University of Notre Dame
2021-2022

Notre Dame Rocketry Team
Proposal

NASA Student Launch 2022

Launch Vehicle Identification System and Apogee Control System

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365 Fitzpatrick Hall of Engineering
Notre Dame, IN 46556

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1 Team Information

1.1 General Information

School Name:	University of Notre Dame
Team Name:	Notre Dame Rocketry Team
Location:	University of Notre Dame 365 Fitzpatrick Hall of Engineering Notre Dame, IN 46556
Faculty Advisor:	Dr. Hirotaka Sakaue Associate Professor Department of Aerospace and Mechanical Engineering e: hsakaue@nd.edu p: (574) 631-4336
Graduate Student Advisor:	Joseph Gonzales Ph.D. Graduate Student Department of Aerospace and Mechanical Engineering e: jgonza21@nd.edu p: (703) 887-9974
Team Lead:	Jacob Shapiro e: jshapir1@nd.edu p: (847) 527-7881
Safety Officer:	Michael Bonaminio e: mbonamin@nd.edu p: (708) 567-9696
Mentor:	Dave Brunsting (NAR/TAR Level 3) e: dacsmema@gmail.com p: (269) 838-4275
NAR/TRA Section:	TRA #12340, Michiana Rockety

1.2 Team Organization

This year, the Notre Dame Rocketry Team is organized into four design groups: vehicles, recovery, apogee control system (ACS), and payload in addition to four operations groups: safety, systems, technical editing, and educational outreach. A description of each design group is as follows:

- **Vehicles** - Responsible for the design, construction, and testing of the launch vehicle airframe, and conducting flight simulations for analysis and testing. Additional responsibilities include motor selection, integration supervision, and structural analysis.
- **Apogee Control System** - Responsible for the design, construction, and testing of a drag-inducing mechanisms that controls the trajectory of the launch vehicle such that it does not exceed the target apogee.
- **Recovery** - Responsible for the design, construction, and testing of a system that safely deploys parachutes to control the descent of the launch vehicle after reaching apogee.
- **Lunar Vehicle Identification System (LVIS) Payload** - Responsible for the design, construction, and testing of an experimental payload that completes the requirements specified in the NASA Student Launch Handbook.
- **Safety** - Responsible for creating and implementing construction procedures, launch checklists, tool and machine certifications, and other safety documentation such as a Safety Handbook, Safety Data Sheet Document, and Standard Operating Procedures necessary to ensure the safety of the team, community, and environment. Additional responsibilities include performing hazards analysis and implementing effective, hazard-specific mitigations, enforcing regulations imposed by NAR/TRA, and acting as the point of contact for the RSO at the launch site.
- **Systems** - Responsible for creating and updating team-derived requirements to guide system-level design, managing system integration and CAD assemblies, creating test procedures, and ensuring NASA requirements are fulfilled. Additional responsibilities include performing tests on all systems, compiling mass and size budgets, and organizing stand-up design reviews with design leads.
- **Technical Editing** - Responsible for creating and managing team document files for proposal, design reviews, and presentations, and ensuring all necessary information is included in an organized, coherent manner. Additional responsibilities include authoring a technical editing document for general team guidelines on writing style, structure, and formatting figures and tables.

- **Educational Outreach** - Responsible for organizing, tracking, and documenting STEM outreach efforts, both in-person and virtually, in addition to preparing materials such as presentations, demonstrations, or activities for learning.

With another year of membership increase and shifting responsibilities, NDRT has elected to re-structure the leadership team to better account for needs and allocation of tasks. Replacing the Chief Engineer position is the Systems Lead, which will lead the derivation of requirements, system integration, and testing plan completion. Additionally, the Public Relations Lead was replaced by a team of three Technical Editors, specializing in report organization and formatting, report content, and presentations, respectively. Additionally, a Social Media Lead will be responsible for publicizing team activities, posting on team social media accounts, and organizing team images throughout the year.

Consistent with past years, the Project Manager and Safety Officer roles will remain, in addition to four design leads. The Project Manager oversees the leadership team, manages budgets, maintains schedules, and communicates with team mentors and advisors, corporate sponsors and department and university leadership. The Safety Officer leads the Safety group, organizes safety certifications, communicates with university leadership, and sources necessary tools and PPE. The design leads oversee each design group and facilitate the design and construction of each system. Finally, an Educational Outreach lead organizes STEM outreach events for team members to engage in with local participants. Figure 1 depicts a figure of the team structure for the 2021-22 mission.

1.3 Hours Tracking

Hours will be tracked spent working on milestones to fulfill Req. 1.14. The hours tracked for work towards proposal are as follows, in Table 1.

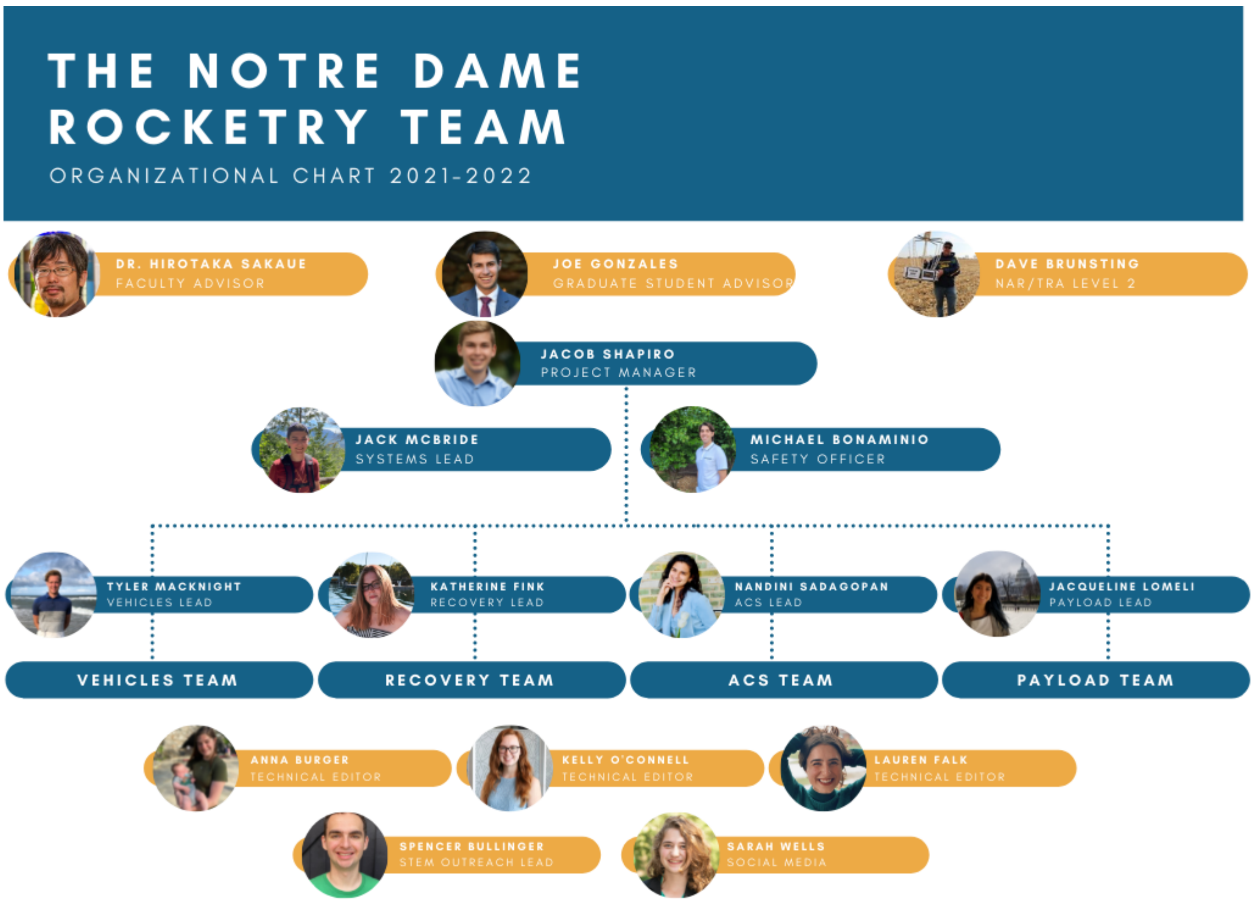

Figure 1: NDRT Organizational Chart 2021-22

Table 1: NDRT Hours Spent on Proposal

Project Subject	Hours
Vehicle Design	**15**
Meetings	6
Writing & Design	9
ACS	**11**
Meetings	6
Writing & Design	5
Recovery	**18**
Meetings	7
Writing & Design	11
PLS	**20**
Meetings	8
Writing & Design	12
Safety	**15**
Meetings	6
Writing & Planning	9
Educational Outreach	**18**
Meetings	10
Writing & Planning	8
Technical Editing	**19**
Meetings	4
Writing & Editing	15
Systems	**24**
Meetings	10
Writing & Management	14
Project Management	**25**
Meetings	11
Writing & Management	14
Total	**165**

2 Facilities Overview

2.1 Stinson-Remick Hall of Engineering

NDRT Workshop: Room 217
Electrical Engineering Senior Design Lab: Room 205
Meeting Spaces: Rooms 212 and 213
Storage Facility: Room 214

Stinson-Remick Hall of Engineering is home to the Notre Dame Rocketry Team workshop, located in Room 217. The team workshop is shared with one other aerospace design team, and contains storage space, whiteboards, launch equipment, some basic machinery such as a drill press, belt sander, and laser cutter. Tools in the team workshop include, but are not limited to, basic hand tools, dremels, sanders, drills, and soldering irons. Additionally, NDRT stocks PPE specifically for the workshop, which is a responsibility of the Safety Officer. Stinson-Remick is accessible 24/7 for team members, but the workshop is only accessible by team leadership. All tools and machines cannot be used before relevant certifications have been completed successfully. Any work done in the workshop must be supervised by a lead, mentor, or advisor. In addition to the workshop space in Room 217, Room 214 is a large-scale storage facility for previous vehicles, payloads, and raw materials.

Stinson-Remick also includes the Electrical Engineering Senior Design Lab, which houses electronics used for prototyping, assembly, and testing. The Payload team will utilize the Senior Design Lab for assembly, soldering, testing, and consulting Electrical Engineering faculty.

2.2 Cushing Hall of Engineering

Schlafly Electronic Circuit Laboratory: Room 253
Contact: Clint Manning | cmanning@nd.edu

The Schlafly Electronic Circuit Lab, housed in the Cushing Hall of Engineering, contains tools, resources, and equipment for students to design, create, and test prototypes. The Apogee Control System, Recovery, and Payload teams will use the Schlafly Lab to test electronics, solder circuit boards, and create basic prototypes.

2.3 Fitzpatrick Hall of Engineering

College of Engineering Dean's Office: Room 257
Department of Aerospace and Mechanical Engineering: Room 365
Engineering Innovation Hub: First Floor
Contact: Will Mathis | wmathis@nd.edu
Materials Tensile Properties Lab: Room B14
Contact: John Ott | jott@watt.ame.nd.edu

Fitzpatrick Hall of Engineering houses the College of Engineering Dean's Office, the Office for the Department of Aerospace and Mechanical Engineering, the Materials Tensile Properties Lab, and the Engineering Industry Hub (EIH).

The Materials Tensile Properties Lab will be used by the Vehicle Design team to test and evaluate structural components. The tests conducted would provide the stress and strain profiles of particular materials in consideration for components such as couplers, bulkheads, motor mounts, and other structural elements. This information is then utilized by the team so that they may make better unformed design decisions. The lab is supervised by John Ott, and all tests must be supervised by John Ott.

The Engineering Industry Hub is a brand new, state-of-the-art manufacturing facility for student groups at the University of Notre Dame. Including new CNC machinery, 3D printers for plastics, resins, polymers, and metals, and extraneous equipment such as water jets and metal bending equipment, the EIH is where a majority of NDRT construction will occur. The EIH has more space than the NDRT workshop, and is supervised by full-time staff members who are trained and experienced with each tool and machine.

2.4 Hessert Laboratory for Aerospace Research

Contact: Dr. Eric Matlis | ematlis@nd.edu

Hessert Laboratory contains a full suite of aerodynamics testing equipment, including wind tunnels available for testing subscale vehicles prior to flight. If available, the Vehicles team will utilize the wind tunnel to perform a variety of analyses. Hessert Laboratory contains an anechoic free jet wind tunnel, subsonic wind tunnels, transonic wind tunnels, an atmospheric wind tunnel, a high pressure blow down tunnel, and a low speed subsonic tunnel. All use of the wind tunnel facilities will be supervised and led by the team's faculty and/or graduate advisor, in addition to other relevant faculty of facility staff.

2.5 Acquisitions

The team does not currently intend to acquire additional equipment or space during the 2021-22 mission cycle. With the opening of the Engineering Innovation Hub in the Fitzpatrick Hall of Engineering, the team has open access to a state-of-the-art machine shop, including CNC machinery, water cutters, and 3D printers for metal, plastic, carbonfiber and fiberglass.

3 Safety

3.1 COVID-19 Precautions

3.1.1 Local, State, and University Policies

It is the responsibility of all NDRT members to combat the COVID-19 pandemic. The NDRT team adheres to and will comply with all University of Notre Dame policies regarding COVID-19. The full list of University policies can be found here. While there are more University policies, the following are notable for most major team activities:

- All undergraduate, graduate, and professional students are required to be fully vaccinated before arriving on campus for the fall semester.
- For fully vaccinated Notre Dame faculty, staff, and students, masking is optional indoors on campus, including in residence halls. There are some exceptions to this, primarily involving spaces and times where visitors are commonly present.
- All visitors to campus, regardless of vaccination status, are expected to wear masks inside campus buildings (except when eating and drinking), again in an effort to help protect community.
- Every member of the Notre Dame community is expected to carry a mask at all times.
- In-person student activities will take place without most of the COVID restrictions that were in effect throughout the 2020-2021 academic year.
- University-related domestic travel may resume without the need for special pre-approvals.

Additionally, NDRT will adhere to and comply with all local, state, and federal COVID-19 policies. The state of Indiana's dashboard, where all policies and updates regarding COVID-19 are located, can be found at https://www.coronavirus.in.gov/. St. Joseph's County dashboard, where all policies and updates regarding COVID-19 are located, can be found at https://www.sjcindiana.com/1814/COVID-19.

3.1.2 Educational Outreach Precautions

Given that only 52 percent of the South Bend area is fully vaccinated, compared to 96 percent of campus, the risk of contracting COVID-19 is greater at educational outreach events. Therefore, further rules will be imposed for every educational outreach event. The following actions are the responsibility of both the Safety Officer and the Educational Outreach lead to enforce:

- All members present at educational outreach events will be required to wear face masks while indoors.
- For outdoor events, all members present at educational outreach events are encouraged to wear face masks, but they will not be required.
- NDRT will communicate with the educational outreach group before the event to ensure their cooperation with the team's mask-wearing policies.
- Face masks will be available at every event in the off chance any person forgets a mask or their mask becomes unusable.

Any member present found violating such rules will first be given one warning to follow the rules. Any further violations will result in being asked to leave the event.

3.2 Safety Plan

The Safety Officer for the Notre Dame Rocketry Team for this year's competition is Michael Bonaminio. The role of Safety Officer includes, but is not limited to, the following responsibilities:

- Ensure the team is actively updating safety procedures throughout the design, construction and test process.
- Enforce the use of appropriate PPE at all stages of design, construction, test, and launch.
- Require that active team members are properly certified on the necessary equipment and inform them of safety hazards and procedures.

- Maintain and distribute a safety handbook to all members of the team.
- Compile and update all necessary SDS sheets into one readily available document which is easily accessible in the workshop.
- Provide standard operating procedures for all tools, machines, and procedures.
- Apply a risk assessment matrix to classify risks based on severity and probability of occurrence to appropriately mitigate hazards.
- Restrict launch personnel to only members that have passed a launch test and have attended the pre-launch briefing.
- Compile and distribute launch checklists and procedures to all team members before launch.
- Create and follow a plan for the obtaining, using, and disposing of all hazardous materials.
- Create a repair action summary to establish protocols for repairing components that are damaged or destroyed.
- Ensure team compliance with all local, state, and federal laws and regulations.
- Ensure team compliance with all NAR/TRA rules and regulations.
- Ensure team compliance with all NASA Student Launch rules and regulations.
- Ensure team compliance with all University of Notre Dame rules and regulations.

These responsibilities result from the team's paramount goal of ensuring the safety of all individuals, both public and team members, at every stage of the project. The Safety Officer will be assisted by a Safety Team who will aid in the execution of the responsibilities and increase safety involvement in each squad. Safety Team members are either primary Safety Team members or Safety Team liaisons and are also a member of a design squad. This distinction allows for Safety Team members to focus on their strong suits; primary Safety Team members can work on general team safety, while Safety Team liaisons can analyze the risks and mitigations of specific components of the launch vehicle's airframe, recovery system, payload, and apogee control system.

3.2.1 Hazard Analysis

Hazards are categorized by their level of risk based on a numerical analysis of both their severity and probability of occurrence. This method will be applied to every aspect of the team's operations. The Safety Team shall thoroughly evaluate the hazards generated and compile them in a document for the rest of the team to utilize in their efforts to be proactive in hazard identification and mitigation implementation.

The probability of occurrence of the hazard shall be scored on a scale of 1 to 5, with 5 being an extreme likelihood of the hazard to occur under present condition and 1 signifying the hazard is improbable to occur under present conditions. The full probability occurrence value criteria is in Table 2.

Table 2: Probability of Occurrence Value Criteria

Description	Value	Criteria
Improbability	1	Less than a 1% chance the event will occur
Rare	2	Between a 1 - 10% chance the event will occur
Sporadic	3	Between a 10 - 20% chance the event will occur
Likely	4	Between a 20 - 40% chance the event will occur
Frequent	5	Greater than a 40% chance the event will occur

The probability of occurrence is scored on its current conditions. This method leads to many major assumptions. First, all personnel who will operate on the hazard are assumed to have already performed all training and have been notified of and understand the rules and regulations outlined in the safety documents. The list of safety documents includes, but is not limited to: the Safety Handbook, SDS document, FMEA tables, launch procedures, construction procedures, testing procedures, and the latest design review. Second, it is assumed that all personnel involved are properly wearing all required PPE, and that the equipment used was properly inspected prior to use. Lastly, given that the probability of occurrence value criteria determines its value based on current conditions, it is assumed that the criteria will be re-evaluated and updated if current conditions change. Other minor assumptions may be made, but they hold less weight over the probability of occurrence.

The hazard's severity shall be scored on a 1 to 4 scale, with 4 being catastrophic to the mission or the personnel involved, and 1 having a negligible impact on the mission or the personnel involved. The full severity value criteria is in Table 3.

By multiplying the probability of occurrence and severity values together, a total risk score can be assigned to the hazard. The risk score falls within a range of 1 to 20, and an increased score indicates an increased risk. The Safety Team then works to identify ways to mitigate the risks, which will lower the total risk score through lowering the probability, severity, or both.

Table 3: Severity Value Criteria

Description	Value	Personnel	Vehicle Damage	Environmental Impact	Mission Success
Negligible	1	Minor Injury	Insignificant	Insignificant	Complete Mission Success
Minimal	2	Slight Injury	Slight	Reversible	Slight Mission Failure
Dangerous	3	Severe Injury	Severe	Somewhat Reversible	Major Mission Failure
Catastrophic	4	Critical Injury	Loss of Vehicle	Irreversible	Complete Mission Failure

Mitigation implementation will be prioritized from the highest risk scores to the lowest risk scores until all foreseeable hazards have been reduced to the best of the team's ability. While all risks will eventually be addressed, this hierarchy of mitigation implementation helps the Safety Officer better allocate the team's time and resources to the hazards that require the greatest attention. Mitigations can take multiple forms, such as design adjustments to reduce the probability and severity of failure, newly designed physical systems to ensure proper operating conditions, and rewrites on procedures. Risk scores and risk levels associated with each total score are outlined in Tables 4 and 5, respectively.

Every mitigation will be subject to verifications in order to ensure that the necessary actions will occur to foster a consistent, safer working environment in a timely manner. There are a variety of verification methods, such as approval from team members or leaders, limiting actions to certain team members, or requiring written documentation before further action. The Safety Team has already begun to identify and categorize potential hazards using the tables' criteria.

3.2.2 Risk Identification

The Safety Team will be re-analyzing and updating all hazards, including their risk values, throughout the design process. All major risks identified shall be undertaken immediately with the necessary mitigations. Further hazards may be identified later in the design process,

Table 4: Risk Assessment Table

Probability	Severity			
	Negligible (1)	Marginal (2)	Critical (3)	Catastrophic (4)
Improbable (1)	1	2	3	4
Unlikely (2)	2	4	6	8
Moderate (3)	3	6	9	12
Likely (4)	4	8	12	16
Unavoidable (5)	5	10	12	20

Table 5: Risk Levels

Level	Color	Range
Desired	Green	Less than 5
Acceptable	Yellow	Between 5 and 9
Unacceptable	Red	Greater than 10

and the design squads shall be notified promptly in order to reduce the potential for further hazards or design problems. In the end, the Safety Team strives to make the safety of the team as robust as possible. Preliminary risk assessment documentation can be found at Table 23 in Appendix A.

3.2.3 Construction Procedures

Prior to construction, the Safety Team will primarily work alongside the Systems Team to develop a list of construction procedures for the vehicle and subsystems. Vehicle construction procedures will be prioritized given the squad's abundance of first-time members who have never been through a vehicle construction process before. Detailed construction procedures are intended to provide as much information on the step-by-step process for constructing specific components to mitigate the possibility of misinformation. Technical design squad leaders will also provide input in the construction procedure process to ensure the procedures lead to high-quality construction techniques. Once written, the Safety Officer will review the construction procedures to ensure all construction methods are low risk, specific, realistic, and, most importantly, safe. Upon review, the Safety Officer has the right to suggest edits to any procedure that they deem high risk, vague in detail, unrealistic, or unsafe. Construction of any component may only proceed upon the completion and approval of the respective construction procedure. Once approved, construction procedures will be administered to the team electronically and be physically available in the team workshop at all times. Team members will be permitted to assist in construction only after they read the relevant construction procedures, understand everything they entail, and have passed all required safety certifications.

3.2.4 Launch Procedures

Prior to both the first launch and the end of CDR, the Safety Team will work with the rest of the team leaders to develop detailed launch procedures, checklists, and troubleshoots for launch day. Technical design leaders will be allowed to and are encouraged to give input in the launch process in order to ensure the procedures generated will facilitate a safe and successful launch. Once written, the Safety Officer will evaluate the launch procedures to ensure all launch methods are low risk, specific, realistic, and, most importantly, safe. Upon review, the Safety Officer has the right to suggest edits to any section that they deem high risk, vague in detail, unrealistic, or unsafe. All launch-related actions will be adjourned until the appropriate amendments to the launch procedures have been made and approved. Upon full completion and approval, all launch procedures will be administered to the team electronically and be physically available in the team workshop and at every launch. Team members will be permitted to attend and assist on launch day only after they read the launch procedures, understand everything they entail, and have passed the required safety certifications. Furthermore, all launch day attendees must be present at the safety briefing held the day prior to launch. This launch safety briefing will include a mock launch preparation run in order to familiarize the members with the launch process and the necessary safety measures. At the safety briefing and on the day of the launch, all members will be reminded of and fully comply with all NAR/TAR codes and proper launch procedures.

3.2.5 Materials Handling Procedures

A Safety Data Sheet (SDS) will be acquired from the manufacturer for the materials and chemicals used in the construction process of the launch vehicle. NDRT members are required to know how to access the SDS document and understand all the hazards and risks associated with the materials they are intending on using. A physical copy of the SDS document will be readily available in the workshop, and a digital version is always available on the NDRT website. Therefore, there is never any reason one cannot acquire access to the SDS document. It is the responsibility of the Safety Officer to communicate updated hazards and risks to all team members once amended; all relevant hazards and risks to material handling should also be communicated to the respective team members if need be. The Launch manager, Dave Brunstring, is the only individual who will handle the energetics.

3.2.6 Personal Protection Equipment

Personal protective equipment (PPE) is crucial for the safety of all team members. Therefore, NDRT will standardize PPE as a requirement for all activities to foster an environment of safety. The Safety Team will compile a list of all hazardous actions, and a detailed list of necessary PPE for such actions will be administered to the entire team. If PPE training is necessary, the appropriate measures will occur to educate team individuals on both the appropriate use of the respective PPE and one's personal responsibility for its proper use. The Safety Handbook lists all PPE in Section 2, and this document will be readily available to the team. Section 2 includes images of the PPE along with the appropriate scenarios when the PPE is necessary. Furthermore, PPE Standard Operating Procedures will be written for instructions on the proper usage of the PPE. The locations of PPE are clearly labeled in the workshop, and any questions about the locations of PPE can be found in Section 2 of the Safety Handbook or by asking any team leader.

3.3 NAR/TRA Documentation

The Notre Dame Rocketry Team's TRA certified member is the Launch Manager Dave Brunsting. The motor required for the launch will be an dangerous, high energy device capable of extreme damage to personnel, the vehicle, and the environment if handled improperly. Therefore, the team's TRA certified member, primarily the Launch Manager Dave Brunstring, will be responsible for all energetics operations, including the motor, black powder, and igniters. These measures demonstrate the team's compliance with the NAR High Power Rocket Safety Code, specifically, Section 3.2.1.

3.3.1 NAR Safety Code Compliance

The Notre Dame Rocketry Team will adhere to all rules and regulations in the National Association of Rocketry High Power Rocket Safety Code, which has been in effect since August 2012. To ensure compliance, Table 24 in Appendix A outlines the entire 13 point safety code and how the team will comply with every point of it.

3.4 Team Safety

The Safety Handbook is a detailed document that compiles all information regarding team safety into one location, and it is available to all team members. If any modifications are made to the handbook, the team shall be informed of the update in the team's next weekly meeting. The Safety Handbook includes information on the following topics:

- Personal Protective Equipment (PPE)
- Materials Safety
- Energetics
- Construction Safety
- Testing Safety
- Launch Safety
- Educational Outreach Safety
- Environmental Considerations
- NAR/TAR Regulatory Compliance
- Local, State, Federal Law Compliance
- University Compliance
- Safety Certification
- Team Agreements
- COVID-19 Precautions

All team members are required to sign a contract complying with the information included in the Safety Handbook. Additionally, team members are required to sign specific contracts complying with all rules and regulations on launches, construction, COVID-19 policies, workshop safety, and discrimination and harassment policies. If a member is found violating a section in any signed contract, they will instantly lose access to the following privileges: workshop access, participation in construction, and attendance at any upcoming launch events. Members may regain access to such privileges after discussing their violations with the Safety Officer. The Safety Officer will evaluate the severity, context, and frequency of their violations before reinstating lost privileges.

Team members will be administered a safety quiz to assess their understanding of the risks and hazards associated with the respective event, before launch and construction. Team members must score 100% before being eligible to participate.

A team lead must be present if launches or machining is to occur. Launches may only occur if the Project Manager, Safety Officer, and Range Safety Officer all sign off in approval. Launches may not occur if determined unsafe or if the risk is at a severe level.

3.5 Local, State, and Federal Law Compliance

The Notre Dame Rocketry Team has read and will comply with all rules and regulations regarding unmanned, high-powered rocket launches and motor handling. In particular, the Safety Officer is personally responsible for reading and understanding the the rules and regulations regarding the use of airspace, Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; Amateur Rockets, Code of Federal Regulation 27 Part 55: Commerce in Explosives; and fire prevention, and NFPA 1127 "Code for High Power Rocket Motors." These documents will be readily accessible to all team members in the team safety documents. It will be the responsibility of the Range Safety Officer, NAR representatives, and team leads present at the launch site to ensure full compliance with the listed rules and regulations. Any team member who is concerned about the safety or compliance of the rules and regulations while at the launch site shall notify the Project Manager or Safety Officer immediately. From there, the team will operate in the best manner to resolve the concerns while in full compliance with the listed rules and regulations. Lastly, the team will be in full compliance with all local, state, and federal laws during the construction process, testing, and on the day of the launch.

3.6 Motor Handling

The Notre Dame Rocketry Team's mentor, Dave Brunstring, has acquired a Level 3 TRA certification. Level 3 TRA certification allows the individual to launch High Power Rockets with total installed impulse greater than 5120 newton-seconds; this is the largest impulse allowed per NASA requirement 2.12. Therefore, only a Level 2 TRA certification is required for the launch, for it allows the individual to launch High Power Rockets in the H to L range. Any individual who also possesses Level 3 TRA certification, according to the Tripoli Rocketry Association, has clearly demonstrated their ability to successfully launch Level 2 rockets in the past and have designed and successfully flown a level M-O High Power Rocket. As a result, the team mentor is fully qualified for safe motor handling. Dave Brunstring will be responsible for obtaining, handling, and transportation of all team rocket motors at all times. Any team member who also has at least Level 2 TRA certification may assist in the tasks previously listed and any individual who handles or stores team motors must comply with all applicable procedures. All motors shall be transported to the respective launch or test site by car, driven by any Level 2 or greater TRA certified individual.

3.7 Written Safety Compliance Agreement

The Notre Dame Rocketry Team agrees with and will comply with the following NASA rules regarding launch safety. The following rules are included in the team's safety contracts that all members are required to sign preceding any participation in launches or construction.

1. Range safety inspections will be conducted on the launch vehicle before it is flown. Each team shall comply with the determination of the safety inspection or may be removed from the program.
2. The Range Safety Officer has the final say on all vehicle safety issues and has the right to deny the launch of any vehicle for safety reasons.
3. The team mentor is ultimately responsible for the safe flight and recovery of the team's launch vehicle. The team will not fly until the mentor has reviewed the design, examined the build and is satisfied the vehicle meets established amateur rocketry design and safety guidelines.
4. Any team that does not comply with the safety requirements will not be allowed to launch their vehicle

3.8 NASA Safety Requirements

Table 6: NASA Safety Requirements

Req. ID	Description
5.1	Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations.
5.2	Each team shall identify a student safety officer who will be responsible for all items in section 5.3.
5.3	The role and responsibilities of the safety officer will include, but are not limited to:
5.3.1	Monitor team activities with an emphasis on safety during:
5.3.1.1	Design of vehicle and payload
5.3.1.2	Construction of vehicle and payload components
5.3.1.3	Assembly of vehicle and payload

Table 6: NASA Safety Requirements

Req. ID	Description
5.3.1.4	Ground testing of vehicle and payload
5.3.1.5	Subscale launch test(s)
5.3.1.6	Full-scale launch test(s)
5.3.1.7	Competition Launch
5.3.1.8	Recovery activities
5.3.1.9	STEM Engagement Activities
5.3.2	Implement procedures developed by the team for construction, assembly, launch, and recovery activities.
5.3.3	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.
5.3.4	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.
5.4	During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.
5.5	Teams will abide by all rules set forth by the FAA.

4 Technical Design: General Requirements

The NASA requirements for the 2022 Student Launch are outline in Table 7. Additional requirements will be identified throughout the design process.

Table 7: NASA General Requirements

Req. ID	Description
1.1	Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Teams will submit new work. Excessive use of past work will merit penalties.

Table 7: NASA General Requirements

Req. ID	Description
1.2	The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.
1.3	Foreign National (FN) team members must 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.
1.4	The team must identify all team members who plan to attend Launch Week activities by the Critical Design Review (CDR). Team members will include:
1.4.1	Students actively engaged in the project throughout the entire year.
1.4.2	One mentor (see requirement 1.13).
1.4.3	No more than two adult educators.
1.5	The team will engage a minimum of 250 participants in direct 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. A template of the STEM Engagement Activity Report can be found on pages 40-43.
1.6	The team will establish and maintain a social media presence to inform the public about team activities.
1.7	Teams will 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. Late submissions of milestone documents will be accepted up to 72 hours after the submission deadline. Late submissions will incur an overall penalty. No milestone documents will be accepted beyond the 72-hour window. Teams that fail to submit milestone documents will be eliminated from the project.
1.8	All deliverables must be in PDF format.
1.9	In every report, teams will provide a table of contents including major sections and their respective sub-sections.
1.10	In every report, the team will include the page number at the bottom of the page.
1.11	The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.

Table 7: NASA General Requirements

Req. ID	Description
1.12	All teams attending Launch Week will be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted at the NASA Launch Complex. At launch, 8-foot 1010 rails and 12-foot 1515 rails will be provided. The launch rails will be canted 5 to 10 degrees away from the crowd on Launch Day. The exact cant will depend on Launch Day wind conditions.
1.13	Each team must identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certifi- cation, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to Launch Week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attend Launch Week in April.
1.14	Teams will track and report the number of hours spent working on each milestone.

5 Technical Design: Launch Vehicle

5.1 Vehicle Description

The proposed vehicle will carry the Launch Vehicle Identification System to an altitude between 4000 and 6000 feet. The vehicle's design will be driven by meeting this altitude requirement, allowing for safe vehicle recovery, and allowing the Apogee Control System to function as intended. The launch vehicle will include an increased-diameter payload bay, three in-flight separation points for recovery events and payload jettison, and the ACS near the center of pressure in order to safely manipulate apogee.

5.2 Mission Requirements

The NASA-provided vehicle requirements are included in Table 8.The team will also identify and document further requirements for the success of each system as the design process progresses. These requirements drive the vehicle design and will be carefully verified.

Table 8: NASA Vehicles Requirements

Req. ID	Description
2.1	The vehicle will deliver the payload to an apogee altitude between 4,000 and 6,000 feet above ground level (AGL). Teams flying below 4,000 feet or above 6,000 feet on their competition launch will receive zero altitude points towards their overall project score and will not be eligible for the Altitude Award.
2.2	Teams shall identify their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team's altitude score.
2.3	The vehicle will carry, at a minimum, two commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events (see Requirement 3.4). An altimeter will be marked as the official scoring altitude used in determining the Altitude Award winner. The Altitude Award winner will be given to the team with the smallest difference between the measured apogee and their official target altitude for their competition launch.
2.4	The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.
2.5	The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.
2.5.1	Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length.
2.5.2	Nosecone shoulders which are located at in-flight separation points will be at least 1/2 body diameter in length.
2.6	The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.
2.7	The launch vehicle and payload will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged.

Table 8: NASA Vehicles Requirements

Req. ID	Description
2.8	The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.
2.9	The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).
2.10	The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).
2.10.1	Final motor choices will be declared by the Critical Design Review (CDR) milestone.
2.10.2	Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment will not be approved. A penalty against the team's overall score will be incurred when a motor change is made after the CDR milestone, regardless of the reason.
2.11	The launch vehicle will be limited to a single stage.
2.12	The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).
2.13	Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria:
2.13.1	The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.
2.13.2	Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank.
2.13.3	The full pedigree of the tank will be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.
2.14	The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.
2.15	The launch vehicle will have a minimum thrust to weight ratio of 5.0 : 1.0.

Table 8: NASA Vehicles Requirements

Req. ID	Description
2.16	Any structural protuberance on the rocket will 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.
2.17	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.
2.18	All teams will successfully launch and recover a subscale model of their rocket prior to CDR. The sub- scale flight may be conducted at any time between proposal award and the CDR submission deadline. Subscale flight data will be reported at the CDR milestone. Subscales are required to use a minimum motor impulse class of E (Mid Power motor).
2.18.1	The subscale model should resemble and perform as similarly as possible to the full-scale model; however, the full-scale will not be used as the subscale model.
2.18.2	The subscale model will carry an altimeter capable of recording the model's apogee altitude.
2.18.3	The subscale rocket shall be a newly constructed rocket, designed and built specifically for this year's project.
2.18.4	Proof of a successful flight shall be supplied in the CDR report. Altimeter flight profile graph(s) OR a quality video showing successful launch and recovery events as deemed by the NASA management panel are acceptable methods of proof.
2.18.5	The subscale rocket shall not exceed 75% of the dimensions (length and diameter) of your designed full-scale rocket. For example, if your full-scale rocket is a 4" diameter 100" length rocket your subscale shall not exceed 3" diameter and 75" in length.
2.19	All teams will complete demonstration flights as outlined below.
2.19.1	Vehicle Demonstration Flight - All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown shall be the same rocket to be flown for their competition launch. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). The following criteria shall be met during the full-scale demonstration flight:
2.19.1.1	The vehicle and recovery system will have functioned as designed.
2.19.1.2	The full-scale rocket shall be a newly constructed rocket, designed and built specifically for this year's project.

Table 8: NASA Vehicles Requirements

Req. ID	Description
2.19.1.3	The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply:
2.19.1.3.1	If the payload is not flown, mass simulators will be used to simulate the payload mass.
2.19.1.3.2	The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.
2.19.1.4	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 will be active during the full-scale Vehicle Demonstration Flight.
2.19.1.5	Teams shall fly the competition launch motor for the Vehicle Demonstration Flight. The team may request a waiver for the use of an alternative motor in advance if the home launch field cannot support the full impulse of the competition launch motor or in other extenuating circumstances.
2.19.1.6	The vehicle shall be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the maximum amount of ballast that will be flown during the competition launch flight. Additional ballast may not be added without a re- flight of the full-scale launch vehicle.
2.19.1.7	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).
2.19.1.8	Proof of a successful flight shall be supplied in the FRR report. Altimeter flight profile data output with accompanying altitude and velocity versus time plots is required to meet this requirement.
2.19.1.9	Vehicle Demonstration flights shall be completed by the FRR submission deadline. No exceptions will be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. THIS EXTENSION IS ONLY VALID FOR RE-FLIGHTS, NOT FIRST TIME FLIGHTS. Teams completing a required re-flight shall submit an FRR Addendum by the FRR Addendum deadline.

Table 8: NASA Vehicles Requirements

Req. ID	Description
2.19.2	Payload Demonstration Flight - All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown shall be the same rocket to be flown as their competition launch. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. The following criteria shall be met during the Payload Demonstration Flight:
2.19.2.1	The payload shall be fully retained until the intended point of deployment (if applicable), all retention mechanisms shall function as designed, and the retention mechanism shall not sustain damage requiring repair.
2.19.2.2	The payload flown shall be the final, active version.
2.19.2.3	If the above criteria are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required.
2.19.2.4	Payload Demonstration Flights shall be completed by the FRR Addendum deadline. NO EXTENSIONS WILL BE GRANTED.
2.20	An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA- required Vehicle Demonstration Re-flight after the submission of the FRR Report.
2.20.1	Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline will not be permitted to fly a final competition launch.
2.20.2	Teams who successfully complete a Vehicle Demonstration Flight but fail to qualify the payload by satisfactorily completing the Payload Demonstration Flight requirement will not be permitted to fly a final competition launch.
2.20.3	Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload at launch week. Permission will not be granted if the RSO or the Review Panel have any safety concerns.

Table 8: NASA Vehicles Requirements

Req. ID	Description
2.21	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.
2.22	All Lithium Polymer batteries will be sufficiently protected from impact with the ground and will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.
2.23	Vehicle Prohibitions
2.23.1	The launch vehicle will not utilize forward firing motors.
2.23.2	The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)
2.23.3	The launch vehicle will not utilize hybrid motors.
2.23.4	The launch vehicle will not utilize a cluster of motors.
2.23.5	The launch vehicle will not utilize friction fitting for motors.
2.23.6	The launch vehicle will not exceed Mach 1 at any point during flight.
2.23.7	Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad (i.e. a rocket with an unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast).
2.23.8	Transmissions from onboard transmitters, which are active at any point prior to landing, will not exceed 250 mW of power (per transmitter).
2.23.9	Transmitters will not create excessive interference. Teams will utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams.
2.23.10	Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of light- weight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.

5.3 Vehicle Overview

A model of the proposed launch vehicle was created using OpenRocket with all internal systems placed and masses assigned as seen in Figure 2. All air frame sections are labelled along with major internal components.

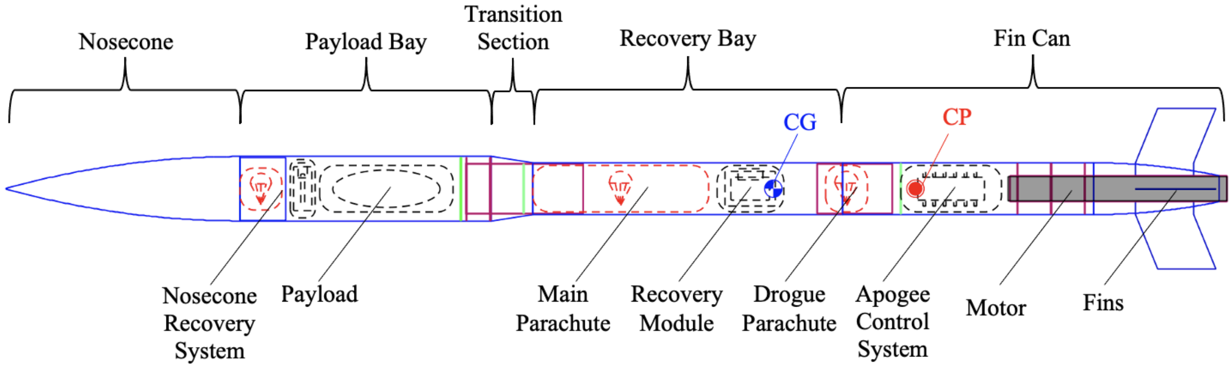

Figure 2: Proposed Launch Vehicle Diagram

The proposed launch vehicle consists of three major airframe sections as well as a nosecone, a boattail, and a variable-diameter transition section. The payload bay houses the payload and nose recovery hardware and has an increased diameter to allow for increased payload volume. The recovery bay houses the main recovery hardware and parachutes. The fin can houses the ACS, the motor mount and the fin structure. Each section is fitted into adjacent sections with couplers of at least one full body tube caliber. A summary of the major sections is included in Table 9.

The vehicle has three in-flight separation points: one at each end of the recovery bay for main and drogue parachutes, and one at the front end of the payload bay for the nosecone parachute and payload jettison. There are three main bulkheads: one at the aft end of the payload bay, one in the transition section coupler, and one at the front end of the ACS. These bulkheads provide structural rigidity to the airframe, separate pressure zones for recovery charges, and keep internal components properly positioned.

The center of pressure and center of gravity locations are also labelled on Figure 2. Importantly, the CP is situated aft of the CG such that the vehicle is stable is flight. The locations of these points will be manipulated such that the stability meets the NASA Requirement of 2 at rail exit. Additionally, the CP is positioned with the ACS such that drag added will not adversely affect stability.

Table 9: Launch Vehicle Sections

Section	Description
Nosecone	Reduces drag and protects payload
Payload Bay	Increased diameter to allow ample payload volume
Transition Section	Allows for high-strength body diameter transition
Recovery Bay	Houses main recovery hardware and parachutes
Fin Can	Houses motor mount tube, fins, and ACS

5.3.1 Vehicle Dimensions

The dimensions of the major airframe components of the proposed launch vehicle are listed in Table 10.

Table 10: Launch Vehicle Dimensions

Component	Dimension (in.)
Overall length	146
Fore section outer diameter	7.5
Aft section outer diameter	6
Nosecone length	38
Payload bay length	30
Recovery bay length	37
Fin can length	45
CG Location	88.011
CP Location	109

5.3.2 Mass Estimate

Preliminary mass estimates for each internal subsystem were determined to begin estimating the mass of the launch vehicle. Growth allowances and margins were then applied, resulting in reasonable predictions for the final mass of each subsystem. These subsystem masses were then used to design the launch vehicle. Table 11 lists the preliminary mass predictions for the vehicle and each subsystem. Figure 3 depicts a percentage breakdown of the mass of the fully-loaded launch vehicle. Ballast weight may also be added if necessary and will not exceed the allowed 10% of the total unballasted mass.

Table 11: Subsystem Mass Estimate

System	Allowable Mass (oz.)
Propulsion	146
Vehicle Airframe	352
Recovery System	170
Apogee Control System	60
Launch Vehicle Detection System	80
Total	**808**

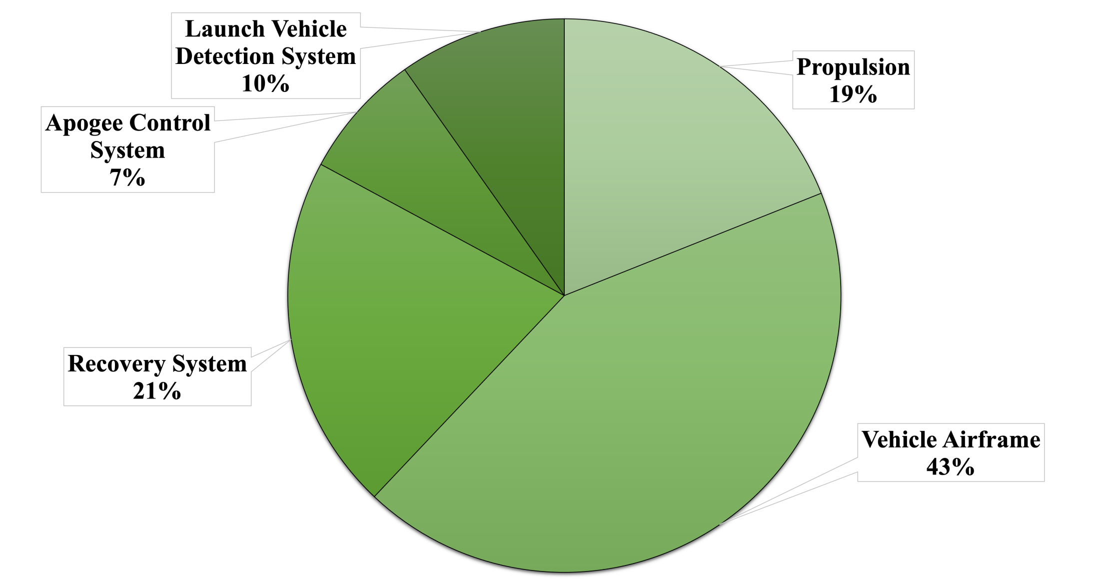

Figure 3: Subsystem Vehicle Mass Estimate

5.3.3 Proposed Target Apogee Altitude

Simulation flights with the selected motor, the Cesaroni L2375-WT-P, were carried out at the two extreme cases of the lowest and the highest apogees to arrive at a preliminary target apogee. The NASA Requirements specify a safe-launch wind speed range up to 20 mph and a launch rail cant between 5 and 10 degrees. Therefore, the highest apogee case was simulated with 0 mph winds at a 5 degree launch angle while the lowest apogee case was simulated with 20 mph winds and a 10 degree launch angle. The details of these simulations are presented in Table 12.

Table 12: Target Apogee Simulation Cases

Scenario	Minimum Apogee Case	Maximum Apogee Case
Wind Speed (mph)	20	0
Launch Rail Cant (deg)	10	5
Apogee (ft)	5216	5603

The average apogee was determined to likely fall between these extremes at about 5,400 feet. The listed target apogee will be set lower at 5150 feet because the team intends to use the ACS to accurately control apogee. This target apogee will be reassessed utilizing a similar process and will be finalized in the Preliminary Design Report as the team continues to further refine the subsystem and vehicle design.

5.4 Apogee Control System

The Apogee Control System (ACS) is this year's nonscoring payload, which is proposed in order for the launch vehicle to be competitive in the NASA SL Altitude Award. The subsystem will consist of a set of variable area drag tabs which will actuate to decelerate the launch vehicle and prevent excessive overshoot of the target apogee. A microcontroller will continuously read in sensor data corresponding to launch vehicle altitude and acceleration after burnout. The microcontroller will then employ data filtering and control algorithms and read out a signal corresponding to a specified amount of drag tab extension. As the launch vehicle decelerates, the error between the predicted and target apogees will decrease, which will correspond to a continuously changing drag tab extension.

Success criteria for the Apogee Control System include the following:

- System shall be located aft of launch vehicle burnout center of gravity (Table 7 Req. 2.16)
- System shall not negatively impact the stability margin of the launch vehicle
- System shall not actuate until launch vehicle burnout stage has been reached
- System shall accurately read in and filter data corresponding to launch vehicle trajectory
- System shall ensure launch vehicle does not exceed target apogee by greater than 25 ft.
- System shall retract and enter a dormant phase once apogee has been achieved
- System shall retract if a jam is detected

- System shall be able to be fully integrated into the launch vehicle in 30 minutes or less and remain on launch pad for up to two hours prior to launch

5.4.1 Mechanical Design

The two primary design drivers for the drag tab actuation mechanism are maximizing overall surface area perpendicular to flow direction and minimizing mechanism complexity. The system will be designed so that it is mechanically impossible for any single drag tab surface to actuate independently from the others to prevent unsymmetrical drag tab actuation. The system must be able to support and maintain small changes in actuation when acted upon by the drag vector to provide a high degree of control.

The drag tab actuation in previous years was controlled by a servo motor, whose rotational motion was coupled to parallel linear motion of the drag tabs by a set of linkages. This mechanism will be considered along with a variety of other mechanisms that satisfy the requirements laid out above in the ideation design stage.

5.4.2 Material Selection

A number of high strength materials are being considered for drag tab fabrication to ensure vehicle structural integrity and satisfy NASA Requirement 2.4 (Table 7). Finite Element Analysis will be conducted on each material considered, with specific attention given to the worst case scenario of impact loading on the extended drag tabs. The top bulkhead is another critical component and will serve as a recovery attachment point, transmitting parachute loading to the body of the fin can. Computational and analytical stress calculations will be used to ensure acceptable factors of safety for this bulkhead, as well as all load bearing members of the Apogee Control System. Secondary material design drivers include cost and weight minimization, as well as ease of manufacturability.

5.4.3 Controller Design

Drag tab actuation will be controlled by a microcontroller which will estimate the expected launch vehicle apogee from current conditions. The combination of acceleration and altitude data will likely suffice to create a complete picture of the launch vehicle's current state. The system will be activated during assembly, and will provide both visual and auditory confirmation of data acquisition. Raw data will then be fed into a data filtering algorithm, which will extract usable signal from the sensors.

The filtered data will be read into a multistage control algorithm, which will determine which of several distinct stages the launch vehicle is in and instruct the system accordingly. Upon activation, the system will begin reading in filtered data until it has determined that burnout has been achieved. Once burnout is detected, the system will transition into active mode, during which a control algorithm will instruct the drag tab actuation mechanism to actuate continuously if it is predicted that the launch vehicle will overshoot its target apogee. This stage will continue until the launch vehicle has reached its apogee. The tabs will retract and remain retracted throughout the duration of the recovery and landing stage once apogee is reached.

5.4.4 Electrical Design

The electrical system of the ACS will consist of a variety of redundant sensors, a microcontroller, and an actuation mechanism such as a servo motor integrated onto a printed circuit board (PCB). It is likely that each of these components will require significantly different operational currents and voltages depending on component selection. As such, PCB design is critical to ensuring safe operation of each component.

A primary design driver of component sourcing is data collection frequency and accuracy. Sampling frequency is critical in maximizing system sensitivity because the active stage of the ACS is likely to be around 30 seconds. However, a trade-off exists between sampling frequency and accuracy for many sensors, which will need to be examined in trade studies. Additionally, environmental factors may affect sensor data fidelity, including magnetic interference and local flow field turbulence. Sensors will be isolated from components with large current draws and will be placed in locations with minimal flow disturbances to mitigate these effects.

5.4.5 Test Plan

Table 13: ACS Test Plan

Test Method	Purpose
Sub-Scale Flight	Verify that drag tabs retain stability, are appropriately sized, and reduce apogee as expected. Test sensor data acquisition and filtration.
Finite Element Analysis	Ensure acceptable factor of safety for material strength and gather stress data for the proposed design.
Mechanism Ground Test	Ensure the functionality of the mechanism and actuator.
Electronics Ground Test	Confirm that all electrical components function correctly together.
Software Unit Tests	Rigorously prove software reliability in an isolated manner.
Software Simulation Test	Examine the response of the entire software system to simulated flight data. Test with noisy data to examine response of data filtration algorithms.
Ensemble Ground Test	Examine the behavior of the entire system to simulated sensor data. Gain insight into proper control parameters.
Full Scale Test	Verify apogee decrease and stable flight in a full scale launch. Plan to launch a control flight without system active followed by a flight with the system active to quantify difference in performance. This will also ensure drag tab extension and the validity of sensor data.

5.5 Air Frame Design Elements

All airframe components will be designed to transfer propulsion loads and withstand in-flight forces with minimum safety factors of 1.5 to ensure amble strength while minimizing weight.

Final material and shape design for each component will be determined through trade studies with strength and drag reduction as major design drivers.

5.5.1 Body Tube Design

The launch vehicle body tubes will be designed to withstand in-flight aerodynamic forces, transfer thrust loads throughout the vehicle, and protect the internal systems. The proposed launch vehicle will have a variable diameter with a 6-inch main diameter and a 7.5-inch payload bay. The materials will be chosen based on durability, strength, RF transparency, and weight. Composite materials such as fiberglass and carbon fiber will be utilized due to their high strength-to-weight ratio.

5.5.2 Nose Cone Design and Dimensions

The nosecone will be designed to minimize drag while protecting the payload bay from aerodynamic forces during flight. The base diameter will be 7.5 inches to interface with the payload bay. It will have a tangential ogive geometry with a length of 28 inches. In addition, it will have a 5.5 in. shoulder to provide structural support in flight. The nosecone will be commercially purchased and made from fiberglass.

5.5.3 Fin Design and Dimensions

The fins, designed to increase launch vehicle stability, will be made from a durable composite material such as carbon-fiber or fiberglass. The vehicle will have four fins, spaced out radially around the fin can for maximum stability while maintaining a symmetric pattern for ease of assembly. The fin shape will be swept rectangular, and the dimensions are outlined in Table 14. Additionally, the fins will be sanded such that their cross section resembles an airfoil for maximum aerodynamic efficiency. With this fin set installed, the vehicle reached a static stability margin of 2.7 calibers, above the required 2 calibers at launch rail exit.

Table 14: Fin Dimensions

Fin characteristic	Dimension
Root chord	7 in.
Tip chord	7 in.
Height	6.5 in.
Sweep angle	25°
Thickness	0.125 in.

5.6 Integration

Each vehicle section will be joined with couplers extending 6 inches into the adjacent body tubes, satisfying the requirement of one full body tube diameter of coupler at in-flight separation points. The nosecone will integrate with the payload bay via a shoulder on the nosecone. The payload bay will be fixed to the transition section which will include 6 inches of coupler to integrate with the recovery bay. The recovery bay will then have a fixed coupler at the aft end in order to integrate with the fin can. Finally, the boattail will be a permanently-fixed feature of the fin can.

The transition section assembly will feature a coupler fixed with centering rings to the aft end of the payload bay. This coupler will extend out such that it is able to integrate with the fore end of the recovery bay. A non-structural, 3D-printed transition fairing will be incorporated at the aft end of the payload bay to provide a streamlined transition from the 7.5-inch diameter to the 6-inch diameter.

The fin can assembly will consist of a body tube, an inner motor mount tube, centering rings, a boattail, and the four fins. The motor mount will be fixed to the aft end of the body tube with centering rings, and the boattail will be permanently fixed to the motor mount and the body tube. Slots cut in the boattail will allow the fins to be fixed to the motor mount as well as the boattail.

In addition, bulkheads located between each subsystem will be included to provide structural rigidity, ensure proper positioning of internal components, and separate pressure zones for recovery charges.

5.7 Propulsion

OpenRocket flight simulations were used as the primary method of choosing a motor for the launch vehicle. Three main motor configurations were analyzed and are listed in Table 15. Only motors resulting in apogees above the minimum of 4000 feet were considered. The Cesaroni L2375-WT-P, the Cesaroni L1090SS-P, and the Cesaroni L1115-P were identified as preliminary candidates. All simulations were performed at highest apogee conditions to minimize the likelihood that the chosen motor overshoots the allowed apogee range.

Table 15: Comparison of Considered Motors

Motor Designation	Cesaroni L2375-WT-P	Cesaroni L1090SS-P	Cesaroni L1115-P
Predicted Apogee (ft)	5642	4752	5510
Diameter (in.)	2.95	2.95	2.95
Length (in.)	24.45	26.18	24.45
Weight (oz)	146.77	69.5	155.35
Average Thrust (lbs)	551	246	250.54
Total Impulse (lb-s)	1093.5	1082.5	1127.42
Burn Time (s)	1.9	4.4	4.5

The Cesaroni L2375-WT-P was ultimately identified as the preliminary motor target due to its ability to place the vehicle the highest in the maximum apogee condition. This will give the ACS the most potential to control the apogee. The vehicle has a thrust-to-weight ratio of over 10:1 with an average thrust of 551 pounds and an overall mass of 808 ounces fulfilling the requirement of the ratio being at least 5:1 (Table 8).

5.8 Construction Methods

Most vehicle components will be commercially purchased, and some will be fabricated by the team. The team has a number of methods available for team-fabricated parts. The team has a dedicated workshop with hand tools and simple machining operations and access to the Notre Dame Engineering Innovation Hub which provides access to other machining capabilities as well as additive manufacturing options.

Components that are commercially purchased such as the body tubes, nosecone, and boattail will be inspected for quality and measured for accuracy prior to assembly. Components with complex geometries will be 3D-printed and two-dimensional components like fins and bulkheads will be machined with CNC routers. The team also has access to a manual mill, lathe, drill press, band saw, and sanding belt for custom parts and component adjustments.

Vehicle Component will mainly be assembled using epoxy in combination with custom jigs to ensure proper alignment and placement while epoxy dries. Epoxied surfaces will be well-prepared and correct dry times and ambient conditions will be observed in order to ensure effective epoxy strength. Additional precaution will be taken to ensure epoxies used near the motor are capable of withstanding the heat produced by the motor.

Additionally, a subscale vehicle will be constructed and assembled using similar techniques.

5.9 Vehicle Testing, Simulation, and Verification

The team will utilize a variety of methods to analyze, simulate, and test the launch vehicle. Each method of numerical analysis will be verified with the corresponding method of hardware testing. These methods are summarized in Table 16.

Table 16: Analysis and Testing Methods

Analysis Method	Testing Method	Purpose
FEA	Structural testing	simulate loading from launch, landing, and recovery events
CFD	Wind tunnel testing	Verify aerodynamic properties of launch vehicle such as drag coefficient and CP location
Flight simulation software	Test launches	predict and verify flight profile characteristics such as apogee, stability, drift, and descent time

5.10 Technical Challenges and Mitigation

The most significant technical challenges facing the team in regards to vehicle design are the ability to accurately simulate and test component strength and performance. As for component structural testing, the load on the vehicle during flight will mostly be dynamic loads which the team is not able to perfectly test. The team has historically utilized FEA and static load testing and will also attempt to design dynamic loading tests. Additionally, the team is unable to properly test how fatigue and load cycles effect the structural integrity of certain parts. These challenges will be mitigated by increasing the structural safety margins for components at thought to be effected by these loading patterns.

Additionally, as the team seeks to define the aerodynamic forces of the vehicle, the team is unable to perform wind tunnel tests that can match in-flight mach and Reynold's number conditions. Therefore, coefficient of drag estimates will be based on flight simulations and CFD analysis. Additionally, the team will seek to further mitigate this challenge by comparing flight data drag coefficients to those from simulations attempting to understand the pattern between the simulated drag coefficients and those experienced in flight.

6 Technical Design: Recovery System

6.1 Recovery System Overview

The main vehicle will be recovered by a dual-deployment parachute system. A drogue parachute will deploy at apogee, and a main parachute will deploy around 600 ft AGL. The vehicle's nose will be recovered under its own parachute that will deploy at about 800 ft AGL. Parachute deployment will be controlled by two independent integration modules – one for the nose recovery and one for the main vehicle recovery. Each integrated module will contain commercially available and redundant altimeters, which will control the deployment sequence.

6.2 Mission Requirements

The NASA Requirements for the recovery system are outlined in Table 17. Additional requirements will be derived by the team before the Preliminary Design Report.

Table 17: NASA Recovery Requirements

Req. ID	Description
3.1	The full scale launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee, and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue stage descent is reasonable, as deemed by the RSO.
3.1.1	The main parachute shall be deployed no lower than 500 feet.
3.1.2	The apogee event may contain a delay of no more than 2 seconds.
3.1.3	Motor ejection is not a permissible form of primary or secondary deployment.
3.2	Each team will perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full scale vehicles.
3.3	Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing.
3.4	The recovery system will contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.

Table 17: NASA Recovery Requirements

Req. ID	Description
3.5	Each altimeter will have a dedicated power supply, and all recovery electronics will be powered by commercially available batteries.
3.6	Each altimeter will 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.
3.7	Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).
3.8	The recovery system electrical circuits will be completely independent of any payload electrical circuits.
3.9	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.
3.10	The recovery area will be limited to a 2,500 ft. radius from the launch pads.
3.11	Descent time of the launch vehicle will be limited to 90 seconds (apogee to touch down).
3.12	An electronic GPS tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.
3.12.1	Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic GPS tracking device.
3.12.2	The electronic GPS tracking device(s) will be fully functional during the official competition launch.
3.13	The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).
3.13.1	The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.
3.13.2	The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.
3.13.3	The recovery system electronics will 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.
3.13.4	The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.

6.3 Structural Design

The recovery harnesses will be secured to the bulkheads via quicklinks and eyebolts. The two recovery bulkheads will also serve as the main structural components for the avionics bay and will be screwed into the airframe. The other bulkheads will be components of the ACS and payload systems. The method of securing these bulkheads and their material will be determined late rin the design process. The material of the recovery bulkheads will be the subject of trade studies later in the design process. A secondary recovery system, containing the electronics that control nose jettison, will be located in the fore of the payload bay. The recovery harness for this secondary system will also be attached to the airframe via a bulkhead on one side and will be epoxied into the nose cone on the other.

6.4 Separation Method

Black powder charges will control all of the separation events. The ignition of these charges will be controlled by a system of independent, and redundant altimeters. The first charge will be triggered by apogee for the drogue, and by specific altitude requirements for the main and nose systems. Each successive charge will be delayed by one second, meaning that the apogee event will not occur more than 2 seconds after apogee (Req. 3.1.2). Motor ejection will not be used as part of the recovery process (Req. 3.1.3). Each of the parachute compartments will be secured using removable shear pins (Req. 3.9).

6.5 Electrical Design

Each of the altimeters will have its own dedicated mechanical arming switch. These switches will be keyed rotary switches, which will prevent the switches from being accidentally armed or disarmed by in-flight forces. These components will be integrated into airframe in the integration module which will also contain batteries, altimeter shielding, and all of the required wiring. The charge wells will be secured to the outward faces of the integration module.

6.6 Recovery System Testing, Simulation, and Verification

The planned recovery system tests are listed in Table 18.

Table 18: Recovery Test Plan

Test Method	Purpose
Ground Ejection Test	Verify that the ejection charges are properly sized to completely separate the vehicle sections.
Finite Element Analysis	Ensure acceptable factor of safety for material strength and gather stress data for the recovery bulkheads.
Altimeter Test	Ensure the functionality and sufficient battery life of the altimeters prior to flight using simulated flight data.
Full Scale Test	Verify recovery system adequately slows descent of launch vehicle, and that vehicle lands meets required drift radius and descent time.
Electronic Tracking Device Test	Ensure that electronic tracking device will reliably transmit vehicle location data during flight.
Failed Deployment Charge Safe Test	Ensure that undetonated ejection charge can be safely removed from the vehicle.

6.7 Technical Challenges and Mitigation

The main technical challenge of the recovery system is the simulations and analysis of the system. In the past, the team has used overly conservative models for the parachute opening time, and therefore the loading on recovery hardware. To mitigate this, more realistic models will be integrated into a flight simulator code.

7 Technical Design: Launch Vehicle Identification System

The scoring payload will be an unmanned aircraft system (UAS) consisting of an unmanned aerial vehicle (UAV) and a ground station. The UAV will autonomously locate the launch vehicle's grid position on an aerial image of the launch site without the use of a global positioning system (GPS) and transmit the information to a ground station. The payload will be secured inside the rocket during flight and will be deployed after RSO confirmation as outlined in Requirement 4.3.4. The following subsections will discuss the systems involved in the UAS and the foreseen technical challenges and mitigation techniques.

7.1 System Overview

The Table 19 lists the system components for the payload and a brief description. The sections to follow will provide more details.

Table 19: Payload System Overview

System	Description
Retention	Holding and securing the payload in the launch vehicle until deployment.
Deployment	Correctly orient the UAV once the launch vehicle has successfully recovered.
Orientation	Deploy the UAV from the launch vehicle after orientation. Following deployment, the UAV will begin target detection.
Unmanned Aerial Vehicle	The UAV will contain all the systems such as electronic, navigation, and target detection to locate the launch vehicle.
Target Detection	Accurately locate the grid location of the launch vehicle once it has safely landed in the launch field.
Grid Location Transmission	Wirelessly transmit the identified launch vehicle's numbered grid box.

7.2 Mission Requirements

Table 20 delineates the numerous requirements for the Launch Vehicle Identification System (LVIS) as provided by the NASA 2020-2021 Handbook. In the following weeks, team requirements will be derived to further develop the LVIS.

Table 20: NASA Payload Requirements

Req. ID	Description
4.1	College/University Division – Teams shall design a payload capable of autonomously locating the launch vehicle upon landing by identifying the launch vehicle's grid position on an aerial image of the launch site without the use of a global positioning system (GPS). 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. An additional experiment (limit of 1) is allowed, and may be flown, but will not contribute to scoring. If the team chooses to fly an additional experiment, they will provide the appropriate documentation in all design reports so the experiment may be reviewed for flight safety.
4.2	Launch Vehicle Landing Zone Mission Requirements
4.2.1	The dimensions of the gridded launch field shall not extend beyond 2,500 feet in any direction; i.e., the dimensions of your gridded launch field shall not exceed 5,000 feet by 5,000 feet.
4.2.1.1	Your launch vehicle and any jettisoned components must land within the external borders of the launch field.
4.2.2	A legible gridded image with a scale shall be provided to the NASA management panel for approval at the CDR milestone.
4.2.2.1	The dimensions of each grid box shall not exceed 250 feet by 250 feet.
4.2.2.2	The entire launch field, not to exceed 5,000 feet by 5,000 feet, shall be gridded.
4.2.2.3	Each grid box shall be square in shape.
4.2.2.4	Each grid box shall be equal in size, it is permissible for grid boxes occurring on the perimeter of your launch field to fall outside the dimensions of the launch field. Do not alter the shape of a grid box to fit the dimension or shape of your launch field.
4.2.2.5	Each grid box shall be numbered
4.2.2.6	The identified launch vehicle's grid box, upon landing, will be transmitted to your team's ground station.
4.2.3	GPS shall not be used to aid in any part of the payload mission.
4.2.3.1	GPS coordinates of the launch vehicles landing location shall be known and used solely for the purpose of verification of payload functionality and mission success.
4.2.3.2	GPS verification data shall be included in your team's PLAR.
4.2.4	The gridded image shall be of high quality, as deemed by the NASA management team, that comes from an aerial photograph or satellite image of your launch day launch field.

Table 20: NASA Payload Requirements

Req. ID	Description
4.2.4.1	The location of your launch pad shall be depicted on your image and confirmed by either the NASA management panel for those flying in Huntsville or your local club's RSO. (GPS coordinates are allowed for determining your launch pad location).
4.2.5	No external hardware or software is permitted outside the team's prep area or the launch vehicle itself prior to launch.
4.3	General Payload Requirements
4.3.1	Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics will not be permitted for any surface operations.
4.3.2	Teams shall abide by all FAA and NAR rules and regulations.
4.3.3	Any experiment element that is jettisoned during the recovery phase will receive real-time RSO permission prior to initiating the jettison event, unless exempted from the requirement at the CDR milestone by NASA.
4.3.4	Unmanned aircraft system (UAS) payloads, if designed to be deployed during descent, will be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAS.
4.3.5	Teams flying UASs will abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112-95 Section 336; see https://www.faa.gov/uas/faqs).
4.3.6	Any UAS weighing more than .55 lbs. will be registered with the FAA and the registration number marked on the vehicle.

7.3 Mechanical Design

The team is considering a UAS consisting of a UAV to accomplish the launch vehicle detection mission. The vehicle will be powered with four propellers and will deploy from the launch vehicle during descent. The vehicle will be tethered to the launch vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAV. Once deployed, the UAV will identify the grid location of the launch vehicle through an image detection system, transmit the grid location to the ground station, and safely land. The disadvantage of this design is that the navigation and flight algorithms are complex and the UAV weight is restricted. Furthermore, any UAV weighing more than .55 lbs. must be registered with the FAA and the registration number marked on the vehicle. The advantages of this system is that the UAV is capable of producing aerial images to locate the launch vehicle and is able to move without obstruction in the air.

7.4 Electrical Design

The payload electrical system will be responsible for the control, detection, communication, and power mechanisms. Trade studies will be conducted to determine the specific components.

7.4.1 Deployment

A jettisoning event is being considered for the UAV payload. It will be deployed from the launch vehicle through a nose cone ejection with the use of black powder charges connected to an ematch and altimeter. Furthermore, the system will be remotely activated from the ground once given the approval from the RSO and will be tethered to the rocket until cleared by the RSO.

7.4.2 Orientation

A parachute will be used to orient the payload after deployment. The parachute will ensure that the payload descends smoothly in the proper upright orientation. Furthermore, the UAV will orient through the use of a flight controller or a microprocessor.

7.4.3 UAV

The UAV will be powered by brushless motors due to their high efficiency, high torque to weight ratio, and high speed controllability. They will be attached to an electronic speed controller to regulate their speed. The UAV will be powered by a lithium polymer battery due to its light weight, robustness, and flexibility. Moreover, the UAV will include a flight controller to ensure smooth operation with possible models like the Pixhawk line or a small microcontroller that integrates the various sensors, communication systems, and navigation systems. Trade studies will be conducted to determine the method and the model.

7.4.4 Target Detection

An attached UAV camera will be used for target detection. Possible camera selections include Raspberry Pi model cameras. The camera will feed images to the on-board processor such as a Raspberry Pi. Raspberry Pi's have the ability to use libraries such as OpenCV, so trade studies will be conducted to determine the exact model. Moreover, the team is considering several detection methods and sensors such as infrared, a dead reckoning system without GPS, and radio detection finding to locate the launch vehicle.

7.4.5 Grid Transmission

Data transmission will occur through an RF transceiver module such as an Adafruit RFM connected to the UAV CPU such as a Raspberry Pi. A trade study will be conducted to determine the exact module and antenna for communication. The UAV RF module will communicate with the ground station computer through a matching transceiver module.

7.5 System Components

7.5.1 Retention, Orientation, and Deployment

Retention of the UAV will be achieved through the use of hairpin cotter pins that are inserted through the base of the UAV. The pins are tied with string to a bottom bulkhead, so when the UAV is jettisoned from the rocket through the nose cone, the strings are pulled taut and out releasing the UAV. After a black powder charge, the nose cone and the payload will eject releasing the UAV from the retention system. The UAV will deploy with its own parachute aiding orientation.

7.5.2 UAV Flight, Target Detection, Grid Location Transmission

Once deployed, the UAV will descend under its own parachute. The parachute will be released and commence the autonomous target detection sequence at a specified altitude. The team is considering two separate processing centers for flight and target detection. The UAV will transmit the grid where the launch vehicle resides to a host computer in the ground station through a RF module after determining the specific target method through trade studies. The UAV will safely land within the launch zone and power off when the mission is completed.

7.6 Technical Challenges and Mitigation

Table 21 matches the challenge with a mitigation technique in light of a possible technical challenge.

Table 21: Payload Technical Challenges and Mitigations

Challenge	Solution
Size and Weight	Communicate with the vehicle design and systems team to ensure appropriate dimensions.
Retention	Design a mechanism that prevents any movement until intended inside the launch vehicle and conduct thorough analyses and testing.
Deployment	Design a mechanism that accurately releases the UAV and the parachute to ensure no tangling. Conduct thorough analyses and testing to verify.
Flight	Use a separate controller to efficiently operate the UAV and provide proper power to motors.
Target Detection	Use a separate controller to operate the target detection system and algorithms. Ensure proper mounting of the camera to provide an unobstructed view of the launch field. Conduct in-house tests of target detection.
Wireless Transmission	Ensure specified antenna, transmission, and receiver systems transmit to a minimum of 2 km.

8 STEM Engagement

STEM Engagement continues to be a focal point of the team's mission, goals, and resources. The team will be sponsoring a combination of both in-person and virtual STEM Engagement events with the local community. Great attention, precaution, and planning is being devoted to the challenge of the pandemic to keep our attendees and volunteers safe as well as comply with the health guidelines of the partner organizations and the University.

The team is implementing a new approach to events this year. Some of the events will now be recurring series with partner schools and organizations. The intention of these events is to focus on sustainable STEM engagement and relationship building between the students and NDRT volunteers. A series of eight weekly one-hour events is planned with the Robinson Community Learning Center (RCLC) for the fall semester, with each event having a different STEM topic and activity. An additional purpose of the series event is to respond to the students' interests, questions, and learning style as the series approaches its later events. For the spring semester, NDRT will run another series with RCLC focusing on building and launching model rocket kits.

Additionally, the team will continue the existing partnerships with the Society of Women Engineers, Girl Scouts of Northern Michiana, the RCLC, the Children's Dispensary, STARBASE, and the Boys and Girls Club of St. Joseph County. The team is currently in contact with more organizations in the South Bend area to forge more partnerships, including 100 Black Men of Greater South Bend, the South Bend Community School Corporation, and the Saint Joseph County Public Libraries.

The goal for this upcoming school year is to reach at least 700 students. The team are focusing on the quality of our events to make them as meaningful, fun, and substantive as possible. There will be an educational outreach squad on the team, akin to the previous school year, where NDRT members can assist with the before/after planning of events to help serve more students. The focus of this year's outreach will be providing hands-on interest and engagement in rocketry, space, and related STEM topics while building sustainable, authentic relationships with the team's community partners and students.

8.1 Mission Requirements

Per NASA Requirements as outlined in the Student Launch Handbook, events will reach a wide variety students. Each event will have its content optimized for a certain age group, or range, of students. These events will be interactive and hands-on while in alignment with safety protocols. The team recognizes that the pandemic has greatly impacted K-12 schooling and will seek the opinion of partner organizations and campus professionals on the best and safest approach, development, and implementation of events. The content of the events will center on rocketry while exploring and expanding to other general aeronautic, aviation, and STEM topics.

8.2 Programmatic Lesson Plans

The following plans will be implemented throughout the year at various events to engage with students of different ages and experience levels:

- Paper Straw Rockets: This event is optimized for younger students and has been run by the team before. Students will learn basic physics and motion behind launching a rocket. Students will design the shape of a rocket from paper and customize it as they please. The paper is wrapped around a straw so that one of the ends of the straw is covered. The rocket attached to the straw will slide over a slightly smaller straw. The student will blow on this straw, launching the rocket. Following the activity, the students can share their designs to the full group. A discussion will be had on what makes certain rocket shapes fly farther.

- Engineering Design Space Tours: The team will create tours of Notre Dame's local engineering spaces for outreach event attendees. These tours will not require additional safety measures of precautions. These tours will focus on showing the interesting engineering items and applications present in the buildings in a tailored way to each age group. For example, the students can see a clean room and the team can discuss why the room requires special features to operate. Additionally, students will be shown design machinery and tools (that are off) to share how the team builds the rockets. These tours will be interactive, question-based, and will respond to the questions and curiosities of the attendees.

- Rocketry Jeopardy: This event can be optimized for various age groups of students and has been run by the team before. This activity showcases rocketry basics in a fun game-style setting. The game is rocketry-focused trivia in the form of Jeopardy, and it can be run as a virtual or in-person event. A slide deck with the game will be run by the NDRT moderator and students will be able to participate individually or in teams depending on the preferences of our partner organizations.

- Coding 101: This event can be optimized for various age groups of students. Students will complete a lesson from Code.org corresponding to their prior knowledge with coding. Following, they will breakout into smaller groups where they will complete a short coding challenge with NDRT members. They will have an opportunity to share and demonstrate to the whole group if they would like. NDRT members will ask and answer questions, as well as provide scaffolding if needed. This activity, while still in development by the team, offers the opportunity to share and showcase coding with our students and attendees.

- Paper Mars Helicopter: This event can be optimized for various age groups of students and has been run by the team before. This activity comes directly from JPL and discusses the concepts of forces, flight, drag, and lift. Students cut and fold a piece of paper in a given pattern to provide for two "helicopter blades". Following, the helicopter is dropped from a height of around two meters. Students observe its motion for varying distances dropped. After drawing conclusions, NDRT facilitators introduce the idea of drag and compare the helicopter to dropping a piece of paper. Students will make changes to their helicopter and observe how its motion is impacted. This project is inspired in part by the Mars Ingenuity Helicopter, and it is a fun way to incorporate the engineering design process into educational outreach events.

- Girl Scout Design Challenge: The team plans to partner with the Society of Women Engineers (SWE) at Notre Dame to plan a design challenge for local Girl Scouts in the Spring 2022 semester. The event is still in development. The event would welcome middle and high school age Scouts to Notre Dame to participate in a multiple-hour long design challenge. The event would coincide with SWE's yearly Girl Scout Day. This design challenge will incorporate the Engineering Design Process and allow the Scouts to develop a hands-on solution of their creation. SWE and NDRT members will be present at the event to support its implementation. Additionally, Scouts will present their designs and conclusions to a board of SWE and NDRT members. The design prompt has not been decided yet. The purpose of this event is to support, amplify, and celebrate women in STEM through sharing the STEM experiences and interests of the women in attendance (both volunteers and attendees).

8.3 RCLC/NDRT Student Launch Initiative

NDRT is excited and thankful to unveil a new initiative for the coming school year. We have partnered with the RCLC to create our own Student Launch Initiative that focuses on building model rockets with a small group of high school students. These students will participate in a weekly series of outreach events with NDRT, learning about the construction and flight of rockets. These events will be tailored to the students' interests as they progress. Additionally, they will be built around the engineering design process, where students will build their own model rockets from a kit. These rockets will be theirs to customize as they would like given safety constraints set by the team and the RCLC. These students will be invited to NDRT's local demonstration launch, where they will also launch their rockets.

This initiative has multiple purposes. It will support under-resourced students. All supplies and travel fees will be paid for by a grant received by one of our NDRT members, allowing all students to participate while supporting the RCLC financially. This experience will also provide real, substantial hands-on engineering design experience for the students to support their discernment of STEM careers. The initiative will begin at the start of the spring semester and is still currently under development with input from NDRT and RCLC leadership.

8.4 Lesson Plan Assessment

In continuity with previous years of STEM engagement, a feedback form will be sent out to partner organization leaders, attendees, and NDRT volunteers after our events. This feedback will be reviewed and applied to improve future programming to yield higher engagement, efficiency, and ease in future events. Additionally, this feedback will allow NDRT volunteers to improve series events so that they cater to the interests and curiosities of the respective students. The Educational Outreach Squad will likely implement additional leadership roles, such as Feedback Focal, Content Focal, and Supplies Focal, to aid in the facilitation of events. Specifically, the Feedback Focal will be responsible for ensuring feedback is taken and received at outreach events as well as provided to the squad. The Supplies Focal will be in charge of buying supplies, keeping a current inventory of supplies, and ensuring supplies are ready prior to outreach events. The Content Focal will review current educational outreach content and recommend strategies for its improvement. Any positions that are not filled by squad members will be run by the Educational Outreach Lead. The whole squad will likely meet biweekly, focusing on equitable and inclusive lesson planning, logistics, and reviewing feedback. The Educational Outreach Lead will send out weekly notices to the full team concerning what outreach events are coming up and how many students the team has served. The squad, and full team, looks forward to a great year of educational outreach events and activities.

9 Project Plan

9.1 Schedule Overview

The Notre Dame Rocketry Team uses Gantt charts to set deadlines, track progress, and determine both short- and long-term priorities. The major milestones can be viewed in Figure 4. Figures 5 through 10 depict the Gantt charts for the systems and safety teams, as well as the four design teams.

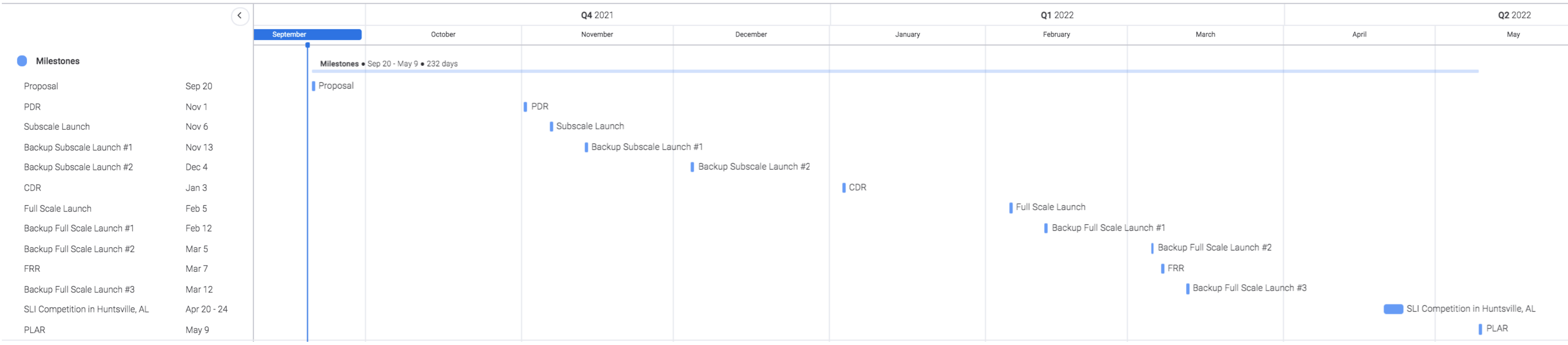

Figure 4: Gantt chart schedule for mission milestones.

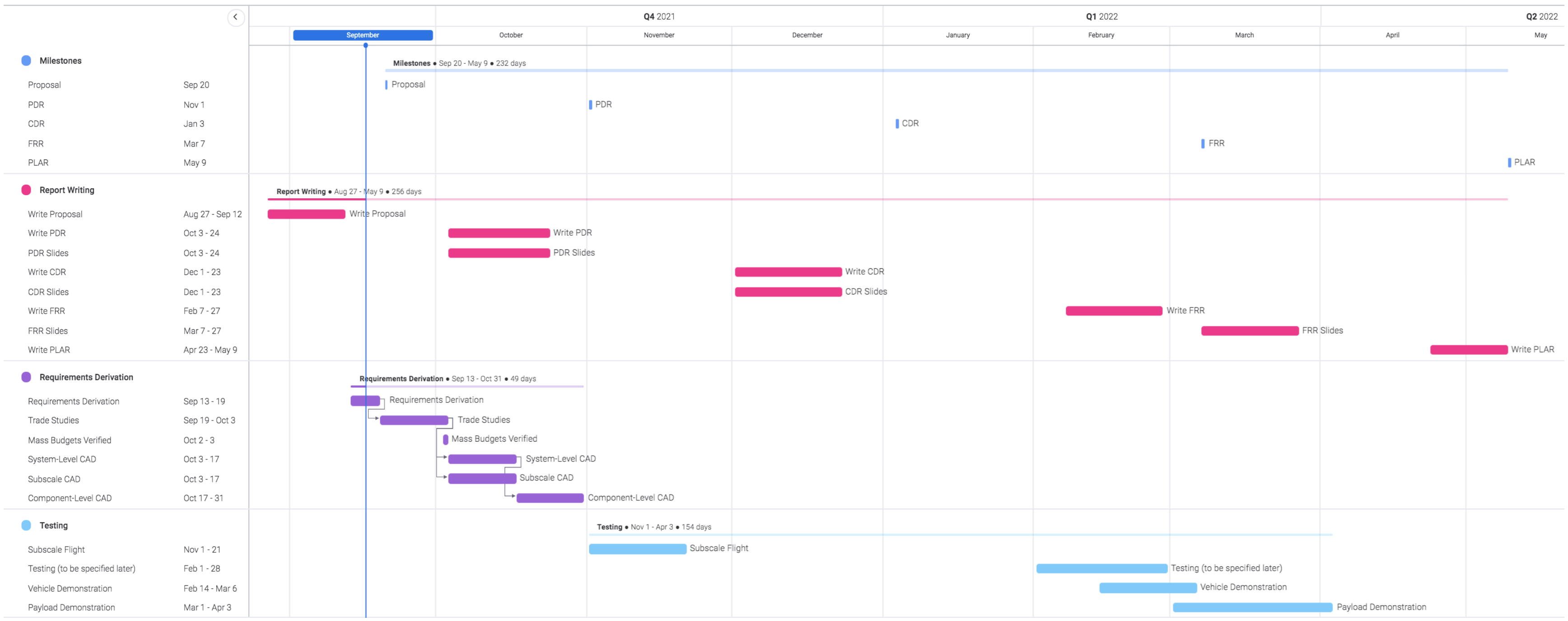

Figure 5: Gantt chart schedule for the systems team.

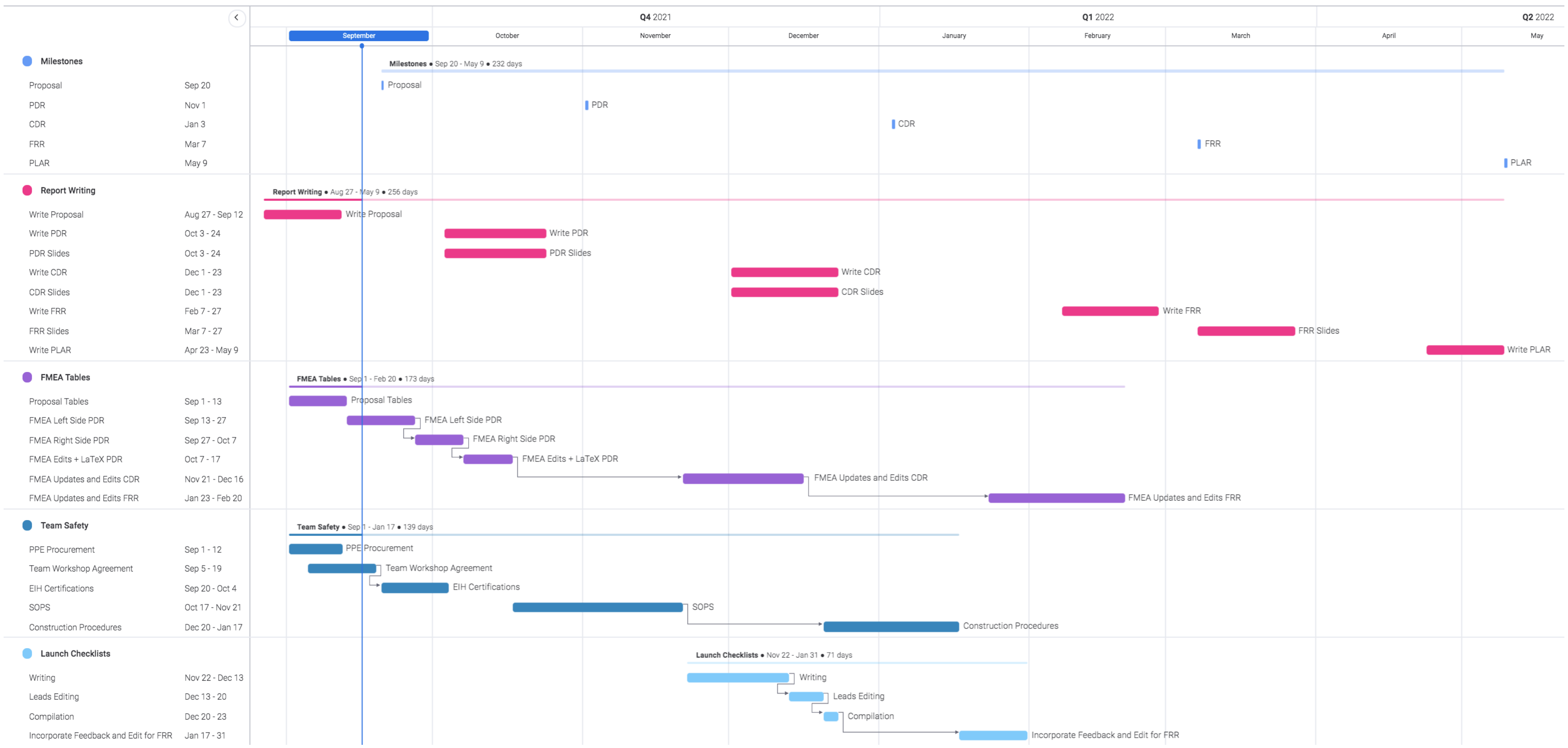

Figure 6: Gantt chart schedule for the safety team.

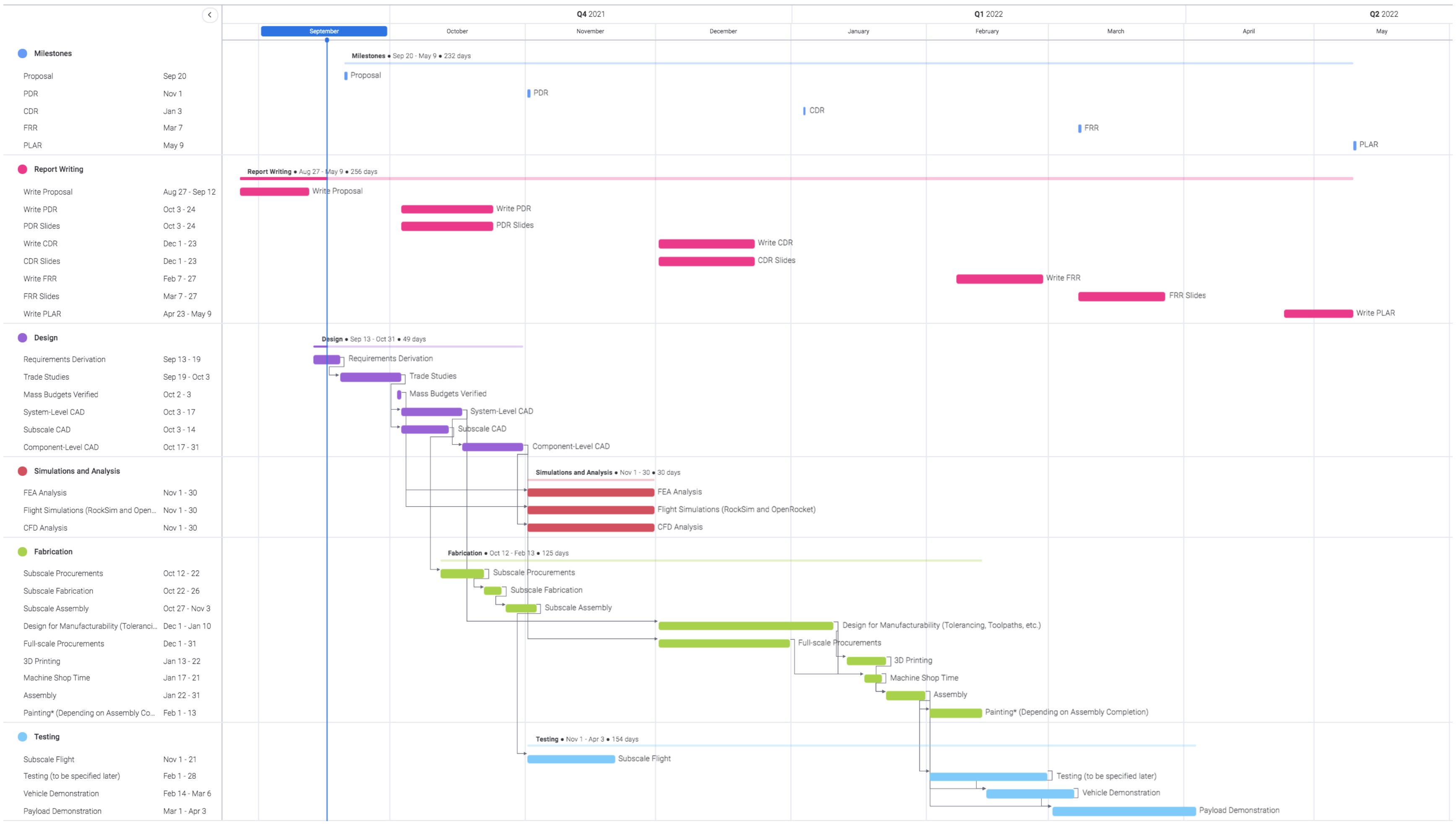

Figure 7: Gantt chart schedule for launch vehicle development.

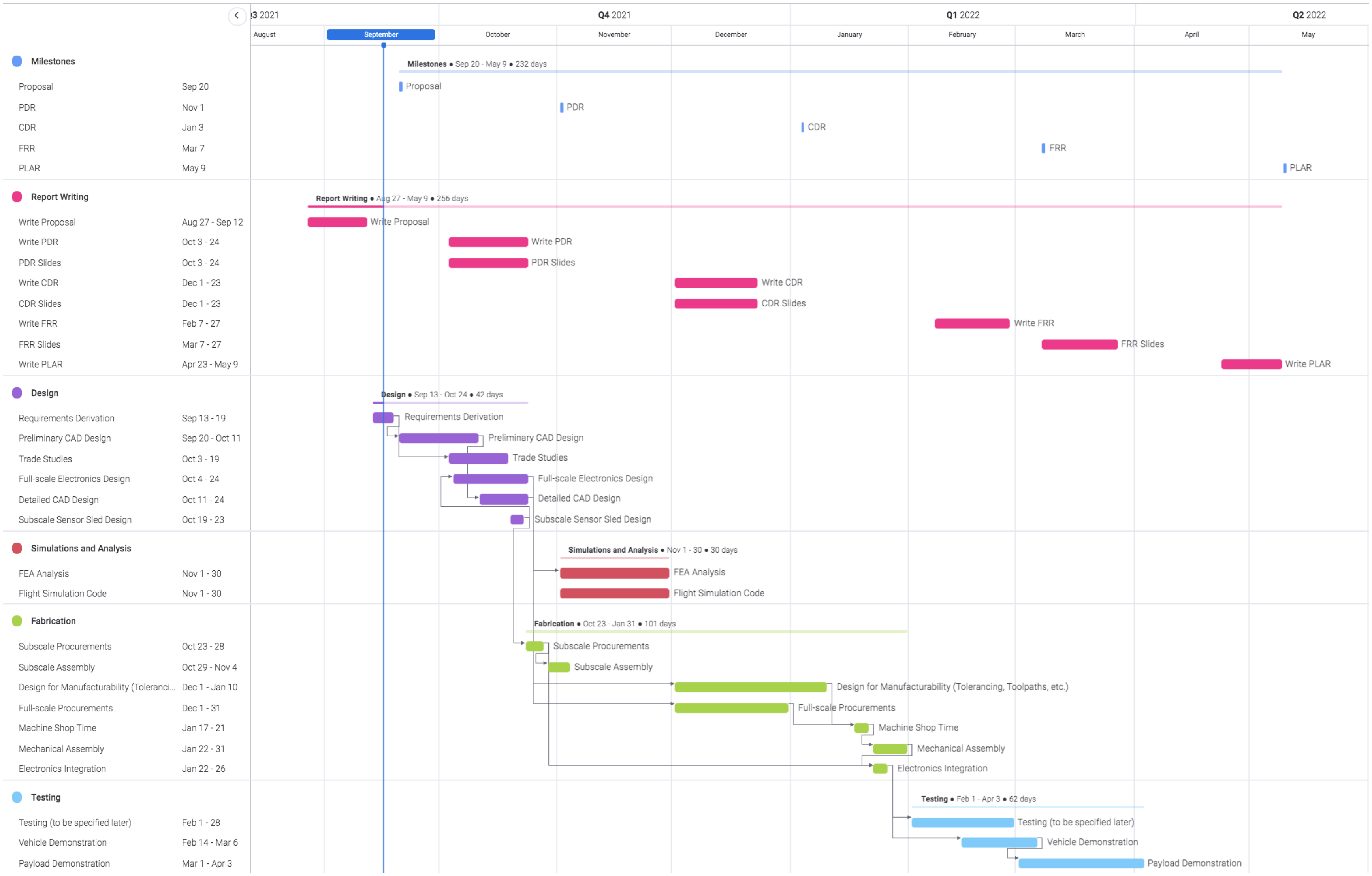

Figure 8: Gantt chart schedule for recovery system development.

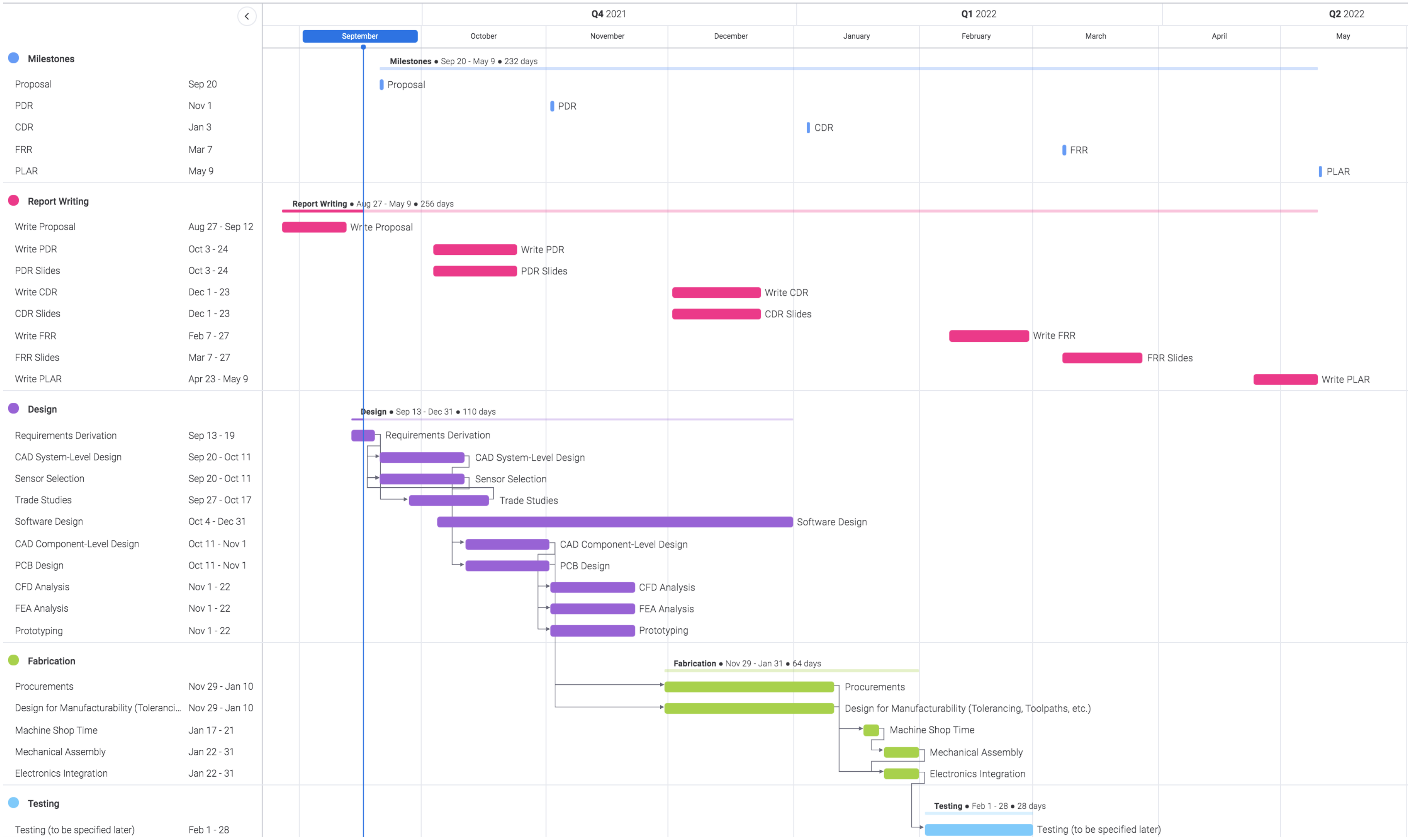

Figure 9: Gantt chart schedule for apogee control system (ACS) development.

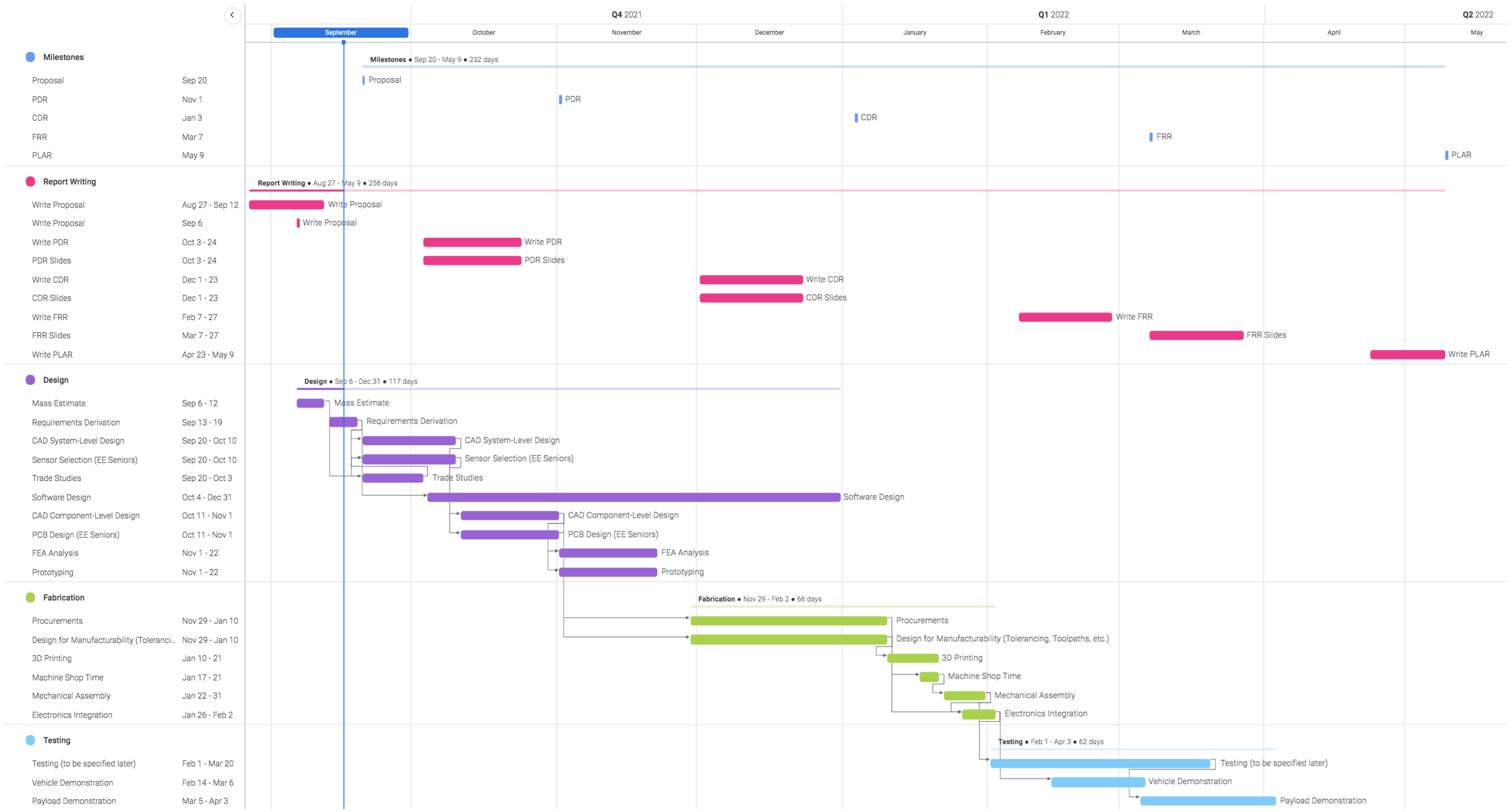

Figure 10: Gantt chart schedule for Launch Vehicle Identification System (LVIS) development.

9.2 Budget

The team has determined a budget based off of previous years expenses, leftover raw materials, and re-usable electronics and hardware. The goal of the budget this year is to operate efficiently and effectively while limiting wasteful expenses. Aspects of this year's purchasing strategy will be responsible sourcing, reusing functional components, and using cost as an important factor in design decisions. The budget for this year's project can be seen in Table 22 based on these criteria.

Table 22: NDRT 2021-22 Budget

Allocation	Amount
Vehicle Design	$4,000
Apogee Control System	$1,200
Recovery Subsystem	$1,000
Planetary Landing System	$1,800
Vehicle Subtotal	**$8,000**
Safety	$300
Educational Outreach	$200
Competition Travel	$10,000
Miscellaneous	$500
Total	**$19,000**
Revenue	$26,430
Remaining Funds	$7,430

9.3 Sustainability

The Notre Dame Rocketry Team includes students from the tri-campus community, consisting of the University of Notre Dame, St. Mary's College and Holy Cross College. Students from all three universities are represented on the team. Additionally, the team interfaces with the greater South Bend area, industry leaders, and Notre Dame alumni. Creating, developing, and maintaining mutually supportive relationships with all these groups is important for the short- and long-term growth of the team, and is a priority in 2021-22. Plans for engaging with specific groups are detailed in the following sections.

9.3.1 Recruitment

The Notre Dame Rocketry Team actively recruits students from all schools of the University of Notre Dame, St. Mary's College, and Holy Cross College. A multidisciplinary team of individuals with diverse backgrounds allows for the team to access an exceptional number of ideas, designs, and processes. Recruitment efforts take place in the form of the Notre Dame Activities Fair, classroom visits, email blasts, and social media advertisements. the following list describes the team media presence:

- **Social Media** - The team regularly engages with followers on social media platforms including Facebook, Instagram, Twitter, and LinkedIn. These social media sites have been used to spread the word about meetings, team activities, and accomplishments from past years.
- **Website** - The team has continued to use a website that displays information about the team organization, and an overview of past years' designs. This website also includes options to contact the team or sign up for the team's email listserv as a university student. To view the NDRT website click here.
- **Flyers** - The team has developed several flyers with pertinent information about team meetings, listserv, and opportunities. These flyers have been sent out to classes in the various departments, as well as to prospective corporate sponsors.
- **Videos** - The team has used videos on the website, social media, and during education outreach events. A team overview video for 2021-22 is viewable at: here.

9.3.2 Community Partnerships

NDRT is committed to community partnerships and maintaining relationships with local organizations. Most notably, NDRT continues to have a strong relationship with Michiana Rocketry, which organizes launches and offers guidance on aspects such as design and safety. Additionally, NDRT's mentor, Dave Brunsting, is the present Secretary of Michiana Rocketry.

9.3.3 Corporate Partnerships

NDRT focuses heavily on corporate partnerships and sponsorships throughout the year. The team is fully funded by corporate sponsorships and team fundraising efforts. The team continues to partner with Boeing in their mentorship program. The team leads are able to connect with Boeing employees individually to discuss designs and processes. Additionally, Boeing mentors provide technical guidance and suggestions for reports and presentations. The team is also focusing on expanding corporate partnerships for fundraising efforts, as well as professional development for team members career aspirations in the space industry.

9.3.4 Educational Outreach

NDRT is committed to an in-person, hands-on outreach environment in 2021-22. STEM outreach is organized by the Educational Outreach Lead, and partners with a number of educational, extracurricular, and other groups in the greater South Bend area. Ideally, the team will greatly exceed the minimum required number of participants, and develop mentorship relationship with students in the area. See a more detailed plan of the STEM Outreach outlook for 2021-22 in Section 8.

10 Conclusion

NDRT is returning to NASA Student Launch Initiative in 2021-22 to build off of a successful mission in 2020-21. By meeting the following goals, NDRT hopes to exceed the minimum technical requirements of the competition, provide opportunities for experiential learning and professional development, and positively impact our community through STEM education and strategic partnerships.

- To promote knowledge sharing on the team and empowering all members to gain critical skills that will supplement their undergraduate education before entering industry or furthering their education.
- To ensure sophisticated documentation and a growth mindset that will drive the team to improve in future years.
- To provide STEM educational engagement opportunities for 1,000+ students in the community to show what is possible with education and passion.
- To design two, fully functional payloads that will integrate into the launch vehicle, meet all mission requirements, and provide technical challenges for the team to solve.
- To partner with sponsors and organizations that will lead to the professional and educational development of team members, aiding in career and personal aspirations.

A Safety

Table 23: NASA Safety Requirements

Hazard	Cause	Outcome	Probability	Severity	Risk Level	Mitigation
Power tooling and machining	Improper use of equipment and lack of training	Injury to personnel and damage to equipment or nearby objects	3	2	6	1. EIH Level 1 Certification are required to utilize equipment in the workshop. 2. Proper PPE will be enforced to be worn at all times in the workshop 3. No person is allowed to work alone in the workshop 4. Standard Operating Procedures for the workshop equipment will be written
Use of chemicals or powders	Inhalation of powders or fumes, or chemicals are splashed on personnel	Injury to personnel	3	2	6	1. The SDS document, which includes detailed information on all applicable chemicals, will be physically available to all members in the workshop, and the document is avaliable to all on the NDRT website 2. Proper PPE must be worn by all personnel 3. All containers in the workshop will be properly marked, and all hazards will be labeled

Motor Failure	Motor improperly installed, motor's chemical composition is faulty, ignition issues	Potential injury or death due to motor explosion	4	1	4	1. All motors will be inspected by our Launch Manager, Dave Brunstring, who possess a Level 3 TRA Certification. 2. All team members will be briefed on launch safety before launch day. 3. A launch quiz will be administered before launch day, and any member who fails to score an 100% will be unable to attend the launch. 4. All personnel will conduct launches from a safe distance away, as determined by the NAR and and the Range Safety Officer.
Motor Separation	Motor is improperly constrained in the launch vehicle	Motor destroyed the launch vesicle, and damage is potentially done to nearby personnel	4	1	4	1.The motor mount and retainment system are to be commercially bought from a reputable source 2. Commercially bought motor mount and retainment system are rated to withstand flight forced
Recovery Failure	Altimeter Failure, and/or the parachute fails to deploy	Launch vehicle crashes into the ground at terminal velocity, and the launch vehicle is destroyed upon impact	4	2	8	1. Ground testing of recovery systems will occur with the Launch Manager prior to launch 2. All altimeters and deployment energetics will be redundant

Premature Recovery Deployment	The altimeter data reads incorrect data	Complete destruction of the launch vehicle	4	2	8	1. All altimeters will contain safety checks in the software to ensure proper data is read 2. Prior to the launch, all altimeters will be turned off and shunt pins will seperate the connections so no potential data could theoretically interfere
Parachute Failure	Parachute fails to unfold, or it tears mid-flight	Launch vehicle crashes into the ground at terminal velocity, and the launch vehicle is destroyed upon impact	4	2	8	1. Parachutes will be inspected for signs of tears prior to launch 2. Parachute folding procedures will be written, approved by the Safety Officer and Recovery Design Leader, and implemented into launch procedures. Launch procedures will also be accessible to all team members
LiPo Battery Damage	Impact to LiPo battery or overuse	LiPo battery explodes, causing injury or death to personnel and/or damage to launch vehicle	4	1	4	1. All LiPo batteries will be stored in a fireproof container when not in use 2. All batteries shall be inspected prior to use 3. Any batteries suspected to be faulty are to be disposed of properly
Indoor/Outdoor Fire	Motor burns or electrical component failure occurs	Injury and/or death to personnel, or damage to launch vehicle	4	2	8	1. Fire extinguishers will are available in the workshop, and at least one will be brought to all launches and tests 2. Launch stands will be used to prevent the grass from catching on fire 3. All wired connections in the launch vehicle will be assessed prior to launch

Battery Waste	Improper disposal of old and/or faulty batteries	Battery waste is harmful to the enviorment	3	1	3	All batteries will be disposed of in compliance with all University, local, state, and federal standards. 2. Procedures for battery disposal will be located in the Safety Handbook
Low Cloud Cover	Weather conditions on the day of the launch	Inability to launch due to inability to locate launch vehicle mid-flight	3	2	6	Multiple backup launch dates will be scheduled in case weather conditions inhibit our ability to launch. Backup launch dates will ensure the project stays on track with the project schedule and deliverable dates

Table 24: NAR Compliance Tables

Topic	Description	Team Compliance
Certification	I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.	The Team Mentor, Dave Brunsting, is Level 3 certified, and the team will only use a maximum of L class motors.
Materials	I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.	An emphasis on lightweight materials will be undertaken by all design squads, especially the vehicles squad. At the same time, any material that does not meet the lightweight requirements will simply not be used. If uncertainly arises, the team will consult the NASA SLI officials.
Motors	I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.	Motors will only be purchased from reputable, certified, and trusted rocket motor manufacturers. As well, the team mentor, Dave Brunsting, will handle all motor operations. The single use of the motor will be for launching the launch vehicle, and it will be launched under controlled and safe conditions.
Ignition System	I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.	The team mentor, Dave Brunsting, will handle all ignition system installations, and he will act according to all NAR rules and regulations listed here.

Misfires	If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	The team mentor, Safety Officer, and Project Manager must all approve of any method of approaching the launch vehicle in the event of a misfire. Still, any attempt to approach the launch vehicle may only occur after 60 seconds have passed, and the only individuals who may approach the launch vehicle are the team mentor and any other essential personnel once the area is deemed safe.
Launch Safety	I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.	The team will follow all instructions given by the Range Safety Officer, as well as all NAR rules listed here. Additionally, the Safety Officer is required to give a 5 second warning all individuals present at the launch field before any launch may occur.

Launcher	I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.	The team will only use NAR-provided launch rails, and no exceptions to this rule shall be made.
Size	My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.	The team's launch vehicle design and motor selection will adhere to this rule.
Flight Safety	I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.	Weather conditions will be evaluated a week prior to launch as well as launch day. If weather conditions are deemed unsafe, the team will not launch. As well, all necessary FAA waivers and notices will be acquired and in place prior to launch. Lastly, the Range Safety Officer has the final say about all launch day decisions.

Launch Site	I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).	Launches may only occur at NAR/TRA events. As well, the Range Safety Officer has the final say regarding all launch day decisions.
Launcher Location	My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.	The team will fully comply with this rule, and the Range Safety Officer has the final say regarding all launch day decisions.
Recovery System	I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.	The Recovery Design Squad will be responsible for designing, testing, construction, and verifying the ability of their system to properly slow down the descent of the launch vehicle so to comply with this rule. A pre-launch checklist must be signed by the Recovery Leader and verified by the Project Manager, Systems Officer, and Safety Officer.
Recovery Safety	I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.	The team will fully comply with this rule, and the Range Safety Officer has the final say in all launch day decisions. If a safe recovery is not possible for the launch vehicle, the proper authorities will be contacted to ensure a complete and safe recovery.