Carnegie Mellon Rocket Command

Carnegie Mellon University

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1 General Information

1.1 Adult Mentor and Advisors

Table 1: Mentor and Advisor Information

Name	John Haught	Rod Schafer	John Brohm
Professional Title	*General Superintendent Marine & Rail,* Joseph B. Fay Company	*Maintenance Department,* Burrell School District	*Executive Vice President,* Railworks
Position with CMRC	Mentor	Advisor	Advisor
Contact	jhaught@jbfayco.com 412-736-4708	rschafer41@comcast.net 724-822-3027	jrbrohm@zoominternet.net 412-334-3221
Certification Information	Level 3 TRA #1278 Level 3 NAR #91228	TRA #1646 (inactive) Level 2 NAR #36564	Level 1 NAR #78048

1.2 Safety Officer

Roberto Andaya
randaya@andrew.cmu.edu
Safety Officer

1.3 Student Team Leader

Genevieve Parker
gparker@andrew.cmu.edu
CMRC President

1.4 Team Organization

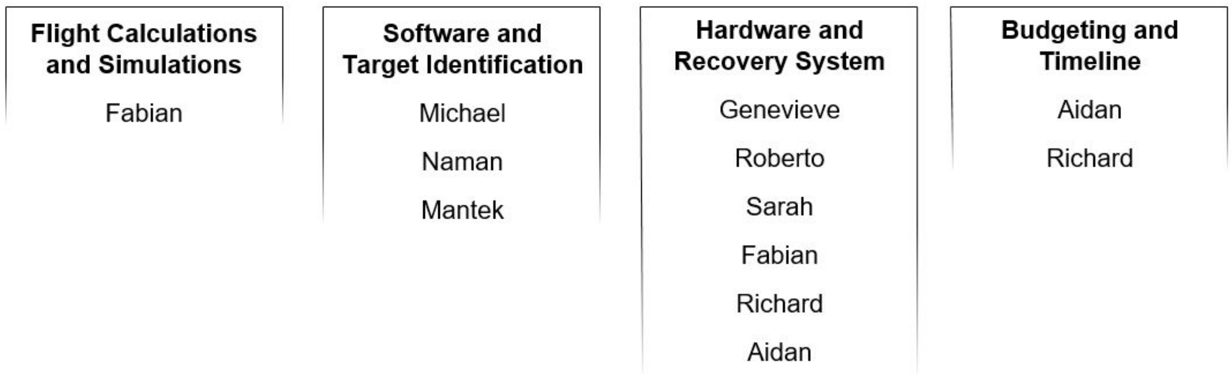

Figure 1: Team Organization Structure

Current plans see the addition of 5-10 more project members.

1.5 NAR/TRA Sections

Carnegie Mellon Rocket Command will be working with TRA Section #1 and NAR Section #473 for the purposes of mentoring, review of designs and documentation, and launch assistance. Through these connections, we have launch sites available at both Grove City, PA and East Millsboro, PA.

2 Team Information

Table 2: Team Member Information

Name	Position	Major	Year	Contact
Genevieve	Student Leader/CMRC President	Mechanical Engineering	Senior	gparker@andrew.cmu.edu
Roberto	Safety Officer	Mechanical Engineering	Graduate Student	randaya@andrew.cmu.edu
Fabian	Flight Calculations and Simulations & Hardware and Recovery Systems	Mechanical Engineering and Physics	Junior	faristiz@andrew.cmu.edu
Michael	Software and Target Identification	Mechanical Engineering	Junior	mmessers@andrew.cmu.edu
Naman	Software and Target Identification	Robotics	Graduate Student	namang@andrew.cmu.edu
Sarah	Hardware and Recovery System	Physics	Freshman	skurelow@andrew.cmu.edu
Aidan	CMRC Vice President	Mechanical Engineering	Sophomore	ahonnold@andrew.cmu.edu
Richard	CMRC Treasurer	Chemical Engineering, Engineering and Public Policy	Junior	rzr@andrew.cmu.edu

3 Facilities

Carnegie Mellon Rocket Command has access to a plethora of machine shops, makerspaces, and other necessary resources for the fabrication of our NASA SL rocket. These facilities include the Mechanical Engineering Machine Shop and Makerspace; IDeATe Machine Shop, Makerspace and Lending Booth; Robotics Club Machine Shop; Spirit Buggy Machine Shop, and the Morewood Gardens Makerspace.

Various safety and machine use trainings are required in order to use these facilities, and several of our members have completed these trainings and gained access to these spaces. The equipment and resources in each facility is detailed in Table 3 on the following page.

Other tools and supplies not in these facilities, such as epoxy, dremels, and spraypaint, are kept in the CMRC storage cabinets in our building space. We have access to these resources 24/7, and no extra personnel are necessary.

Table 3: Facilities Available to CMRC

Facility	Equipment & Resources	Access
Mechanical Engineering Machine Shop and Makerspace	• Sharp 3 axis knee mills w/ Readout • 12" Knuth bench lathes w/ Readout • Knuth gear drive drill presses • Bandsaw • Epilog 50 wt. laser cutter/engraver • MakerBot FDM rapid prototyping machines • Stratasys Dimension Elite FDM Rapid Prototyping machines • Haas 3 axis CNC Office mills • Heat Guns • Hand Tools • Small stock of metals • Guidance from 3 shop employees	M-F 8AM-4:30PM
IDeATe Machine Shop and Makerspace	• CNC Router with 3D axis capabilities • Electronics room with a plethora of sensors and actuators • 3 Laser Cutters • 5 3D printers • Guidance from IDeATe employees	Wood Shop: M-Th 8-4:30 Makerspace: 24/7
Spirit Buggy Machine Shop	• Metal lathe • Micro-Mill • Available composite materials	24/7
RoboClub Machine Shop	• Metal lathe • Mills • Electronic consumables	Select times when shop leaders are available
Art Department Fabrication	• Ventilated spray paint room • CNC router with 2D axis capabilities	M-F 8AM-5PM

4 Safety Plan

4.1 Safety Officer Overview

Roberto Andaya will serve as the CMRC Safety Officer for the NASA Student Launch Competition. As a NAR member with Level 1 Certification for High Power Rocketry, he will work to ensure that all CMRC members remain safe during the design, production, and launch of the team rocket.

4.1.1 Training

The Safety Officer will have completed the following:

- Read the safety regulations for high power rocketry set by the NAR and the TRA.
- Obtained at minimum NAR Level 1 Certification for High Power Rocketry.
- Received training for all CMU facilities that the CMRC members will use during this project.

4.1.2 Responsibilities

The Safety Officer will be responsible for monitoring team activities for safety during:

- Design on vehicle and payload
- Construction of vehicle and payload
- Assembly of vehicle and payload
- Ground testing of vehicle and payload
- Sub-scale launch test(s)
- Full-scale launch test(s)
- Launch day
- Recovery activities
- Educational Engagement Activities

Additional responsibilities include:

- Communicate safety plan to all CMRC Members
- Prepare safety documentation
- Prepare Material Safety Data Sheets for all hazardous chemicals
- Enforce NAR and TRA Safety Regulations and Range Safety Officer policies

4.2 Materials Inventory

The safety officer will oversee what materials are being used and ensure that they are dealt with whatever caution deemed necessary by the distributor.

4.2.1 Composites

The fabrication of the launch vehicle will include cutting fiberglass in order to produce the slots for fins and other necessary modifications to the commercially available fiberglass tubes. The process of cutting fiberglass results in air contamination which can damage the eyes and lungs. Therefore, proper masks and eye protection will be used while cutting fiberglass. In addition, fiberglass will only be handled in proper locations equipped with an exhaust hood to expel the air contamination. Any injuries resulting from contact with the fiberglass will be reported to the safety officer and addressed immediately.

4.2.2 Chemicals

When handling chemicals, we must keep in mind that there are many hazards associated with it. Some of these hazards include irritation to the skin, eye, and respiratory system from contact with or inhalation of the fumes of the material. Other risks can include exposure to chemical spills and destruction of the laboratory.

4.3 Facilities

CMRC will abide by all CMU policies regarding the use of campus facilities during this project. This will include receiving proper training, submitting to inspections, and working with facility managers.

4.3.1 Undergraduate Mechanical Engineering Machine Shop

The Undergraduate Mechanical Engineering Machine Shop works with the school but is also regarded as an independent business. It assists students when constructing their components but also has high standards and requires students to take a class in order to be permitted inside during shop hours.

Shop Manager: Jim Dillinger
Required Training : 24-200 Machine Shop Practices
Website: https://www.cmu.edu/me/facilities/machine-shop.html

4.3.2 IDeATe Lab

This facility houses a standard wood shop and CNC router. The facility is new and does not have a class to authorize students but rather has multiple safety trainings provided by the school.

Shop Manager: John Antinitis
Contact: jantanit@andrew.cmu.edu
Required Training:

- Student Shop Safety Training
- Fire Extinguisher Use Part 1 Training
- Fire Extinguisher Use Part 2 Training
- Hazard Communication Training
- Student Hazardous Materials Training
- Back and Lifting Safety Training
- Hand and Power Tool Safety Training

Website: https://resources.ideate.cmu.edu/spaces/woodshop/

4.3.3 Spirit Buggy Workspace

Buggy is a CMU invented sport that allows students to build a carbon fiber monocoque system. They are allowed to house their own workspace with high power tools to create such devices. For using the high power tools, it is required that students take the class that is required for the mechanical engineering machine shop since they teach the best practices to reduce any risks.

Shop Manager: Frank Andujar
Required Training: 24-200 Machine Shop Practices
Website: http://cmubuggy.org/

4.4 NAR/TRA Personnel Duties

NAR/TRA personnel are members of the team who have received proper certification to launch the rocket. Our vehicle will likely take a K-level motor, so the NAR/TRA personnel must have, at minimum, an NAR Level 2 Certification. These personnel are responsible for:

- Purchasing, handling, storing, and assembling rocket motors
- Transporting rocket motors in an environment isolated from heat or flames
- Assembling all ejection charge igniters and wires
- Handling and loading all ejection charges
- Review safety of rocket during all ground testing launches
- Ensure that all members adhere to NAR/TRA regulations
- Ensure that NAR High Power Safety Code is maintained

4.5 Safety Regulations

The following section outlines the team's compliance with NAR's High Power Rocket Safety Code as well as mentions other regulation by which this project will abide.

Table 4: NAR High Power Rocket Safety Code

[redacted]	
Section	**Compliance**
[redacted] 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.	Mentor John Haught has NAR Level 3 Certification and will possess our high powered motors. CMRC members with NAR Level 1 Certification will only possess motors which fall under their certification
[redacted] I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or, when necessary, ductile metal, for the construction of my rocket.	The CMRC vehicle will be primarily constructed out of fiberglass, wood, and plastic. Metal will only be used for the nosecone tip, electronics, and bulkhead screws.
[redacted] I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, or heat sources within 25 feet of these motors.	We will only purchase certified and commercially made rocket motors such as from Loki. These motors will be stored in a locked engine case which will be kept in a cool room where smoking is prohibited.
[redacted] 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.	CMRC is using electrical motor igniters compatible with our selected motor. These will be installed on the rocket on launch day only, when the rocket is on the launch pad or designated prepping area. The launch switch will be a horizontal spring switch that will remain “on” after release. This switch will not be switched off by the force of the launch of the rocket. This will activate the altimeters and GPS for the launch.
[redacted] 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	This is a standardized practice for all CMRC members. Even at the model rocket level we make sure to follow this safety procedure.

battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	
[redacted] 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.	We go further to even announce that a rocket is launching and then commence the countdown. There have been instances where we even provided a megaphone to so that everyone in the vicinity was properly informed of the launching situation.
[redacted] 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.	CMRC has constructed their own high powered rocket launch pad with all of these criteria kept in mind. We are always cautious of the weather and always adapt the launchpad to ensure the highest level of safety and success.
[redacted] My rocket will not contain any combination of motors that total more than 40,960 N-sec (9,208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified	The highest classification of motor we could possibly use for the NASA SL competition is an L class motor, which contains a maximum of 5,000 N-sec, well underneath the allowable size. Our rocket has a thrust to weight ratio of 14:1, satisfying the minimum 3:1 ratio.

average thrust of the high power rocket motor(s) intended to be ignited at launch.	
[redacted] 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	The CMRC team always makes sure that the launches are made in FAA authorized airspace. We make sure to check up on airspace classification maps to ensure that none of the mentioned objects will be affected in any way.
[redacted] 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 1,500 feet, whichever is greater, or 1,000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1,500 grams, and a maximum expected altitude of less than 610 meters (2,000 feet).	All test launches will be performed at Tripoli Pittsburgh's Dragon Fire launch site or at NAR's Weber Farm launch site. Both sites are in agreement with these specifications.
[redacted] My launcher will be 1,500 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 test launches will be performed at Tripoli Pittsburgh's Dragon Fire launch site or at NAR's Weber Farm launch site. Both sites are in agreement with these specifications
[redacted] 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,	Our rocket is equipped with a dual deploy recovery system with a drogue chute ejected at apogee and main parachute deployed at approximately 800 ft. These will be protected by flame shields to ensure the charges do not

and I will use only flame-resistant or fireproof recovery system wadding in my rocket.	damage the parachutes
[redacted] 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 Safety Officer will enforce safe rocket recover by prohibiting members from recovering the rocket from dangerous places. The Safety Officer will also determine whether the launch location/weather is appropriate prior to the launch.

Table 5: NAR Minimum Distance Table

MINIMUM DISTANCE TABLE

Installed Total Impulse (Newton-Seconds)	Equivalent High Power Motor Type	Minimum Diameter of Cleared Area (ft.)	Minimum Personnel Distance (ft.)	Minimum Personnel Distance (Complex Rocket) (ft.)
0 — 320.00	H or smaller	50	100	200
320.01 — 640.00	I	50	100	200
640.01 — 1,280.00	J	50	100	200
1,280.01 — 2,560.00	K	75	200	300
2,560.01 — 5,120.00	L	100	300	500
5,120.01 — 10,240.00	M	125	500	1000
10,240.01 — 20,480.00	N	125	1000	1500
20,480.01 — 40,960.00	O	125	1500	2000

Note: A Complex rocket is one that is multi-staged or that is propelled by two or more rocket motors

4.6 Risk Assessment

The Risk Assessment Code (RAC) describes the qualifiers used in evaluating the risk associated with specific actions, events, or substances implemented/used throughout the execution of this project. It is borrowed from NASA's MWI 8715.15 directive. Table 1 describes the final labels used while Tables 2, 3 and 4 further define the levels of management approval required, associated severity, and probability of occurrence respectively. These are followed by a risk assessment of different aspects of this project in Tables 10 to 14.

Table 6: Risk Assessment Code

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

Table 7: Level of Risk and Level of Management Approval

Level of Risk	Level of Management Approval/Approving Authority
High Risk	Highly Undesirable. Documented approval from the MSFC EMC or an equivalent level independent management committee.
Moderate Risk	Undesirable. Documented approval from the facility/operation owner's Department/Laboratory/Office Manager or designee(s) or an equivalent level management committee.
Low Risk	Acceptable. Documented approval from the supervisor directly responsible for operating the facility or performing the operation.
Minimal Risk	Acceptable. Documented approval not required, but an informal review by the supervisor directly responsible for operating the facility or performing the operation is highly recommended. Use of a generic JHA posted on the SHE Webpage is recommended.

Table 8: Severity Definitions

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

Table 9: Probability Definitions

Description	Qualitative Definition	Quantitative Definition
A - Frequent	High likelihood to occur immediately or expected to be continuously experienced.	Probability is > 0.1
B - Probable	Likely to occur to expected to occur frequently within time.	0.1≥ Probability > 0.01
C - Occasional	Expected to occur several times or occasionally within time.	0.01 ≥ Probability > 0.001
D - Remote	Unlikely to occur, but can be reasonably expected to occur at some point within time.	0.001≥ Probability > 0.000001
E - Improbable	Very unlikely to occur and an occurrence is not expected to be experienced within time.	0.000001≥ Probability

Table 10: Project Completion

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Project fails to keep up with the projected timeline.	No adherence to project schedule; Unforeseen circumstances take time otherwise spent on completing the project.	Project is not completed; Members are unable to produce an acceptable and reusable final product.	**2C**	Project workload will be distributed among project members according to their areas of comfort and expertise; Progress will be monitored by project leads.	Hold weekly project assessment meetings in which teams report their progress as well as concerns and challenges; Use a Gantt chart, updating it according to progress made.	2E
Budget is exceeded.	Funds are not allocated properly; The price of components is miscalculated.	Purchasing is halted/slowed down until funds are found; Inability to carry out projects elsewhere around the organization; Members required to cover some expense associated with the competition.	**2D**	Conduct thorough research on pricing of components; Budget for additional parts, unforeseen expenses and potential mishaps.	Project finance officer must review every purchasing order and compare it to budgeted funds; Finance officer must authorize an expense not budgeted for; Budget will be reviewed to ensure additional funds.	2E
Parts are damaged or no longer available.	Mishandling of tools or parts; Inability to purchase parts in sufficient quantity or time.	Inability to complete manufacturing of the rocket in a timely manner; Improvisation and deviation from the original design.	**2D**	Purchase additional parts for any component critical to the completion of the project.	Procurement officer will ensure that required parts are available from multiple vendors; Additional parts will be budgeted for.	2E

Table 11: Substance Handling

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Accident occurs while operating workshop tools and/or machines.	Lack of training or supervision; No adherence to established safety protocols and techniques.	Members experience injury and/or maiming; Equipment and/or facilities are damaged.	**1D**	Training on all required tools and machines; Instruction on safe shop and work practices.	All use of tools and/or a shop will be supervised by facility personnel.	**1E**
Accident occurs while using soldering iron or working on circuitry.	Lack of training or supervision; No adherence to established safety protocols and techniques; Exposed wire or power source.	Members experience burns; Equipment and/or facilities are damaged; Components are damaged; Fire can occur.	**3C**	Training on all required tools and machines; Instruction on safe shop and work practices.	All use of tools and/or a shop will be supervised by facility personnel.	**3E**
Mistake is made during manufacturing of rocket.	Improper use of machinery or tools; Lack of attention to instructions and rocket design.	Structural components are damaged; May lead to re-purchasing of parts; Project timeline is delayed; Improvisation and/or deviation from original design may be required.	**2C**	Training on all required tools and machines; Brief all manufacturing team members on rocket design and best practices.	Rocket and parts designs will be available for frequent referral; Progress reviews at the end of each build day.	**2E**

Table 12: Manufacturing

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Black powder detonates unintentionally.	Safety protocol is poorly or not followed; Substance is exposed to fire, a hot surface or live electrical components; Substance experiences friction and or an impact force.	Members may suffer injury and/or maiming or death; Equipment and/or facilities may be damaged.	**1D**	Black powder will only be handled by mentor.	MSDS; Level 3-certified mentor supervision.	**1E**
Superficial exposure to hazardous chemical components.	Improper use of personal protective equipment (PPE); Accidental spill or unforeseen reaction between different substances.	Irritation of the skin; Irritation of the eyes; Burning and/or burning sensation.	**3C**	Training on proper use of PPE as described by a substance's MSDS; Training on hand-washing, eyewash stations, and emergency shower.	MSDS; Work with hazardous substances will be occur in a designated shop/laboratory space supervised by trained personnel.	**3E**
Inhalation of chemical dusts and/or fumes.	Exposure of substances to fire or a hot surface; lack of ventilation for substance with low vapor pressures; Unforeseen reaction between components results in gas products.	Irritation of the respiratory tract; Shortness of breath, dizziness and/or fatigue; Prolonged exposure may lead to internal damage.	**2C**	Limit use of such substances to well-ventilated areas; Use of a fume hood when appropriate; Training on and enforcing of exposure time limitations.	MSDS; Work with hazardous substances will be occur in a designated shop/laboratory space supervised by trained personnel.	**2E**

Table 13: Flight

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Target altitude range is not reached or exceeded.	Miscalculation of net thrust needed by the rocket; Weather cocking lengthens upward trajectory; Inability to reach necessary exit velocity at launch pad.	Failure to meet minimum requirements set by competition; Possible disqualification of competition.	**2B**	Use simulation software to ensure proper motor choice; Perform ground testing to ensure proper motor choice; Accurately measure rocket mass and its CP and CG.	Review data gathered from flight test; Conduct analysis on simulation data.	**2D**
Unstable flight.	Weather cocking knocks rocket off its expected trajectory; Improper exit velocity; Body of rocket is damaged during launch or improper construction.	Spectators may be injured; Rocket may become damaged; Software may be incapable of detecting ground targets.	**2B**	Use simulation software to predict flight pattern; Test the flight with a small-scale model.	Analyze rocket simulations for characteristics of a safe flight trajectory; Analyze flight characteristics of small-scale model for a desired, safe, trajectory.	**2D**
Recovery system fails to deploy or malfunctions during deployment.	Parachute becomes tangled; Ejection charge fails to ignite; Altimeter malfunctions.	Spectators may be injured; Rocket and internal components may become damaged upon landing.	**1C**	Perform ground testing of recovery system; Test the recovery system with a small-scale model.	Analyze recovery system deployment of small-scale model for the desired functionality.	**1E**

Table 14: Vehicle Operation/Handling

Hazard	Cause	Effect	Pre-RAC	Mitigation	Verification	Post-RAC
Electronics fail to activate or malfunction.	Hardware (switch) fails to activate at designated altitude; Power is lost.	Inability to perform technical task; Recovery systems may malfunction.	2C	Test electrical components outside of the rocket; Run test launches carrying the electrical components to have them experience conditions like those at launch.	Ground and flight testing.	2E
Software fails to recognize and detect targets.	Software is not properly coded; Hardware fails to capture targets; Flight trajectory prevents clear detection of the targets.	Inability to perform technical task.	1B	Test the software through footage from old launches.	Ensure reliability of detection system through multiple rounds of testing.	1D
Power supplied to electronics is lost.	Hardware is damaged upon launch; Components shift or disconnect during handling and launching; Batteries run out of charge.	Inability to perform technical task; Ejection charges will not activate; Rocket may be damaged due to failure in recovery system deployment.	1C	Test power levels and activation of electronic components; Secure connections between power sources and electrical components.	Ground and flight testing; Change batteries between launches.	1E
GPS or tracker failure.	Nearby metal components block the signal transmission; Hardware is damaged during launch/handling; Power is lost.	Rocket may not be recovered.	1D	Test transmission of GPS data and RF capabilities.	Conduct both ground and flight tests.	1E

Motor shifts or loosens within the mount tube.	Improper construction of motor mount; Structural damage occurs upon launch.	Motor may be ejected from the body of the rocket; Payload may not separate.	**1C**	Use a robust motor retention system; Robust manufacturing of motor mount and rocket body.	Run test flights; Check state of motor mount and/or body tube frequently.	**1E**
Unintention-al motor ignition.	Exposure to nearby flame, heat, or electric current.	Members and/or spectators may be injured; Fire may occur; Equipment and/or facilities may become damaged.	**1D**	Isolate the motor from possible sources of heat and from electric fields.	Supervision of safety officer and mentor or trained personnel when appropriate.	**1E**
Motor does not ignite.	Malfunction of ignition system; Poor component selection.	Rocket will not launch.	**3C**	Correctly use and set up tested ignition systems.	Verify reliability of component and of its vendor; Ensure that the motor is being used as recommended by the vendor.	**3E**
Unintention-al ejection charge ignition.	Exposure to nearby flame, heat, or electric current.	Members and/or spectators may be injured; Equipment and/or facilities may be damaged.	**2D**	Isolate the ejection charges from possible sources of heat and from electric fields.	Supervision of safety officer and mentor or trained personnel when appropriate.	**2E**
Ejection charge does not ignite.	Malfunction of ignition system; Poor choice of vendor.	Recovery system will not deploy and rocket may be damaged; Bystanders may be injured by falling rocket;	**1C**	Correctly use and set up tested ignition systems.	Verify reliability of component and of its vendor.	**1E**

Burning propellant damages the motor casing upon launching.	Improper assembly of motor set; Poor choice of vendor.	Equipment may become damaged and unusable.	**1D**	Use a certified motor from a reputable vendor.	Verify the motor is certified.	**1E**

4.7 Federal and State Regulations

The CMRC team will abide by all relevant state and federal regulations set forth by the Federal Aviation Association (FAA), National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), National Fire Protection Association (NFPA), and the Department of Transportation (DOT). Refer to Appendix 8.1 for more information.

4.8 Safety Plan Communication

The Safety Officer will hold a meeting with all members of the CMRC team, explaining to them the safety protocols outlined in this section. They will be required to sign a safety agreement, shown in Appendix 8.2, in order to remain on the CMRC team. In addition, prior to beginning the rocket fabrication process, the Safety Officer will brief the members on the proper procedures and regulations for the facility which the members will be using. Before all launched, the safety officer will remind all members of safety requirements such as minimum launching distance, safe recovery practices, and other relevant information. The Safety Officer is responsible for ensuring that all safety procedures are properly communicated to the team.

5 Launch Vehicle Design

CMRC will develop a rocket consisting of three main components: nose cone, body tube, and booster section. The recovery system will be run by an electronics bay inside the rocket that will deploy a drogue parachute at apogee and the main parachute at a preset altitude. This will ensure that our rocket lands close to the main launch site while falling slowly enough to prevent damage.

5.1 Design Requirements

Some of the main design requirements for this rocket are:

1. The vehicle will be able to withstand all launch forces, recovery system deployment charges, and landing impacts.
2. The vehicle will deliver the payload to an apogee of 5,280 ft
3. The launch vehicle will be designed to be recoverable and reusable.
4. The launch vehicle will be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board components.
5. The 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.
6. The rocket will identify and differentiate between 3 randomly placed ground targets while in the air.

Throughout the rocket design process, we have kept in mind these and all other requirements outlined by NASA SL. The work we have done thus far in the design of our rocket has proven to meet or exceed all of the given requirements.

5.2 Vehicle Launch Stability and Overview

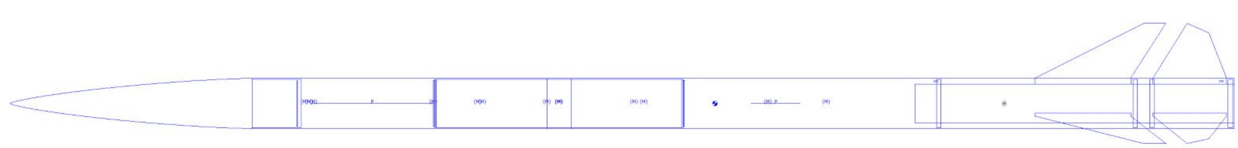

Figure 2: CMRC NASA SL Rocket Design

Our Mentor, John Haught, has graciously offered to donate some parts from the Wildman Extreme Darkstar high power kit for our use in this project. Because of this, we will be building a very similar rocket to the Extreme Darkstar with a modified electronics bay that is longer to accommodate both our recovery system and our target identification system.

A RockSim side view image of the launch vehicle can be seen in Figure 2. The launch vehicle will have a 4 inch diameter airframe. The total length of the launch vehicle is projected to be 99.75 in, and it is composed of three sections: the forward body, the electronics bay section, and the booster section. Length breakdown of these sections can be found in Figures 3 and 4 and Table 15 below.

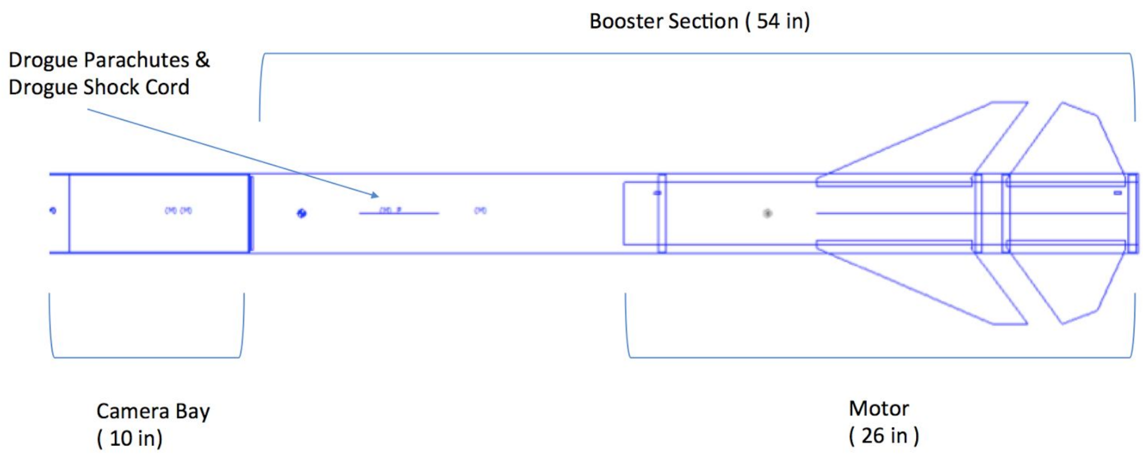

Figure 3: Aft of Rocket

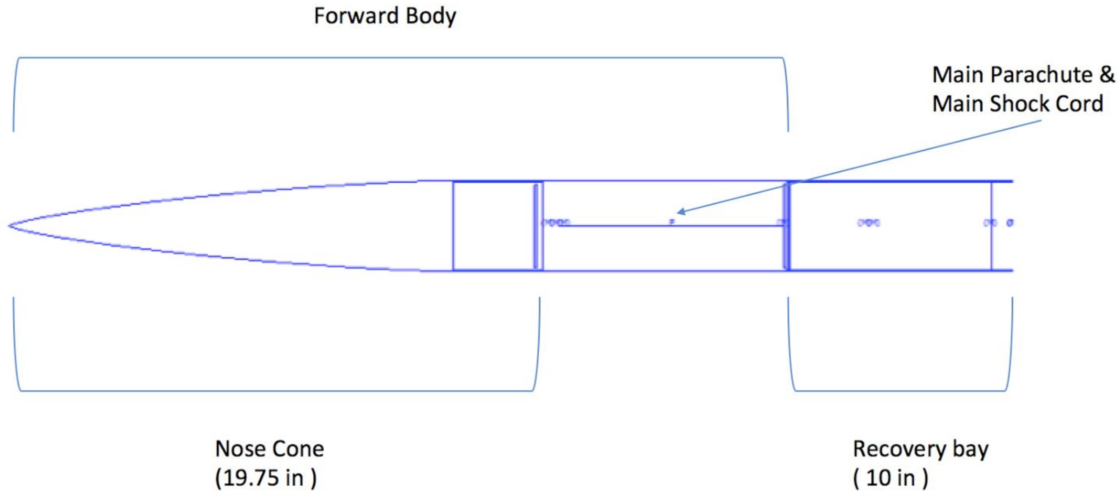

Figure 4: Forward of Rocket

Table 15: Stability Parameters

Parameter	Value (inches from the nose cone tip)
Center of Gravity (CG) before motor burn off	63.372
CG after motor burn off	60.12
Center of Pressure (CP)	85.473
Diameter of rocket	4.0625

Using Equation 1 below, we calculated the stability margins for our design using the Loki K960-LW, where S is stability, x_{cp} and x_{cg} are the location of the CP and CG respectively, and d is the diameter of the launch vehicle.

$$S = \frac{x_{cp} - x_{cg}}{d} \quad (1)$$

$$S_i = \frac{85.473 - 63.372}{4.0625}$$

$$\boxed{S_i = 5.440\ cal}$$

$$S_f = \frac{85.473 - 60.12}{4.0625}$$

$$\boxed{S_f = 6.241\ cal}$$

We obtained a stability margin of 5.440 Calibers before motor ignition and 6.241 after motor ignition. This is well above the 2.0 requirement, to the point where this design is over-stable. An over-stable rocket is not necessarily bad, because it means the rocket is more susceptible to be affected by wind. Because of this, we need to take caution of the wind speed when launching this design. Alternatively, we can put more weight toward the aft end of our electronics bay on the threaded rods to lower the stability margin and mitigate this risk.

5.3 Material Selection & Construction

The structural components of our rocket (the nose cone, body tube, fins, and electronics bay shell) will be made with G10 fiberglass. Fiberglass is an ideal choice for this rocket because of its extremely high strength and low weight. Compared to carbon fiber and other strong composites, it is affordable. Lastly, fiberglass is commercially available, as we do not currently have the expertise to fabricate our own composite components.

Our nose cone will have a metal tip, which will allow us to easily mount a threaded rod in our nose cone for extra payload space and a convenient avenue to add weight and shift the center of gravity if needed.

We will also 3D print some small components, such as an outer shielded case for our recovery system. 3D printing allows us to quickly and cheaply iterate a complex component. The prints will be made from ABS plastic, which has a high impact strength. Other 3D printed materials, like the standard PLA, would break under high impulse loads.

5.4 Construction

We decided on getting an off-the shelf rocket since this is our first attempt and we want to limit the amount of variables and technique required to meet the specifications of the competition. We chose the Wildman DarkStar Xtreme 4.

We will start by drawing lines and finding the placement of the holes for the coupler, payload, and fincan airframe so that internal pressure is relieved. Then, the centering rings will be sanded and epoxied onto the motor mount, along with the shock cord. After that, the part will be epoxied to the motor mount onto the main body tube of the rocket.

We will then sand down the slits so that the fins have the right amount of clearance to fit, we must make sure that we do not go too far such that the slope could become a problem during alignment.

From there, a jig will have to be created so that the fins are perfectly aligned with the body tube. Then the epoxy will be added to permanently hold them in place. We will be using a 3-axis CNC router to get high accuracy and be able to do it quickly. Using a laser cutter for this process would not produce the accuracy we are after since lasers do not cut straight and as materials get thicker it really misaligns components.

3D printed sleds will be made to hold the electronics in place. This will simplify construction since we have to insulate some of the electronics from signals while others need to be out in the open. There will also be a camera system that needs to be shielded and 3D printing would be a perfect system to protect it when not in use.

Finally, the miscellaneous equipment like eye hooks, parachutes, shock cords, and motor caps will be attached so that the rocket can fully be assembled.

5.5 Propulsion

After conducting various simulations through Rocksim under different launch conditions, our team has chosen the K960-LW reloadable composite motor from Loki. This motor has the benefit of a high initial thrust of 1,535 N within the first 0.2 seconds, which helps to counteract weathercocking by providing the rocket with a high rail exit velocity. Other motor types were also tested such as the Aerotech K1050W, K1275R, and K805G, as well the Cesaroni K1200W and the AMW's K950ST. These were all selected for testing due to their high initial thrust. All motors were initially tested under optimal launch conditions: no wind, vertical launch rails (8ft), and minimal cloud coverage (to reduce the number of thermals). This was done in order to filter out motor types that would provide too high an apogee altitude to correct with airframe and mass modifications or too low to ever reach the goal altitude of 5,280 feet without the help of environmental factors such as thermals.

	Simulation	Results	Engines loaded	Max. altitude Feet	Max. velocity Meters / Sec	Max. acceleration Meters/sec/sec	Time to apogee	Velocity at deployment Meters / Sec	Altitude at deployment Feet
1	0		[K1050W-None]	7603.22	259.33	150.57	20.70	0.00	7603.22
2	1		[K1275R-None]	6181.99	228.29	165.69	18.85	0.00	6181.99
3	2		[K805G-None]	4719.59	184.08	127.12	17.19	0.00	4719.59
4	3		[K1200WT-None	5925.59	224.73	150.88	18.48	0.00	5925.59
5	4		[K960-None]	5568.86	209.08	168.55	18.09	0.00	5568.85
6	5		[K960-None]	5531.92	208.94	168.55	18.02	9.75	5531.92
7	6		[K960-None]	5452.07	208.63	168.55	17.89	19.00	5452.07
8	7		[K950ST-None]	5122.67	198.52	128.89	17.55	0.01	5122.68

Figure 5: Summary of simulations on different motor types. Simulations 6 and 7 test the Loki K960-LW in non-ideal conditions with wind speeds of 8-14 MPH for the first and 15-25 MPH for the latter.

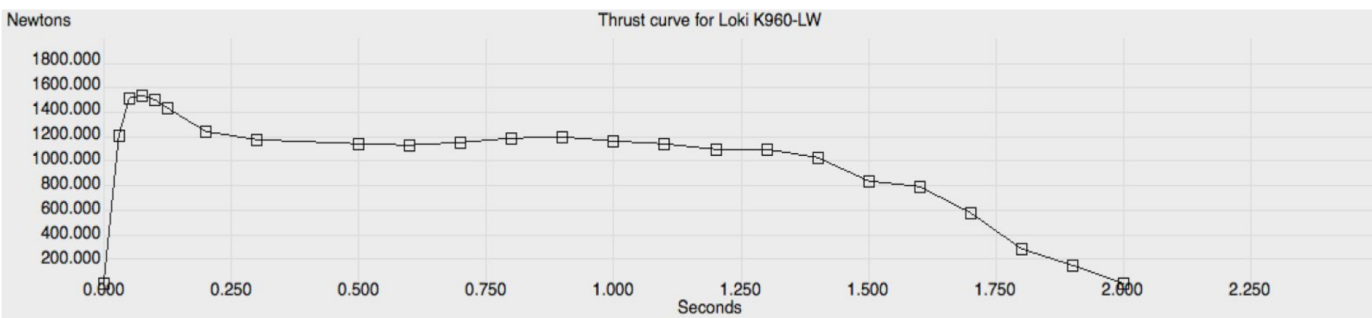

Figure 6: Thrust profile for Loki K960-LW motor.

Other than the Loki K960-LW motor, all other selected motors provided a total impulse that was either too high or too low. The Loki K960-LW, however, maintained the maximum altitude of our rocket at around 5,500 feet even at winds of about 15 to 25 MPH (see Simulation 7 in Figure 1) with a variability of only ±50 feet when changing the wind speed condition. This is within 10 percent of our goal apogee. Furthermore, when utilizing the Loki K960-LW, our rocket's rail exit velocity meets the competition requirement minimum of 52 fps with an exit velocity of 89.2 fps (or 27.2 m/s). With an average thrust of 974 N and a rocket weighing approximately 67 N, this results in a 14.5:1 thrust to weight ratio. The requirement for the minimum thrust to weight ratio is 3:1, but many in practice use 5:1. Our rocket easily satisfies this requirement.

5.6 Recovery

CMRC is utilizing a dual deployment recovery system, with a drogue chute deployed at the apogee of the flight and main parachute deployed later in order to minimize the amount of drift that the rocket experiences during descent. The main parachute will be deployed at 800 feet to allow the vehicle to achieve terminal velocity before landing on the field. The main parachute is the Sky Angle Classic Series Parachute, 60” diameter model. It is made of tubular nylon and has manufacturer supplied coefficient of drag of 1.89 with effective area of 39.3 square feet. Our drogue parachute is made of ripstop nylon and is 48” in diameter.

The recovery bay will be located in the upper section of the electronics bay. It will contain two altimeters, one for redundancy purposes in case the primary altimeter malfunctions. In addition, there will be independent power sources for each altimeter, and ejection charges placed both ends of the electronics bay. In order to shield the recovery system from any signals from the transmitter and GPS located in the avionics bay, we will 3D print a casing to place around the recovery bay. This casing can be coated in RF shielding material. In addition, the exposed wires will be wrapped in RF shielding tape.

The drogue parachute will be located underneath the aft end of the electronics bay and the main parachute will be located above the electronics bay. The first ejection charge occurs at the apogee of the launch, resulting in detachment of the booster section and the release of the drogue parachute. The second ejection charge occurs at 800 ft, resulting in the detachment of the forward body and the release of the main parachute. The forward body, electronics bay, and booster section will all be tethered using Kevlar shock cords. Since all vehicle components are tethered, we will only have one GPS, located in the avionics bay, which will transmit the rocket’s location to ground control during all stages of flight.

To avoid damage to the rocket, we selected our parachute such that the kinetic energy on landing will be less than the maximum threshold of 75 ft-lbs. Using the surface area and coefficient of drag supplied by the manufacturer, we determined the terminal velocity of the vehicle, and consequently calculated kinetic energy upon landing. The results from this analysis indicate that our vehicles lands with approximately 40 ft-lbs of energy, a factor safety of 1.875 with respect to the maximum allowed kinetic energy.

$$\sum F_Y = mg - F_D = 0 \quad (2)$$

$$mg = \frac{1}{2}\rho C_D A V^2 \quad (3)$$

$$V = \sqrt{\frac{2mg}{\rho C_D A}} \quad (4)$$

$$KE = \frac{1}{2}mV^2 \quad (5)$$

$$KE = \frac{m^2 g}{\rho C_D A} \quad (6)$$

$$KE = \frac{(6.879kg)^2(9.81\frac{m}{s^2})}{(1.225\frac{kg}{m^3})(1.89)(3.651m^2)} * \frac{ft\ lbs}{1.3558\,J} = 40.44\ ft\ lbs \quad (7)$$

$$KE = 40.44\ ft\ lbs$$

5.7 Target Detection

5.7.1 Experiment Requirements

1. Design an onboard camera system which can identify and differentiate between three randomly placed targets.
    a. Each target will be a differently colored ground tarp placed on the field.
    b. Target samples and RGB values will be provided prior to launch.
    c. Targets will be approximately 40 ft x 40 ft.
    d. All three targets will be adjacent to one another.
    e. The group of adjacent targets will be within 600 ft of launch pad.

2. Data from the camera system will be analyzed in real time by a custom designed on-board software package that shall identify, and differentiate between the three targets. The system should fulfill the following functions:
    a. Capture image of the targets during launch.
    b. Analyze images in real time to detect whether they contain the targets.
    c. Distinguish between the three targets to verify that the targets have been identified.
    d. Store the image of the targets for retrieval after the rocket lands for verification of correct target identification.

5.7.2 Target Detection System Overview

The Target Detect System (TDS) will be contained in the Avionics Bay section of the Electronics Bay. The TDS will include a Raspberry Pi 3B, Raspberry Pi Sense HAT, altimeter, wide angle camera, power sources, and transmitter. A custom 3D printed camera mount will be fixed to the side of the Avionics Bay in order to house the camera. A hole will be drilled through the side of the Avionics Bay in order to connect the camera to the Raspberry Pi 3B.

Given the limited storage of the Raspberry Pi 3B, it will be necessary to ensure that it only will take video footage during critical moments of the flight. We intend to address this by incorporating a Raspberry Pi Sense HAT, which includes an accelerometer, gyroscope, and barometric pressure sensor. The Sense HAT will detect the launch of the vehicle and trigger the camera to begin recording. As a redundancy measure, the Raspberry Pi 3B may also interface with an altimeter. When the altimeter records a predetermined altitude during ascent, such as 100 ft, it will automatically trigger the camera to begin recording if it has not already started.

The video feed will be analyzed in real time using OpenCV on the Raspberry Pi 3B. The Raspberry Pi 3B was chosen for its compact size, ability to sufficiently process real time data, reasonable cost, and compatibility with OpenCV, Sense HAT, camera, and other devices.

We will specify three RGB ranges, with each centered about the RGB values of the three tarps. This will isolate the colors of the tarp from the noise of the surroundings. Our algorithm will look for clusters of pixels with RGB values in each of those ranges, check the distances between each cluster, and check the sizes of those clusters against the expected sizes of the tarps using data from the altimeter. This will ensure that our algorithm does not mistakenly identify background noise as the tarps. When those criteria have been satisfied, the Raspberry Pi 3B will record the image containing the three tarps. This data can be retrieved from the rocket after landing or transmitted to ground control. Transmission of signal (both, image data and telemetry) will be achieved with the use of a XBee-Pro controller interfaced with Raspberry Pi 3B for real-time communication with the ground control.

In summary, the TDS will be running three primary programs

1. Monitor acceleration and pressure changes using the Sense HAT. If acceleration or pressure exceed a threshold, begin recording video.
2. Monitor altitude by interfacing with the altimeter. If altitude surpasses a threshold and the camera has not started recording yet, begin recording video.
3. Analyze video footage during ascent to detect the three targets on the field. When the clusters of RGB values are identified, save the image which captured those targets.

5.8 Technical Challenges and Solutions

While we cannot anticipate every challenge, we can plan for the ones we know. CMRC has a few years of high power rocket fabrication experience, and from this experience we have gleaned some lessons learned and best practices. We also have the knowledge and experience of our mentor and advisors to aid us in coming up with solutions to challenges we may have never come across before. The following tables are a subset of the challenges we will face as we build our first NASA SL rocket.

Table 16: Rocket Challenges

Challenge	Solution
Deliver the payload to an apogee of 5,280 ft	Use Rocksim to test different motors, and choose the one closest to desired apogee. Then modify the airframe and mass of rocket to hone in on goal apogee altitude. Collect apogee data during full size test flight and adjust design specifications as needed.
Variable wind speed on launch day	A threaded rod in our nose cone will allow us to adjust ballast as needed in front of the CG. Weight may also be added to the aft of the payload to adjust the CG back.
Relying on the recovery charge	The recovery charge will be tested prior to launch. We can also make a redundant recovery charge in case there is a malfunction with the first one.
Extended electronics bay may bind instead of deploying	As we will be testing the recovery charge, possibly multiple times, we will be able to observe whether the electronics bay will bind instead of deploying. If it does, we will need to short our bay and pack our payloads closer together.
Rocket movement is very sensitive to fin alignment precision	We will CNC a jig to ensure precise fin alignment.
Shielding the recovery system to prevent inadvertent charge detonation	We will 3d print an enclosure and coat the inside of it with shielding material to allow for both RF shielding and easy access to the recovery bay.
Finding the rocket if it lands in a forested area	Test the GPS in an area with a lot of trees or other obstructions.

Table 17: Target Detection Challenges

Challenge	Solution
Rocket motion is turbulent and fast, providing difficulty to get a good view of the launch field	Plan for main target detection to occur during ascent, when the thrust of the rocket keeps the view steady. Use our own flight videos from the past as test cases for our algorithm to test if we can detect targets during ascent.
Given RGB values of target may differ from RGB value in camera feed	Include a small range of RGB values centered around the given value for the program to look for. Alternatively, map a known RGB value to the RGB value the camera sees and shift all values by some delta.
There may be other small objects with similar RGB values in the launch field (e.g. cars, tents)	Ensure the algorithm is looking for large clumps of similar RGB values. We may need to provide our program with the approximate size of the target in frame as a function of time.
Electronic components need to withstand the shock of launch and recovery charge	The base of the camera will be enclosed by a bulk plate designed to absorb the shock of launch and recovery charges to protect electrical components. The camera will be protected by a custom fit 3D printed mount securely fixed to the Camera Bay.

6 Educational Engagement

One of the main goals of Carnegie Mellon Rocket Command is to nurture and cultivate the interest of students in our community in STEM-related fields and demonstrate how different disciplines coalesce to achieve great feats in aerospace engineering. One of the communities of particular interest for our team is the Carnegie Mellon community itself. We know that there is a lot of interest in the aerospace industry at CMU, but that many students find it difficult to find opportunities to engage in aerospace-related work on campus. We seek to provide an opportunity for these students to utilize their knowledge and skills to develop a purely aerospace-oriented project and to encourage aerospace research at CMU.

In an effort to do this, we have involved ourselves in many of our university's events including the Activities Fair and MCS Pride Day. We are also considering holding presentations at the end of lectures where we can present and promote our project before CMU's engineering students. Furthermore, our team is also interested in reaching out to an even younger and broader audience ranging from elementary to high school students. Because of this, we have reached out to organizations such as the YMCA in Pittsburgh and the Pittsburgh Science and Technology Academy (middle and high school) and are planning to volunteer in the Moving 4th Into Engineering event at CMU.

6.1 YMCA of Greater Pittsburgh

The YMCA is a charitable organization dedicated to promoting the mental and physical health of children across the nation. It offers afterschool programs, community technology labs, math and language literacy programs, Y Creator Space, and several other initiatives. Our team has been in contact with the program director of Pittsburgh's Y Creator Space, Alex Rice, to see how our team can help promote STEM learning in the Pittsburgh community. We have scheduled a presentation day for November 3.

6.2 Moving 4th into Engineering

Every spring our campus hosts an engineering outreach event to which 30 fourth grade students from various schools in the Pittsburgh area are invited. During their time at CMU they are given the opportunity to participate in a full day of fun, educational, hands-on engineering activities particularly tailored toward their age and skill. Moving 4th into

Engineering is a collaborative effort between the College of Engineering, Engineering Research Accelerator, the departments of Civil and Environmental Engineering and Chemical Engineering, the Center for University Outreach, and the Pennsylvania Infrastructure Technology Alliance. Our team will be joining this collaborative effort this spring to teach 4th grade students in our community how math, science, and engineering come together to create mind blowing technologies to propel the future of space exploration.

6.3 MCS Pride Day

Every year the Mellon College of Science hosts a party for MCS students (physics, chemistry, biology, and mathematics). Our group will be participating in this event launching various of our model rockets. We will use this opportunity to promote our project to both students and professors in the college. Estimated attendance to this event is around a 100 students, not including staff.

6.4 End-of-Lecture Presentations

Oftentimes student organizations request a few minutes before the end of lectures to talk about what they do and encourage those interested to join particularly in the first few weeks of classes. Our group intends to target courses where there is a high attendance of engineering students, particularly the introductory courses where we can reach out to first-year student who are looking for opportunities to get real-world engineering experience. Attendance in lectures averages around 100 to 150 students.

6.5 Pittsburgh Science and Technology Academy, Burrell High School, and Houston Middle School District Presentation

The Pittsburgh Science and Technology Academy is a middle/high school whose focus is preparing students for future careers in Science, Technology, Engineering, and Math (STEM). Carnegie Mellon Rocket Command has been in contact with Michael Miller, one of the school's engineering teachers, who is interested in hosting us for a presentation on rocketry in his class. We are currently negotiating a date for the presentation and there is great potential for multiple presentations at the school. We estimate that every class will contain about 20 to 30 students. Furthermore, our contact at the NAR, Rod Schafer, has requested that we present our NASA Student Launch project in an assembly before students from Houston Middle School and Burrell High School. The students who will be attending are those taking engineering, physics and other science related classes at the middle and high school level. We expect more than 50 students to attend this event.

6.6 Activities Fair

The Activities Fair is an opportunity for student organizations to showcase their group, recruit new members, and present what they do. This year Carnegie Mellon Rocket Command participated in the event and recruited over a 100 students several of whom will be actively contributing to the NASA Student Launch project while others will be commencing their journey into the world of rocketry via construction of their own model rockets (some of them for level certifications).

Table 18: Educational Engagement Schedule

Event	Date	Estimated Number of Students	Estimated Grade Level
YMCA of Greater Pittsburgh	November 3	6-12 students	Grades 1-12
Moving 4th into Engineering	Spring 2018	30 students	4th Grade
MCS Pride Day	September 19	100 students	College Freshman College Sophomore College Junior College Senior
End-of-Lecture Presentations	TBD	100-150 students	College Freshman College Sophomore College Junior College Senior
Pittsburgh Science and Technology Academy Presentations	TBD	20-30 students	Grades 6-12
Activities Fair	September 6	More than a 100 students	College Freshman College Sophomore College Junior College Senior
Burrell High School & Houston Middle School Assembly	TBD	50 students	Grades 6-12

7 Project Plan

7.1 Development Schedule

The chart below describes the timelines and deadlines we intend to follow through the project. The deadlines have been planned with room for delays in parts and slowdowns in development of critical systems.

Info		*Date*	
Task	**Type**	**Start Date**	**End Date**
Full Scale Structure	Design	Sep 01 17	Sep 30 17
Proposal Submission	**NASA**	**Sep 20 17**	
Recovery System	Design	Sep 25 17	Oct 13 17
Avionics Payload	Design	Oct 01 17	Oct 31 17
Scale Model	Design	Oct 16 17	Oct 31 17
Web Presence Established	**NASA**	**Nov 03 17**	
PDR Documentation	**NASA**	**Nov 03 17**	
Avionics Payload	Assembly	Nov 01 17	Nov 15 17
PDR Teleconference	**NASA**	**Nov 06 17**	**Nov 29 17**
Scale Model	Fabrication	Nov 01 17	Nov 30 17
Avionics Payload	Testing	Nov 15 17	Dec 20 17
Scale Model	Flight(s)	Dec 01 17	Dec 20 17
Full Scale Freeze	Design	Dec 20 17	
Avionics Payload	Integration	Jan 05 18	Jan 15 17
CDR Documentation	**NASA**	**Jan 12 18**	
CDR Teleconference	**NASA**	**Jan 16 18**	**Jan 31 18**
Full Scale Final Modification	Design	Jan 25 18	Feb 05 18
Full Scale	Fabrication	Jan 25 18	Feb 25 18
Full Scale	Assembly	Feb 01 18	Feb 28 18
Full Scale	Testing	Feb 15 18	Mar 05 18
FRR Documentation	**NASA**	**Mar 05 18**	
FRR Teleconference	**NASA**	**Mar 06 18**	**Mar 22 18**
Full Scale	Flight(s)	Mar 01 18	Mar 31 18
Competition	**NASA**	**Apr 04 18**	**Apr 07 18**
PLAR Documentation	**NASA**	**Apr 27 18**	

Figure 7: Schedule of work for NASA SL Competition

7.2 Estimated Budget

Below is an estimated budget of the team for the entirety of the project, including room for unknown costs. We estimate that a majority of our expenses will be due to travel to and from testing sites, along with travel and boarding at the competition.

Table 19: Estimated Budget

Rocket	*Body*	$ 500
	Nosecone	$ 50
	Fiberglass Panels	$ 100
	Parachute	$ 150
	Building Materials	$ 200
	Motors	$ 400
	Scale model	$ 500
	Miscellaneous	$ 100
Flight Electronics	*Camera*	$ 100
	Processing	$ 50
	GPS System	$ 150
	Altimeters	$ 150
	Ejection System	$ 200
	Battery System	$ 50
Outreach	*Demonstrations*	$ 200
	Recruiting	$ 50
	Miscellaneous	$ 50
Travel	*Transportation*	$ 1,000
	Boarding	$ 2,000
	Total	**$ 6,000**

7.3 Funding Plan

There are many sources of funding that we are actively pursuing. Our university grants us a budget every year for running the club, which is around $1,000. We also have the opportunity to solicit other programs within the university to grant funding, such as a SURG (Small Undergraduate Research Grant) and the CMU Physics department. Depending on the number of travelers to the competition, we will be able to acquire funding for specifically that purpose through a special funding (CMU Common Funding) system.

The team intends to solicit sponsorship from local companies for material or financial support. We will be able to leverage the connections existing members have to companies to aid in acquiring funding. We will also conduct a crowdfunding campaign through CMU's crowdfunding system, with special contacts sent to alumni of CMRC. Some funding can be gained through the collection of team dues.

We have already had offers of donations of materials, and intend to solidify these donations as early as possible.

Table 20: Funding Sources

Source	Value
University Funds	$ 1,000
SURG Funding	$ 2,000
Sponsorship	$ 800
Team Dues	$ 200
CMU Physics Department	$ 500
CMU Common Funding	$ 1,000
Crowdfunding	$ 500
Total	**$ 6,000**

7.4 Team Sustainability

Carnegie Mellon Rocket Command (CMRC) has been a university club for over 10 years, and has steadily grown in membership and project scope over the past two years, with members often working towards Level 1 and 2 Certifications. We have strong partnerships with departments on campus, such as the university's Physics Department and CMU's Mellon College of Science. These strong relationships have grown out of our diverse interdisciplinary representation of colleges in CMRC. We have conducted demonstrations and events for the Mellon College of Science, and we are always actively searching for ways to spread excitement for rocketry and science in general. We see our growing engagement on campus as a driving factor in the growth in membership of CMRC.

We have established relationships with outside organizations in terms of sponsorship and mentorship through company sponsorships and local organization relationships, for example. These have often grown through internships of current members, employment of alumni, and also with fellow rocket organizations such as Pittsburgh Space Command and Tripoli Pittsburgh. The relationships with local rocket associations have allowed access to resources for learning and launching with safety (such as FAA waivers). We also seek to grow our outreach in education by offering demonstrations and presentations to the multiple high schools adjacent to our university campus.

With the growth in members and scope of projects of CMRC, we have also expanded our funding. We construct a yearly budget for review by the student organization budget allocations office, and provide reasoning for the items and projects listed. With the growing numbers and set of projects in CMRC, the allocations office will likely provide more funding, as the calculations are based on membership and project scope. The university is a strong supporter of undergraduate research, and is open to granting money to organizations such as CMRC for conducting projects with a scientific focus. In addition, we are looking to greatly expand the relationships we have with companies related to CMRC's focus and mission, and we have a goal of increasing sponsorship by aerospace and engineering companies by a significant degree.

8 Appendix

8.1 Applicable Laws and Regulations

8.1.1 FAA Regulations, Title 14, Chapter 1, Part 101, Subpart C - Amateur Rockets

101.21 Applicability.

(a) This subpart applies to operating unmanned rockets. However, a person operating an unmanned rocket within a restricted area must comply with §101.25(b)(7)(ii) and with any additional limitations imposed by the using or controlling agency.

(b) A person operating an unmanned rocket other than an amateur rocket as defined in §1.1 of this chapter must comply with 14 CFR Chapter III.

101.22 Definitions.

The following definitions apply to this subpart:

(a) *Class 1—Model Rocket* means an amateur rocket that:

(1) Uses no more than 125 grams (4.4 ounces) of propellant;

(2) Uses a slow-burning propellant;

(3) Is made of paper, wood, or breakable plastic;

(4) Contains no substantial metal parts; and

(5) Weighs no more than 1,500 grams (53 ounces), including the propellant.

(b) *Class 2—High-Power Rocket* means an amateur rocket other than a model rocket that is propelled by a motor or motors having a combined total impulse of 40,960 Newton-seconds (9,208 pound-seconds) or less.

(c) *Class 3—Advanced High-Power Rocket* means an amateur rocket other than a model rocket or high-power rocket.

101.23 General operating limitations.

(a) You must operate an amateur rocket in such a manner that it:

(1) Is launched on a suborbital trajectory;

(2) When launched, must not cross into the territory of a foreign country unless an agreement is in place between the United States and the country of concern;

(3) Is unmanned; and

(4) Does not create a hazard to persons, property, or other aircraft.

(b) The FAA may specify additional operating limitations necessary to ensure that air traffic is not adversely affected, and public safety is not jeopardized.

101.25 Operating limitations for Class 2-High Power Rockets and Class 3-Advanced High Power Rockets.

When operating *Class 2-High Power Rockets* or *Class 3-Advanced High Power* Rockets, you must comply with the General Operating Limitations of §101.23. In addition, you must not operate *Class 2-High Power Rockets* or *Class 3-Advanced High Power* Rockets—

(a) At any altitude where clouds or obscuring phenomena of more than five-tenths coverage prevails;

(b) At any altitude where the horizontal visibility is less than five miles;

(c) Into any cloud;

(d) Between sunset and sunrise without prior authorization from the FAA;

(e) Within 9.26 kilometers (5 nautical miles) of any airport boundary without prior authorization from the FAA;

(f) In controlled airspace without prior authorization from the FAA;

(g) Unless you observe the greater of the following separation distances from any person or property that is not associated with the operations:

(1) Not less than one-quarter the maximum expected altitude;

(2) 457 meters (1,500 ft.);

(h) Unless a person at least eighteen years old is present, is charged with ensuring the safety of the operation, and has final approval authority for initiating high-power rocket flight; and

(i) Unless reasonable precautions are provided to report and control a fire caused by rocket activities.

101.27 ATC notification for all launches.

No person may operate an unmanned rocket other than a Class 1—Model Rocket unless that person gives the following information to the FAA ATC facility nearest to the place of intended operation no less than 24 hours before and no more than three days before beginning the operation:

(a) The name and address of the operator; except when there are multiple participants at a single event, the name and address of the person so designated as the event launch coordinator, whose duties include coordination of the required launch data estimates and coordinating the launch event;

(b) Date and time the activity will begin;

(c) Radius of the affected area on the ground in nautical miles;

(d) Location of the center of the affected area in latitude and longitude coordinates;

(e) Highest affected altitude;
(f) Duration of the activity;
(g) Any other pertinent information requested by the ATC facility.

101.29 Information requirements.

(a) *Class 2—High-Power Rockets.* When a Class 2—High-Power Rocket requires a certificate of waiver or authorization, the person planning the operation must provide the information below on each type of rocket to the FAA at least 45 days before the proposed operation. The FAA may request additional information if necessary to ensure the proposed operations can be safely conducted. The information shall include for each type of Class 2 rocket expected to be flown:

(1) Estimated number of rockets,
(2) Type of propulsion (liquid or solid), fuel(s) and oxidizer(s),
(3) Description of the launcher(s) planned to be used, including any airborne platform(s),
(4) Description of recovery system,
(5) Highest altitude, above ground level, expected to be reached,
(6) Launch site latitude, longitude, and elevation, and
(7) Any additional safety procedures that will be followed.

(b) *Class 3—Advanced High-Power Rockets.* When a Class 3—Advanced High-Power Rocket requires a certificate of waiver or authorization the person planning the operation must provide the information below for each type of rocket to the FAA at least 45 days before the proposed operation. The FAA may request additional information if necessary to ensure the proposed operations can be safely conducted. The information shall include for each type of Class 3 rocket expected to be flown:

(1) The information requirements of paragraph (a) of this section,
(2) Maximum possible range,
(3) The dynamic stability characteristics for the entire flight profile,
(4) A description of all major rocket systems, including structural, pneumatic, propellant, propulsion, ignition, electrical, avionics, recovery, wind-weighting, flight control, and tracking,
(5) A description of other support equipment necessary for a safe operation,
(6) The planned flight profile and sequence of events,
(7) All nominal impact areas, including those for any spent motors and other discarded hardware, within three standard deviations of the mean impact point,
(8) Launch commit criteria,
(9) Countdown procedures, and
(10) Mishap procedures.

8.1.2 NAR High Power Rocket Safety Code

1. **Certification**. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.
2. **Materials**. I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.
3. **Motors**. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.
4. **Ignition System**. I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.
5. **Misfires**. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.
6. **Launch Safety**. I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.
7. **Launcher**. I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees 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.

8. **Size**. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.
9. **Flight Safety**. I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.
10. **Launch Site**. I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).
11. **Launcher Location**. My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.
12. **Recovery System**. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.
13. **Recovery Safety**. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

8.1.3 National Fire Protection Association Regulations

For brevity, the following codes will be summarized.

NFPA 1122: Code for Model Rocketry

According to the NFPA 1122 Code for Model Rocketry, ‘model rockets’ weight less than 1500 grams, contain less than 125 grams of total fuel, have a motor will less than 62.5 grams of fuel or less than 160 S of total impulse, use pre-manufactured solid propellant motors, and do not use metal body tubes, nose cones, or fins. The safety code specified in NFPA 112 is the same as the NAR safety code.

NFPA 1127: Code for High Powered Rocketry

According to the NFPA 1127 Code for High Powered Rocketry, ‘high power rockets’ exceed the total weight, propellant, or impulse restrictions of model rockets, but only use pre-manufactured rocket motors and don’t use metal body tubes, nose cones, or fins. Metal components may be used for structural integrity. While there is no upper weight limit, there is a single motor limit of an 40,960NS of total impulse or a 81,920 NS of total impulse between all motors. The safety code specified in NFPA 1127 is the same as both the NAR and TRA safety codes.

8.2 Safety Agreement

2017 NASA SL Carnegie Mellon University CMRC Safety Agreement

I,____, agree to abide by the following rules and procedures detailed in this safety agreement.

I will adhere to the policies of all Carnegie Mellon University facilities which CMRC will use during this project, including the Undergraduate Mechanical Engineering Machine Shop, IDeATe Lab, Buggy Workspace, and more.

I will adhere to the policies set forth by the CMRC safety officer during the project's duration.

I will refer to safety documentation and MSDS of chemicals to ensure proper safety precautions are taken.

I will ask the Safety Officer if I have a question regarding safety procedure.

I will notify the Safety Officer if I see or hear of a safety incident or unsafe practices.

I will adhere to the following safety regulations:

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

I understand that failure to adhere to any of the above will result in disciplinary action and potential removal from the CMRC Team. By signing this document, I verify that I have read and understand this agreement completely.

______________________________ ________________
Name (Printed) Date

______________________________ ________________
Signature Date

8.3 References

NASA SL 2018 College and University Handbook:
https://www.nasa.gov/audience/forstudents/studentlaunch/handbook/index.html

NAR High Power Rocket Safety Code:
http://www.nar.org/safety-information/high-power-rocket-safety-code/

FAA Regulations:
https://www.ecfr.gov/cgi-bin/text-idx?SID=2a741450282cd8b53c7f689dcef7972d&mc=true&node=pt14.2.101&rgn=div5#sp14.2.101.c

NFPA Regulations
http://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1122

Parachute Supplier:
http://www.b2rocketry.com/Classic.htm