberglass board called the avionics sled while the ejection charges and recovery harness mounts will be located on the outside of fiberglass end caps that, along with a housing made of a long tube fiberglass coupler, sequester and protect the electronics from ejection gases and electromagnetic interference from other rocket sections. The coupler, end caps, and avionics sled will all be made of fiberglass because of the low density of the material, which will help minimize the overall weight of the rocket. The recovery harness mounts will be U-bolts, as opposed to eyebolts, since the former spread out force over a larger area while the latter are known to bend during flight if it isn't forged or welded properly. The aforementioned components are the constituent parts of the avionics bay.

Figure 4 – 15: U-Bolt

The altitude control of the rocket will be managed by a pair of PerfectFlite StratoLoggerCF altimeters as they can perform their programmed tasks from 100 to 9,999 feet AGL, store up to 9 minutes of flight data, and are capable of sending electric signals even after 24 hours of operation while powered by a 9V battery. These devices have pressure sensors capable of reading the altitude of the rocket and ascertaining when a predetermined altitude above ground level has been reached.

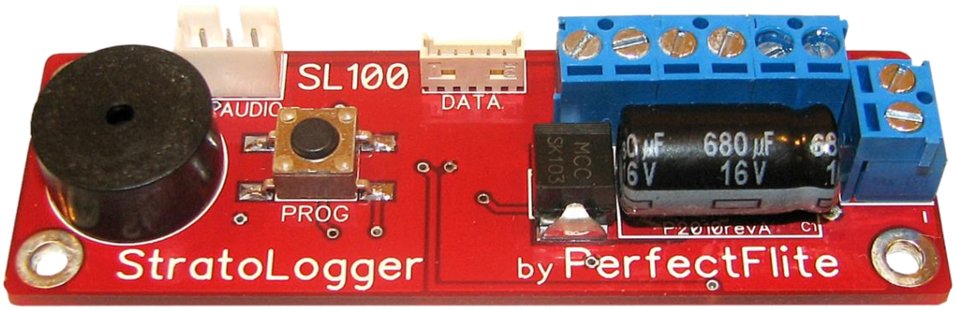


Figure 4 – 16: PerfectFlite StratoLoggerCF Altimeter

Once this is done, the altimeter sends a signal to electric matches in order to ignite black powder charges, causing the rapid heating and expansion of gases that will separate the rocket sections, eject the shock cord, and deploy the drogue and main parachutes at the proper altitudes.

The system of activating the parachutes will be fully redundant in order to prevent recovery failure due to malfunctions and mishaps. For this purpose, each of the altimeters will be connected to a 9V power supply, two black powder charges contained in aluminum charge cups, and electric matches for ignition. Thus, if one of the powder charges managed by one altimeter fails to ignite, the other altimeter will do so instead. The charge cups will be made out of aluminum, and will be custom-made in order to pack in the correct amount of powder without being too large to fit with the rest of the components.

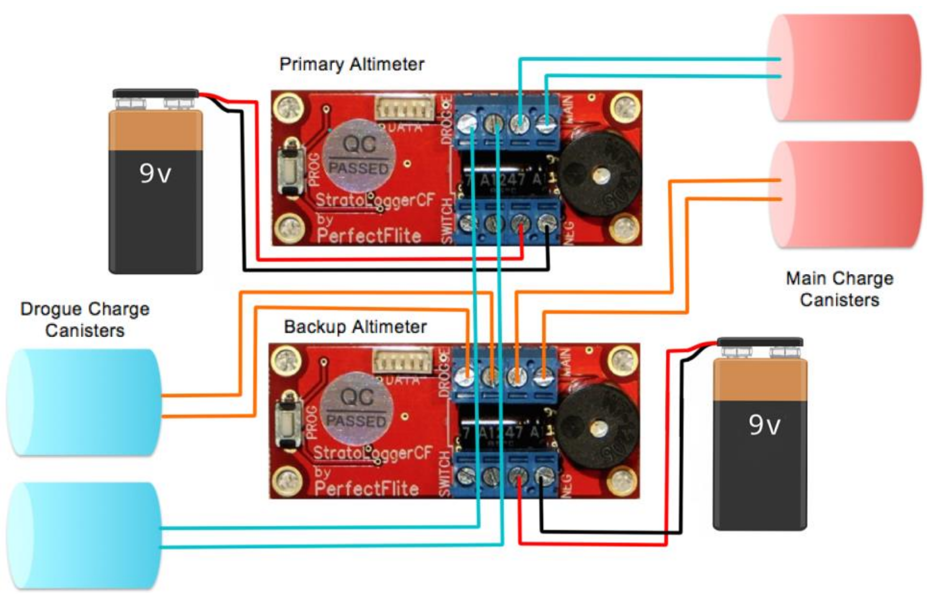


Figure 4 – 17: Altimeter Circuit Diagram

The air pressure outside the rocket must be sampled in order for the system to work, so a static pressure port must be implemented along the outside of the rocket as well in order to allow the pressures of the inside and outside to equalize. To that end, holes will need to be drilled in the airframe and coupler. In addition, the avionics bay system will be locked in the "on" position during flight by using keylock switches accessible on the surface of the rocket, which will prevent accidental disarms due to unforeseen circumstances in the air. This configuration will also help conserve battery power when the rocket is not in use.

Figure 4 – 18: Example of Avionics Bay Full Design

After the rocket is launched, the components of the rocket will need to be located and retrieved as the rocket tends to drift while in the air. Thus, telemetry equipment is required. For our purposes, we have selected the BigRedBee BRB900 Transmitter, which will send its location to a ground station that is designed specifically to communicate with it. In order to actually receive the positioning data, the MAX-8 GPS module will interact with satellites and transfer the information to the transmitter. These devices will be located in a bay near the nose cone in order to prevent interference with the avionics bay electronics.

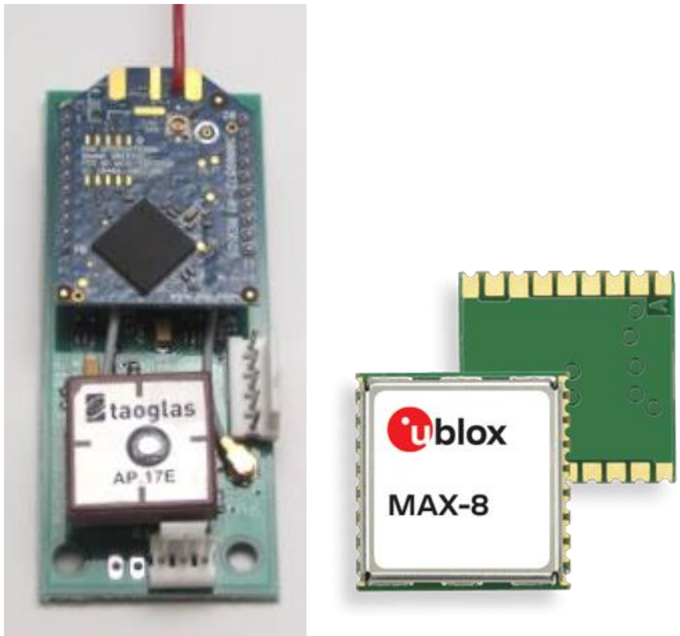


Figure 4 – 19: BRB900 Transmitter (left) and the MAX-8 GPS Module (right)

4.4 Technical Challenges.

There are numerous technical challenges that will have to be contended with. One such challenge is to balance out the mass of the rocket. If the rocket is too heavy, it will be difficult to reach apogee, if at all, as the motor required will be much larger and more expensive. On the other hand, if the rocket is too light, it may be easily affected by weather conditions such as air currents. In addition, if the mass of the rocket is too centered on one side it may experience instability due to moments of inertia. A solution to deal with the challenge is to take into account the mass of each component of the rocket, and simulate how that would affect the rocket's flight, as well as design the fins properly to counteract instability due to mass. A mass balance sheet would be beneficial in achieving this.

Size constraints are also a major challenge that will have to be worked around in order for the project to be successful. All of the required components must be a part of the rocket, so the rocket therefore must be large enough to fit everything inside. For example, the payload must be compact enough to fit inside the rocket and still complete its task. However, if the rocket is too big, it may be too heavy or end up being unstable in the air. In addition, a very large rocket would result in more material purchased, and thus a higher cost. It is very important that the cost is minimized due to a limited budget; thus, the rocket's size cannot be larger than absolutely necessary. To ensure that our rocket is not too small or large, we plan on designing the rocket to be the exact size that we need based on the components that we are looking into buying, with a tolerance range to allow for some unforeseen issues.

For navigation and recovery, there are several distinct issues that need to be addressed. Firstly, the kinetic energy of impact cannot exceed 75 lb·ft as per the rules of the competition and for the general well-being of the rocket. Secondly, the rocket's descent from apogee cannot exceed 90 seconds, and thirdly, the recovery area will be limited to a 2,500 ft. radius from the launch pads. These challenges may be overcome by careful consideration of the parachute deployment procedure. In order to ensure the kinetic energy remains low, a drogue and main parachute will be deployed, slowing the rocket down. However, the main parachute will only be deployed when the rocket is about 600 feet AGL so the descent time is not too long. For the last challenge, we must take drift into account during the rocket's descent. We can perform this through the use of mathematical models.

5 Technical Design: Payload

5.1 Payload Requirements

Our launch vehicle will be deploying a rover that will collect and transport a simulated lunar ice sample. The payload will meet the following design criteria as set forth by 2020 NASA Student Launch Handbook.

1. The payload will be deployed from within the internal structure of the launch vehicle.
2. The payload will have the ability to recover sample material extending from ground level to at least 2 inches below the surface.
3. The sample material will be a minimum of 10 milliliters (mL).
4. The payload will store the recover material and transport it 10 linear feet from the recovery area.
5. Any batteries powering the rover will be clearly labeled as a fire hazard.
6. The payload must be fully retained using a mechanical retention system until it is designed to be deployed.
7. The retention system will be robust enough to successfully endure flight forces experienced during both typical and atypical flights.
8. The retention system will not exclusively use shear pins.
9. All FAA and NAR rules and regulations must be followed.

To fulfill the requirements listed by the student handbook a mission objective verification list was created. The verification plan is displayed in Table 5 – 1.

Table 5 – 1: Payload Requirements Verification Plan

Payload Requirement	Solution
The payload will be deployed from within the internal structure of the launch vehicle.	The rover will be housed in the bay underneath nose cone of the launch vehicle.

The payload must be fully retained using a mechanical retention system until it is designed to be deployed.	The rover will be secured on a mount and will only deploy after the safe landing of the launch vehicle. The deployment mechanism will be activated by using a remote controller.
The retention system will be robust enough to successfully endure flight forces experienced during both typical and atypical flights.	The retention system will utilize materials with high strength properties to prevent mid-flight failure.
The payload will have the ability to recover sample material extending from ground level to at least 2 inches below the surface.	The sample recovery mechanism will utilize an auger drill design to collect material.
The sample material will be a minimum of 10 milliliters (mL).	The sample storage unit will have sufficient volume to collect the required amount of sample material.
The payload will store the recovered material and transport it 10 linear feet from the recovery area.	The rover will utilize tank treads to traverse over rough terrain. This will allow the rover to safely transport the sample the required distance.
Any batteries powering the rover will be clearly labeled as a fire hazard.	All batteries will be marked with easily distinguishable brightly colored fire hazard labels.

5.2 Tank Overview

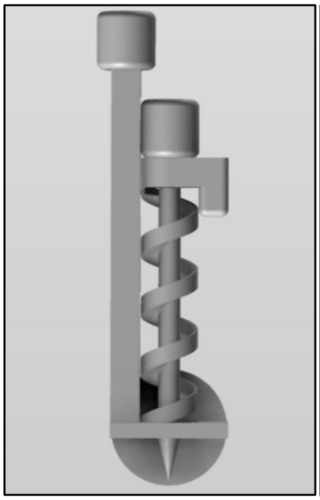
The team intends on building a tank for our payload design. This configuration was picked because of the stability offered by tank treads in traversing difficult terrain. The chassis of the tank will have a hexagonal shape with openings on the top and the bottom. This type of design will provide enough ground clearance on the front and rear end of the tank to prevent it from getting caught in soft terrain. The shape of the chassis also allows for extra space to house electronics in the front and the rear. The openings on the top and the bottom of the tank provide clearance space for the sample recovery unit. The tank will be controlled by a Bluetooth connection and will use a two wheel drive configuration with a gear train for the rear wheels. The tank chassis will be made from carbon fiber. This will protect the tank and its components from failing under the forces experienced during flight and landing. The general tank design can be seen in Figures 5 – 1 and 5 – 2 below.

Figure 5 – 1: Top view of the Tank

Figure 5 – 2: View of rover during soil sampling process

To achieve the mission requirements of collecting a 10 mL lunar ice sample we designed a sample recovery unit that incorporates an auger drill. The drill will be housed horizontally inside the chassis on the base plate. Once the tank will reach one of the designated recovery areas the tank operator will command the drill to move from its horizontal position to a vertical ready position.

This will be done by a servo motor attached to the drill housing. Once the drill is in vertical position a stepper motor will activate an attached lead screw upon which the drill assembly is mounted. This will move the drill assembly towards the ground. The drill will begin rotating and penetrate the sample layer. When the auger is retracted from the sample material it will drop some of the sample in the collection tank. The auger drill housing and assembly can be seen in Figure 5 – 3 below.



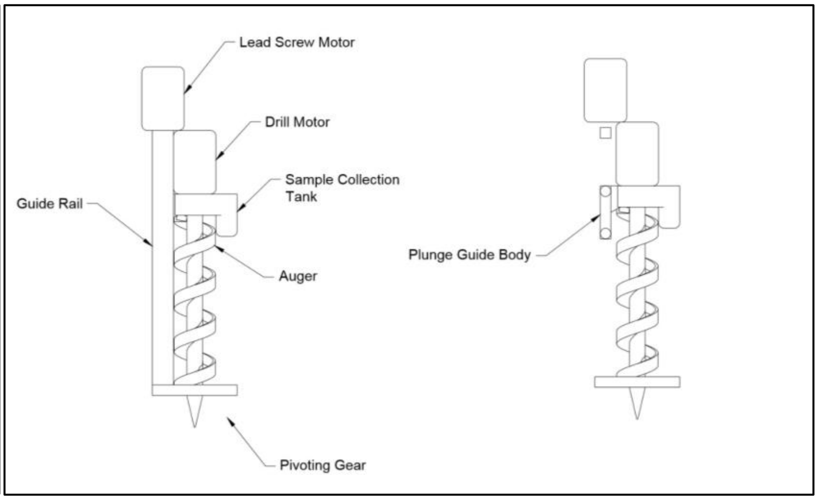


Figure 5 – 3: Auger Housing CAD Assembly and Drawings

Tank Parts List:

- Arduino Uno
- DC Motor
- Servo Motor
- Motor Drive Controller
- Motor Drive Shield
- RF Transceiver
- Bluetooth Controller
- Li-Po and Alkaline Batteries
- Auger Drill

5.3 Tank Exiting and Reorienting System.

The mission requirements state that the payload must exit from the internal structure of the launch vehicle. Successful completion of this objective requires an exiting and reorienting mechanism for the payload. The team designed the Tank Exiting and Reorienting system (TEARS) to successfully deploy the payload. The primary components of TEARS are shown in Figure 5 – 4.

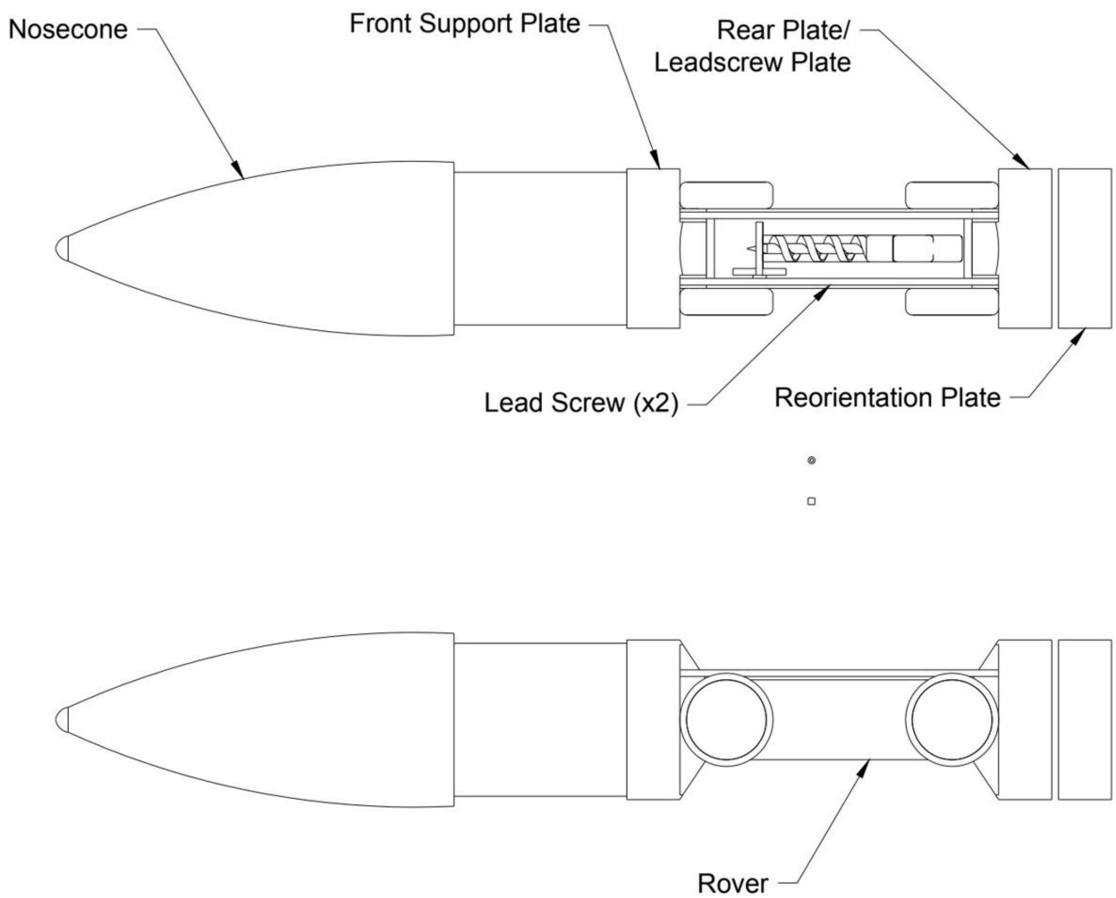


Figure 5 – 4: TEARS inside the airframe before rover deployment.

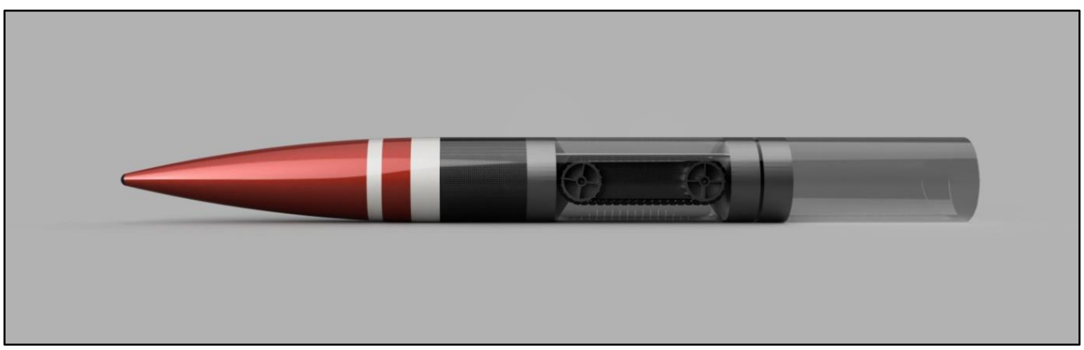


Figure 5 – 5: TEARS inside payload bay prior to deployment

The tank housing is attached to the lead screw via a set of nuts. The lead screw is mounted on the stepper motor which in turn is rigidly attached to the mounting plate. The counterweight on the opposite side of the mounting plate from the stepper motor will ensure that the mounting plate is not spinning freely. A dc motor will control the orientation of the mounting plate. A gyroscope and an accelerometer will send a signal to the brushless motor on which direction and how much the mounting plate will need to turn to reorient the rover in the upright position.

The tank is deployed in 3 steps. First step is to reorient the tank right side up. It will be accomplished by the brushless motor that will turn the mounting plate until a gyroscope and an accelerometer detects that the rover is in the necessary position. Second step is for stepper motor to push the nose cone and the tank forward via lead screw and nuts. When the tank is fully extended out, the third and final step is for stepper motor to reverse direction and thus pulling the housing back into the payload bay. Since the nut closer to the nose cone is only screwed in by a few inches it will no longer be actuated by the lead screw. When driven in reverse the lead screw will only retract the tank housing closer to the payload bay, thus releasing the tank. After tank deployment the TEARS should look like illustrated in Figure 5 – 6 below.

Figure 5 – 6: TEARS after rover deployment.

TEARS part list:

- Lead screw (Threaded Rod) and nuts
- Tank housing
- Stepper motor
- Brushless motor
- Mounting plate
- Arduino Nano
- MPU-6050

5.4 Tank Electronics Layout

A powerful lithium-polymer battery has been chosen to supply all motors on the rover. This is necessary because the motors will consume significant power and will require a high voltage. With a rated voltage of 22.2 V and rated milliamp-hours of 5000mAh, this power supply will prove sufficient for our rover.

Figure 5 – 7: Li-Po Power Supply

Breadboards will be necessary for our initial designs because they allow for quick circuit building. Prototyping boards will be used in the final design.

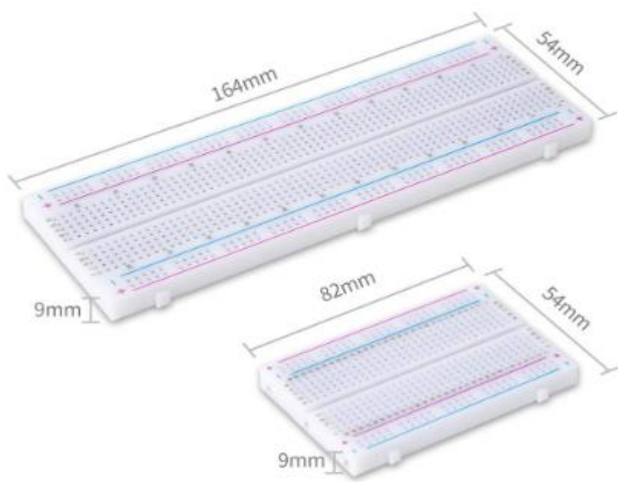


Figure 5 – 8: RexQualis Breadboard Kit

For our resistors, we chose 1/4W resistors with a wide range of values and a 925 piece set. This will allow us to have the correct values for resistors under any circumstances. A 5% tolerance was picked because it is sufficient for our needs.

Figure 5 – 9: AUSTOR Resistors

Jumper wires will be necessary for wiring the breadboard. A 120 piece set of varying sizes is satisfactory to our needs.

Figure 5 – 10: EDGELEC Jumper Wire Set

For our finished payload design, prototyping boards will be necessary as breadboards with jumper wires are not as reliable and can fall apart. A 36 piece breadboard set of varying sizes will be useful here.

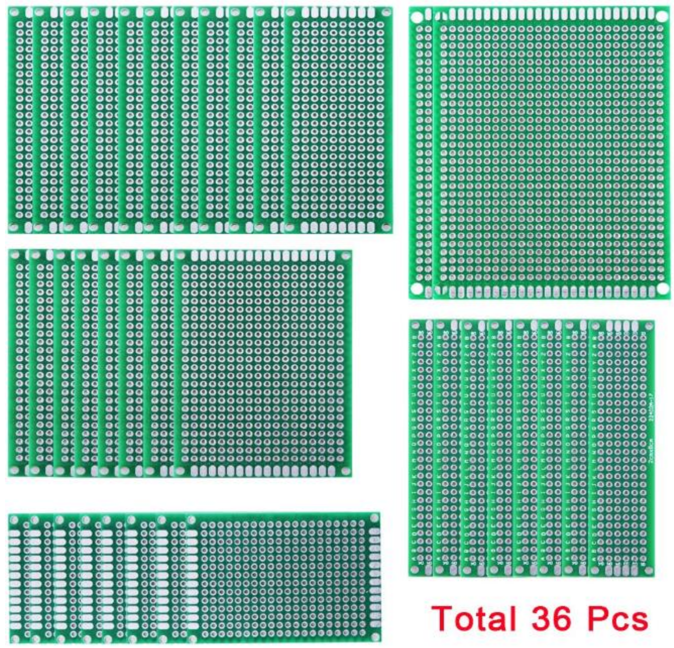


Figure 5 – 11: AUSTOR Prototype Board Kit

Alkaline batteries will be a necessary power source for our components. These will serve to power all components except for the rover motors. Therefore, the batteries must have a large supply with minimal size. The LICB 23A 12V Alkaline Batteries meet these requirements and thus we have chosen them.

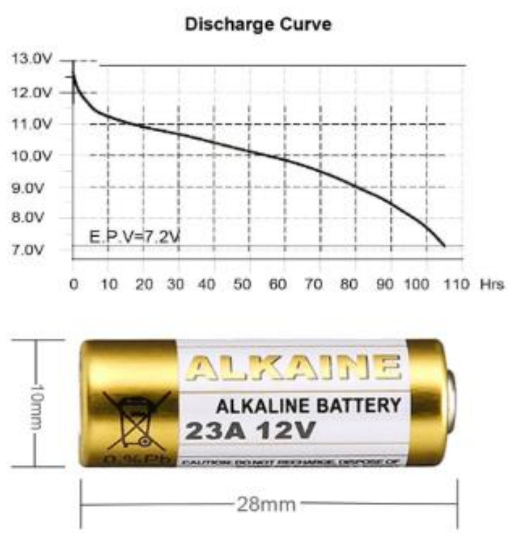


Figure 5 – 12: LiCB A23 23A 12V Alkaline Battery Pack

Two high torque motors are required for our wheels since they must carry the entire weight of the rover. Additionally, the motor cannot move at a very slow pace because the faster it can move, the more data it can acquire in smaller periods of time. The Greartisan DC 12V 550RPM motor meets these requirements. The drill has similar requirements, it must have high torque because we do not know the specifics of the terrain we are drilling into and it must be fast so that the ice sampel particulates travel up the auger drill and into the sample storage container. The requirements are similar and the Greartisan DC 12V 550RPM meets the requirements of both the drill and the wheels, thus we will order three of these motors with one driving the drill and two driving the wheels.

Figure 5 – 13: Greartisan DC 12V 550RPM

The ANNIMOS 20KG Digital Servo suits us well because we will need two powerful servos. The first will move the drill to an upright position such that it is normal to the rover chassis, the second will rotate the drill.

Figure 5 – 14: ANNIMOS 20KG Digital Servo

The Raspberry Pi and Arduino were both considered for the main microcontroller of the system. The Arduino Uno Rev 3 was picked for its ease of use, weight, dimensions, technical specifications, and versatility.

Figure 5 – 15: Arduino Uno Rev 3

The Arduino Nano will be required where space is more of a factor, such as in the TEARS. It is very similar to the Arduino Uno while also being much smaller and thus was chosen.

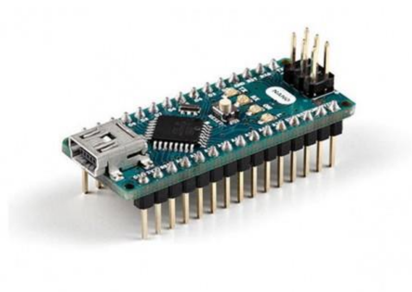


Figure 5 – 16: Arduino Nano

RF Transceivers will be required for the DIC. These transceivers are ideal because they’re small, have a range of up to 50 meters and can be configured as either a receiver or a transmitter.

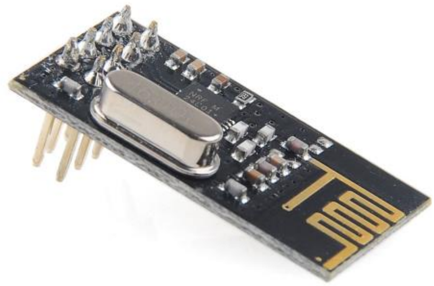


Figure 5 – 17: Makerfire Wireless RF Transceiver

Our controller will require a Bluetooth connection which will be plugged into the USB Shield. This dongle works well because it is small, and we know it is compatible with our controllers.

Figure 5 – 18: GMYLE Bluetooth Adapter Dongle

The PlayStation 4 Bluetooth Controller will be used as our rover controller and our TEARS controller because of its ease of use and price savings. Multiple team members own this controller and purchasing this controller will not be necessary. The team has familiarity with this controller and will achieve better handling of the tank through this controller.

Figure 5 – 19: PlayStation 4 Bluetooth Controller

An Arduino Nano USB Shield will be needed for the Bluetooth Dongle such that TEARS can be controlled.

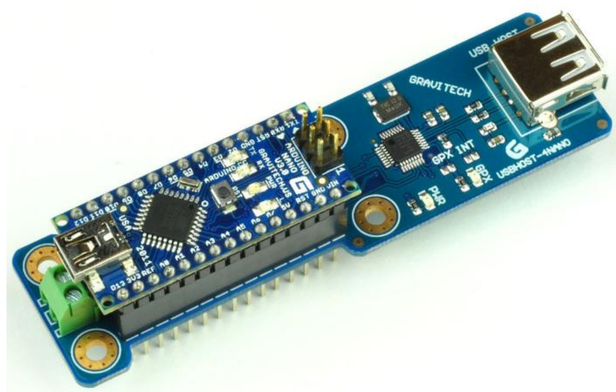


Figure 5 – 20: Arduino Nano USB Shield

An Arduino Uno USB Shield will be needed such for the Bluetooth Dongle such that the rover can be controlled.

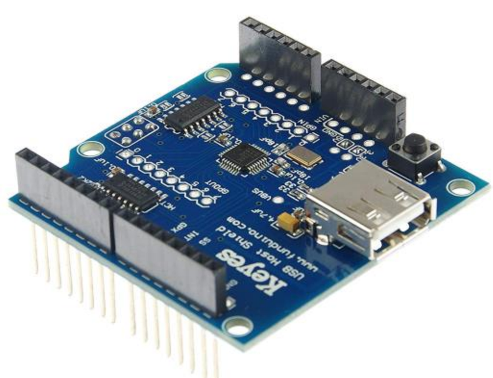


Figure 5 – 21: Arduino Uno USB Shield

The NEMA-17 stepper motor will be used in the exiting system for TEARS. A stepper motor was picked because it offers precise incremental movement and maximum torque at low speeds. This motor will be suitable for the linear actuating mechanism that TEARS will utilize.

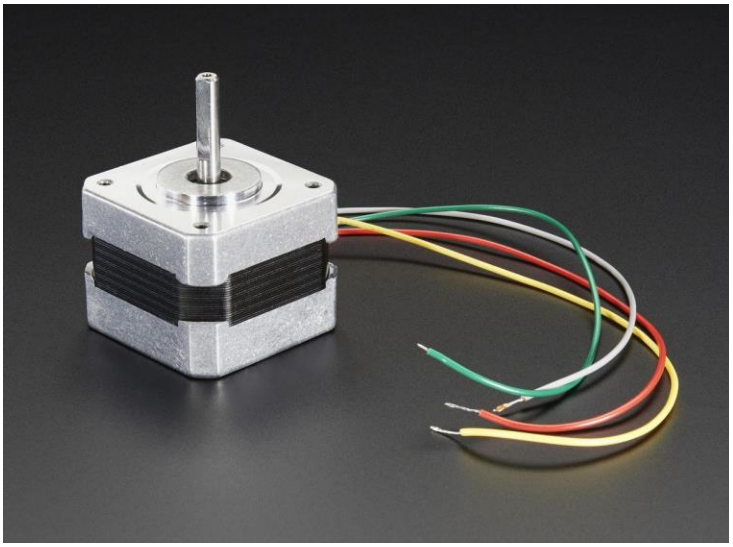


Figure 5 – 22: Stepper Motor

The Greartisan DC motor with gear reduction will be utilized to reorient the tank mounting frame once the Launch Vehicle has landed. The gear box in this motor will serve to increase torque output at slower speeds.

Figure 5 – 23: Greartisan DC Motor with gear reduction.

The L293D Motor Drive Shield will be used on the rover since it can control up to four motors and two servos. We will be using two servos and three motors, so this suits us well.

Figure 5 – 24: HiLetgo L293D DC Motor Drive Shield

For TEARS we will only have two motors, therefore a smaller Motor Drive will be used to save space. Here we use the Qunqi L298N Motor Drive Controller because it meets these requirements and is commonly used with Arduino.

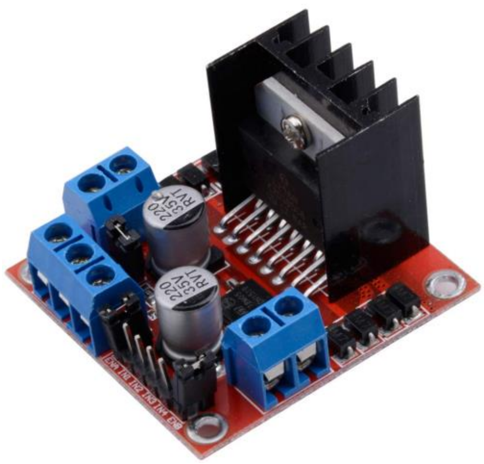


Figure 5 – 25: Qunqi L298N Motor Drive Controller

For the DIC, a display will be needed. The display cannot be too small, because we need to see all the information that is displayed. It must also be compatible with Arduino, low price, and color would be an added benefit. The HiLetgo 3.5" IPS TFT LCD Display checks all these boxes.

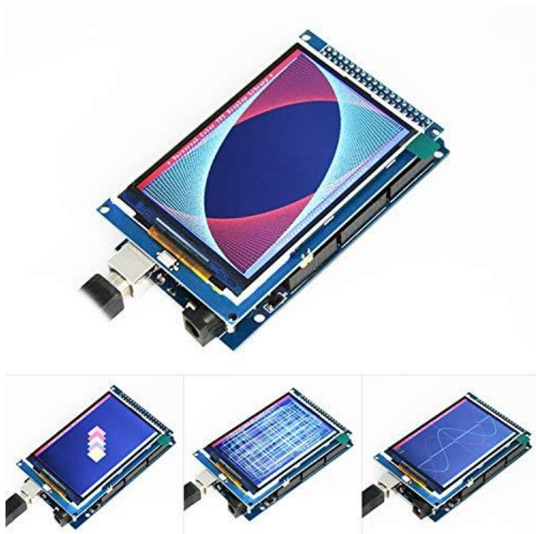


Figure 5 – 26: HiLetgo 3.5" IPS TFT LCD Display

For the reorientation system of the tank a sensor was needed that could determine the upright position. The MPU-6050 by SparkFun was picked for this task. This device is an inertial measurement unit (IMU) that incorporates a 3-axis gyroscope and accelerometer with an onboard Digital Motion Processor. This unit will be connected to our microcontroller to send position and orientation feedback of the Tank mounting frame.

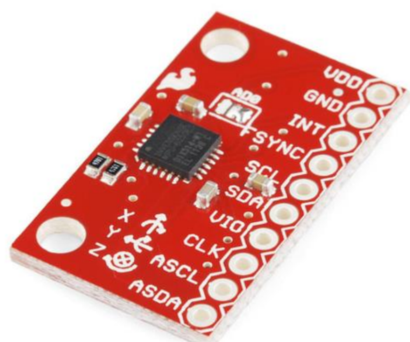


Figure 5 – 27: MPU 6050 IMU sensor.

5.5 Payload Electronics Block Diagrams.

In Figure 5 – 28 below, we can see the general interfacing between electrical components on the rover. An Arduino Uno will be connected to a USB Shield, a Motor Controller, an alkaline battery power source, and a transceiver which will be configured as a transmitter. The USB shield will run off the Arduino Uno's power supply and have a USB Bluetooth Receiver connected to it. The Li-Po battery will serve as an external power source for all components of the motor controller.

Finally, the transceiver, configured as a transmitter, will connect to the DIC which also has a transceiver, except it is configured as a receiver.

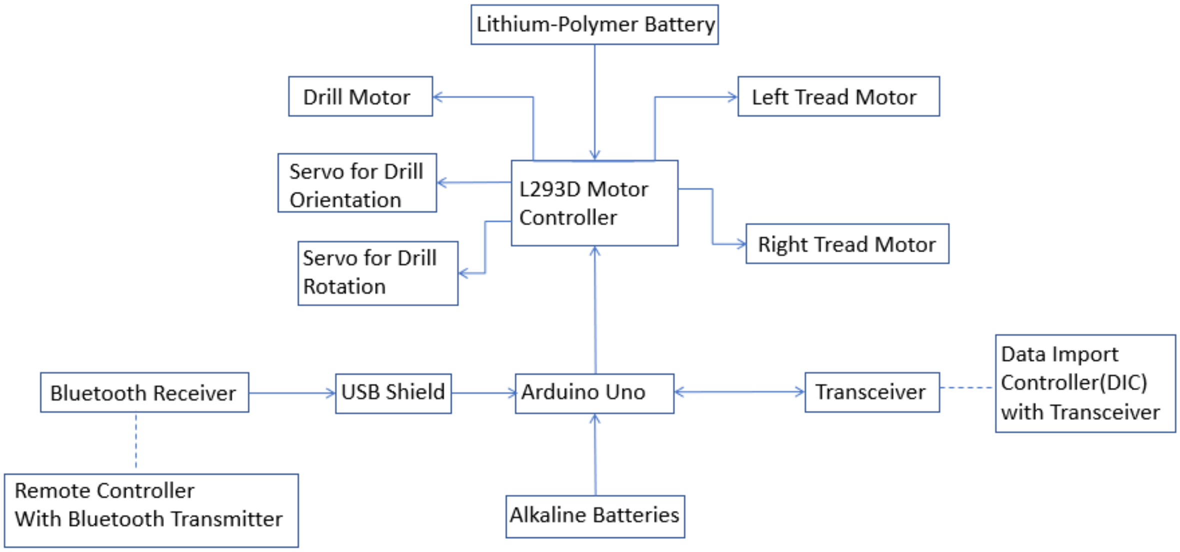


Figure 5 – 28: Tank Block Diagram

For Figure 5 – 29 we see the block diagram for TEARS. We will have two power supplies, both alkaline batteries. One power supply will power the Arduino Nano and its connections, whereas the other will power the motor controller's motors. The Bluetooth receiver will connect to the USB shield to allow for remote operation. The MPU-6050 will provide feedback to the Arduino Nano such that reorientation is successfully achieved.

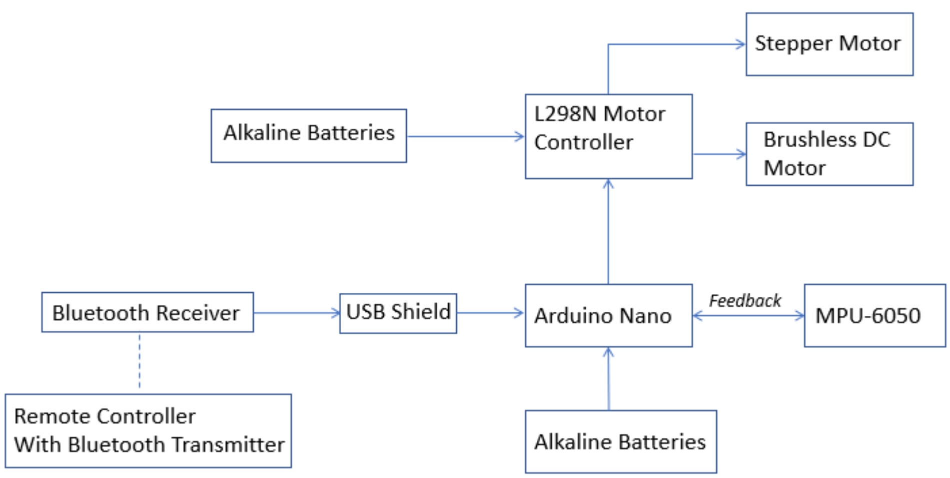


Figure 5 – 29: TEARS Block Diagram

In Figure 5 – 30, there's a few components which the DIC is comprised of. The Arduino Uno is powered by alkaline batteries. Data is received from the rover, then this data is put onto an LCD Display.

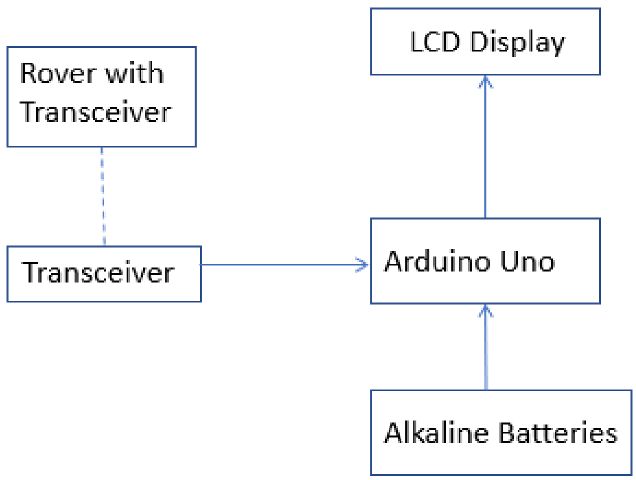


Figure 5 – 30: DIC Block Diagram

5.6 Data Import Controller

The DIC will serve to provide us with real time data and analytics, it will run remotely from the rover. Onboard data, from the rover, will be sent remotely to the DIC. The Arduino Nano will then perform analysis on this data and then present this on a display. Note that the sensors for data acquisition are not yet final and thus have not been included in the block diagram nor in the components list. Some of the data we would like to take might include:

1. Battery Levels - Battery levels of all devices can be shown, this can be done via a multimeter circuit.
2. System Status - Whether all systems are operating correctly, this could be based upon power consumption and reading status via Arduino. On many components we can read status of their actions, for example, we could move the servo to a certain angle then read if the angle was correctly achieved to determine whether it is functioning as intended.
3. Distance Traveled - Measured through the wheels' movement. For example, if the circumference of a wheel is 1ft, and the rotations achieved is 3.5 rotations. We can determine, without slip, it has travelled 3.5 ft.
4. Velocity - Shown by change in distance divided by change in time.
5. Acceleration - Shown by change in velocity divided by time.
6. Temperature - For this we would either need a temperature sensor, such as the DHT22, or access to the internet such that we can read temperature online.

7. Humidity - The DHT22 can also read humidity, alternatively, we could find this via internet access.
8. Experimental Data Analysis - Once more information is given on the lunar ice sample we are required to obtain, we would like to work with NASA to determine whether further experiments can be conducted on the retrieved sample.

5.7 Technical Challenges and Test Plan

The designed payload will undergo various tests and simulations that will ensure the success of the launch day mission. A list of the technical challenges that the payload will encounter and a respective test plan for each challenge has been outlined in Table 5 – 2.

Table 5 – 2: Challenges and Test Plan

Technical Challenges	Test Plan
Payload deployment failure from the rocket.	TEARS will undergo simulation of multiple landing configurations. An airframe will be attached to TEARS and different terrains will be used during testing.
Traversing difficult terrain.	The tank will be tested under various terrains such as rocky terrain, soil, and dirt to ensure proper functionality of the tank.
Auger drill failure during sample collection.	The drill mechanism will be tested against various samples that will closely replicate the mission sample. The collection mechanism will be tested under varying loads, speeds, and angles to obtain the optimum drilling configuration.
Communication Loss with Payload	The communications system of the tank will be tested at various ranges to determine the limitations of the communications system.
Loss of connection between electronics.	An apparatus will be used that will simulate vibrations that the tank may face while in flight. Experimental testing with this apparatus will determine the best configuration to house the electronics in the tank chassis.

5.8 Future Considerations

The design of the payload was created to best complete the mission to travel to one of the sample collection zones, collect a minimum of 10ml of simulated lunar ice, and transport the sample at least 10 linear feet away from the collection zone. As more information about the terrain, sample and other variables are released, our future iterations will reflect that mission. Our main concerns are stability over obstacles in the terrain, as our rover has high length and small width to accommodate the drill, resulting in a higher center of gravity and therefore a higher rollover risk. Possible solutions are to incorporate the auger drill mechanism into a cylindrical rover if terrain and rollover become primary concerns. If drilling the simulated lunar ice sample is not feasible, a more efficient and lighter mechanism can be incorporated into the payload's design to best serve the mission. Any revisions to the payloads shape, orientation, driving method, or collection method will require design iterations on our mounting mechanism and deployment system. These revisions along with design parameters will be communicated to the other subsystem teams (SAP and NAR) so that the required design revisions can be made to other sub-systems as a consequence of payload design revisions.

6 Stem Engagement

6.1 AIAA-SBU Collaboration.

The Stony Brook Rocket Team will be partnering with the Stony Brook University American Institute of Aeronautics & Astronautics (AIAA) branch to bring interesting and engaging programs to the Stony Brook campus and the surrounding Long Island community in order to promote interest in STEM. A number of technical workshops targeted towards university students with topics in FEA/CFD, Arduino programming, and 3D printing which are a collaborative effort between the Space Wolves rocket team and AIAA. Each workshop is projected to have a minimum of 20 people in attendance. An Intro to SolidWorks workshop was recently hosted by AIAA that led participants through the design and modeling of a CO2 canister rocket which attracted 46 attendees. The success of this event is a good indicator of the popularity of future events.

6.2 Outreach Events

Independently, the Space Wolves rocket team is planning to visit a few grade schools around the Stony Brook area to hold low power rocket demonstrations as well as present the science behind how rocketry works. This will allow the students to see firsthand how the science they learn in school can directly impact the things they make, as they will be participating in building and flying their own rockets. Last year's team also did this and received positive feedback which significantly influenced our decision to continue the trend. This will hopefully inspire some curiosity in the younger generation and get them excited about future possibilities in STEM fields.

6.3 Engagement Summary

In order to improve outreach and engagement for the future, the Stony Brook rocket team will follow up after each of the workshops and school visits to gauge interest levels and to see how each event could be improved in the future. This will be done by providing surveys to be given out at the events as well as following up through email with additional information about future events. Additionally, the team will encourage everyone involved to follow the Stony Brook rocket team social media which will provide them a way to be updated on our progress as well as ask further questions about our programs.

7 Project Plan

7.1 Project Timeline

Our team has divided the project into 5 main phases. In the first proposal phase our team will focus on idea generation and determining team structure. PDR phase mainly consist of creating a design that meets all the general, vehicle, and payload requirements of the competition. CDR phase ensures that the previously created design is ready to fabricate. If it is not ready, necessary changes to the design are made to meet fabrication criterion. FRR phase tests vehicle and payload readiness for the competition. And finally, the Launch Phase mainly consist of Student Launch competition week and post launch assessment review. A detailed project timeline is shown in Table 7 – 1. A general overview of the schedule is summarized in Figure 7 – 1.

Table 7 – 1: Project Timeline.

ID	Task	Duration	Start Date	Finish Date
1	**Proposal Phase**	28 days	8/22/2019	9/18/2019
2	Request for Proposal Released	1 day	8/22/2019	8/22/2019
3	Team Meetings and Design Development	18 days	8/23/2019	9/9/2019
4	Proposal First Draft	5 days	9/9/2019	9/13/2019
5	Proposal Report	5 days	9/13/2019	9/17/2019
6	Proposal Submission	1 day	9/18/2019	9/18/2019
7	**PDR Phase**	43 days	10/9/2019	11/20/2019
8	PDR Q&A	1 day	10/9/2019	10/9/2019
9	PDR Report	30 days	10/3/2019	11/1/2019
10	Social Media Established	1 day	10/25/2019	10/25/2019
11	Subscale Fabrication	40 days	10/14/2019	11/22/2019
12	Subscale Launch	1 day	11/16/2019	11/16/2019
13	PDR Submission	1 day	11/1/2019	11/1/2019
14	PDR Video Teleconferences	17 days	11/4/2019	11/20/2019
15	**CDR Phase**	65 days	11/25/2019	1/28/2020
16	CDR Q&A	1 day	11/25/2019	11/25/2019
17	CDR Report	47 days	11/25/2019	1/10/2020
18	Full Scale Fabrication	24 days	1/23/2020	2/15/2020
19	CDR Submission	1 day	1/10/2020	1/10/2020
20	CDR Video Teleconferences	16 days	1/13/2020	1/28/2020
21	**FRR Phase**	53 days	1/31/2020	3/23/2020
22	FRR Q&A	1 day	1/31/2020	1/31/2020
23	FRR Report	35 days	1/28/2020	3/2/2020
24	Vehicle Demonstration Flight Deadline	1 day	3/2/2020	3/2/2020
25	Final Testing	45 days	2/16/2020	3/31/2020
26	FRR Submission	1 day	3/2/2020	3/2/2020
27	FRR Video Teleconferences	14 days	3/6/2020	3/19/2020
28	Payload Demonstration Flight Deadline	1 day	3/23/2020	3/23/2020
29	**Launch Phase**	33 days	3/26/2020	4/27/2020
30	Launch Week Q&A	1 day	3/26/2020	3/26/2020
31	LRR Report	1 day	4/1/2020	4/1/2020
32	Launch Day	1 day	4/4/2020	4/4/2020
33	PLAR Report	22 days	4/6/2020	4/27/2020
34	PLAR Submission	1 day	4/27/2020	4/27/2020

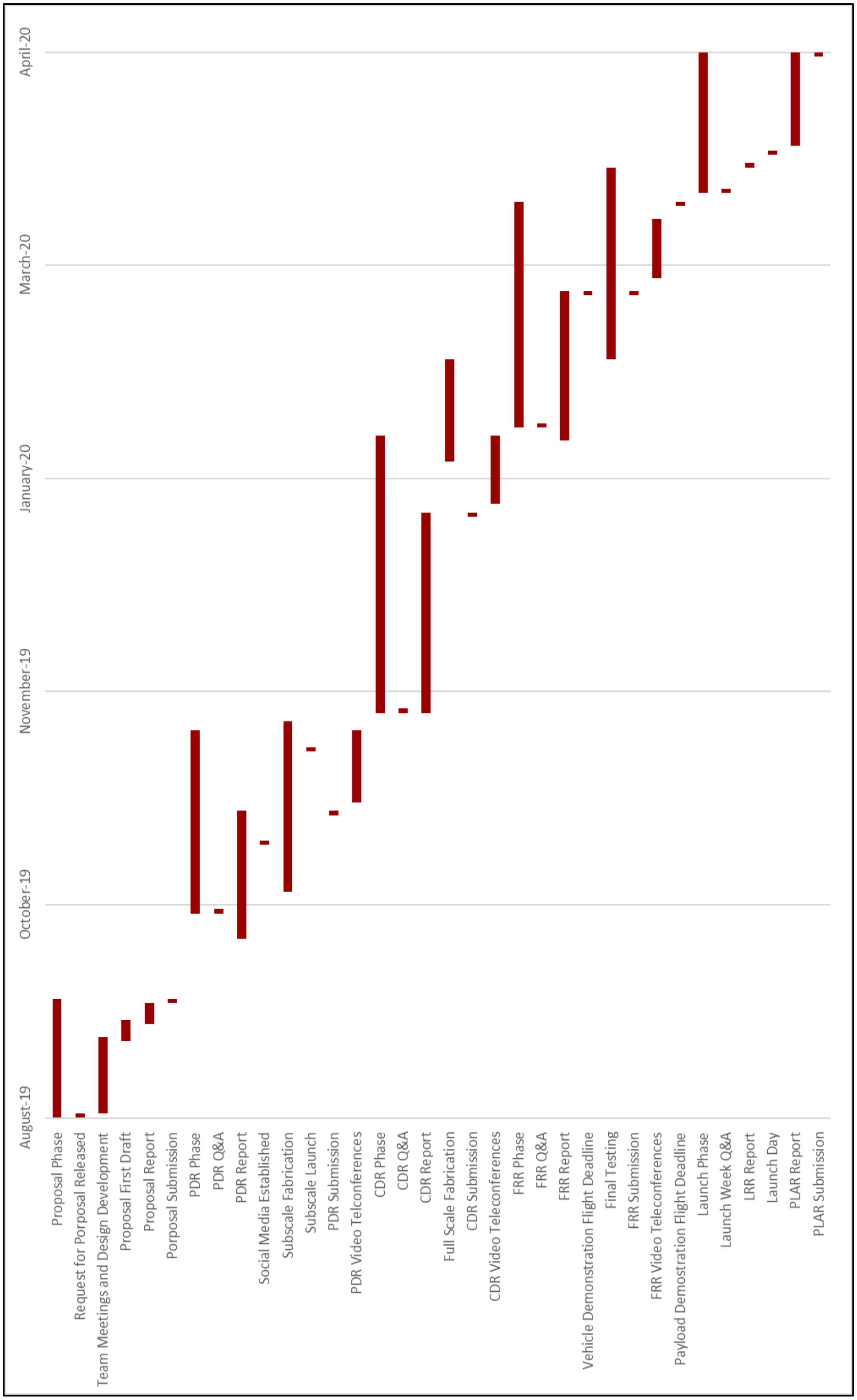


Figure 7 – 1: Project Gantt Chart

7.2 Budget

The budget is divided into 4 main section: Structures, Aerodynamics, and Propulsion (SAP); Navigation and Recovery (NNR); Payload (PAY); and Travel. Table 7 – 2 shows a general overview of the distribution among these 4 categories.

Table 7 – 2: General Budget Distribution

Section	Amount
SAP	$1700
NNR	$1000
PAY	$500
Travel	$2000
Total:	**$5200**

Detailed budget distribution within each section is shown in Tables 7 – 3, 7 – 4, and 7 – 5

7.2.1 SAP Budget

Table 7 – 3: Detailed SAP Budget

Item	Quantity	Unit Cost	Subtotal
VDS	1	$ 100.00	$ 100.00
L2200G-P	3	$ 279.99	$ 839.97
75mm LOC MMT	1	$ 16.00	$ 16.00
Aero Pack 75mm Retainer - L	1	$ 56.67	$ 56.67
Fins	1	$ 20.00	$ 20.00
G12 Fiberglass Filament Wound Tube	2	$ 217.14	$ 434.28
J-B Weld 8237 Epoxy Putty	4	$ 7.52	$ 30.08
Raw Material	1	$ 100.00	$ 100.00
General Hardware	1	$ 50.00	$ 50.00
Shipping Overhead	1	$ 20.00	$ 20.00
Total:			**$ 1,667.00**

7.2.2 NNR Budget

Table 7 – 4: Detailed NNR Budget

Item	Quantity	Unit Cost	Subtotal
Altimeter	2	$ 54.95	$ 109.90
Recovery Harness	1	$ 47.00	$ 54.00
U-Bolt	2	$ 6.66	$ 13.32
E-Matches (6 pk)	1	$ 7.02	$ 7.02
GPS Chip	1	$ 9.80	$ 9.80
GPS Transmitter	1	$ 199.00	$ 199.00
Main Parachute	1	$ 432.46	$ 432.46
Drogue Parachute	1	$ 64.00	$ 64.00
Nuts (100 pk)	1	$ 16.58	$ 16.58
Threaded Rods	2	$ 5.68	$ 11.36
ACDelco 9 Volt Batteries (12 pk)	1	$ 18.12	$ 18.12
Total:			**$ 935.56**

7.2.3 PAY Budget

Table 7 – 5: Detailed PAY Budget

Item	Quantity	Unit Cost	Subtotal
Lithium Polymer Batteries	1	$ 118.46	$ 118.46
Alkaline Batteries (5 pk)	1	$ 0.49	$ 0.49
Breadboard (4 pc)	1	$ 9.86	$ 9.86
Prototyping Boards (36 pc)	1	$ 11.99	$ 11.99
Resistors (37 pc pack)	1	$ 8.99	$ 8.99
Jumper Wires (120 pc)	1	$ 5.79	$ 5.79
Motor for drill, wheels, reorientation	4	$ 14.49	$ 57.96
Servo Motor	2	$ 16.99	$ 33.98
Arduino Uno	3	$ 22.00	$ 66.00
Arduino Nano	1	$ 22.00	$ 22.00
RF Transceivers (10 pc)	1	$ 11.98	$ 11.98
Arduino Nano USB Shield	1	$ 24.95	$ 24.95
Arduino Uno USB Shield	1	$ 10.98	$ 10.98
Bluetooth adapter dongle	2	$ 13.98	$ 27.96
Stepper Motor	2	$ 14.00	$ 28.00
Tank Motor Controller	1	$ 5.39	$ 5.39
TEARS Motor Controller	1	$ 6.89	$ 6.89
DIC LCD Display	1	$ 14.49	$ 14.49
MPU-6050	1	$ 29.95	$ 29.95
Total:			**$ 496.11**

7.3 Funding

The main source of funding that will go into this project will come from the money provided by Department of Mechanical Engineering to senior design teams. Each person is given $280 to cover their senior design project expenses. Our team consist of 13 seniors, which gives us a total of $3640.

Another big portion of funds is expected to come from College of Engineering and Applied Sciences (CEAS). CEAS has played a crucial role in the past to help obtain third party sponsorships. We expect to receive around $2000 from local companies and CEAS sponsoring this project.

Department of Mechanical Engineering historically has been very supportive of competitive projects and thus we expect to receive $500 both during Fall and Spring semester, totaling $1000 for the entire project.

And the last avenue our team plans on exploring is grants. We are in the process of applying to numerous grants such as NASA NY Space Grant. We expect to receive around $2000 total from grants throughout both Fall and Spring semesters.

Table 7 – 5 summarizes the funding Stony Brook Rocket Team expects to receive for this project.

Table 7 – 5: Expected Funding Sources.

Source	Amount
Senior Design Funding	$3640
CEAS	$2000
Department of Mechanical Engineering	$1000
Grants	$2000
Total:	**$8640**

7.4 Sustainability Plan

Our team has always almost exclusively consisted of mechanical engineering students who worked on the student launch as their senior design project. Thus, it is crucial to capture the interest of upcoming future seniors in order to sustain our team's effort. Our plan consists of 3 steps: student recruitment, community engagement, and future funding. Following these steps will ensure our team's success in the future.

7.4.1 Student Recruitment

To prevent having a shortage of active members in the future, our team works closely with AIAA-SBU to build an interest in rocketry among our peers. Since many of our team members are also a part of AIAA club it gives us direct access to new potential recruits who are already interested in aerospace engineering. By mentoring and guiding them to work on their own aerospace projects (such as AIAA's Design/Build/Fly Competition) we give them all the necessary knowledge and tools to succeed in future Student Launch competitions. We look forward to offer workshops and shadowing programs to teach younger members all the necessary technical skills required to compete in future Student Launch events.

7.4.2 Community Engagement

Similarly, to promote overall interest in our local community, our team will hold workshops and lectures to attract new people outside of Stony Brook University. The goal is to find people in our local community who are interested in rocketry to act as advisors and/or mentors. We are in the process of contacting local rocketry clubs and nearby AIAA chapters to ensure that our team will have all the support it needs in the future. Community engagement is closely connected to the last step of our plan – future funding. The more active our team is in our community, the more chances we get to land sponsorships and support from local businesses. This is a very important part of our plan, since a lot of the rocket components are not made in-house but outsourced from third party suppliers.

7.4.3 Future Funding

Due to lack of dedicated aerospace engineering department at Stony Brook University it has been always a challenge to fund Student Launch projects. To prevent future team members from having the same problem we are very dedicated to spend a lot of our time looking for new ways to fund our team. Besides local business sponsorships mentioned in the previous section, our team is currently in the process of getting funding from Stony Brook University College of Engineering and Applied Sciences.

Another potential plan we are actively looking into is becoming an official university club. In doing so, our team will be eligible for a separate funding from Undergraduate Student Government (USG) besides all the support we get from AIAA-SBU. This will open an entire new avenue for club funding and USG grants.

And lastly, we hope to start our own crowdfunding campaign. By looking into our last year's competitor's reports, we noticed that crowdfunding is a viable option to raise money. Our goal is to reach out to industry partners and previous team members to raise awareness for our team.

We believe that by executing this 3-step plan, our team will ensure a sustained interest in the aerospace industry and NASA Student Launch competition among our peers and local community.