Tacho Lycos
2021 NASA Student Launch
Proposal

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

September 21, 2020

Common Abbreviations & Nomenclature

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

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1. General Information

1.1 General Requirements

Table 1-1 below lists the general requirements for the 2020-2021 NASA Student Launch project.

Table 1-1 2020-2021 NASA Student Launch General Requirements

Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
NASA 1.1	Students on the team SHALL do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Teams SHALL submit new work. Excessive use of past work will merit penalties.	The students of the High-Powered Rocketry Club at NC State design and construct a solution to the requirements as listed in the Student Launch Handbook using new and original work.	Inspection	Project Management	Not Verified	TBD

NASA 1.2	The team SHALL provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	The project management team, including the team lead, vice president, treasurer, secretary, safety officer, webmaster, and social media lead manage the project planning tasks pertaining to this requirement.	Inspection	Project Management	Not Verified	TBD
NASA 1.3	Foreign National (FN) team members SHALL be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during Launch Week due to security restrictions. In addition, FN's may be separated from their team during certain activities on site at Marshall Space Flight Center.	Foreign National (FN) team members are identified and reported in the PDR milestone document.	Inspection	Project Management	Not Verified	TBD

NASA 1.4	The team SHALL identify all team members who plan to attend Launch Week activities by the Critical Design Review (CDR).	All team members attending launch week activities are identified and reported in the CDR milestone document.	Inspection	Project Management	Not Verified	TBD
NASA 1.4.1	Team members attending competition SHALL include students actively engaged in the project throughout the entire year.	The project management team identifies and selects members actively engaged in the project throughout the year to attend competition.	Inspection	Project Management	Not Verified	TBD
NASA 1.4.2	Team members attending competition SHALL include one mentor (see requirement 1.13).	The project management team invites the mentors listed in Section 1.2 to attend competition.	Inspection	Project Management	Not Verified	TBD
NASA 1.4.3	Team members attending competition SHALL include no more than two adult educators.	The project management team invites the adult educator listed in Section 1.2 to attend competition.	Inspection	Project Management	Not Verified	TBD

NASA 1.5	The team SHALL engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities. These activities can be conducted in-person or virtually. To satisfy this requirement, all events must occur between project acceptance and the FRR due date. The STEM Engagement Activity Report SHALL be submitted via email within two weeks of the completion of each event.	The outreach lead implements STEM engagement plans with K-12 student groups throughout the project lifecycle. The outreach lead submits a STEM Engagement Activity Report via email within two weeks of the completion of each event.	Inspection	Project Management	Not Verified	TBD
NASA 1.6	The team SHALL establish a social media presence to inform the public about team activities.	The webmaster and social media lead coordinate to develop an educational and engaging social media presence on platforms including, but not limited to: the club website, Facebook, Instagram, and Twitter.	Inspection	Project Management	Not Verified	TBD

NASA 1.7	The team SHALL email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient.	The team lead sends all deliverables to the NASA project management team prior to each specified deadline. In the event that the deliverable is too large, the webmaster posts the document on the team's website, and the team lead sends the NASA project management team a link to the file.	Inspection	Project Management	Not Verified	TBD
NASA 1.8	All deliverables SHALL be in PDF format.	The team lead converts all deliverables to PDF format prior to submission to the NASA project management team.	Inspection	Project Management	Verified	This report is submitted in PDF format.
NASA 1.9	In every report, the team SHALL provide a table of contents including major sections and their respective sub-sections.	The team lead creates and manages a Table of Contents in each milestone report.	Inspection	Project Management	Verified	A Table of Contents is included on page ii of this document.
NASA 1.10	In every report, the team SHALL include the page number at the bottom of the page.	For each milestone report, the team uses a document template which includes page numbers at the bottom of each page.	Inspection	Project Management	Verified	Page numbers are listed at the bottom of each page of this document.

NASA 1.11	The team SHALL provide any computer equipment necessary to perform a video teleconference with the review panel.	Each team member participating in the video teleconference acquires the necessary equipment for them to perform a video teleconference with the review panel.	Inspection	Project Management	Not Verified	TBD
NASA 1.12	The team SHALL be required to use the launch pads provided by Student Launch's launch services provider.	The aerodynamics lead designs a launch vehicle to be launched from either an 8-foot 1010 rail or a 12-foot 1515 rail. The structures lead fabricates the launch vehicle according to this design.	Inspection	Aerodynamics; Structures	Not Verified	TBD
NASA 1.13	Each team SHALL identify a "mentor."	The team lead identifies qualified community members to mentor team members throughout the design process.	Inspection	Project Management	Verified	See Section 1.2 for mentor listing and contact information.
NASA 1.14	Each team SHALL track and report the number of hours spent working on each milestone.	The team reports the number of hours spent on each milestone in the associated milestone report.	Inspection	Project Management	Verified	See Section 1.9 for time spent on this milestone.

1.2 Team Advisors and Mentors

i. **Name: Dr. Felix Ewere**
ii. Email: feewere@ncsu.edu
iii. Phone: (919) 515-8381
iv. Biography: Dr. Ewere is a teaching professor in the Mechanical and Aerospace Engineering department at North Carolina State University. He is currently teaching Aerospace Senior Design and is the academic advisor for undergraduates pursuing an Aerospace Engineering degree. Dr. Ewere holds a PhD in Mechanical Engineering and a Master's in Aerospace Engineering, both from the University of Alabama in Huntsville. Dr. Ewere's research interests are in the science and technology of the combination of aerodynamics, structural mechanics, energy, and smart materials. His recent works have focused on using aeroelastic instabilities on piezoelectric structures for engineering applications. Recently, he received a patent for an airflow sensor which mimics protuberances on a humpback whale flipper. Dr. Ewere is an AIAA senior member and an ASME member.

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

i. **Name: James (Jim) Livingston**
ii. Email: livingston@ec.rr.com
iii. Phone: (910) 612-5858
iv. TRA Certification: 02204
v. Biography: Jim Livingston joined TRA in 1993 and achieved his Level 3 certification in 1997. Since 1998, Livingston has served as a member of the TRA TAP and has supervised more than 20 TRA members in achieving their Level 3 certifications. He has also been involved in Tripoli research since 1997 and manufactures all of the motors he has flown (I through N sizes).

1.3 High-Powered Rocketry Club

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

1.4 Safety Officer

i. **Name: Frances McBride**
ii. Email: fcmcbrid@ncsu.edu
iii. Responsibilities: Frances McBride will act as the safety officer for the 2020-2021 year. Frances is responsible for ensuring the safe operation of lab tools and materials, including, but not limited to, drill presses, hand tools bandsaws, power tools, flammable items, and hazardous materials. Frances is required to attend all launches and to be always present during construction of the launch vehicle, payload, or associated components. Additionally, she is responsible for maintaining all lab space and equipment up to and exceeding NASA, MAE, and Environmental Health and Safety standards. This includes, but is not limited to, displaying proper safety information and documentation, maintaining safe operation of a flame and hazardous materials cabinet, and stocking an appropriate first aid kit. In the event that Frances is not present in the lab, an appropriately trained team member will be appointed to perform all of Frances' in-lab responsibilities, including, but not limited to, ensuring proper usage of PPE, educating members on proper equipment operation, and fostering a culture of safety within and outside of the lab.

1.5 Student Team Leader

i. **Name: Evan Waldron**
ii. Email: emwaldro@ncsu.edu
iii. Phone: (919) 448-1396
iv. Responsibilities: Evan Waldron will act as the NC State University Student Team Leader for the 2020-2021 NASA Student Launch competition. Evan is also serving as the president of HPRC, and as Team Lead for the Senior Design team, identified in Section 1.5.1. Evan is responsible for managing each of the subsystem teams, defined in Section 1.7, and project integration at the systems level.

1.5.1 Senior Design Team

The remainder of the senior design team consists of six Aerospace Engineering seniors using the SL competition to fulfill their senior capstone project requirements. These members and their respective roles are described below. Subsystems are defined in Section 1.7.

i. Name: Alex Thomas
ii. Subsystem: Structures
iii. Biography and Responsibilities: Alex is a senior studying Aerospace Engineering with a minor in Graphics Communications. In his free time, he enjoys biking and playing board games with friends. He plans to apply his knowledge of CAD and FEA to the structural design of the launch vehicle.

i. Name: Evan Patterson
ii. Subsystem: Payload Vehicle
iii. Biography and Responsibilities: Evan is a senior pursuing a B.S. degree in Aerospace Engineering as well as a minor in Graphic Communications. Evan works with the MAE department studying non-destructive structural health analysis. Outside of school, Evan enjoys playing guitar and rock climbing. Evan is responsible for designing and constructing the lander itself, as well as the self-levelling system.

i. Name: Justin Parkan
ii. Subsystem: Aerodynamics
iii. Biography and Responsibilities: Justin is a senior in Aerospace Engineering. He is an MAE Ambassador and is currently working for the Institute of Transportation Research and Education performing research on the use of Bike/Ped paths and micromobility legislation. In his free time, Justin likes to listen to podcasts, visit state and national parks, and play racquetball with his friends. Justin is responsible for conducting flight simulations, designing the aerodynamic components of the launch vehicle, and selecting the launch vehicle motor.

i. Name: Daniel Jaramillo
ii. Subsystem: Payload Integration
iii. Biography and Responsibilities: Daniel is finishing his senior year as an Aerospace Engineering student. He has been a member of HPRC for over 2 years and acted as the Outreach Chair at the beginning of 2020. He is also conducting research with the Department of Mechanical and Aerospace Engineering performing aerodynamic studies of propeller-wing interactions using the subsonic wind tunnel. Daniel is responsible for designing the payload integration, retention, and deployment systems.

i. Name: Emma Jaynes
ii. Subsystem: Payload Imaging
iii. Biography and Responsibilities: Emma is a 5th year senior completing a bachelor's degree in Aerospace Engineering. She has completed three rotations with the NASA Multi-Center Pathways program, and also serves as an Ambassador for NC State's Mechanical and Aerospace Engineering department. Emma has been a member of HPRC since 2016 and hopes to apply her prior work and club experience to the design and development of the payload imaging system.

i. Name: Robert Kempin
ii. Subsystem: Recovery
iii. Biography and Responsibilities: Robert is a senior in Aerospace Engineering with this being his fourth year in the club. Outside of the club he works as a combustion researcher at NC State studying energetic materials and as an aerodynamics intern at Blue Force Technologies. In his free time, he enjoys working on old cars. As recovery lead he is responsible for selecting parachutes, designing the avionics and the tracking electronics, and ensuring the launch vehicle lands safely after each flight.

1.6 Leadership Team Organization

For the 2020-2021 school year, the leadership team consists of two primary groups: Senior Design and Club officers. While they are each responsible for different aspects of the team's operation for the SL competition, both groups are responsible for guiding approximately forty undergraduate students through the SL project. Senior Design members and their duties are listed in Section 1.5.1. Club officers and their duties are listed below.

i. Position: President
ii. Name: Evan Waldron
iii. Prior Years in Club: 3
iv. Prior Experience: Vice President, Safety Officer
v. Biography and Responsibilities: Evan is a senior in Aerospace Engineering with a minor in History. As Club president, he organizes club activities and guides the club's participation in Student Launch. Evan is also the NC State Team Leader for the 2020-2021 NASA SL competition.

i. Position: Vice President
ii. Name: Myers Harbinson
iii. Prior Years in Club: 2
iv. Prior Experience: N/A
v. Biography and Responsibilities: Myers serves as the Vice President of the NCSU High-Powered Rocketry Club. He functions as a supervisor for team projects and activities outside of Student Launch along with aiding other officers in fulfilling their duties.

i. **Position: Treasurer**
ii. Name: Meredith Patterson
iii. Prior Years in Club: 2
iv. Prior Experience: Treasurer
v. Biography and Responsibilities: Meredith is a junior in Aerospace Engineering. As treasurer, her responsibility is to acquire and organize all Club funds. This includes reaching out to funders and interviews/applications to university organizations for Club funding. She also has the responsibility of ordering, shipping, and obtaining all materials for construction of the team's rockets. She hopes to grow new company connections throughout the year to further develop the Club's sponsorship network, as well as, put more funding towards outreach and underclassmen involvement.

i. **Position: Safety Officer**
ii. Name: Frances McBride
iii. Prior Years in Club: 2
iv. Prior Experience: Safety Officer
v. Biography and Responsibilities: Frances is a junior in Aerospace Engineering. Her responsibilities as safety officer include generating safety documentation and risk analysis, assisting in creation and implementation of safety standards, and monitoring lab and launch safety practices. She hopes to continue efforts to make safety documentation available for all members.

i. **Position: Secretary**
ii. Name: Trent Couse
iii. Prior Years in Club: 1
iv. Prior Experience: N/A
v. Biography and Responsibilities: Trent is a second year Physics and Aerospace Engineering Student. As the Secretary for High-Powered Rocketry Club, he is responsible for ensuring effective communication between the club's officers and the general body members through weekly emails. He is also responsible for collaborating with external and internal entities to organize events for the Club as well as communicate with any contacts who reach out to the Club.

i. **Position: Outreach Chair**
ii. Name: Mike Pudlo
iii. Prior Years in Club: 1
iv. Prior Experience: N/A
v. Biography and Responsibilities: Mike is a sophomore in Aerospace Engineering with a minor in physics. This is his second year in the Club, and as the Outreach Chair, will lead the teams outreach program. This year the team's goal is to expand outreach to involve as many students of all ages as possible. Mike will reach out to schools and

organizations where team members can provide STEM outreach opportunities, as well as lead most outreach events.

i. **Position: Social Media Chair**
ii. Name: Sean Aiton
iii. Prior Years in Club: 2
iv. Prior Experience: N/A
v. Biography and Responsibilities: Sean is a third year Aerospace Engineering student. As social media chair, he is responsible for making sure that the world is able to see all the amazing work the Club does through the team's social media accounts. He is responsible for taking, compiling, and editing photos and videos before they are ultimately posted on all Club social media platforms. Sean also uses these platforms to remind Club members of important events such as launches and meetings.

i. **Position: Webmaster**
ii. Name: Haydn Spurrell
iii. Prior Years in Club: 1
iv. Prior Experience: N/A
v. Biography and Responsibilities: Haydn is currently a junior in Aerospace Engineering. He plans to work in public or private space exploration. As Webmaster, Haydn organizes and keep the Club website up to date. He is responsible for making the website a nexus for Club activities and resources.

1.7 Subsystem Definition

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

- Project Management
- Safety
- Aerodynamics
- Structures
- Recovery
- Payload Vehicle
- Payload Integration
- Payload Imaging

The project management team, led by team lead Evan Waldron, is responsible for managing the team's schedule and mitigating any conflicts that arise between subsystems. The safety team, led by safety officer Frances McBride, is responsible for monitoring lab and launch field safety along with maintaining safety documentation. The aerodynamics team, led by senior design member Justin Parkan, is responsible for flight simulations, motor selection, and stability management of the launch vehicle. The structures team, led by senior design member Alex Thomas, is responsible for material selection and analysis along with the construction of the launch vehicle. The recovery team, led by senior design member Robert Kempin, is responsible for the entirety of the recovery system, including altimeters, black powder charges, and parachutes. The payload vehicle team, led by senior design member Evan Patterson, is responsible for designing the body of the lander as well as the self-levelling system. The payload integration team, led by senior design member Daniel Jaramillo, is responsible for the payload retention, deployment, and recovery systems. The payload imaging team, led by senior design member Emma Jaynes, is responsible for all aspects of the imaging and image transmission system onboard the lander.

1.8 Local NAR/TRA Chapter Information

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

1.9 Time Spent on Proposal

Including time spent on brainstorming, attending meetings, and writing this document, the team spent approximately 55 hours on the proposal.

2. Facilities and Equipment

2.1 Description

The team uses the MAE Student Fabrication Lab (referred to as the "Rocketry Lab") in Room 2003, Engineering Building III. This workspace is equipped with a small drill press, belt sander, band saw, 3D printer, and handheld power tools. Club members who have completed specialized training also have access to the Entrepreneurship Initiative Garage, located in the Partners I building on NC State's Centennial Campus. The Garage is equipped with a laser cutter and assorted handheld power tools.

The Club also has access to a high-precision machine shop in Engineering Building III. The machine shop supervisor, Chris Anderson, is able to take machining requests and deliver the product within approximately one week. The Club also has access to the Structures Lab in Engineering Building III, which allows for structural testing to be performed using a tensile and compressive loading machine.

2.2 Hours of Accessibility

The Rocketry Lab in 2003 Engineering Building III is open seven days a week from 6 am – 12 am for undergraduate student leader and senior design access. Due to access restrictions in place as a result of the COVID-19 pandemic, it is uncertain whether or when members outside of the senior design team will receive access.

The Entrepreneurship Initiative Garage is open 8:30 am – 4:30 pm Monday-Wednesday, and 11 am – 7 pm Thursday-Friday.

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

2.3 Necessary Personnel

The club safety officer, identified in Section 1.4, must be present for all construction or testing conducted in the Rocketry Lab. Dr. Jaideep Pandit, MAE Lab Director, must be present for any use of the Structures Lab. Chris Anderson, Research Operations Manager, must be present for any use of the precision machine shop.

2.4 Available Equipment

The team has access to a wide variety of tools, equipment, and supplies for use throughout the design and construction process. The team has access to a drill press with 12 inches of travel, a scroll saw, a band saw, a belt sander, and a soldering iron. Each of these are low-power tabletop tools with lockout keys to prevent unauthorized use. The team also has access to a DeWalt 18V drill, a DeWalt jigsaw, a Dremel 4300 rotary tool, a Rigid oscillating cutting tool, and a Wagner heat gun. These tools are all handheld and stored in a locking storage cabinet to regulate their usage. The Rocketry Lab is equipped with compressed air lines, which are used for the vacuum bagging of composite layups. The team has access to an assortment of hand tools, including files, screwdrivers, wrenches, cutting implements, and clamps. The team also has a SeeMeCNC Rostock Max V2 3D printer which is used for prototyping and the production of small, non-load bearing components.

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

2.5 Supplies Required

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

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

3. Safety

3.1 Safety Requirements

Table 3-1 lists the safety requirements from the NASA Student Launch Handbook.

Table 3-1 2020-2021 NASA Student Launch Safety Requirements

Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
NASA 5.1	The team SHALL use a launch and safety checklist. The final checklists SHALL be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations.	The safety team creates a launch and safety checklist. The safety team includes these checklists in the FRR milestone report and verifies their use during LRR and Launch Day operations.	Inspection; Demonstration	Safety	Not verified	TBD
NASA 5.2	Each team SHALL identify a student safety officer who will be responsible for all items in requirements Section 5.3.	A safety officer is identified in each milestone report.	Inspection	Project management	Verified	See Section 1.4 for safety officer identification and contact information.

NASA 5.3.1.1	The safety officer SHALL monitor team activities with an emphasis on safety during the design of the launch vehicle and payload.	The safety officer is present for and engages in at least half of all launch vehicle and payload design meetings.	Inspection	Safety	Not verified	TBD
NASA 5.3.1.2	The safety officer SHALL monitor team activities with an emphasis on safety during the construction of the launch vehicle and payload components.	The safety officer is present and engaged for all launch vehicle and payload construction meetings.	Inspection	Safety	Not verified	TBD
NASA 5.3.1.3	The safety officer SHALL monitor team activities with an emphasis on safety during the assembly of the launch vehicle and payload.	The safety officer is present and engaged during the assembly of the launch vehicle and payload.	Inspection	Safety	Not verified	TBD
NASA 5.3.1.4	The safety officer SHALL monitor team activities with an emphasis on safety during the design of the ground testing of the launch vehicle and payload.	The safety officer is present and engaged for all ground tests of the launch vehicle and payload.	Inspection	Safety	Not verified	TBD

NASA 5.3.1.5	The safety officer SHALL monitor team activities with an emphasis on safety during the subscale launch test(s).	The safety officer is present and engaged at any subscale launch test.	Inspection	Safety	Not verified	TBD
NASA 5.3.1.6	The safety officer SHALL monitor team activities with an emphasis on safety during the full-scale launch test(s).	The safety officer is present and engaged at any full-scale launch test.	Inspection	Safety	Not verified	TBD
NASA 5.3.1.7	The safety officer SHALL monitor team activities with an emphasis on safety during Launch Day.	The safety officer is present and engaged at Launch Day.	Inspection	Safety	Not verified	TBD
NASA 5.3.1.8	The safety officer SHALL monitor team activities with an emphasis on safety during recovery activities.	The safety officer is present and engaged for all recovery activities.	Inspection	Safety	Not verified	TBD
NASA 5.3.1.9	The safety officer SHALL monitor team activities with an emphasis on safety during STEM engagement activities.	The safety officer is present and engaged for at least half of all STEM engagement activities.	Inspection	Safety	Not verified	TBD

NASA 5.3.2	The safety officer SHALL implement procedures developed by the team for construction, assembly, launch, and recovery activities.	The safety officer develops a safety plan for construction, assembly, launch, and recovery activities, and verifies team adherence to this plan.	Demonstration	Safety	Not verified	TBD
NASA 5.3.3	The safety officer SHALL manage and maintain current revisions of the team’s hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	The safety officer manages and maintains current revisions of all hazard analyses, procedures, and MSDS/chemical inventory data.	Demonstration	Safety	Not verified	TBD
NASA 5.3.4	The safety officer SHALL assist in the writing and development of the team’s hazard analyses, failure modes analyses, and procedures.	The safety officer assists in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	Demonstration	Safety	Not verified	TBD

NASA 5.4	During test flights, the team SHALL abide by the rules and guidance of the local rocketry club's RSO. Teams SHALL communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	The safety officer communicates the team's intentions to the local club's President or Prefect and RSO prior to attending any NAR or TRA launch. The safety officer verifies team adherence to the rules and guidance of the local club's RSO.	Demonstration	Safety	Not verified	TBD
NASA 5.5	Teams SHALL abide by all rules set forth by the FAA.	The safety officer verifies the team adheres to all rules set forth by the FAA.	Demonstration	Safety	Not verified	TBD

3.2 Safety Plan

Table 3-2 below shows potentially hazardous materials used by the team.

Table 3-2 Potentially Hazardous Materials used During the Student Launch Project

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

3.3 Facilities Involved

Facilities used for the 2020-2021 year will be the Rocketry Lab which is located in room 2003 EBIII on NCSU's centennial campus. Because of the coronavirus pandemic, a limit of three people from HPRC are allowed in the lab at any given time. Due to this, much of the subscale, full-scale, and payload fabrication will take place outside under a tent. Similarly, launch days will take place in a field in Bayboro, North Carolina.

3.4 Identification of Safety Officer

The Safety Officer for the 2020-2021 year will be Frances McBride, a junior majoring in Aerospace Engineering. As Safety Officer, Frances is committed to upholding a rigorous set of safety standards which is defined below in this section of the proposal. She will ensure that risk analysis is thoroughly performed throughout the year by using Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA). FTA was used in the 2019-2020 year as a supplement to FMEA and will be continued as a way for the team to better visualize hazards that may impact mission success and any personnel involved. Frances is additionally committed to making safety documentation available and accessible to all members by continuing the implementation of a lab safety handbook that will be available on HPRC's website and in the lab.

3.5 Identification of Risks/Risk Assessment

Within Table 3-3, a "likeliness-severity" (LS) matrix is defined. This matrix will be used to characterize all risk assessment in the form of FMEA tables. In Table 3-4, a preliminary risk assessment is performed with hazards identified due to the coronavirus pandemic and material concerns.

Table 3-3 LS-Matrix

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

Table 3-4 Preliminary Risk Assessment

Hazard	LS Before	Mitigation	LS After
Material spill due to improper storage	2C	Storage instructions in Table 3-2 shall be followed after using a hazardous material	1A
Premature energetics detonation	4B	Launch vehicle components containing loaded black powder shall be packed in static shielding bags	2A
		Ignitors shall be affixed after all except required personnel have vacated the launch site	
		After altimeters have been armed, AV bay pressure shall remain constant until parachute deployment	
Epoxy weakening from external particulates due to working outside	3B	An overhead tent shall be placed when filleting and making layups	3A

		Members shall work outside with epoxy only when wind speeds are less than 15 mph	
Exposure to COVID-19 through working closely together	4D	Facemasks shall always be worn, even when the use of particulate masks is required	4B
		No more than three people shall be allowed in HPRC's lab at one time	
		No more than ten members shall be occupying the same space	

3.6 State and Local Law Compliance

The laws and regulations below are always to be followed by the team and its mentors; the team recognizes that a failure to follow these guidelines will result in an inability to launch and mission failure.

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

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

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

3.6.2 NFPA 1127 Code for High Power Rocketry

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

3.7 Pre-Launch/Hazard Briefing Plan

Due to the COVID-19 pandemic, only essential personnel (senior design members and the safety officer) will be permitted to attend launches. Despite this, prior to launch, the team shall be given a launch safety briefing presentation lead by the safety officer. This presentation will give an overview of launch field etiquette, required personal protective equipment and how to follow the team's checklists. Team members will be instructed to defer to the RSO's advice first and the safety officer's advice second. The presentation will have an emphasis on common-sense safety and compliance to team-derived and NASA-given safety requirements.

3.8 Safety in Documentation

3.8.1 Fault Tree Analysis

Similar to the 2019-2020-year, FTA will be used to contextualize the FMEA tables and make them more accessible to the general viewer of the team's reports. An example of FTA from 2019-2020's CDR is in Figure 3-1 below.

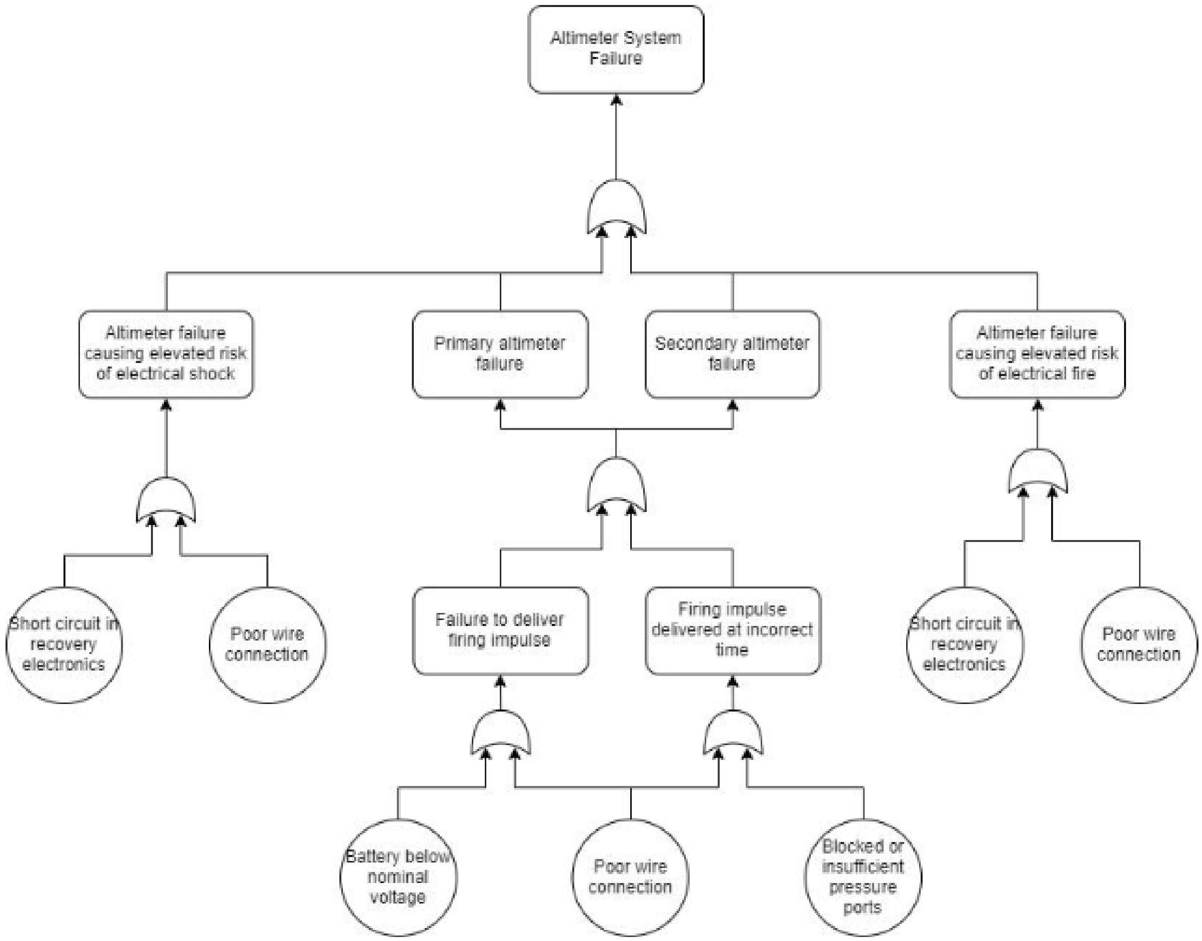

Figure 3-1 FTA for Altimeter System Failure

3.8.2 Checklists

Checklists, as required by NASA requirement NASA 5.1, shall be used on launch day to ensure safe practices by all launch attendees. These checklists shall include a list of steps for assembly of each section of the launch vehicle and payload, the PPE required for each step, and a stamp box in which the leads of the respective subsystem will stamp approval when a task is completed to satisfaction. Especially dangerous and high-risk activities shall be highlighted in red and limited to trained required personnel. Additionally, emergency checklists are present in case of emergency. Both sets of checklists are to be followed at all times.

3.8.2.1 Hazard Labels

Hazard labels are to be placed as a warning to those using checklists – if a task is not carried out correctly, its consequence will be listed in the appropriate box.

Figure 3-2 Caution boxes mark low risk, low likelihood

Figure 3-3 Yellow warning boxes mark medium risk, medium likelihood

Figure 3-4 Red warning boxes mark high risk, high likelihood

3.9 NAR/TRA Personnel Procedures

The team shall abide by the NAR High Power Rocket Safety Code that details the NAR/TRA personnel procedures required to safely launch the launch vehicle.

3.9.1 NAR High Power Rocket Safety Code

The team will comply to the NAR safety code in the following ways, additionally summarized in the safety agreement in Section 3.11:

1. Certification: Team mentors are all NAR Level 3 certified and will assist members in handling dangerous vehicle components.
2. Materials: The team shall avoid using heavy body materials unless necessary for structural safety of the system.

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

3.10 NAR/TRA Personnel Purchase of Club Energetics

All energetics, including (but not limited to) black powder and launch vehicle motors, shall be purchased by NAR/TRA club mentors through a commercially available source. These materials shall be stored in the lab's flame cabinet when not in use and transported from the lab to the launch field in static bags.

3.11 Safety Agreement

Team members are required to agree to a safety agreement, detailed below. Due to the COVID-19 pandemic, it is unlikely that team members will be able to sign a physical copy in the lab space prior to starting fabrication of the launch vehicle and payload, but a digital copy will be sent out to be signed before personnel are permitted to work on the launch vehicle.

Mission and personnel safety are the highest concerns of the High-Powered Rocketry Club. By signing this form, I agree that the club's ability to launch successfully depends on my compliance with the following safety requirements. As a member of the club, I agree to abide by the following rules:

Members shall…

1. Wear a protective mask during the coronavirus pandemic at all times when engaged in club activity on- or off-campus
2. Wear/use the correct PPE for the task being performed
3. Understand proper procedures for tool use before using a tool, both powered and unpowered
4. Comply with range safety inspections prior to launch
5. Follow all guidance and direction of the Range Safety Officer

By signing below, I agree that I have read, understood, and committed to following the rules shown above.

4. Technical Design

4.1 Launch Vehicle Requirements

Table 4-1 below shows the launch vehicle requirements for the 2020-2021 NASA Student Launch project.

Table 4-1 2020-2021 NASA Student Launch Launch Vehicle Requirements

Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
NASA 2.1	The vehicle SHALL deliver the payload to an apogee altitude between 3,500 and 5,500 feet above ground level (AGL).	The aerodynamics lead designs a launch vehicle to reach an apogee between 3,500 and 5,500 feet AGL. The team then constructs the vehicle as designed and the launch vehicle flies between 3,500 at 5,500 feet AGL.	Analysis; Demonstration	Aerodynamics	Not verified	See Section 4.3 for apogee predictions.
NASA 2.2	The team SHALL identify their target altitude goal at the PDR milestone.	The aerodynamics lead declares the team's target altitude goal in the PDR milestone report.	Inspection	Aerodynamics	Not verified	TBD

NASA 2.3	The vehicle SHALL carry one commercially available, barometric altimeter for recording the official altitude used in determining the Altitude Award winner.	The recovery lead designates one onboard altimeter to record the official altitude used in determining the Altitude Award winner.	Inspection	Recovery	Not verified	TBD
NASA 2.4	The launch vehicle SHALL be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	The structures and recovery leads design the launch vehicle such that it is capable of being recovered with minimal damage and launched again on the same day without repairs or modifications.	Demonstration	Recovery; Structures	Not verified	See Section 4.4 for the leading recovery design.
NASA 2.5	The launch vehicle SHALL have a maximum of four (4) independent sections.	The aerodynamics and recovery subsystem leads design a launch vehicle that has fewer than four (4) independent sections.	Inspection	Aerodynamics; Recovery	Verified	See Section 4.2.1 for the leading launch vehicle design.
NASA 2.5.1	Coupler/airframe shoulders which are located at in-flight separation points SHALL be at least 1 body diameter in length.	The aerodynamics lead designs the airframe such that couplers/shoulders at in-flight separation points are at least 1 body diameter in length.	Inspection	Aerodynamics	Not verified	See Section 4.2.1 for the leading launch vehicle design.

NASA 2.5.2	Nosecone shoulders which are located at in-flight separation points SHALL be at least 1/2 body diameter in length.	The aerodynamics lead designs the airframe such that nosecone shoulders at in-flight separation points are at least 1/2 body diameter in length.	Inspection	Aerodynamics	Partially verified	See Section 4.2.1 for the leading launch vehicle design.
NASA 2.6	The launch vehicle SHALL be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	The project management and safety teams develop launch day checklists that can be executed in less than two (2) hours.	Demonstration	Project Management; Safety	Not verified	TBD
NASA 2.7	The launch vehicle and payload SHALL be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components.	The project management and safety teams monitor the power consumption of each electrical launch vehicle and payload component and verify functionality of each component after two (2) hours.	Demonstration	Project Management; Safety	Not verified	TBD

NASA 2.8	The launch vehicle SHALL be capable of being launched by a standard 12-volt direct current firing system.	The project management and safety teams select a motor ignitor capable of being ignited from a 12-volt direct current firing system.	Demonstration	Project Management; Safety	Not verified	TBD
NASA 2.9	The launch vehicle SHALL require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).	The project management and safety teams limit the launch vehicle such that no external circuitry or ground support equipment is required for launch.	Demonstration	Project Management; Safety	Not verified	TBD

NASA 2.10	The launch vehicle SHALL use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	The aerodynamics lead selects a commercially available solid motor propulsion system using APCP that is approved by NAR, TRA, and/or CAR for use in the launch vehicle.	Inspection	Aerodynamics	Not verified	See Section 4.5 for the leading motor selection.
NASA 2.10.1	Final motor choices SHALL be declared by the Critical Design Review (CDR) milestone.	The aerodynamics lead declares the team's final motor choice in the CDR milestone report.	Inspection	Aerodynamics	Not verified	TBD
NASA 2.10.2	Any motor change after CDR SHALL be approved by the NASA Range Safety Officer (RSO).	The project management team requests approval from the NASA RSO for motor changes following submission of the CDR milestone report.	Inspection	Project Management	Not verified	TBD

NASA 2.11	The launch vehicle SHALL be limited to a single stage.	The aerodynamics lead designs the launch vehicle such that it only utilizes a single stage.	Inspection	Aerodynamics	Not verified	See Section 4.2 for the leading launch vehicle design.
NASA 2.12	The total impulse provided by a College or University launch vehicle SHALL not exceed 5,120 Newton-seconds (L-class).	The aerodynamics lead selects a motor that does not exceed 5,120 Newton-seconds of total impulse.	Inspection	Aerodynamics	Not verified	See Section 4.5 for the leading motor selection.
NASA 2.13	Pressure vessels on the vehicle SHALL be approved by the RSO.	The structures lead provides the necessary data on any onboard pressure vessels to the NASA RSO and home field RSO.	Inspection	Structures	Not verified	TBD
NASA 2.13.1	The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) for pressure vessels on the vehicle SHALL be 4:1 with supporting design documentation included in all milestone reviews.	The structures lead includes design documentation supporting a factor of safety of 4:1 for any pressure vessel on the launch vehicle in each milestone report.	Analysis; Inspection	Structures	Not verified	TBD

NASA 2.13.2	Each pressure vessel SHALL include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.	The structures lead selects any onboard pressure vessels such that they 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.	Analysis; Inspection	Structures	Not verified	TBD
NASA 2.13.3	The full pedigree of any pressure vessel on the launch vehicle SHALL be described, including the application for which the tank was designed and the history of the tank. This SHALL include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.	The structures lead records the full history of each pressure vessel, including the number of pressure cycles, the dates of pressurization/depressurization, and the name of each person or entity administering the pressure events.	Inspection	Structures	Not verified	TBD

NASA 2.14	The launch vehicle SHALL have a minimum static stability margin of 2.0 at the point of rail exit.	The aerodynamics lead designs the launch vehicle such that it has a static stability margin of at least 2.0 at the point of rail exit.	Analysis	Aerodynamics	Not verified	See Section 4.3 for stability calculations for the leading launch vehicle design.
NASA 2.15	Any structural protuberance on the rocket SHALL be located aft of the burnout center of gravity. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.	The aerodynamics lead designs the launch vehicle such that there are no structural protuberances forward of the burnout center of gravity. If any camera housings are included, the aerodynamics lead shows that the housings cause minimal aerodynamic effects on launch vehicle stability.	Analysis; Inspection	Aerodynamics	Not verified	See Section 4.2 for the leading launch vehicle design.
NASA 2.16	The launch vehicle SHALL accelerate to a minimum velocity of 52 fps at rail exit.	The aerodynamics lead designs the launch vehicle such that a minimum velocity of 52 fps is achieved by rail exit.	Analysis	Aerodynamics	Not verified	See Section 4.3 for performance calculations for the leading launch vehicle design.

NASA 2.17	The team SHALL successfully launch and recover a subscale model of their rocket prior to CDR. Subscale flight data SHALL be reported at the CDR milestone.	The team launches and recovers a subscale model of the launch vehicle. The team reports subscale flight data in the CDR milestone report.	Demonstration	Project Management	Not verified	See Section 6.1 for the project plan timeline.
NASA 2.17.1	The subscale model SHALL resemble and perform as similarly as possible to the full-scale model, however, the full-scale SHALL not be used as the subscale model.	The aerodynamics lead designs a unique subscale launch vehicle which performs similarly to the full-scale launch vehicle.	Inspection	Aerodynamics	Not verified	TBD
NASA 2.17.2	The subscale model SHALL carry an altimeter capable of recording the model's apogee altitude.	The recovery lead installs an altimeter capable of recording the subscale launch vehicle' apogee altitude in the subscale launch vehicle.	Inspection	Recovery	Not verified	TBD
NASA 2.17.3	The subscale rocket SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The team constructs a new subscale launch vehicle, designed and built specifically for this year's project.	Inspection	Project Management	Not verified	TBD

NASA 2.17.4	Proof of a successful flight SHALL be supplied in the CDR report.	The team supplies proof of a successful subscale flight in the CDR milestone report.	Inspection	Project Management	Not verified	TBD
NASA 2.18.1	Vehicle Demonstration Flight - All teams SHALL successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration.	The team launches and recovers the full-scale launch vehicle in its final flight configuration prior to the FRR milestone.	Demonstration	Project Management	Not verified	See Section 6.1 for the project plan timeline.
NASA 2.18.1.1	The vehicle and recovery system SHALL function as designed during the VDF.	No anomalies are detected in the performance of the launch vehicle and its recovery system during the VDF.	Demonstration	Project Management	Not verified	TBD
NASA 2.18.1.2	The full-scale rocket SHALL be a newly constructed rocket, designed and built specifically for this year’s project.	The team constructs a new full-scale launch vehicle, designed and built specifically for this year's project.	Inspection	Project Management	Not verified	TBD
NASA 2.18.1.3.1	If the payload is not flown on the VDF, mass simulators SHALL be used to simulate the payload mass.	If the payload is not flown on the VDF, the structures lead installs mass simulators to simulate the payload mass.	Inspection	Structures	Not verified	TBD

NASA 2.18.1.3.2	Payload mass simulators SHALL be located in the same approximate location on the rocket as the missing payload mass.	If the payload is not flown on the VDF, the structures lead install mass simulators in the same approximate location of the missing payload mass.	Inspection	Structures	Not verified	TBD
NASA 2.18.1.4	If the payload changes the external surfaces of the rocket (such as camera housings or external probes) or manages the total energy of the vehicle, those systems SHALL be active during the full-scale Vehicle Demonstration Flight.	If the payload changes the external surfaces or manages the total energy of the launch vehicle, the project management team activates those systems during the VDF.	Inspection	Project Management	Not verified	TBD
NASA 2.18.1.5	Teams SHALL fly the Launch Day motor for the Vehicle Demonstration Flight.	The aerodynamics lead installs the Launch Day motor for the VDF.	Inspection	Aerodynamics	Not verified	TBD
NASA 2.18.1.6	The vehicle SHALL be flown in its fully ballasted configuration during the full-scale test flight.	The structures lead installs all required ballast for the VDF.	Inspection	Structures	Not verified	TBD

NASA 2.18.1.7	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components SHALL not be modified without the concurrence of the NASA Range Safety Officer (RSO).	Following a successful VDF, the project management team does not allow modification of the launch vehicle or any of its components without approval from the NASA RSO.	Inspection	Project Management	Not verified	TBD
NASA 2.18.1.8	Proof of a successful flight SHALL be supplied in the FRR report. Altimeter data output is required to meet this requirement.	The recovery lead includes altimeter data from the VDF in the FRR milestone report.	Inspection	Recovery	Not verified	TBD
NASA 2.18.1.9	Vehicle Demonstration flights SHALL be completed by the FRR submission deadline. Teams completing a required re-flight SHALL submit an FRR Addendum by the FRR Addendum deadline.	The team completes the VDF by the FRR milestone report submission deadline. If a re-flight is required, the team submits an FRR addendum by the FRR addendum deadline.	Inspection	Project Management	Not verified	TBD

NASA 2.18.2	Payload Demonstration Flight - All teams SHALL successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown SHALL be the same rocket to be flown on Launch Day.	The team completes the PDF prior to the PDF deadline using the same rocket to be flown on Launch Day.	Inspection	Project Management	Not verified	See Section 6.1 for the project plan timeline.
NASA 2.18.2.1	The payload SHALL be fully retained until the intended point of deployment (if applicable), all retention mechanisms SHALL function as designed, and the retention mechanism SHALL not sustain damage requiring repair.	The payload remains fully retained until the point of intended deployment with each retention mechanism functioning as designed and not sustaining damage requiring repair during the PDF.	Demonstration	Payload Integration	Not verified	TBD
NASA 2.18.2.2	The payload flown SHALL be the final, active version.	The payload flown on the PDF is the final, active version of the payload.	Inspection	Project Management	Not verified	TBD

NASA 2.18.2.4	Payload Demonstration Flights SHALL be completed by the FRR Addendum deadline.	The PDF is completed by the FRR Addendum deadline.	Inspection	Project Management	Not verified	See Section 6.1 for the project plan timeline.
NASA 2.19	An FRR Addendum SHALL be required for any team completing a Payload Demonstration Flight or NASA-required Vehicle Demonstration Re-flight after the submission of the FRR Report.	If the team is completing the PDF or a NASA-required VDF re-flight after the submission of the FRR Report, the team lead submits an FRR Addendum by the FRR Addendum deadline.	Inspection	Project Management	Not verified	TBD
NASA 2.19.1	If a re-flight is necessary, the team SHALL submit the FRR Addendum by the FRR Addendum deadline.	The team lead submits the FRR Addendum by the FRR Addendum deadline.	Inspection	Project Management	Not verified	TBD
NASA 2.19.2	The team SHALL successfully execute a PDF to fly a final competition launch.	The project management team manages the schedule such that a PDF is successfully completed by the FRR Addendum deadline.	Demonstration	Project Management	Not verified	TBD

NASA 2.20	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.	The team lead places their contact information on the rocket airframe and any section of the vehicle that is not tethered to the main airframe in a manner that allows this information to be retrieved without opening or separating the vehicle.	Inspection	Project Management	Not verified	TBD
NASA 2.21	All Lithium Polymer batteries SHALL be sufficiently protected from impact with the ground and SHALL be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.	The safety team ensures all Lithium Polymer batteries are sufficiently protected from ground impact and are marked appropriately.	Analysis; Inspection	Safety	Not verified	TBD

NASA 2.22.1	The launch vehicle SHALL not utilize forward firing motors.	The aerodynamics lead designs the launch vehicle such that it does not utilize forward firing motors.	Inspection	Aerodynamics	Not verified	TBD
NASA 2.22.2	The launch vehicle SHALL not utilize motors that expel titanium sponges (Sparky, Skidmark, Metal-Storm, etc.).	The aerodynamics lead selects a motor that does not expel titanium sponges.	Inspection	Aerodynamics	Not verified	See Section 4.5 for the leading motor selection.
NASA 2.22.3	The launch vehicle SHALL not utilize hybrid motors.	The aerodynamics lead selects a motor containing exclusively APCP.	Inspection	Aerodynamics	Not verified	See Section 4.5 for the leading motor selection.
NASA 2.22.4	The launch vehicle SHALL not utilize a cluster of motors.	The aerodynamics lead selects a single motor only for use in the launch vehicle.	Inspection	Aerodynamics	Not verified	See Section 4.5 for the leading motor selection.
NASA 2.22.5	The launch vehicle SHALL not utilize friction fitting for motors.	The structures lead installs a motor retention system that does not use friction fitting.	Inspection	Structures	Not verified	See Section 4.2 for the leading launch vehicle design.
NASA 2.22.6	The launch vehicle SHALL not exceed Mach 1 at any point during flight.	The aerodynamics lead designs the launch vehicle such that it does not exceed Mach 1 at any point during flight.	Analysis	Aerodynamics	Not verified	See Section 4.3 for the leading launch vehicle performance predictions.

NASA 2.22.7	Vehicle ballast SHALL not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad.	The aerodynamics lead designs the launch vehicle such that it does not require ballast exceeding 10% of the total unballasted weight of the launch vehicle.	Analysis; Inspection	Aerodynamics	Not verified	See Section 4.2 for the leading launch vehicle design.
NASA 2.22.8	Transmissions from onboard transmitters, which are active at any point prior to landing, SHALL not exceed 250 mW of power (per transmitter).	The safety team verifies all transmitters activated prior to landing are not capable of transmissions exceeding 250 mW of power per transmitter.	Analysis	Safety	Not verified	TBD
NASA 2.22.9	Transmitters SHALL not create excessive interference. Teams SHALL utilize unique frequencies, hand-shake/passcode systems, or other means to mitigate interference caused to or received from other teams.	The safety team verifies no transmitter creates excessive interference. The safety team enforces the usage of unique frequencies to mitigate interference with other teams.	Analysis; Demonstration	Safety	Not verified	TBD

NASA 2.22.10	Excessive and/or dense metal SHALL not be utilized in the construction of the vehicle.	The structures lead minimizes the amount of metal onboard the launch vehicle.	Inspection	Structures	Not verified	TBD

4.2 Launch Vehicle Specifications

Per the 2021 NASA SL competition rules, the team must successfully design, construct, and launch a recoverable and reusable high-powered rocket of original design. Additionally, the launch vehicle will contain the deployable lander system as its payload.

4.2.1 Launch Vehicle Dimensions

The launch vehicle was designed using RockSim, a rocket design software made by Apogee Components. OpenRocket has been used in the past, but it was found that RockSim's data tends to be more reliable. The current proposed launch vehicle design has a length of 106.68 inches and a constant body diameter of 6 inches. The launch vehicle will consist of three separate sections: the nose section, the mid-section, and the fin can. Prior to launch, these sections will be secured to each other using shear pins through the couplers to ensure the sections do not separate prematurely. Figure 4-1 shows the configuration of the launch vehicle with each section labelled accordingly.

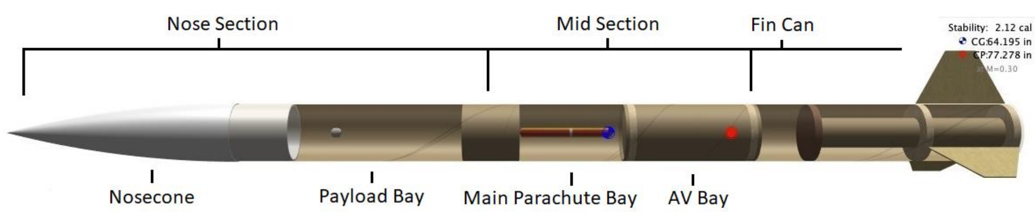

Figure 4-1 OpenRocket Schematic of Launch Vehicle with Labelled Sections

This launch vehicle configuration has a center of gravity (CG) at 64.0 inches and a center of pressure (CP) at 77.1 inches, each measured from the tip of the nosecone. These values give the launch vehicle a static stability margin of 2.13 at launch. The launch vehicle is predicted to weigh 40.65 pounds on the launchpad and 32.55 pounds upon burnout. These values meet the NASA requirement of having a static stability margin of at least 2.0 upon launch rail exit

4.2.1.1 Nosecone Design

The nosecone for the proposed launch vehicle design is a 4:1 ogive with a metal tip, an outer diameter of 6 inches, and a tip to shoulder length of 24.68 inches. This nosecone geometry was selected to achieve the desired stability margin and because of commercial availability.

The club has used ballast in the past to reach the required stability margin, but with the current design, it is unnecessary. The current model uses an estimated payload weight of 7 pounds. Once the payload design has been finalized, the model will be updated with a more accurate weight and the need for ballast to achieve the required stability margin will be reassessed.

Additionally, there will be a bulkhead attached in the aft end of the nosecone. This bulkhead will have an electronic latch attached which will hold the payload during flight.

4.2.1.2 Avionics Bay Design

The avionics (AV) bay consists of a coupler section 14 inches in length with a 2-inch band of body tube centered on the coupler. The AV bay houses the recovery avionics and holes drilled in the band of body tube will serve as access point to activate the screw switches. The launch vehicle is designed to separate at the aft end of the AV bay and the forward end of the AV bay will remain attached to the main parachute bay with screws. This allows for a fully removable AV bay.

4.2.1.3 Fin Can Design

The fin can will contain the drogue parachute and the fin-motor tube assembly.

By keeping the design of the fins simple, the team increases the likelihood that the fins manufactured will perform the same as the fins in the simulations. It is for this reason that the team has chosen a trapezoidal fin design that is built without sweep angle in mind. The root of the fin is 9.75-inches long, with a 3.25-inch chord tip placed 3.25-inch behind the leading edge. The chord tip will run parallel to the root chord so there is no induced spin, and they are separated by 5.6-inches. Figure 4-2 shows a sketch of the fin design.

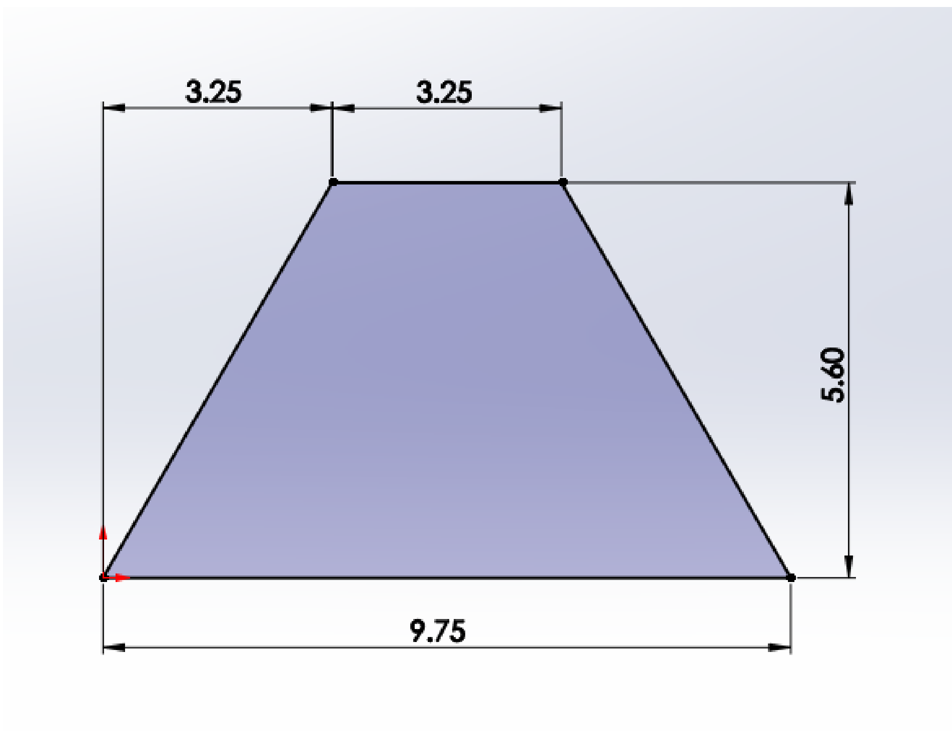

Figure 4-2 Dimensioned Sketch of Fin Design

The semi-span of the fin is larger than in previous years, which allows the fin to reach further out of the turbulent boundary layer around the launch vehicle, allowing them to have a greater stabilizing effect. The larger semi-span allows us to have a safe stability margin with three fins instead of four, cutting down on weight and increasing the apogee of the launch vehicle.

The fin tabs will extend into the body of the launch vehicle and be attached to the motor tube using two-part epoxy. For extra security, fillets are added using a mix of silica powder and epoxy where the fins intersect the body tube. These fillets help to reduce stress concentrations and reduce aerodynamic drag on the launch vehicle. The fin tabs will fit snugly between the centering ring and engine block to assist with alignment and to simplify the assembly of the fin can.

4.2.1.4 Bulkhead Design

Each bulkhead consists of layers of 1/8 inch aircraft grade birch plywood. This material has been used successfully by the club in past launch vehicles. For bulkheads which need an anchor point for shock cords, U-bolts will be used to split the loading among two contact points. Based on an initial estimation, it is expected that the bulkheads will experience loadings of 300-400 lbf upon drogue deployment and 600 lbf upon main deployment. Using a simple structural simulation in ANSYS it was found that a 3/4-inch-thick bulkhead will withstand all in-flight forces. Under a 600 lbf loading, the maximum principle stress on the bulkhead is 14814 psi on the U-bolt. The ultimate tensile strength of stainless steel is 84992 psi, giving the U-bolt a factor of safety of 5.74 as seen in Figure 4-3. Since the plywood is of greater concern, stress analysis was performed on a 3/4-inch thick plywood bulkhead, excluding the U-Bolt. Figure 4-4 shows the results of this analysis, with a maximum principle stress on the plywood of 2956.8 psi. Since plywood's maximum tensile strength is 4496.2 psi, this gives a factor of safety of 1.52. Based on this, all bulkheads will be made to be 3/4 inch.

4.2.1.4(a) Engine Block

One bulkhead of specific importance is the engine block. The engine block is located at the aft end of the fin can and is responsible for holding the motor tube in place. This bulkhead will take most of the force produced by the motor, so the team wants to ensure that it can withstand the forces without failing. The chosen motor has a peak thrust of 302.6 lbf. Using a structural simulation in ANSYS it is shown in Figure 4-5 that a 3/4-inch-thick engine block experiences a maximum tensile stress of 255.72 psi, giving it a factor of safety of 17.6. This design is more than enough to handle the motor's thrust.

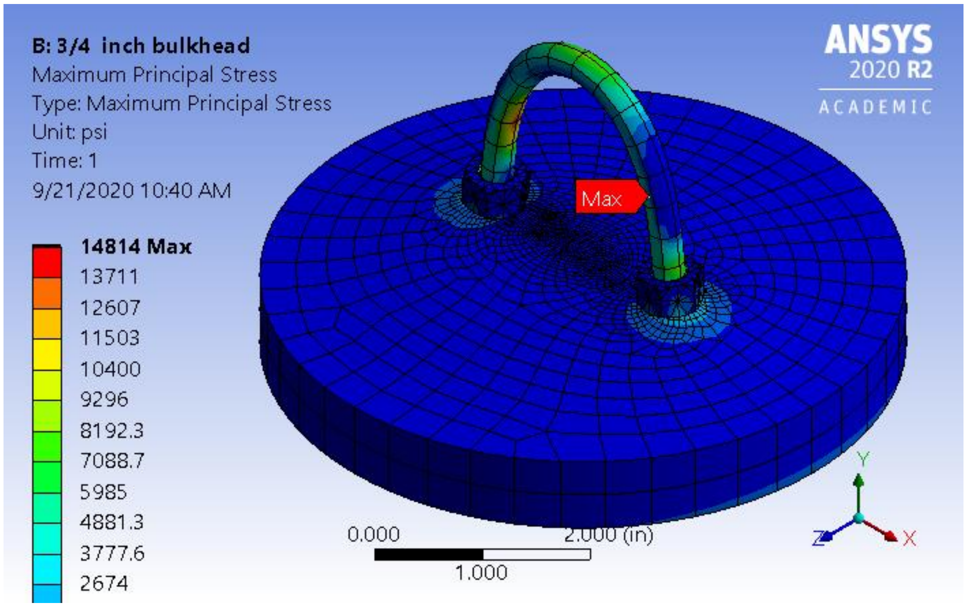

Figure 4-3 Maximum principal stress for 3/4-inch thick bulkhead and U-bolt under 600 lbf loading

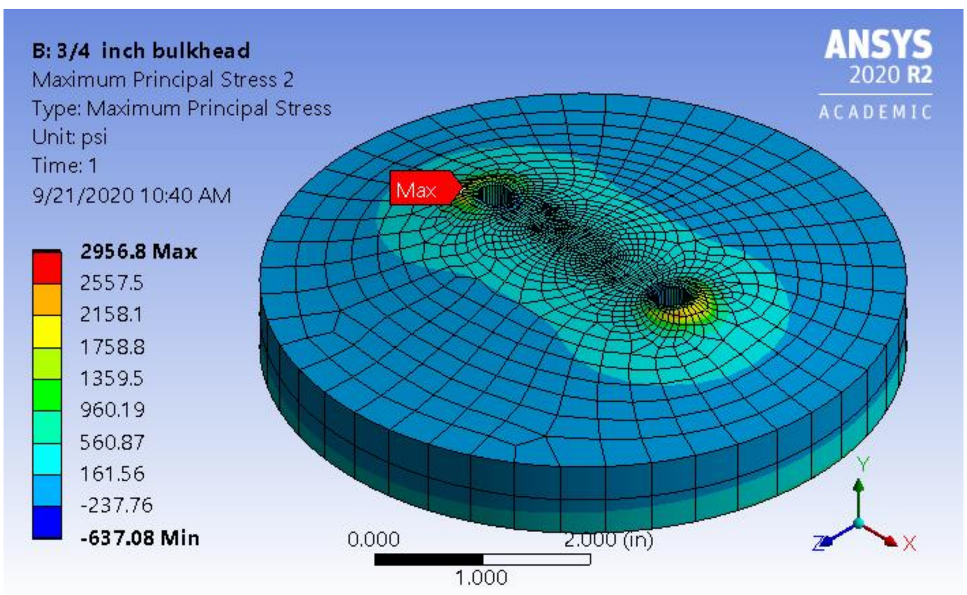

Figure 4-4 Maximum principal stress for 3/4-inch thick bulkhead under 600 lbf loading

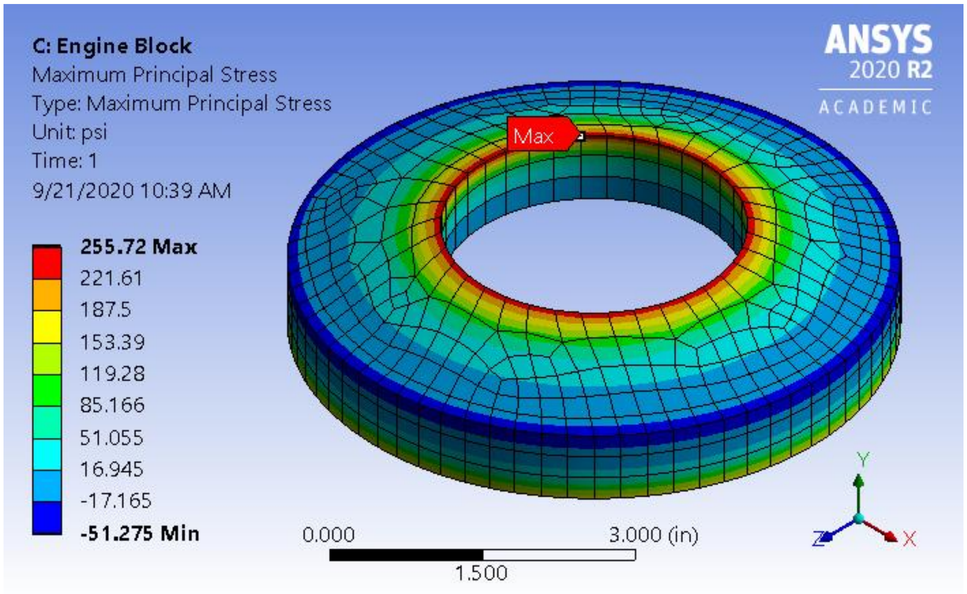

Figure 4-5 Maximum principal stress for 3/4-inch thick engine block under 302.6 lbf load

4.2.2 Material Selection

Choosing an appropriate material is a critical part of designing the launch vehicle. Ideally, the chosen material should be lightweight and inexpensive, but still strong enough to handle in-flight forces. Through RockSim analysis, it is expected that the launch vehicle will not exceed a Mach number of 0.478. Since the launch vehicle will not experience supersonic flight, there are more materials that the team is able to choose from.

4.2.2.1 Phenolic Tubing

Phenolic tubing is a stronger type of cardboard tubing and is known for its heat resistance and low price. It is resin impregnated, spiral wrapped, and heat cured allowing it to withstand 5x the compressive forces of basic cardboard tubing. Phenolic tubing costs $12.25/foot at a weight of 9.2 oz for a 6-inch diameter airframe. However, phenolic tubing is prone to impact damage and the airframe may shatter upon rough landings. Per NASA's requirements, the team is to make a reusable rocket. Because of the risk of damage associated with phenolic tubing, it would not be a wise choice of material.

4.2.2.2 Blue Tube

Blue Tube is another form of spiral wound cardboard tubing, but it is more resilient than phenolic tubing. It is less brittle than phenolic giving it the ability to withstand far more stress and it is also more abrasion resistant. Blue tube costs $16.75/foot at a weight of 10.4 oz for a 6-inch diameter airframe. While Blue Tube is more expensive and heavier than phenolic tubing, its performance is far better. It is also lighter and cheaper than both fiberglass and carbon fiber. However, Blue Tube is not water-resistant. The launch field used by the Club has multiple water-filled ditches for rockets to land in, which has happened in the past. Water damage could render the launch vehicle unusable meaning Blue Tube is not an ideal material choice.

4.2.2.3 G12 Fiberglass

G12 fiberglass is a very durable and strong composite which makes for a good airframe with the main downside being its weight. Fiberglass also takes impacts better than cardboard tubing, showing little to no damage. G12 fiberglass costs $45.60/foot and weighs 24.2 oz for a 6-inch diameter airframe. While the cost and weight are much higher than either type of cardboard tubing, the strength and damage resistance of G12 fiberglass makes up for these drawbacks. Additionally, fiberglass is water resistant making it a great choice for a reusable rocket.

4.2.2.4 Carbon Fiber

Carbon fiber is an even better option than fiberglass as it has a higher strength-to-weight ratio and it more lightweight. However, carbon fiber is the most expensive material option costing $107.80/foot with a weight of 17.6 oz for a 6-inch diameter airframe. While its material properties are an improvement over fiberglass, the cost increase is enough to dissuade the team from using the material.

Considering the materials above, the team will use G12 fiberglass for the launch vehicle airframe. It is stronger and more damage resistant than phenolic tubing or Blue Tube, making it a good choice for constructing a reusable launch vehicle. It is also water resistant, unlike the two types of cardboard tubing, which will make the possibility of landing in water less stressful. Although the price and weight of the material are somewhat high, the tradeoff for improved durability and strength is worth it. The weight of the launch vehicle should not be an issue; based on RockSim flight simulations, the launch vehicle will meet NASA's altitude requirements.

4.2.3 Construction Methods

It is uncertain whether the team will have access to a laser cutter and the machine shop this year, so some alternative construction methods will need to be considered.

4.2.3.1 Bulkhead Fabrication

Each bulkhead in the launch vehicle is made from layers of 1/8 inch aircraft grade birch plywood epoxied together. These layers are drafted in Solidworks, each with two 1/16-inch holes. These holes will later be used for alignment during assembly. Once the CAD file is ready, the layers are manufactured using a laser cutter.

Since the team may not have access to a laser cutter, there are alternatives to create these layers. The easiest, but possibly more expensive option would be to purchase a 6-inch hole saw. These bits can be attached to a drill press or hand drill to cut a circle out of the target material. While the result may not be precise, it would be fast, and the layer could be sanded as necessary. Another alternative is to use a band saw setup. Using a template found online, a jig can be built and attached to the bandsaw. This jig would have a peg that the plywood could rest on for cutting. The desired circle radius can be measured between the blade and peg and the plywood can be rotated through the blade and cut to a constant radius. A slightly easier method may be to cut a slightly larger rough circle by hand and use a disc sander with a similar setup to sand the circle to a constant radius. Once the layers are made, the holes can be added with a drill press.

Once the layers are ready, each one is sanded on both sides to prepare for epoxy. The bottom layer is placed down on a vinyl sheet with dowel rods cut to match bulkhead thickness being placed in the holes. Two-part epoxy is spread on the upward face of the first layer and the downward face of the second layer. The second layer is stacked on the first using the rods for alignment. This process is repeated until the bulkhead is complete. Each bulkhead is wrapped in peel-ply then breather material and a second layer on vinyl is placed over top. Plumber's putty is used to seal the vinyl and a vacuum line is added. The setup is then left to cure for 24 hours.

To add the bulkheads to the body tube, a layer of epoxy is added to the edge of the bulkhead which is then slid into the body in the required location. Silica filler is mixed with two-part epoxy and used to add fillets where the bulkhead meets the body tube. The epoxy is then left to cure for 24 hours.

4.2.3.2 Cutting Body Tubes

Assuming the team has access to the machine shop, the team only needs to mark where to cut on the body tube and pass it off to machine shop personnel. The body tube will be cut using the shop's drop bandsaw and returned when finished.

If the team does not have machine shop access, the team will have to use the tools in the Rocketry Lab. The body tube would be marked at the length where it needed to be cut. This marking would then be covered with masking tape and redrawn to prevent the fiberglass splintering while cutting. A Dremel can then be used to cut along the circumference of the tube. Alternatively, a hacksaw can be used in conjunction with a hose clamp as a guide. Should the cut edge come out rough, the belt sander can be used to smooth it down.

4.2.3.3 Adhering Couplers to Body Tubes

For each coupler, the extent of the contact areas on both the coupler and the inside of the body tube sections is first measured and marked. These areas are then sanded to promote a better surface bond. Two-part epoxy is then be prepared and applied to both the coupler and the body tube within the contact areas. The coupler is then carefully inserted into the body tube up to the marked length. The completed coupler section is then set aside to cure for 24 hours before it is handled again.

4.2.3.4 Fin Can Assembly

To begin, the forward fin can bulkhead is inserted and epoxied into place. Fillets are added between the bulkhead and body tube for extra strength. While this setup cures, the middle centering ring can be epoxied onto the motor tube in the correct location and fillets applied where the centering ring contacts the motor tube. Once all epoxy has cured, more epoxy is added to the forward fin can bulkhead where the motor tube is to be fitted and to the centering ring attached to the motor tube. The motor tube with centering ring can then be inserted in the aft end of the fin can.

Once the motor tube is in and the epoxy has cured, the fins can be inserted through their slots. The fins are typically laser-cut beforehand but if the team does not have access to a laser cutter, they can be manufactured using a bandsaw. Epoxy is added to the motor tube and the middle centering ring where the fins contact. Before the aft centering ring is placed, more fillets are added where the fins touch the motor tube and on the inside and outside of the body tube around the fin slots. The engine block is then epoxied into place and fillets added where it contacts the body tube. As a final step, the motor retainer is epoxied to the end of the motor tube.

4.2.3.5 Ballast Installation

Should the launch vehicle's stability margin need to be adjusted, the team has the option of adding ballast to the nosecone bulkhead. Ballast would consist of lead blocks or lead pellets epoxied into a custom 3D-printed casing. The ballast could then be secured to the bulkhead using two-part epoxy.

4.2.3.6 Safety Standards

During construction, team members will follow the safety procedures put forth by the team's safety officer, including:

a) Training for the safe operation of power tools and machining equipment before use.
b) Proper usage of PPE while operating power tools and machining equipment. This includes safety glasses and disposable respirators.
c) Proper usage of PPE while handling epoxy. This includes safety glasses and disposable nitrile gloves.
d) Proper usage and storage of epoxy, which is classified as a hazardous material.

These standards are discussed in more detail in Section 3.2.

4.3 Projected Altitude

RockSim was used to simulate launches of the launch vehicle. The estimated apogee of the launch vehicle, assuming standard sea-level conditions and an 8 ft launch rail canted to 7.5°, is 4458 ft above ground level (AGL) with 4-7 mph winds. Projected altitude was calculated by running ten simulations and taking the average of the apogees. It should be noted that the estimated descent time is 80 seconds and the estimated range is 1479 ft, both of which are within the required guidelines. The stability margin at launch is 2.14; the team aimed to keep the launch stability low to prevent the potential of weathercocking while staying above the NASA requirement of 2.0. The velocity of the launch vehicle at launch guide departure is 55.49 ft/s. Figure 4-6 shows simulated altitude and range of the launch vehicle.

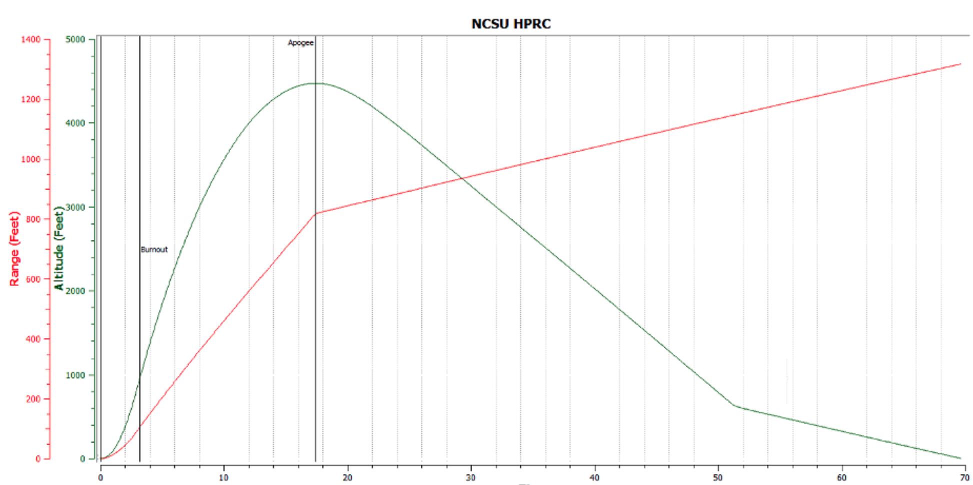

Figure 4-6 Predicted Altitude and Wind Drift

4.4 Launch Vehicle Recovery Specifications

The launch vehicle will utilize a dual-deployment recovery system to ensure the vehicle makes a safe landing after each flight and complies fully with competition requirements. Two fully independent altimeter systems will be housed in the avionics bay ensuring redundancy and reliability. These altimeters will be configured to detonate pyrotechnic charges that will separate launch vehicle body sections and deploy parachutes. A drogue parachute will be deployed at apogee and a main parachute will be deployed at a lower altitude, in compliance with requirement NASA 3.1. Main parachute deployment will serve the secondary function of removing the experimental payload from the launch vehicle body. The payload will separate from the main parachute recovery harness at 500 ft. AGL. The recovery of the experimental payload is described in Section 4.6.3. To ensure that the launch vehicle can be tracked in the event visual contact is lost during recovery, a radio tracker in the avionics bay will provide location data to the ground recovery team. Figure 4-7 below shows the sequence of recovery events.

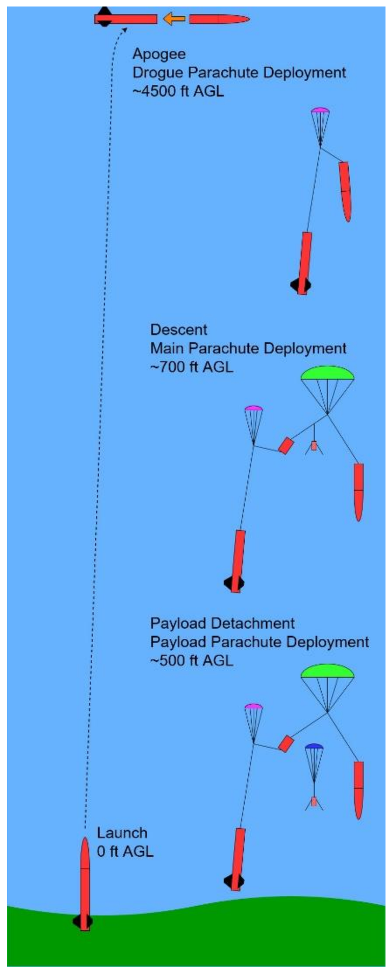

Figure 4-7 Recovery Events Sequence

4.4.1 Recovery System Requirements

In Table 4-2 below, the recovery system requirements for the 2021 NASA Student Launch are addressed.

Table 4-2 2020-2021 NASA Student Launch Recovery System Requirements

Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
NASA 3.1	The full scale launch vehicle SHALL stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee, and a main parachute is deployed at a lower altitude.	The recovery lead designs a dual-deployment recovery system.	Demonstration	Recovery	Not verified	See Section 4.4 for leading recovery system design.
NASA 3.1.1	The main parachute SHALL be deployed no lower than 500 feet.	The recovery lead designs the recovery system such that the main parachute deploys no lower than 500 feet.	Demonstration	Recovery	Not verified	See Section 4.4.2 for leading recovery system design.
NASA 3.1.2	The apogee event SHALL contain a delay of no more than 2 seconds.	The recovery lead designs the recovery system such that the apogee event has a delay of no more than 2 seconds.	Demonstration	Recovery	Not verified	See Section 4.4 for leading recovery system design.
NASA 3.1.3	Motor ejection SHALL not be used for primary or secondary deployment.	The recovery lead designs a recovery system that does not utilize motor ejection.	Inspection	Recovery	Not verified	See Section 4.4 for leading recovery system design.

NASA 3.2	The team SHALL perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full scale vehicles.	The recovery lead performs a ground ejection test for each electronically initiated recovery event prior to the initial flights of the subscale and full scale launch vehicles.	Demonstration	Recovery	Not verified	TBD
NASA 3.3	Each independent section of the launch vehicle SHALL have a maximum kinetic energy of 75 ft-lbf at landing.	The recovery lead designs a recovery system that results in no launch vehicle section having a kinetic energy greater than 75 ft-lbf at landing.	Analysis	Recovery	Not verified	See Section 4.4.2 for leading recovery calculations.
NASA 3.4	The recovery system SHALL contain redundant, commercially available altimeters.	The recovery lead includes at least two independent commercially available altimeters in the recovery system.	Inspection	Recovery	Not verified	See Section 4.4.4.1 for leading altimeter selection.
NASA 3.5	Each altimeter SHALL have a dedicated power supply, and all recovery electronics SHALL be powered by commercially available batteries.	The recovery lead designs the recovery system such that each altimeter has a dedicated power supply of commercially available batteries.	Inspection	Recovery	Not verified	See Section 4.4.4 for leading avionics system design.

NASA 3.6	Each altimeter SHALL be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	The recovery lead installs dedicated mechanical arming switches accessible from the exterior of the launch vehicle airframe for each altimeter.	Inspection	Recovery	Not verified	See Section 4.4.4 for leading avionics system design.
NASA 3.7	Each arming switch SHALL be capable of being locked in the ON position for launch.	The recovery lead selects mechanical arming switches capable of being locked in the ON position.	Inspection	Recovery	Not verified	See Section 4.4.4 for leading avionics system design.
NASA 3.8	The recovery system electrical circuits SHALL be completely independent of any payload electrical circuits.	The recovery lead designs the recovery system so that its electrical circuits are completely independent of any payload electrical circuits.	Inspection	Recovery	Not verified	See Section 4.4.4 for leading avionics system design.
NASA 3.9	Removable shear pins SHALL be used for both the main parachute compartment and the drogue parachute compartment.	The recovery lead designs the recovery system to use removable shear pins for the main parachute compartment and drogue parachute compartment.	Inspection	Recovery	Not verified	See Section 4.4 for leading recovery system design.

NASA 3.10	The recovery area SHALL be limited to a 2,500 ft. radius from the launch pads.	The recovery lead selects parachutes that prevent the launch vehicle from drifting more than 2,500 ft. from the launch pads.	Analysis; Demonstration	Recovery	Not verified	See Section 4.4.2 for leading recovery system performance calculations.
NASA 3.11	Descent time of the launch vehicle SHALL be limited to 90 seconds (apogee to touch down).	The recovery lead selects parachutes that allow the launch vehicle to touch down within 90 seconds of reaching apogee.	Analysis; Demonstration	Recovery	Not verified	See Section 4.4.2 for leading recovery system performance calculations.
NASA 3.12	An electronic tracking device SHALL be installed in the launch vehicle and SHALL transmit the position of the tethered vehicle or any independent section to a ground receiver.	The recovery lead selects and installs an electronic tracking device capable of transmitting the position of the launch vehicle or any independent section to a ground receiver.	Inspection; Demonstration	Recovery	Not verified	See Section 4.4.4.2 for leading tracking device selection.
NASA 3.12.1	Any rocket section or payload component, which lands untethered to the launch vehicle, SHALL contain an active electronic tracking device.	The recovery lead installs an electronic tracking device in any launch vehicle section or payload component which lands untethered to the launch vehicle.	Inspection	Recovery	Not verified	See Section 4.4.4.2 for leading tracking device selection.

NASA 3.13	The recovery system electronics SHALL not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	The recovery lead designs the recovery system such that it is not affected by other on-board electronic devices.	Demonstration	Recovery	Not verified	See Section 4.4.4 for leading avionics system design.
NASA 3.13.1	The recovery system altimeters SHALL be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	The recovery lead designs an avionics bay which houses the recovery system altimeters in a physically separate compartment within the launch vehicle.	Inspection	Recovery	Not verified	See Section 4.4.4 for leading avionics system design.
NASA 3.13.2	The recovery system electronics SHALL be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.	The recovery lead designs and installs shielding for the recovery system electronics from all onboard transmitting devices.	Inspection	Recovery	Not verified	See Section 4.4.4 for leading avionics system design.

NASA 3.13.3	The recovery system electronics SHALL be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	The recovery lead designs and installs shielding for the recovery system electronics from all devices which may generate magnetic waves.	Inspection	Recovery	Not verified	See Section 4.4.4 for leading avionics system design.
NASA 3.13.4	The recovery system electronics SHALL be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	The recovery lead designs and installs shielding for the recovery system electronics from all devices which may adversely affect the proper operation of the recovery system electronics.	Inspection	Recovery	Not verified	See Section 4.4.4 for leading avionics system design.

4.4.2 Parachute Descent Calculations and Selection

Recovery events begin at apogee with the detonation of the primary aft pyrotechnic charge by the primary altimeter, separating the fin can and midsection of the launch vehicle. The redundant altimeter will fire the secondary aft pyrotechnic charge at a one second delay from apogee detection. Separation of the fin can and midsection deploys the drogue parachute, a Fruity Chutes 18 inch Classic Elliptical parachute. This parachute will be stowed in the fin can wrapped in a Nomex cloth serving to shield the parachute and shroud lines from the heat of the pyrotechnic charge. At this point in time the launch vehicle weighs 39.24 lbf after burnout but before payload separation from the launch vehicle. Equation 1 provides the descent velocity of the launch vehicle under drogue.

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

Where v_D is drogue descent velocity, g is gravitational acceleration, m is the mass of the launch vehicle under drogue, S is the projected parachute area, C_D is the drag coefficient and ρ is the air density. For the 18 inch Classic Elliptical parachute manufacturer data is used to compute C_D = 1.43 with an area of S = 1.77 ft^2 resulting in a calculated descent velocity of 122.8 ft/s using SSL values for atmospheric parameters. A 40 ft shock cord will be used for the drogue recovery harness to ensure that there is adequate separation between the fin can and the connected nose section and midsection.

Following drogue descent, the next event in the recovery sequence occurs when the primary altimeter detects the launch vehicle passing 700 ft AGL and triggers the primary forward pyrotechnic charge. This event separates the nosecone and payload bay from the midsection, made up of the main parachute bay and the avionics bay. Separation of these sections serves two purposes, removing the payload from the launch vehicle in preparation of payload separation and deploying the Fruity Chutes 120 inch Iris Ultra Compact parachute. A Nomex deployment bag will be used to pack the parachute in the main parachute bay during flight, serving to protect the parachute from the pyrotechnic charges and to prevent the shroud lines from becoming tangled during deployment. Under main parachute, using S = 78.54 ft^2 and C_D = 2.11, the descent velocity of the launch vehicle under main parachute following payload separation is 13.9 ft/s, a sufficient descent rate for all sections of the launch vehicle to safely land. Should the payload fail to deploy from the main parachute recovery harness, the descent rate increases to 15.2 ft/s which constitutes sufficient deceleration to make a safe landing.

Once the launch vehicle assembly passes through 500 ft. AGL, the payload will separate from the main parachute recovery harness as described in Section 4.6.3.2. Following separation, the payload will descend under a furled FruityChutes 60” Classic Elliptical parachute. This parachute will be secured by a Jolly Logic Chute Release device, which contains an altimeter, a latch, and a rubber band that is wrapped around the parachute. The furled parachute will function as a streamer as is permissible under competition rules, stabilizing and slowing the payload during descent. At 200 ft., the Jolly Logic will deploy the payload parachute, which will slow the payload to landing. Once landing is detected, the payload will jettison the payload parachute as described in Section 4.6.3.3.

Table 4-3 shows the calculated descent velocities for each stage of the recovery sequence for both the case where the payload is successfully jettisoned and the case where the payload remains attached to the launch vehicle or recovery harness.

Table 4-3 Descent Velocity of the Launch Vehicle during Various Descent Stages

Descent Stage	Descent Velocity
Drogue Parachute	122.8 ft/s
Main Parachute - Payload Attached	13.9 ft/s
Main Parachute – Payload Jettisoned	15.2 ft/s
Payload Parachute - Furled	200.0 ft/s
Payload Parachute – Opened	11.8 ft/s

These quantities are calculated in 5 mph intervals from zero wind speed to the maximum permissible launch conditions of 20 mph. At a maximum permissible launch wind speed of 20 mph, wind drift is calculated to be at maximum 2285 ft. which is within the 2500 ft. radius set forth by requirement NASA 3.10. The 90 second descent time requirement set forth by requirement NASA 3.11 is met with a computed maximum descent time of 80 seconds. The RockSim results and calculations are in good agreement, confirming that this recovery configuration can perform within both the required wind drift limit and descent time limit. Descent time and wind drift at different wind speeds are compiled in Table 4-4 below as calculated and as determined by RockSim simulation results.

Table 4-4 Descent Time and Wind Drift Predictions

Wind Speed	RockSim Descent Time	RockSim Drift Distance	Descent Time -	Drift Distance
0 mph	54.4 s	1301 ft	80 s	0 ft
5 mph	54.4 s	1349.2 ft	80 s	593 ft
10 mph	56.4 s	1415.4 ft	79 s	1189 ft
15 mph	61.8 s	1561.4 ft	79 s	1784 ft
20 mph	58.8 s	1528.8 ft	78 s	2370 ft

Table 4-5 Payload Wind Drift Predictions

Wind Speed	Drift Distance
0 mph	0 ft
5 mph	349.6 ft
10 mph	699.1 ft
15 mph	1048.7 ft
20 mph	1398.3 ft

To ensure safety of ground personnel and spectators, requirement NASA 3.3 specifies that each independent section of the launch vehicle is required to have a kinetic energy of less than 75 ft-lbf upon landing. The highest kinetic energy of any section is the fin can, with a kinetic energy of 57.0 ft-lbs. in the worst-case scenario, which meets the 75 ft-lbs. limit set forth by NASA 3.3. Table 4-6 lists the post-burnout mass and kinetic energy of each section with payload still attached and with the payload separated.

Table 4-6 Launch Vehicle Section Mass and Landing Kinetic Energy

Launch Vehicle Section	Post-Burnout Mass	Kinetic Energy – Payload Attached	Kinetic Energy – Payload Separated
Nose Section	0.2521 slugs	N/A	24.5 ft-lbs.
Nose Section w/ Payload	0.4696 slugs	54.0 ft-lbs.	N/A
Midsection	0.4401 slugs	50.6 ft-lbs.	42.8 ft-lbs.
Fin Can	0.4957 slugs	57.0 ft-lbs.	48.2 ft-lbs.
Payload	0.2176	N/A	15.1 ft-lbs.

To ensure safe separation between each independent section of the launch vehicle during the recovery sequence, 40 ft of shock cord will be used for both the drogue and the main parachute. This length of shock cord is sufficient to allow the two sections to decelerate following the pyrotechnic separation event, thus reducing the loading on the recovery harness and bulkheads when the shock cord is placed in tension at full extension. All shock cord used will be 5/8 inch tubular Kevlar, rated at 2000 lbf, sufficient for withstanding decoupling and opening forces. Team experience and mentor recommendation indicate that this shock cord material will be sufficient for a launch vehicle of this size and weight.

Sections that are to separate during the recovery sequence will be secured together during flight using four removable nylon shear pins as per requirement NASA 3.9. These fasteners are designed to break at a calibrated shear loading corresponding to the force applied by the pyrotechnic charges. Per competition rules, ground tests of the pyrotechnic ejection system will be conducted to confirm that the calculated black powder charges will be sufficient to provide reliable and safe section separation.

4.4.3 Ejection Calculations

Black powder charges will be used to separate body sections and deploy parachutes. Two charges are used for each deployment event, a primary and a backup. The backup charge will be larger than the primary to ensure separation in the event the primary charge detonates but fails to separate the launch vehicle sections. Ground ejection tests mandated by requirement NASA 3.2 will be performed to confirm that the calculated amount of black powder separates body sections with sufficient force to deploy parachutes without damaging any launch vehicle components.

In prior years, the club has found that available calculators underestimate the size of the black powder charge needed for a clean separation and parachute deployment. As such, hand calculations will be used in addition to Chuck Pierce's Ejection Charge Calculator to compute the needed mass of black powder for section separation.

4.4.4 Avionics Bay Design

The avionics bay will consist of a section of coupler tube capped by two bulkheads on either end. A 2-inch-long band of body tube will be secured to the midpoint to allow access to the altimeter arming switches while the launch vehicle is on the launch pad. Methods of forming an airtight seal around the AV bay bulkheads will be investigated following the observation of pressure spikes in altimeter data corresponding to pyrotechnic charge firing. Better sealing of the avionics bay will further protect the altimeters from the hot combustion gases and ensure more accurate altitude readings. Threaded rods will connect these bulkheads and serve to mount the avionics (AV) sled. The AV sled will hold two 9 V alkaline batteries, two PerfectFlite StratoLogger CF altimeters, and an Eggfinder TX GPS tracker powered by 7.4 V LiPo battery. As required by requirement NASA 3.4, the recovery system altimeters are commercially available and fully redundant.

The AV sled will be constructed of aircraft-grade birch plywood, laser cut to shape, sanded, and bonded using wood glue. The altimeters will be mounted to the AV sled inside a purpose-built faraday cage as required by requirement NASA 3.13 using four M3 machine screws and four plastic standoffs per altimeter. This faraday cage provides both a separate compartment as required by NASA 3.13.1 and the shielding mandated by NASA 3.13.2 through NASA 3.13.4. A laser cut compartment will be built into the AV sled to house the two 9 V batteries used to power the altimeters. Wire organizer clips will be secured to the AV sled using wood screws to ensure that all wires are neatly organized and remain secure during flight. Each circuit will be color coded and all wires will be labeled to prevent any assembly errors and provide ease of maintenance.

4.4.4.1 Recovery Avionics

The StratoLogger connected to the primary pyrotechnic charge will be designated as the competition altimeter for altitude scoring purposes. This primary altimeter will be programed to fire the aft drogue charge at the detected apogee and the forward main parachute charge at 700 ft. The second StratoLogger will be designated as the secondary altimeter and will be wired to separate, backup pyrotechnic charges. The secondary altimeter will be programmed to fire the backup drogue charge on a 1 second delay from apogee and the backup main charge 50 ft lower than the primary. The proposed delays on the backup charges comply with the 2 second apogee event limit set forth by requirement NASA 3.1.2. The proposed delay timings allow sufficient time for separation in the event of successfully primary charge detonation while detonating close enough to the primary charge that the flight forces on the launch vehicle will not have changed significantly.

Both altimeters will be connected to a dedicated, fresh 9 V battery before each flight as required by NASA 3.5. Battery voltage will be checked before every flight during AV sled assembly to confirm adequate battery voltage is 9 V or greater. Independent charges, power sources, and arming switches ensure fully redundant, independent altimeter circuits as per requirement NASA 3.4. This is illustrated in the AV sled electrical block diagram shown below in Figure 4-8.

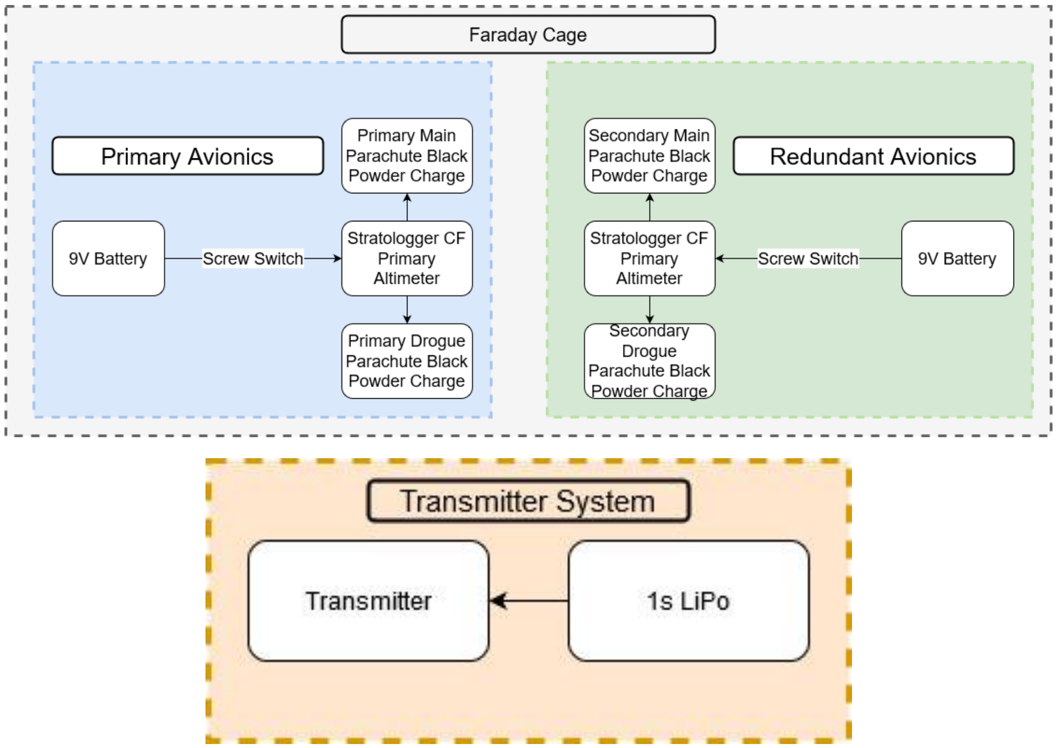

Figure 4-8 AV Sled Electrical Block Diagram

Two screw switches will be mounted to the avionics sled to provide mechanical arming of the altimeters. Holes in the outer airframe will provide access to the screw switches allowing arming of the altimeters while the launch vehicle is on the launch pad as required by NASA 3.6. Using machine screws to complete the connection and power the altimeters ensures that the altimeters will remain in the ON position while withstanding flight forces in accordance with NASA 3.7. Mounting the AV sled on threaded rods allows for the use of nuts and spacers to ensure the AV sled is positioned to allow the AV sled to precisely match the holes in the airframe. Using screw switches allows the AV sled to be fully removed from the AV bay without disconnecting wiring. Each altimeter will have a dedicated screw switch.

In order to ensure correct altimeter functionality, four pressure sampling ports will be drilled into the switch band of the AV bay. Sampling ports will be drilled in accordance with PerfectFlite recommendations. Four ports will be located at 90° from each other at the same axial location. Hole diameter will be selected according to Equation 2 below as taken from the StratoLogger CF user manual where P is the port diameter in inches, L is the length of the AV bay in inches, and D is the diameter of the AV bay in inches.

$$P = 0.0008 * L * D^2 \quad (2)$$

Each flight altimeter will be vacuum tested before flight. The altimeter will be powered and connected to indicator lights before being placed in a vacuum chamber with a view port. A vacuum simulating flight conditions will be drawn, and then slowly released while the indicator lights are monitored for current being sent to the main and drogue pyrotechnic circuits. Detailed flight data will be reviewed to ensure that no unusual or irregular events occurred during the test.

4.4.4.2 Launch Vehicle Tracking Device

The launch vehicle will be equipped with a radio tracking device to transmit the launch vehicle's GPS data to the recovery ground team. Considered options are the BigRedBee 900, the BigRedBee BeeLine, the Marlin Systems Standard RMV Rocketry Transmitter, the Eggfinder TX, and the LightAPRS-WSPR. The candidate trackers are a mix of HF/VHF/UHF amateur radio and 900 MHz ISM band transmitters. Trackers that transmit on amateur radio frequencies require at least one member of the ground recovery team to have a current Technician Class amateur radio license. While trackers transmitting on the 900 MHz band do not require licensed individuals to operate the radio equipment, these trackers do not have the range or flexibility of the amateur radio band trackers.

The Eggfinder TX will be used to provide launch vehicle tracking as required by NASA 3.12. Since the Eggfinder uses ISM frequencies there is no requirement for the field recovery team to have an amateur radio licensed team member. Furthermore, this tracker and dedicated receiver unit are already owned by the team. GPS data will be transmitted to a handheld radio receiver that is connected to a team member's laptop with a USB cable. The laptop can then display the launch vehicle's location in 3 dimensions in the mapping software Google Earth allowing for real time tracking of the rocket. Location data is also logged for post flight analysis and comparison to altimeter data.

The Eggfinder tracker will be powered by a 7.4 V "2S" LiPo battery, powering only the tracker. This is sufficient to meet the required 2-hour pad time, flight time, and post-flight time needed to locate the launch vehicle. The battery will be connected to the tracker during AV sled assembly and powered on at this point to allow the GPS receiver sufficient time to acquire satellite signal before flight. Powering the tracker prior to flight will have no impact on the altimeter circuits since the tracker is on a completely independent circuit and is isolated from the altimeters by a faraday cage.

The launch vehicle does not contain a second tracking device since failure of the tracker would not result in any safety risks or a failure to meet mission success criteria. As such it is not considered a flight-critical or mission-critical component. Indeed, since the primary method of locating the launch vehicle during and after descent is by visual tracking, the tracking device serves as a backup should abnormal flight events prevent team members from establishing a line-of-sight with the launch vehicle during and after descent.

4.5 Motor Brand and Designation

The motor for the launch vehicle was chosen after general estimations were made for the dimensions and weight of the payload. After those estimations were taken into account, along with the apogee requirement and available inventory for the Club, the team decided on the Aerotech L-1150R. The Aerotech L-1390G was considered for a short time based on past performances, but it was found to consistently overshoot the apogee range. The Aerotech L-850W was then considered, but there were concerns with velocity at launch guide departure, so the Aerotech L-1150R made for an excellent Goldilocks motor for the team's launch vehicle. Table 4-7 lists the specific aspects of the motor.

Table 4-7 Motor Specifications

Motor	Aerotech L-1150R
Propellant Weight	1902 g (4.19 lbf)
Total Weight	3674 g (8.10 lbf)
Total Impulse	3517.0 N-s (790.65 lbf-s)
Average Thrust	1150.0 N (258.53 lbf)
Burn Time	3.1 s

4.6 Experimental Payload Specifications

4.6.1 Experimental Payload Requirements

The following passage from the 2020-2021 NASA Student Launch Handbook describes this year's payload challenge:

"Teams will design a planetary landing system to be launched in a high-power rocket. The lander system will be capable of being jettisoned from the rocket during descent, landing in an upright configuration or autonomously up righting after landing. The system will self-level within a five-degree tolerance from vertical. After autonomously up righting and self-leveling, it will take a 360-degree panoramic photo of the landing site and transmit the photo to the team. The method(s)/design(s) utilized to complete the payload mission will be at the teams' discretion and will be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge."

Table 4-8 below lists the payload requirements from the NASA Student Launch Handbook.

Table 4-8 2020-2021 NASA Student Launch Payload Requirements

Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
NASA 4.2	The team SHALL design a planetary landing system to be launched in a high-power rocket. The lander system SHALL be capable of being jettisoned from the rocket during descent, landing in an upright configuration or autonomously uprighting after landing. The system SHALL self-level within a five-degree tolerance from vertical. After autonomously uprighting and self-leveling, it SHALL take a 360-degree panoramic photo of the landing site and transmit the photo to the team.	The payload team designs a planetary landing system to be launched in a high-powered rocket. The payload is capable of being jettisoned from the launch vehicle during descent, landing in an upright configuration or autonomously uprighting after landing, self-levelling within a five-degree tolerance from vertical, and taking a 360-degree panoramic photo of the landing site and transmitting the photo to the team.	Demonstration	Payload vehicle; Payload integration; Payload imaging	Not verified	See Section 4.6 for leading payload design.

NASA 4.3.1	The landing system SHALL be completely jettisoned from the rocket at an altitude between 500 and 1,000 ft. AGL. The landing system SHALL land within the external borders of the launch field. The landing system SHALL not be tethered to the launch vehicle upon landing.	The payload integration lead designs the payload such that it jettisons from the launch vehicle between 500 and 1,000 AGL, lands within the external border of the launch field, and is not tethered to the launch vehicle.	Demonstration	Payload integration	Not verified	See Section 4.6.3.2 for leading payload jettison design.
NASA 4.3.2	The landing system SHALL land in an upright orientation or SHALL be capable of reorienting itself to an upright configuration after landing. Any system designed to reorient the lander SHALL be completely autonomous.	The payload vehicle lead designs the payload such that it lands in an upright position or reorients itself to an upright configuration after landing using a completely autonomous system.	Demonstration	Payload vehicle	Not verified	See Section 4.6.2 for leading payload lander design.
NASA 4.3.3	The landing system SHALL self-level to within a five-degree tolerance from vertical.	The payload vehicle lead designs the payload such that it is capable of self-levelling within a five-degree tolerance from vertical.	Demonstration	Payload vehicle	Not verified	See Section 4.6.2.2 for leading payload levelling system design.

NASA 4.3.3.1	Any system designed to level the lander SHALL be completely autonomous.	The payload vehicle lead designs a payload levelling system that is completely autonomous.	Demonstration	Payload vehicle	Not verified	See Section 4.6.2.2 for leading payload levelling system design.
NASA 4.3.3.2	The landing system SHALL record the initial angle after landing, relative to vertical, as well as the final angle, after reorientation and self-levelling. This data SHALL be reported in the Post Launch Assessment Report (PLAR).	The payload vehicle lead designs a payload levelling system which records the initial angle after landing as well as the final angle relative to vertical. The payload vehicle lead reports this data in the PLAR.	Demonstration	Payload vehicle	Not verified	See Section 4.6.2.2 for leading payload levelling system design.
NASA 4.3.4	Upon completion of reorientation and self-levelling, the lander SHALL produce a 360-degree panoramic image of the landing site and transmit it to the team.	The payload imaging lead designs an imaging system capable of producing a 360-degree panoramic image and transmitting it to the team following self-levelling of the payload vehicle.	Demonstration	Payload imaging	Not verified	See Section 4.6.4 for leading imaging system design.

NASA 4.3.4.1	The hardware receiving the image SHALL be located within the team's assigned prep area or the designated viewing area.	The payload imaging lead selects a ground station capable of receiving the image and being located within the team's prep area or designated viewing area.	Demonstration	Payload imaging	Not verified	See Section 4.6.4 for leading imaging system design.
NASA 4.3.4.2	Only transmitters that were onboard the vehicle during launch SHALL be permitted to operate outside of the viewing or prep areas.	The team does not operate transmitters outside the viewing or prep areas that were not onboard the vehicle during launch.	Demonstration	Payload imaging	Not verified	TBD
NASA 4.3.4.3	Onboard payload transmitters SHALL be limited to 250 mW of RF power while onboard the launch vehicle but may operate at a higher RF power after landing on the planetary surface. Transmitters operating at higher power SHALL be approved by NASA during the design process.	The payload imaging lead selects onboard transmitters limited to 250 mW of RF power while onboard the launch vehicle. The payload imaging lead receives approval from NASA for operating transmitters outside of the launch vehicle at higher power.	Inspection	Payload imaging	Not verified	See Section 4.6.4.5 for leading imaging transmitter system design.

NASA 4.3.4.4	The image SHALL be included in the team's PLAR.	The payload imaging lead includes the captured image in the PLAR.	Inspection	Payload imaging	Not verified	TBD
NASA 4.4.1	Black powder and/or similar energetics SHALL only be used for deployment of in-flight recovery systems.	The payload integration lead designs the payload recovery system such that any energetics are only utilized in-flight.	Demonstration	Payload integration	Not verified	See Section 4.6.3.2 for leading payload deployment design.
NASA 4.4.2	Teams SHALL abide by all FAA and NAR rules and regulations.	The safety team verifies payload compliance with all FAA and NAR rules and regulations.	Demonstration	Safety	Not verified	TBD
NASA 4.4.3	Any experiment element that is jettisoned, except for planetary lander experiments, during the recovery phase SHALL receive real-time RSO permission prior to initiating the jettison event.	The payload integration lead receives real-time RSO permission prior to initiating the jettison of any experiment element except for the planetary lander.	Demonstration	Payload integration	Not verified	TBD

NASA 4.4.4	Unmanned aircraft system (UAS) payloads, if designed to be deployed during descent, SHALL be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAS.	The payload integration lead designs any UAS payload to be tethered to the launch vehicle with a remotely controlled release mechanism until the RSO gives permission to release the UAS.	Demonstration	Payload integration	Not verified	TBD
NASA 4.4.5	Teams flying UASs SHALL abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112-95 Section 336).	The safety team verifies any UAS payload's compliance with all applicable FAA regulations.	Demonstration	Safety	Not verified	TBD
NASA 4.4.6	Any UAS weighing more than .55 lbs. SHALL be registered with the FAA and the registration number marked on the vehicle.	The payload vehicle lead registers any UAS weighing more than .55 lbs with the FAA and marks the registration number of the vehicle.	Demonstration	Payload vehicle	Not verified	TBD

4.6.2 Payload Structure

4.6.2.1 General Structure

The payload will take on a vertical lander-style design. The design features a vertical rectangular prism body that will house the necessary electronics and mechanisms to complete the objective. The legs will be mounted towards the top of the payload vehicle in order to maximize leg length while still maintaining a low center of gravity which will help with the vehicle's stability. A square cross section was chosen for the body as opposed to a circular cross section in order to maximize internal storage space while maintaining a design that can be manufactured easily as cutouts in the body would be necessary to fit the legs for a circular body. Due to the square cross section, the team chose a design utilizing four legs. The legs will have articulating feet in order to accommodate for uneven terrain. The team chose to have the legs mounted on a bracket that can move vertically along the payload's body as opposed to rotating legs changing the angle between the body. The bracket will have plates on either side of the body slots in order to secure it to the body and maintain proper tolerances. The attachment between the bracket and the legs will be made from a flexible metal like aluminum in order to help absorb any shock that might be transferred through the landing process. A clear material is used for the top section of the body so that the imaging hardware can see through the body and collect usable data.

While stowed in the launch vehicle's payload bay, the payload will have its legs folded and the bracket at its highest position in order to keep the payload as compact as possible. Once the payload is deployed, springs around the axis of the leg joint will splay the legs out where they will then lock in the bracket at an angle that will provide the payload with a large footprint for stability while still allowing room for the body to adjust without colliding with the ground. The feet will behave in a similar manner in which they will have a spring keeping it at a desired angle; an alternative to this will be using wheels instead of feet which would also help for accommodating changes from the bracket position.

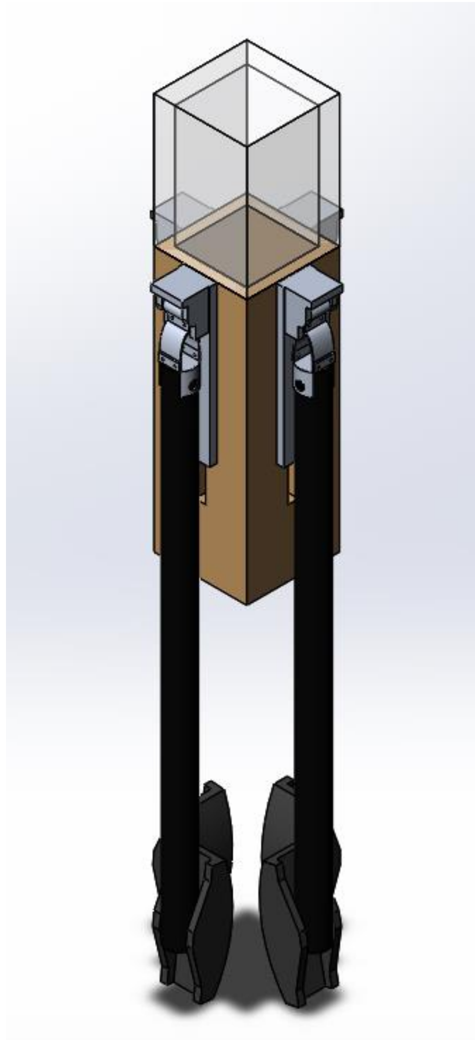

Figure 4-9 Payload in Stowed Configuration

While the payload is being lowered by the parachute, the leg brackets will be lowered to their lowest position. The team’s intention behind this is to utilize the force of gravity to adjust the bracket position relative to the body so that the mechanism raising the bracket does not need to provide as much work.

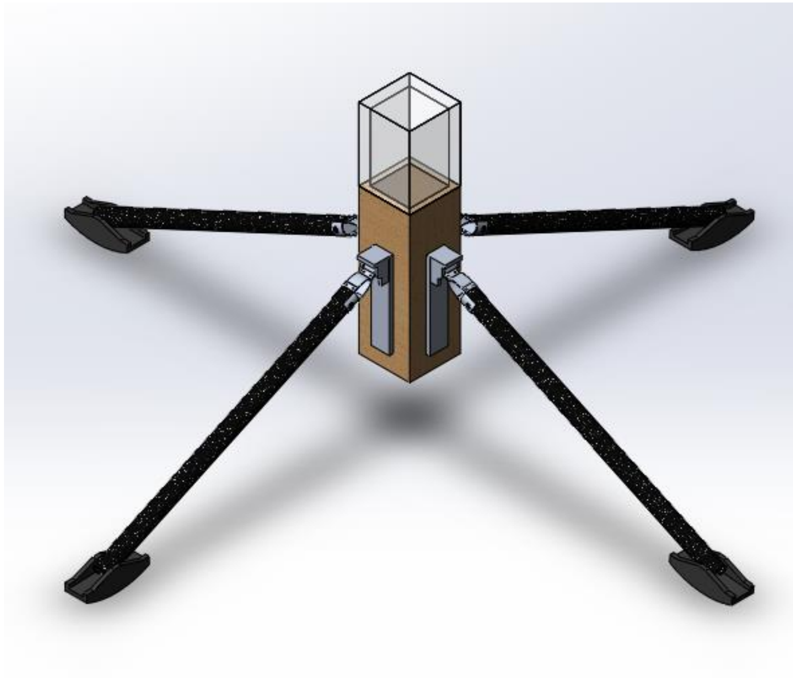

Figure 4-10 Payload in Deployed Configuration

4.6.2.2 Levelling System

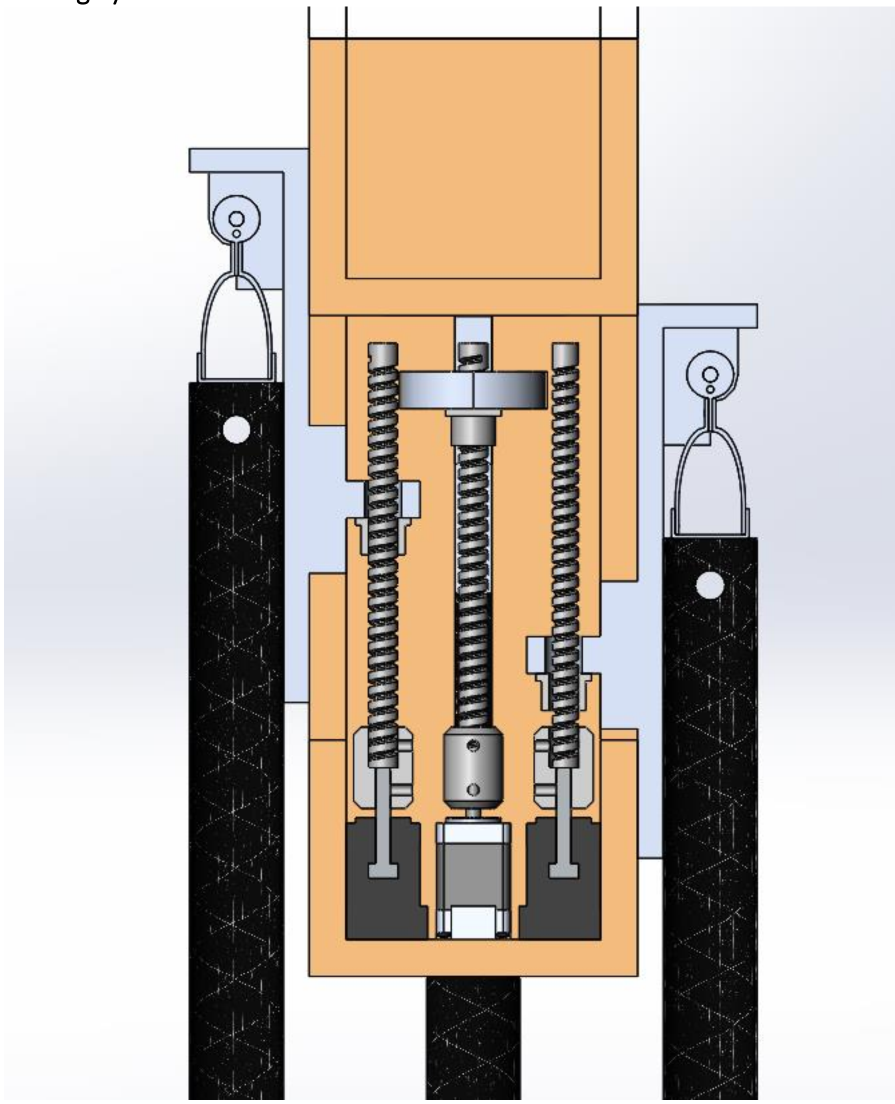

Figure 4-11 Levelling System Lead Screw Connections

The leveling system will use a lead screw mechanism operated by a stepping motor. This option was decided on as opposed to alternatives such as a rack and pinion systems among other types of linear actuators. This is because the lead screw system will take up the least amount of space as well as providing a higher level of reliability. A microcontroller along with the other necessary computing devices and a battery will be stored it the compartment above the lead screw section.

A 9-Degree of Freedom (DOF) breakout board will be used to determine the payload's orientation and position in space with respect to gravity. This information will be communicated to the microcontrollers which will then send a signal to actuate the stepper motors controlling the lead screws in order to change the leg mounting height and to properly orient the vehicle as described in the mission. The desired body orientation is completely in line with gravity which the computer will adjust the body for.

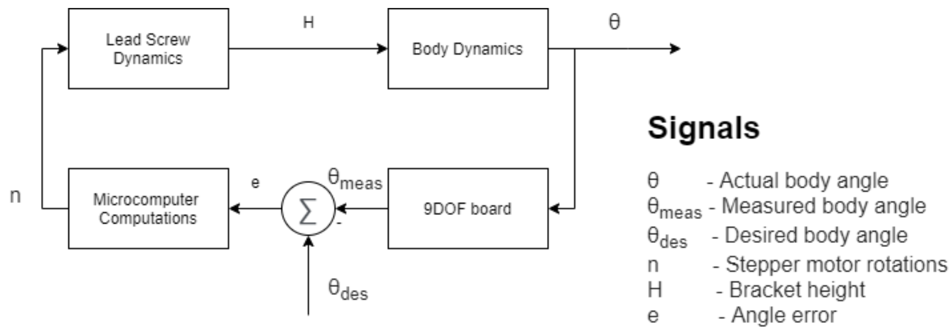

Figure 4-12 Levelling System Control Block Diagram

4.6.2.3 Manufacturing Techniques

The body is designed to be made from two layers of laser-cut balsa wood to ease the manufacturing process while allowing it to be strong, and lightweight. The legs will be made from 1-inch thick carbon fiber rods. The clear section of the body will be acrylic plastic. The joint shock absorbers will be made from bent and cut sheets of aluminum. Most other parts, including the leg brackets and the feet, will be 3D printed.

4.6.2.4 Design Alternatives

4.6.2.4(a) Lander Style legs – Bottom Mounted

An alternative to the legs being mounted towards the top of the body would be to have them mounted towards the bottom of the body and folded up. The benefit of this is that both the legs and body section will be longer. The downside is that this design would be larger than the chosen design. This design cannot compact as much as the chosen design which resulted in it encroaching upon other subsystem's spaces. In order to fix this, the legs were moved to the upper section of the body where they would fold down. A parametric study was conducted between the two styles of the lander comparing the tipping angles determined from the most optimum footprint each design could offer. While the legs were much longer in the bottom-mounted option, the center of gravity would be raised much higher. These two factors resulted in both options having similar estimated tipping angles and, therefore, similar stabilities. Since the upper-mounted option was more space efficient, the team chose it as their design.

4.6.2.4(b) Leg Angle Motors

An alternative to having the legs mounted on a bracket that can move up and down and to having a constant locked angle between the legs and body would be to have the leg angle change by using motors. This would be the method for altering the body's orientation. The feet of the legs would be wheels in order to roll with the surfaces as the leg angle changes. This design was ultimately discarded as the team decided that the torque required to move such long legs would be greater than the size motor and battery that could fit inside the body of the payload.

4.6.2.4(c) Rover

As opposed to the vertical lander-style payload design, a rover design was also considered. The design would consist of a long body with four wheels on the sides of the body. The wheels would be attached to arms that could move independently from each other. The rover could relocate to a more level surface should it land on substantially uneven terrain. Once on acceptable terrain the arms of the rover could pivot, raising and lowering the point where they attach to the body, levelling the body. One of the problems with the design is that it would be difficult for the imaging system to capture an image that would not be mostly obstructed by the rover and its components. An idea was proposed to raise the camera system to a point where the rover's components would now longer obstruct its view. This idea would be very complicated and require many motors with high torque and large batteries. All these components would not be able to fit on such a small body as constrained by the wheels, the arms, and the payload bay.

4.6.3 Payload Integration and Deployment

4.6.3.1 Payload Bay Design

The payload bay has been designed to achieve three main goals: stabilize the payload during flight carriage, release the payload inside the payload bay at apogee, and jettison the payload at a desired altitude. The payload bay shall achieve the forementioned goals autonomously. It was then considered to make use of electronic sensors, electronic actuators, and ejection charge mechanisms to execute a successful payload deployment.

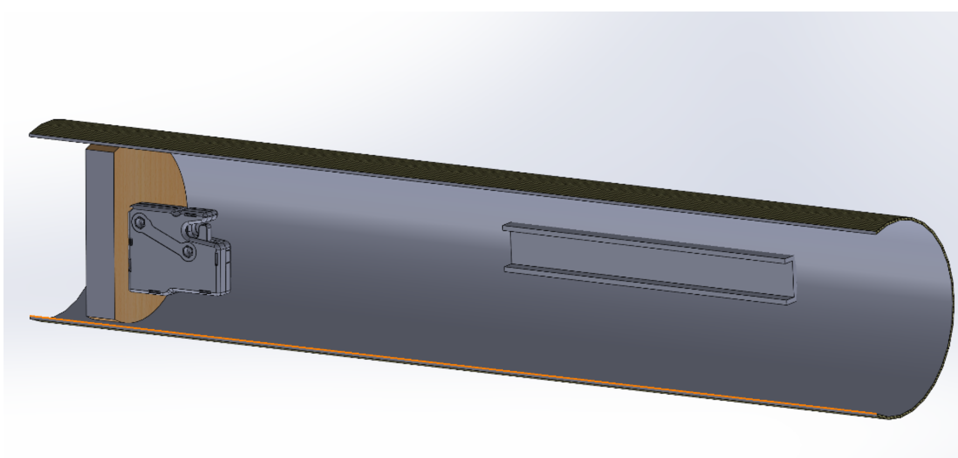

Figure 4-13 Payload Bay Section with Tracks and Electronic Rotary Latch

As seen in Figure 4-13, the payload bay includes an electronic rotary latch that shall be actuated at a preset altitude of 700 feet AGL to release the payload while it remains inside the payload bay. The payload rotary latch will be connected to an electronics section behind the bulkhead where it is attached; this section will have the required battery, controllers and altimeter for the latch to actuate at the preset altitude. The payload bay will also have two shear pins going through the walls that attach to the payload body to help stabilize the payload inside the payload bay as it is carried by the launch vehicle. The payload bay will include two tracks to guide the wheels that will be attached to the outside of the payload. The wheels and tracks will provide more stability as it prevents the rotation of the payload within the payload bay while also providing a smooth path for the payload to roll out of the payload bay. During flight, the payload shall remain secured inside the payload bay by the rotary latch, shear pins, and tracks until the latch is actuated to release the payload and the main parachute pulls the payload out.

Figure 4-14 Southco R4-EM-43-131 Electronic Rotary Latch

4.6.3.2 Jettison Process

As per requirement 4.3.1, the payload shall be jettisoned at an altitude between 500 ft to 1000 ft AGL. In order to allow for a smooth deployment of the payload, the payload bay has been designed to include an electronic rotary latch that will hold on to the payload when the vehicle launches up to a preset altitude that is safe to release the payload, where the payload is not experiencing a high magnitude of acceleration. The electronic rotary latch, as seen in Figure 4-14, is an electronic component that rotates a latch when actuated. The rotary latch is usually used for holding doors closed and actuate to let the doors open. Once the payload is unlatched, the payload will be supported by two shear pins to hold it in place in along the payload; moreover, the payload will rest on wheels that will move along tracks attached to the inner wall of the payload bay to prevent the payload from rotating inside the body. Once the payload is pulled by the main parachute at the main parachute deployment altitude, the shear pins will break allowing the payload to smoothly roll out of the payload bay.

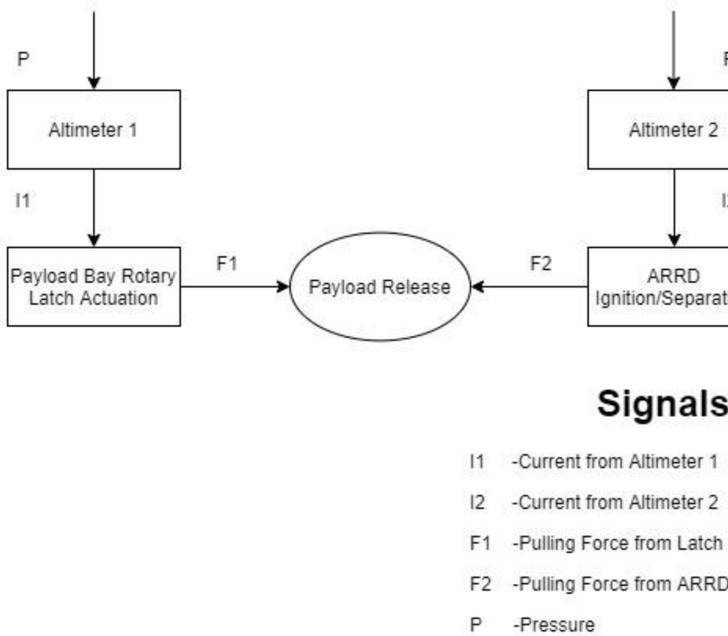

Figure 4-15 Payload Jettison Block Diagram

Once the payload exits the payload bay, the linking point from the payload to the main parachute will break using the ARRD. The ARRD has been attached to the top of the payload as seen in Figure 4-16 using the ARRD housing which consists of two wood platforms and four lead screws. The ARRD should separate into two pieces due to the ignition of a small charge at a lower altitude of 500 ft where it is certain that the payload has exited the payload bay. The altitude for such ignition will be determined using a StratoLogger altimeter that will send an electric signal through an e-match to ignite the ARRD black powder as detailed in Figure 4-15. It is important to note that neither of the payload altimeters will control or be in any way connected to the launch vehicle recovery system electronics.

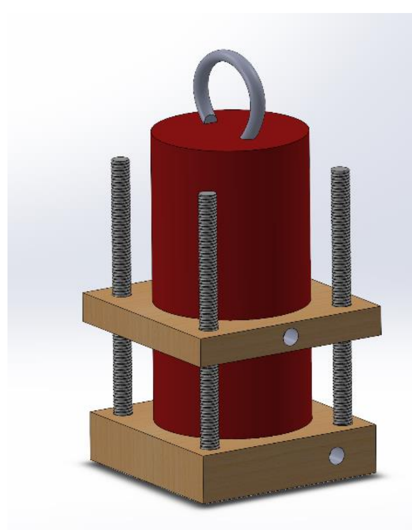

Figure 4-16 RATTWorks ARRD and ARRD Housing

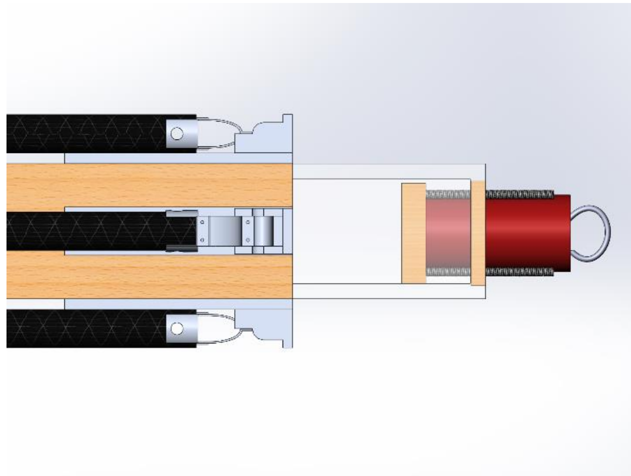

Figure 4-17 ARRD Attached to the Top of the Payload

4.6.3.3 Payload Parachute Release System

One concern regarding the payload parachute was that it could land on top of the payload and block the Planetary Observation System (POS). Another concern was that the payload parachute could pull the payload and interfere with the leveling system if wind were to inflate the parachute after landing. Due to these concerns, the team decided to release the parachute as soon as the payload landed in order to avoid further complications. The parachute shall be released autonomously after the payload lands. To release the parachute, the parachute will be attached at two distinct points to an electronic latch as seen in Figure 4-19. The parachute will be deployed at a lower altitude from the point of payload jettison. The parachute will open at the preset altitude with the use of a Jolly Logic parachute release system that is actuated based on pressure. Once the payload lands safely, the two rotary latches will be actuated after receiving a signal from the accelerometer to release the parachute. The accelerometer will send out a signal based on a preset value of change in acceleration. Alternatively, there are other electronic components that could be used to detach the parachute from the payload such as electronic magnetic latches.

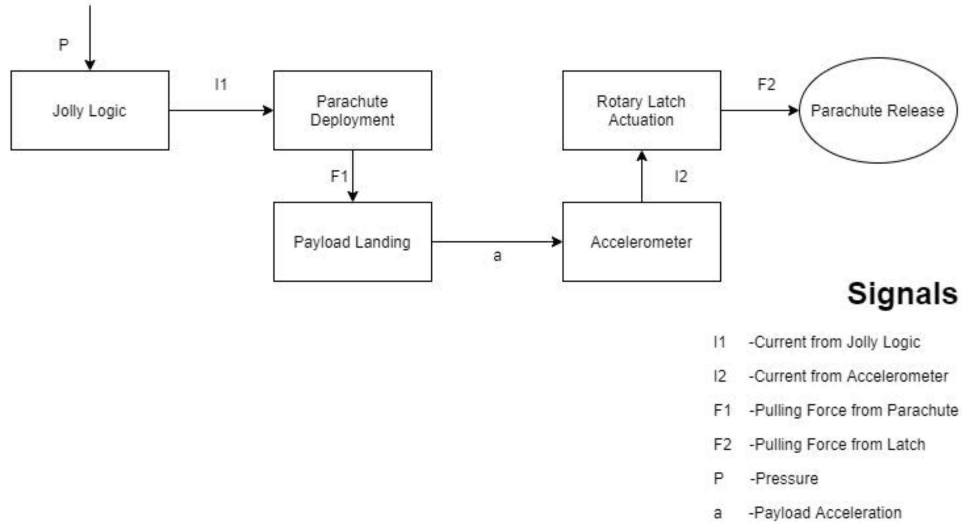

Figure 4-18 Payload Parachute Release Block Diagram

Figure 4-19 shows how the two rotary latches will be fixed to the payload body. The two wooden platforms that hold the ARRD housing together are used as the walls to screw on the rotary latches. The rotary latches are to be placed within the payload body with only the latch sticking out of the top of the payload. The rotary latch, as shown in Figure 4-19, has connections that will run down the payload body under the ARRD housing; this section will hold all the accelerometer and controllers to actuate the latches. The payload will also contain a tracker (BigRedBee 900) for location purposes. The tracker will be connected to a battery inside the payload.

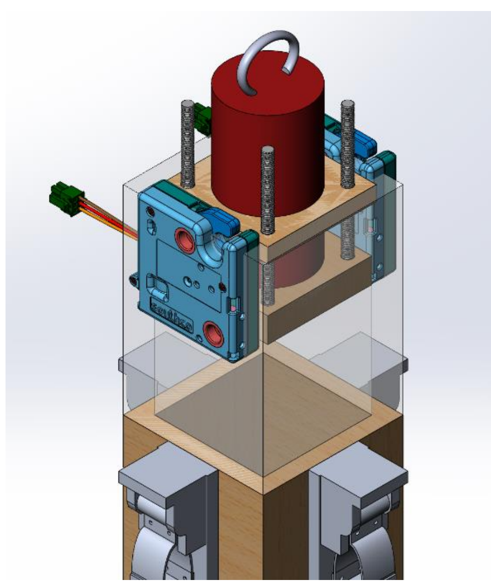

Figure 4-19 Payload Parachute Release Electronic Rotary Latches

4.6.4 Planetary Observation System (POS)

4.6.4.1 System Overview

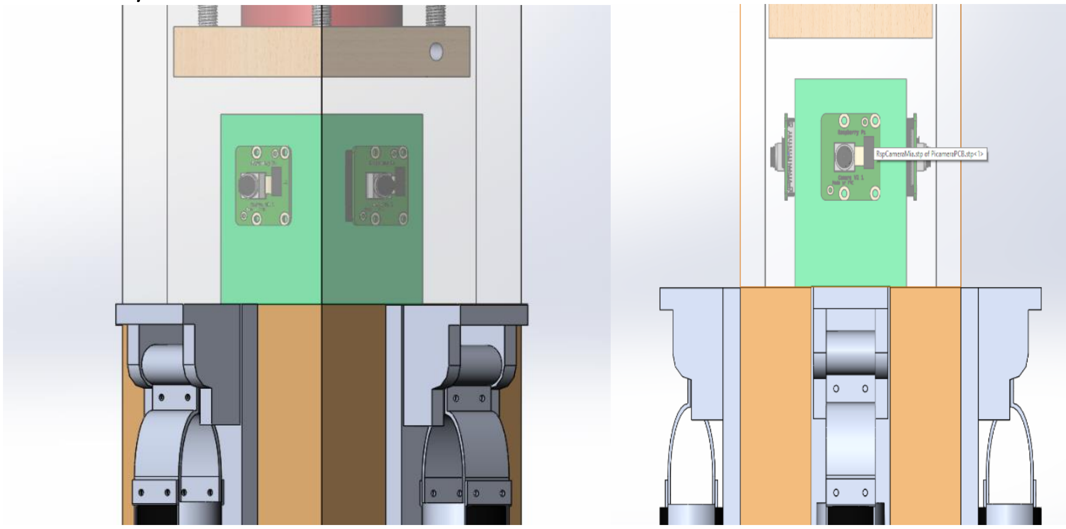

Figure 4-20 POS Placement within Payload Vehicle

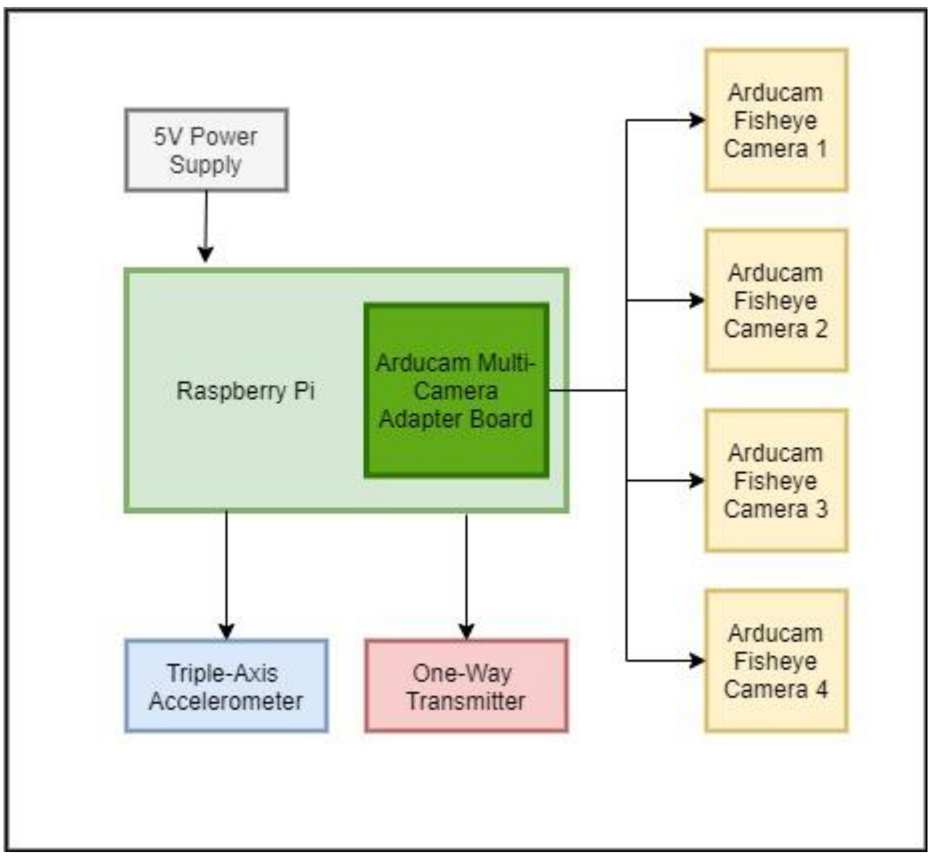

Figure 4-21 POS Electronics Functional Block Diagram

The Planetary Observation System (POS) is the subsystem responsible for the capture and transmission of a 360-degree photograph of the payload's landing site.

This system is located in the forward payload body which will be constructed using transparent material. The POS will be controlled by a Raspberry Pi powered by a 5V battery. Interfacing with the Pi will be four Raspberry Pi camera modules, a triple-axis accelerometer, and a one-way transmitter. The functions and rationale for each of these components are provided in the following sections.

4.6.4.2 POS Cameras

Panoramic photo capture will be achieved with four Raspberry Pi Camera Modules equipped with fisheye lenses. The fisheye lenses allow each camera module to achieve a 194-degree horizontal field of view (HFOV). The camera modules will be housed in the transparent section of the payload chassis and oriented with their lenses facing outward 90 degrees from each other, as shown in Figure 4-22. Due to the wide HFOV, two cameras are capable of capturing the necessary 360-degree view. Combining the 180-degree images from opposite camera modules results in a 360-degree panorama. With the four-camera set-up, two different panoramas will be captured, which adds redundancy to the POS. In the case of one camera failure, one complete panorama can still be captured. In the event of a two-camera failure, image capture cannot be guaranteed, but if the failed modules are opposite from each other, one complete panorama can still be captured.

Figure 4-22 Arducam Fisheye Camera for Raspberry Pi

Raspberry Pi boards only have one Camera Serial Interface (CSI) port, so a multi-camera adapter board will be used. This adapter board allows up to four camera modules to be connected to the Pi via CSI ribbon cables. It should be noted that the adapter board does not allow for simultaneous image capture – however, each camera module can be activated in rapid succession with only a fraction of a second between the capture of each image. In the context of this payload challenge, this was deemed sufficient for achieving a 360-degree photograph.

Figure 4-23 Arducam Multi-Camera Adapter Module V2.2

Only two Pi cameras are needed to capture a single 360-degree photograph. To add redundancy to the system, a total of four camera modules will be used in the POS. Each camera will capture an image, and the images from cameras of opposite orientation will be used to stitch together two panoramic photographs. If one camera fails, one panorama will still be received by the team.

4.6.4.3 Alternate Camera Designs

4.6.4.3(a) Single 360-degree camera

There are a wide variety of 360-degree cameras available from multiple manufacturers. These cameras are contained in a single housing and are designed for ease of use via phone applications. For these cameras, alignment would not be a concern as long as its placement within the payload provides a proper vantage point for photographing the landing area. Many models are also designed for high-stress environments such as what is found in extreme sports, making them a good choice for use in a launch vehicle. Research was done on multiple 360-degree camera models, and it was found that most of these cameras are not designed to easily interface with an SBC such as Raspberry Pi. Many of these models are also very expensive and provide features that are unnecessary for mission success, such as high-definition live video. It was decided that an option with more flexibility would be desired.

4.6.4.3(b) Single Raspberry Pi camera, actuated

Another camera option considered was a single Raspberry Pi or equivalent camera module capable of rotating about its vertical axis. One image would be taken facing one direction, and then the camera module would be rotated by some amount, depending on the HFOV of the camera. The number of images necessary to complete a 360-degree view would then be spliced together using an imaging processing program. Interfacing with a single Raspberry Pi camera would be very simple, however, having a motor and structure for actuating the camera would add complexity and weight. Considering the mass budget necessary for the payload's self-leveling system, it would be best to avoid adding another system requiring actuation.

4.6.4.4 Image Capture Initiation and Processing

Since the panoramic images need to be captured and transmitted after the payload has self-leveled, image capture with the POS will be initiated using a triple-axis accelerometer and a programmed time delay. The payload's self-leveling system will have a separate accelerometer in order to initiate the self-leveling sequence after landing is detected. There will be a period of time between payload landing and completion of the self-leveling sequence with a delay being programmed into the image capture procedure to reflect this amount of time. The exact time required for the payload to self-level will be determined with later testing.

Since the 360-degree photographs are being captured as two separate images, the original images will need to be combined using a computer program. The computing power of the Raspberry Pi will allow image processing to take place on board the payload. The Python 'picamera' library has a large range of capabilities for this type of application.

4.6.4.5 Image Transmission

The two panoramas will be transmitted from the payload to the team via two radio transceivers. There are many factors to consider when determining the necessary transceiver specifications, such as frequency, sensitivity, power output, etc. Considering that the speed of photo transfer is not a project requirement, the most crucial aspect of the transmission will be its range. The required launch vehicle recovery zone is 2500 feet from the launch pad, and assuming a worst-case scenario for landing location, the maximum possible transmission distance will be greater than or equal to 2500 feet. To estimate the required frequency of the payload's transmitter and receiver, a simple RF range calculator from Silicon Labs was used.

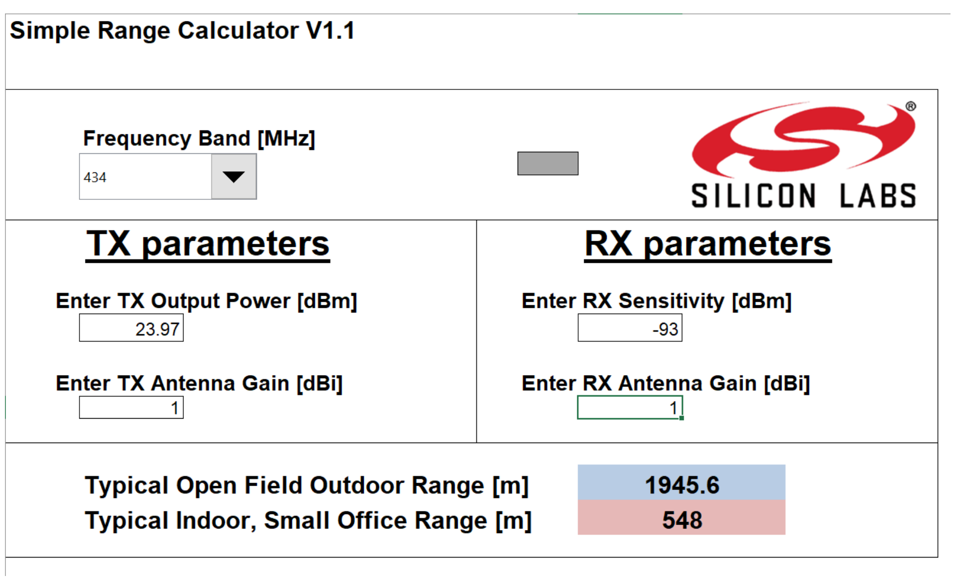

Figure 4-24 RF Range Calculation at 434 MHz

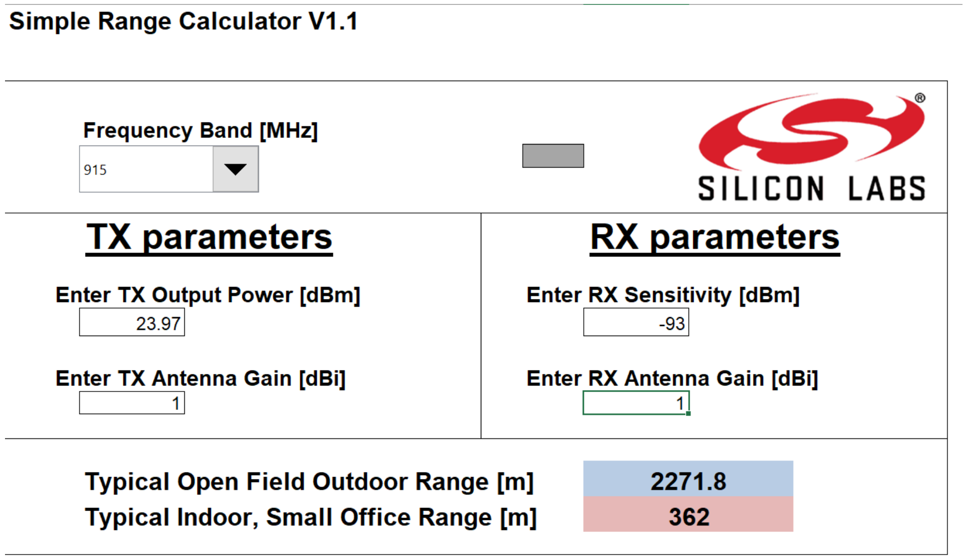

Figure 4-25 RF Range Calculation at 915 MHz

The transmitter output power was estimated to be 23.97 dBm, which is equivalent to the 250 mW requirement from any transmitters active during flight. The POS transmitter does not fall under this requirement, however, this value was used as a starting point for determining necessary output power. Receiver sensitivity was estimated to be –93 dB, as this is a standard for a large number of receiver models. Transmitter and receiver antenna gain were assumed to be 1 dBi. For frequencies of 434 MHz and 915 MHz, the transmission range is well above what would be required of the POS. A 434 MHz transmission frequency results in a range of 1945 m (6381 ft), and a 915 MHz transmission frequency results in a range of 2279 m (7477 ft). This calculator does utilize a few assumptions, such as an antenna height of 1 m, so these values will not be entirely accurate.

Although both of these frequencies achieve the necessary range, using a higher transmission frequency will provide a higher rate of data transfer. For this reason, the 915 MHz frequency will be used for POS image transfer, under the assumption that this value is subject to change with the maturity of this design.

4.6.5 Experimental Payload Challenges

4.6.5.1 Payload Structure Challenges

The greatest design challenge was deciding on the mechanisms used to level the payload vehicle body after landing.

Concerns have been discovered when simulating a ground in order to find the maximum angle that the payload can adjust. A plane was generated using points at the end of the legs.

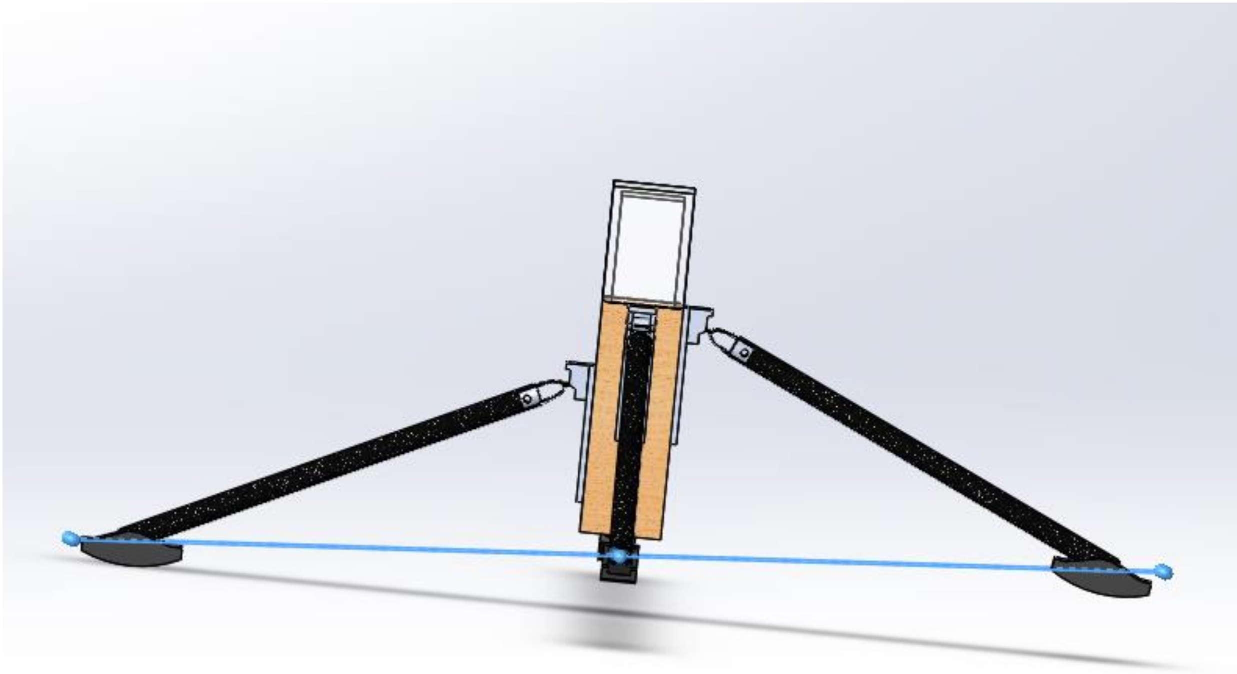

Figure 4-26 Profile View of Tilted Payload

The configuration shown in Figure 4-26 above is the maximum range that the body can adjust. As shown in Figure 4-27 below, the body can only tilt approximately 4 degrees on each axis. This estimate is merely approximate because of the difficulty and inaccuracy of simulating terrain like this, but it can be taken into consideration for the present concerns.

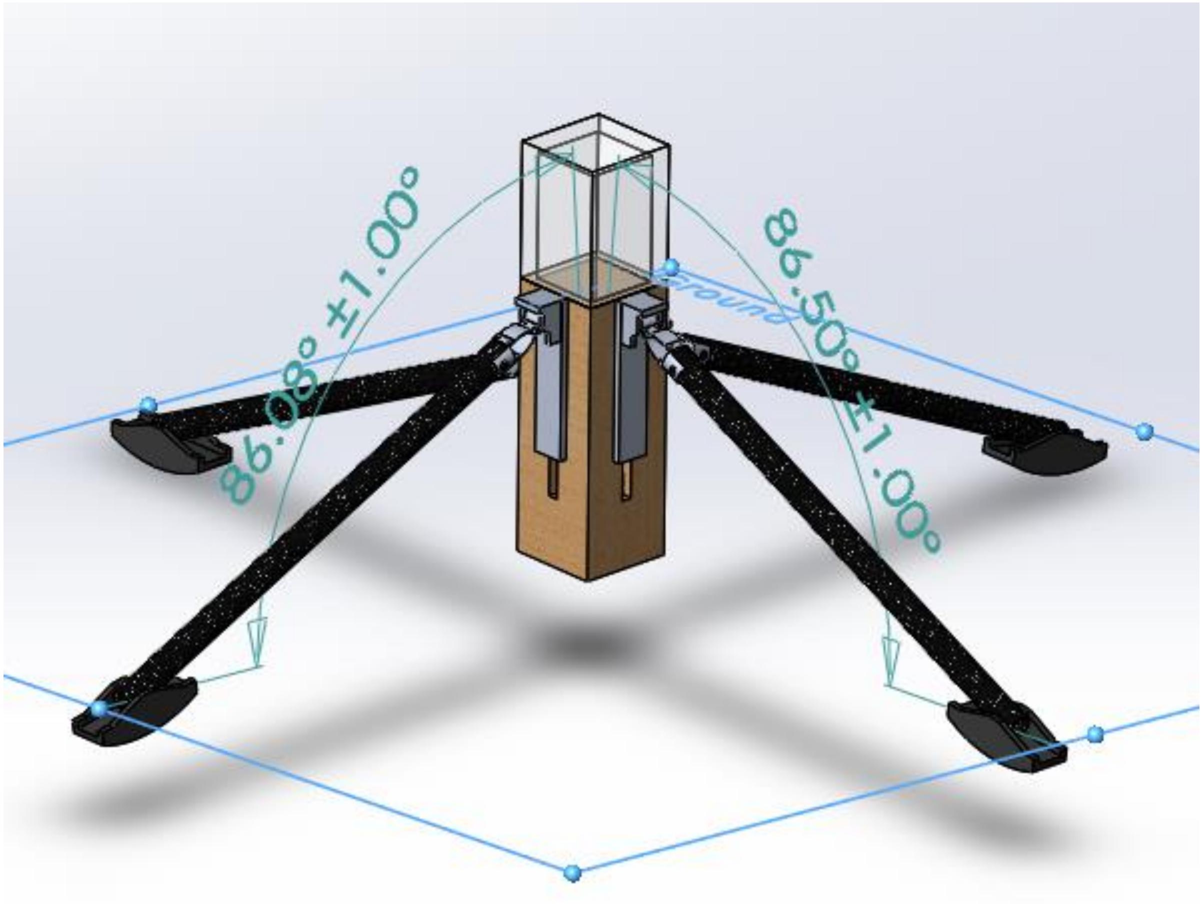

Figure 4-27 Payload Tilt Measurements

These results could be modified by increased the bracket slot length and modifying the bracket's geometry. Optimistically, this would only add about 2 degrees to each axis. Assuming the terrain could offer slopes of 15 degrees or higher, this is not an acceptable range to get within the mission's required 5 degrees of vertical.

Due to this design flaw, other options will be considered in order to complete the mission. The best options to consider are replacing the feet with wheels and changing the leg angles in order adjust the overall body angle as this would be more efficient. Options for actuation include a motor where the legs meet the body or a motor controlling the wheel. The motor's torque requirement would change with either decision. Having the motor towards the body will make use of the chassis interior space while having the motors at the wheels would make them quite bulky and difficult to store.

Another challenge is fitting strong enough stepper motors inside the body. The motor size scales considerably with the torque output. Should larger motors be required, an internal design change would need to be made in order to accommodate for their large size.

Another concept was explored where the body rotates around two axes, the vertical with respect to the body and one perpendicular to it. These two axes shall allow the body to align to any degree offset permitted physically by the body. This design was inspired by a gyroscope.

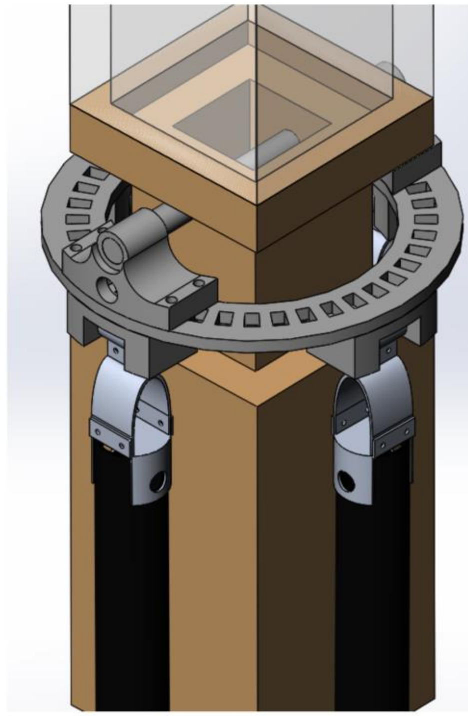

Figure 4-28 Gyroscope Design

Without straying too far from the initial design, allowing for the other subsystems to keep their designs mostly constant, Figure 4-28 above demonstrates the concept. The rod through the body attached to a bracket which is fitted to a ring/rail with gear tooth slots. A motor can be attached to each ring-bracket that will alter the position on the ring with a gear that interfaces with the ring. An additional motor will be fitted inside the body with the ability to alter the body's angle with respect to the through rod. If the team manages to get the center of gravity beneath the through rod, the system will be extremely stably and can self-orient across the through rod's axis, only requiring turning across the ring.

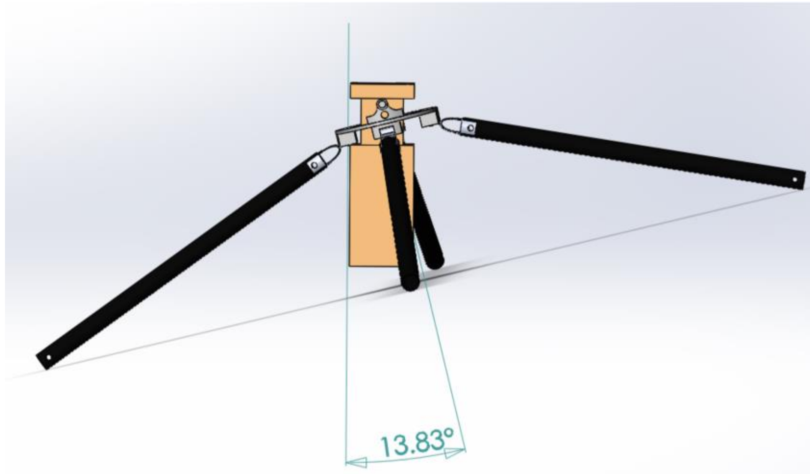

Figure 4-29 Gyroscope Design Angle Demonstration

This offers many benefits to the old design: more structurally sound, less worry about size and capability of the driving motors, better space management, and ultimately a wider range of orientation change.

Figure 4-29 demonstrates how the new concept can greatly increase the angle range. More minor modifications, which can be decided upon later in the design process, could increase the range by a few more degrees if necessary.

This design alternative will be explored further as the previous design might not be capable of performing the mission.

4.6.5.2 Payload Integration and Deployment Challenges

Some of the challenges taken into consideration during the designing of the payload integration system and deployment mechanism include high loading, limited space, electronic failure, and black powder ejection failure. These challenges are still dictating changes in the design as the team moves into modeling and detailing of the payload and payload bay and their electronic systems.

High loading can come from the vehicle launch and from the main parachute when it pulls the payload out of the payload bay. High loading can affect the payload structure to the point of failure. To prevent failure of the payload frame or the internal components, a reinforcement can be added inside the payload such as a beam that goes through the middle of the payload. Another solution could be to use an alternative material for the payload frame such as carbon fiber.

Spacing has proved to be limited during the initial modeling stage of the payload system as the payload bay and payload body are both dependent on electronics due to the autonomous nature of the mission. For every electronic component, there needs to be a power source, controller, and cables. To deal with limited spacing, the systems shall remain small and simple as possible such as controllers, the electronic latches, and the payload wheels.

Having an ARRD for the purpose of separating the payload from the parachute after the main parachute deployment adds to the challenge of successfully jettisoning the payload as the ARRD depends on an altimeter and e-match for ignition. In addition, the ARRD and the main parachute deployment work with black powder charges for which is possible to miss ignition due to failure during assembly. To prevent a charge failure, the team shall follow a step by step assembly check list for the ARRD and another one for the avionics section for successful ejection of the main parachute and the ARRD.

4.6.5.3 Payload Imaging Challenges

One of the biggest challenges for the imaging system will be the successful transmission of the captured 360-degree photograph. Since the launch vehicle and the payload each have their own GPS transmitters per requirement 3.12.1, careful transmitter selection and testing will need to be done to ensure the POS transmitter does not cause interference with the GPS signals and vice versa. There is also the likelihood of RF interference from other electronics on board the launch vehicle as well as electronic devices used by other teams. Initial calculations have been done to determine a range of transmission distances possible with available hardware, and there are a wide range of frequencies available that will work for POS transmission. Variance in image resolution also provides some flexibility. It would be ideal for images transmitted from the POS to be of high quality, but image resolution is not a mission requirement. If available bandwidth or transmitter power pose an issue for photo transmission time, the quality of the images can be reduced to ensure successful transmission and receival.

Requirement NASA 2.7 states that the launch vehicle and payload must maintain launch-ready configuration for a minimum of two hours without losing functionality. This poses a challenge for the POS power system. The selected 5V battery supply will need to provide power for the Raspberry Pi and all connected components while adhering to payload mass and volume constraints. A detailed record of voltage requirements and current draw for all POS components will be taken. Another challenge for the imaging system is the interfacing of all the necessary electronic components. The sensors and boards necessary for the POS have different power and pin requirements. The multi-camera adapter board covers 26 of the Raspberry Pi’s 40 GPIO pins, but not all of these pins are actively used by the adapter board, allowing more pin availability for other electronic components. The likely accelerometer that will be used operates on the I2C1 pins available on the Pi, and one of the likely transceiver options can use SPI0 pins. If necessary, pin extenders can also be used to allow for access to more GPIO pins.

Another challenge is the force of vehicle separation, parachute deployment, and landing on the POS electronics. The 2016-2017 Tacho Lycos team had a payload camera fail during full-scale flight. The most likely cause was determined to be opening shock during payload deployment. Since the POS consists of multiple cameras and other electronics that are susceptible to this type of failure, large acceleration changes will need to be mitigated as much as possible. The payload parachute selected was chosen to lighten the payload landing as much as possible. Later acceleration testing will be done to verify that the POS electronics can withstand in-flight forces.

5. STEM Engagement

5.1 Purpose and Description of Outreach

Outreach events are conducted in conjunction with local schools and community organizations to expose students to STEM concepts. The purpose of these events is to provide students with the opportunity to learn more details about rocketry, STEM, and the engineering design cycle. Additionally, students will be encouraged to apply the concepts they have learned in hands-on activities to develop a better understanding of the topics. Students shall be exposed to the current challenges provided by STEM issues. HPRC aims to increase student interest in these challenges and get students interested in pursuing careers in STEM.

The team shall reach out to local K-12 classrooms and attend STEM events organized by local community organizations. It is likely that outreach events will look very different this year in comparison with the past. The Covid-19 pandemic has caused all outreach events to be online through at least December 2020. Regardless of the many challenges caused by this pandemic, the team is well equipped to deal with them. The team has access to Zoom online meeting software, which can easily be used to connect with students. Additionally, these circumstances also provide the team with the opportunity to provide outreach events to schools that are not local to Raleigh. Events will include presentations about the team, NASA Student Launch, and interactive demonstrations. During the events, students will first learn about a selection of rocketry and STEM topics. Then, team members will lead students in interactive experiments and demonstrations in order to apply the topics covered in the presentation. In the past, these demonstrations have included helping elementary and middle school students construct straw rockets or bottle rockets, as well as assisting high-school engineering students in building and launching low power model rockets of their own. Some of these activities, such as straw rockets, are still possible to administer in a virtual setting while others, such as the construction of bottle rockets, will likely not be possible due to the additional specialized materials required. This year the team will strive to add additional events, such as virtual problem-solving sessions where students brainstorm solutions to engineering challenges and develop solutions. This will allow students to still be engaged in STEM topics while learning in a virtual setting.

The High-Powered Rocketry Club plans to provide outreach to a significant number of students. Requirement NASA 1.5 states that the team shall engage at least 200 K-12 students in hands-on STEM activities. The planned activities listed in Section 5.2 already exceed the minimum requirement, and team members are currently working to arrange new events. The team's Outreach Lead has reached out to the Morehead Planetarium and NC Museum of Natural Sciences in the interest of organizing more virtual events. It is expected that such events would reach anywhere from 25 to 75 participants. Last year, the team reached out to 4711 students. The team's goal is to reach a similar number of students this year. To meet this goal team members are researching local events to attend that will engage more of the community. Additionally, past outreach events have mainly reached middle and elementary school students. This year the team is developing plans to engage more high-school students in outreach events.

5.2 Planned Outreach

5.2.1 East Chapel Hill High-School Engineering Classes

East Chapel Hill High-School offers students the ability to take a class on aerospace engineering. During this class, students complete a project where they design and build their own model rockets. Team members shall give students a presentation about the NASA Student Launch competition. Then, students will be assisted in launching the rockets that they have designed with an emphasis on safe launching procedures. This event will take place in November and is expected to include approximately 60 students.

5.2.2 Astronomy Days

Astronomy Days is a weekend long event hosted by the North Carolina Museum of Natural Science and the Raleigh Astronomy Club. This event hosts displays, talks, and demonstrations about astronomy. HPRC helps host an amateur rocketry booth with Tripoli Rocketry Association. The team walks students through the construction of a rocket motor and allows them to put one together. Members also talk about NASA Student Launch, the team, and how visitors can get involved in local rocket launches. The event will take place in late January, and while attendance and level of engagement vary, the team expects to reach approximately 2000 students.

5.2.3 Weatherstone Elementary STEM Expo

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

6. Project Plan

6.1 Development Schedule

Table 6-1 below shows the development schedule for this year's project. Figure 6-1 below shows more detailed project schedule information in the form of program evaluation and review technique.

Table 6-1 2020-2021 NASA Student Launch Schedule

Event/Task	Start Date	End Date/Submission
Request for Proposal Released	August 19, 2020	N/A
Proposal	August 19, 2020	September 21, 2020, 3 p.m. CDT
Preliminary Design Review (PDR) Q&A	October 07, 2020	N/A
PDR	October 07, 2020	November 02, 2020, 8 a.m. CST
PDR Team Teleconferences	November 03, 2020	November 22, 2020
Subscale Launch Opportunity	November 21, 2020	November 22, 2020
Critical Design Review (CDR) Q&A	November 23, 2020	N/A
CDR	November 23, 2020	January 04, 2021, 8 a.m. CST
CDR Team Teleconferences	January 07, 2021	January 26, 2021
Flight Readiness Review (FRR) Q&A	January 27, 2021	N/A
FRR	January 27, 2021	March 08, 2021, 8 a.m. CST
Full Scale Launch Opportunity	February 20, 2021	February 21, 2021
FRR Team Teleconferences	March 11, 2021	March 29, 2021
Launch Window for Teams Not Travelling to Launch Week	March 30, 2021	May 02, 2021
Post-Launch Assessment Review (PLAR) – Teams Not Travelling to Launch Week	March 30, 2021	14 Days After Launch
Launch Week Q&A	March 31, 2021	N/A
Team Travel to Huntsville, AL (if applicable)	April 07, 2021	N/A
Launch Readiness Review (LRR)	April 07, 2021	April 08, 2021
Launch Week Activities	April 08, 2021	April 09, 2021
Launch Day	April 10, 2021	N/A
Backup Launch Day	April 11, 2021	N/A
Post-Launch Assessment Review (PLAR) – Teams Travelling to Launch Week	April 12, 2021	April 27, 2021, 8 a.m. CDT

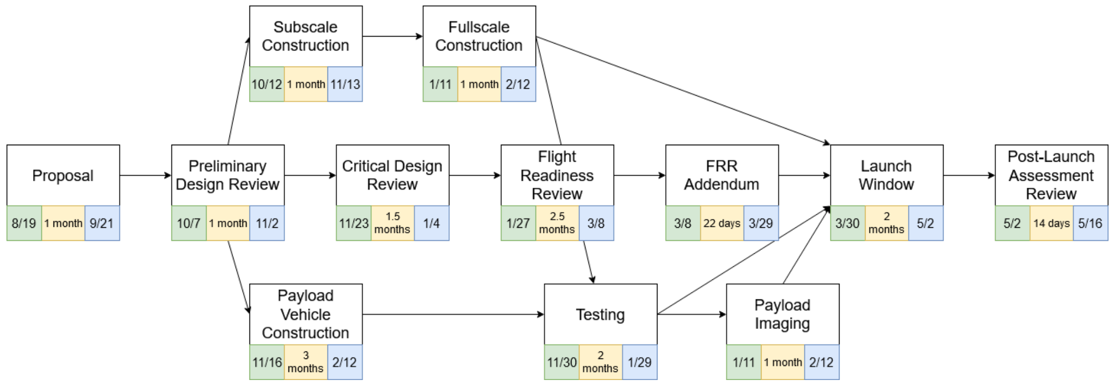

Figure 6-1 Project Schedule in Program Evaluation and Review Technique form

6.2 Budget

Table 6-2 below details the year-long budget for the 2020-2021 NASA Student Launch competition.

Table 6-2 2020-2021 NASA Student Launch Competition Budget

	Item	Quantity	Price per Unit	Item Total
Subscale Structure	Aerotech I435T-14A	2	$56.00	$112.00
	Aero Pack 38mm Retainer	1	$27.00	$27.00
	Motor Casing	1	$340.00	(Already own) $0.00
	38mm G12 Airframe, Motor Tube	1	$64.00	$64.00
	4" Phenolic Airframe, 3 Slots	1	$33.50	$33.50
	4" Phenolic Airframe	2	$26.00	$52.00
	4" Phenolic Coupler	4	$21.00	$84.00
	Plastic 4" 4:1 Ogive Nosecone	1	$23.00	$23.00
	Domestic Birch Plywood 1/8"x2x2	6	$14.82	$88.92
	Rail Buttons	4	$2.50	$10.00
	U-Bolts	4	$1.00	$4.00
	Blast Caps	4	$2.50	$10.00
	Terminal Blocks	3	$7.00	$21.00
	Paint	1	$100.00	$100.00
	Key Switches	2	$12.00	$24.00
	Subtotal:			**$541.42**
Full-Scale Structure	6" G12 Airframe, Full Length (60"), 3 Slots	1	$264.00	$264.00
	6" G12 Airframe, Half Length (30")	1	$114.00	$114.00
	3"/75mm G12 Motor Tube, 22" length	1	$37.00	$37.00
	6” G12 Coupler 14” Length	1	$70.00	$70.00
	6" G12 Coupler 12" Length	1	$60.00	$60.00
	6" Fiberglass 4:1 Ogive Fiberglass Nosecone	1	$149.95	$149.95
	Domestic Birch Plywood 1/8"x2x2	8	$14.82	$118.56

	Aerotech 75/3840 Motor Case	1	$360.00	(Already own) $0.00
	75 mm Motor Retainer	1	$72.00	$72.00
	Rail Buttons	4	$2.50	$10.00
	U-Bolts	4	$1.00	$4.00
	Aerotech L1150R-PS	2	$224.00	$448.00
	Aerotech 75mm Forward Seal Disk	1	$37.50	$37.50
	Blast Caps	4	$2.50	$10.00
	Terminal Blocks	3	$7.00	$21.00
	Paint	1	$150.00	$150.00
	Key Switches	2	$12.00	$24.00
	Subtotal:			**$1,590.01**
Payload	Arducam Camera w/fisheye lens	4	$29.00	$116.00
Payload	Rasberrry Pi multi-camera adapter board	1	$50.00	$50.00
Payload	Rasberrry Pi model 3	1	$35.00	$35.00
Payload	5V battery supply	1	$40.00	$40.00
Payload	Accelerometer	1	$8.00	$8.00
Payload	915 MHz transceiver	2	$6.00	$12.00
Payload	200 mm T8 Lead Screw	4	$10.99	$43.96
Payload	1" OD carbon fiber tube 24" long	4	$39.99	$159.96
Payload	Stepper motor	4	19.95	79.8
Payload	Aluminum sheet metal	1	21.48	21.48
Payload	1/4" thick acrylic Sheet 24x48	1	55.37	55.37
Payload	A4988 Stepper Motor Driver Carrier	4	5.99	55.37
Payload	Arduino uno	1	17.6	55.37
Payload	Accelerometer	1	$15.95	$15.95
Payload	Stratologger CF Altimeter	2	$69.95	(Already Own) $0.00
Payload	ARRD	1	$119	$119
Payload	Threaded Rods	3	$6.88	$20.64
Payload	U-bolt	1	$2.66	$2.66
Payload	T-track	2	$33.50	$67.00
Payload	Southco Latch	2	$62.50	$125.00
Payload	Wheels	1	$10.59	$10.59
Payload	**Subtotal:**			**$1,093.23**
Recovery and Avionics	Standoffs	1	$10.99	$10.99
Recovery and Avionics	Iris Ultra 120" Parachute	1	$541.97	(Already own) $0.00
Recovery and Avionics	Stainless Steel Quick Links	14	$1.97	$27.58
Recovery and Avionics	5/8 inch Kevlar Shock Cord (yard)	26.7	$6.35	$169.55
Recovery and Avionics	Black powder	1	$17.95	$17.95
Recovery and Avionics	E-matches	1	$80.25	$80.25

Miscell.	Shear Pins	1	$1.00	$1.00
	StratoLogger CF	2	$49.46	(Already Own) $0.00
	Classic Elliptical 18" Parachute	1	$57.17	(Already Own) $0.00
	6" Deployment Bag	1	$46.23	$46.23
	18" Nomex Cloth	1	$24.00	$24.00
	Eggfinder TX Transmitter	1	$70.00	(Already own) $0.00
	Eggfinder TX Reciever	1	$55.00	(Already own) $0.00
	4" Deployment Bag	1	$43.00	$43.00
	13" Nomex Cloth	1	$16.00	$16.00
	Subtotal:			**$436.55**
	Epoxy Resin	2	$86.71	$173.42
	Epoxy Hardener	2	$45.91	$91.82
	Nuts (box)	1	$5.50	$5.50
	Screws (box)	1	$5.00	$5.00
	Washers	1	$5.00	$5.00
	Wire	1	$13.00	$13.00
	Zip Ties	1	$11.00	$11.00
	3M Electrical Tape	4	$8.00	$32.00
	9V Batteries	2	$14.00	$28.00
	Wood Glue	2	$3.00	$6.00
	Rubber Bands	1	$5.00	$5.00
	Paper Towels	1	$25.00	$25.00
	Battery Connectors	3	$5.00	$15.00
	Shipping			$1,000.00
	Incidentals (replacement tools, hardware, safety equipment)			$1,500.00
	Subtotal:			**$2,915.74**
Travel	Student Hotel Rooms – 4 nights (# rooms)	4	$791.70	$3,166.80
	Mentor Hotel Rooms – 4 nights (# rooms)	3	$1,178.10	$3,534.30
	Van Rentals (# cars)	2	$198.00	$396.00
	Gas (Miles)	1144	$0.60	$686.40
	Subtotal:			**$7,783.50**
Promotion	T-Shirts	40	$14.00	$560.00
	Polos	30	$25.00	$750.00
	Stickers/Pens	500	$0.37	$185.00
	Banner	1	$250.00	$250.00
	Subtotal:			**$1,745.00**
Total Expenses:				**$16,105.37**

Figure 6-2 below shows a budget breakdown for the 2020-2021 competition cycle.

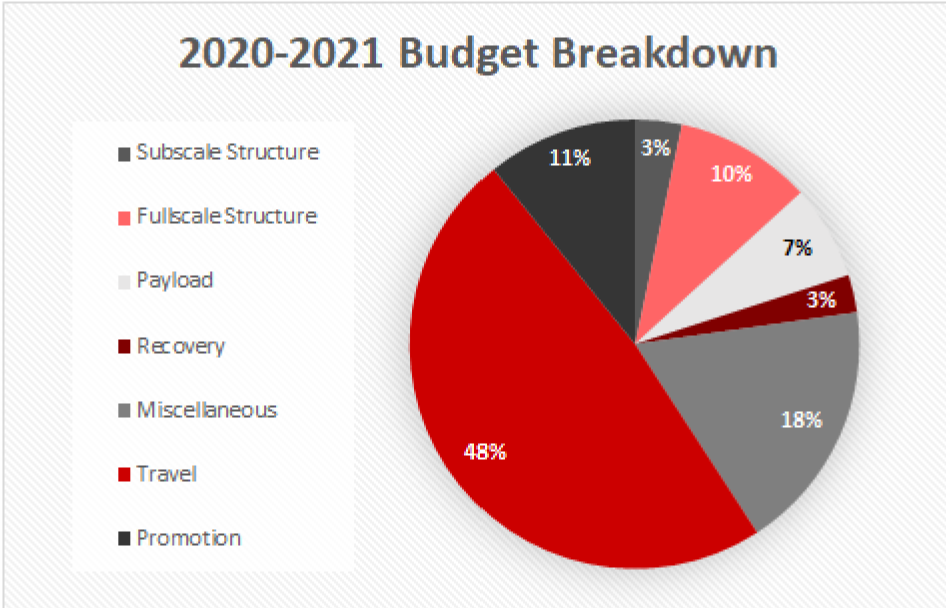

Figure 6-2 2020-2021 Budget Breakdown Chart

6.3 Funding Plan

HPRC receives all funds from multiple NC State University organization and North Carolina Space Grant (NCSG). Below is a breakdown of the team's current funding sources.

The NC State University Student Government Association's Appropriations Committee is responsible for distributing university funds to campus organizations. Each semester the application process consists a proposal, presentation, and an in-person interview. During the 2019-2020 academic year, HPRC received a total of $2,100: $1,030 in the fall semester and $1,070 in the spring semester. A request for $750 has been placed for the current fall semester and $1,350 will be requested in the spring semester, assuming that the Appropriations Committee budget will remain the same.

Educational and Technology Fee is an NC State University fund that allocates funding for academic enhancement through student organizations. Their funding of about $1,500 will primarily pay for the team's faculty advisors travel costs.

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

In addition to funding through NC State organizations, North Carolina Space Grant will provide a large amount of monetary support to the club. NCSG accepts funding proposals during the fall semester and teams can request up to $5,000 for participation in NASA competitions. NCSG will review the proposal and inform the club on the amount awarded, which will likely be the full amount requested. These funds will be available for use starting November 2020.

In the past, HPRC has held sponsorships with Collins Aerospace, Jolly Logic, and more. The team is currently seeking out new sponsorships and reaching out to past sponsors. The team hopes to gain a couple thousand dollars more in funding from various companies.

These totals are listed in Table 6-3 below, which compares the projected costs and incoming grants for the 2020-2021 school year.

Table 6-3 Projected Costs for 2020-2021 Competition

Organization	Fall Semester Amount	Spring Amount	School Year Total
Engineering Technology Fee	-	-	$1,500.00
SGA Appropriations	$750.00	$1,350.00	$2,100.00
Sponsorships	-	-	$2,000
NC Space Grant	-	-	$5,000.00
College of Engineering	-	-	$5,500.00
Total Funding:			**$16,100.00**
Total Expenses:			**$16,105.37**
Difference:			**$5.37**

6.4 Sustainability Plan

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

- University-sponsored recruitment events
- Club enrichment
- North Carolina Rocketry volunteer opportunities
- Community outreach

HPRC recruits new members in the Fall and Spring semesters through several university-sponsored club exposure events. During these events, current Club members advertise the Club by describing the Student Launch competition and rocketry in general, with a focus on this year's specific project. In addition to these events, the Club is advertised on all of the team's social media outlets. By using these resources, the club typically recruits over one-hundred new members per year. As of the submission of this document, the number of new members is approximately forty which is lower than expected. This is likely due to the virtual nature of the recruitment events as a function of the COVID-19 pandemic.

The Club also strives to retain new members once they join. In order to engage new members in past years, the Club has conducted enrichment opportunities such as an underclassmen-led interest launch in the beginning of the Fall semester. Due to university restrictions in place as a result of the COVID-19 pandemic, these in-person enrichment opportunities cannot take place. Therefore, for the 2020-2021 competition year, the Club is shifting its enrichment focus to virtual events. Experienced Club members will hold virtual workshops on the basics of high-powered rocketry, launch vehicle design, and payload design. The Club will also hold regular virtual game and movie nights so that Club members can socialize and get to know each other.

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

HPRC is largely self-sufficient, as all manufacturing equipment and materials are available on-site in the facilities described in Section 2.1. If any additional resources are required, the team will communicate with the team mentors listed in Section 1.2 for assistance in working towards a solution. In addition, the Club uses stable, regularly scheduled funding sources as described in Section 6.3 to ensure a sustainable availability of funds.