PURDUE UNIVERSITY

PROJECT WALKER

2019

500 Allison Road
West Lafayette, IN 47906

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1. Summary of LRR Report

1.1. Team Summary

1.1.1. Team Name and Mailing Address

Team Name	Purdue Space Program Student Launch (PSP-SL) a SEDS chapter
Mailing Address	107 MacArthur Drive, Room 150 West Lafayette, Indiana 47906

1.1.2. Team Lead Contact Information

Position	**Name**	**Phone Number**
Project Manager	Michael Repella	330-495-1270
Acting / Assistant Project Manager	Luke Perrin	219-798-7066
Safety Team Lead	Jory Lyons	219-252-2816
Avionics Team Lead	Bret Reser	779-400-6241
Payload Team Lead	Josh Binion	614-535-5223
Construction Team Lead	Zach Carroll	765-860-0861
Funding Team Lead	Sean Heapy	206-849-7329
Social Team Lead	Isaac Byely	765-631-5828

1.1.3. Mentor Contact Information and TRA/NAR Certifications

Mentor Name	Victor Barlow
Mentor Email / Cell	vmbarlow@purdue.edu / 765-414-2848
TRA/NAR Certifications	NAR 88988 L3CC, TRA 6839 TAP Level 3 Certified

1.2. Launch Vehicle Summary

Launch Vehicle Height [in]	120
Launch Vehicle Nominal Diameter [in]	5.15
Gross Lift-Off Weight (Wet Weight) [lbs]	42.5
Dry Weight [lbs]	34.45
Launch Vehicle Airframe / Nose Cone Material	Filament Wound Composite Fiberglass
Launch Vehicle Fin Material	FR-4 / G-10 Fiberglass
Launch Day Motor	AeroTech Rocketry L1520 Blue Thunder
Launch Day Motor Diameter [in]	2.95276
Launch Day Motor Grain Count	3
Launch Day Motor Total Impulse [N sec]	3,716
Launch Day Motor Burn Time [sec]	2.4
Launch Day Motor Total Thrust [N]	1,779
Launch Day Motor Propellant Weight [lbs]	4.09
Launch Day Motor Loaded Weight [lbs]	8.05

1.2.1. Recovery System

Launch Vehicle Primary Altimeter	Altus Metrum - Telemetrum
Primary Altimeter Receiver	Altus Metrum - TeleDongle with Yagi 3 Arrow Antenna
Primary Altimeter Power Supply	3.7V LiPo Battery - 900 mAh
Launch Vehicle Secondary Altimeter	Missile Works - RRC3+ Sport
Secondary Altimeter Receiver	N/A
Secondary Altimeter Power Supply	Duracell 9V Battery
Drogue Parachute	SkyAngle Cert-III Drogue

Drogue Parachute Diameter [in]	24
Drogue Parachute Coef. of Drag	1.16
Altitude Deployment	Apogee
Main Parachute	SkyAngle Cert-III X Large
Main Parachute Diameter [in]	100
Main Parachute Coef. of Drag	2.59
Altitude Deployment AGL[ft]	700-900
Shock Cord Length [in]	40
Shock Cord Thickness [in]	1/2
Shock Cord Material	Tubular Kevlar
Shock Cord Weight Rating [lbs]	7,200
Launch Vehicle Rail Size [in]	1.5
Launch Vehicle Rail Length [ft]	12

1.3. Payload Summary

1.3.1. Payload Title

The experimental payload that will be flown in this launch vehicle will be known as the "Walker Texas Rover".

1.3.2. Experiment Overview

The PSP-SL team will launch an autonomous rover and soil sampling system as a payload. The rover will be deployed from the payload bay upon landing and must drive at least 10 feet away from any part of the rocket. This motion will employ a system of sensory data collection and execution of obstacle avoidance maneuvers. Once it has travelled at least the decided upon distance from the closest located rocket part, it will begin soil sampling.

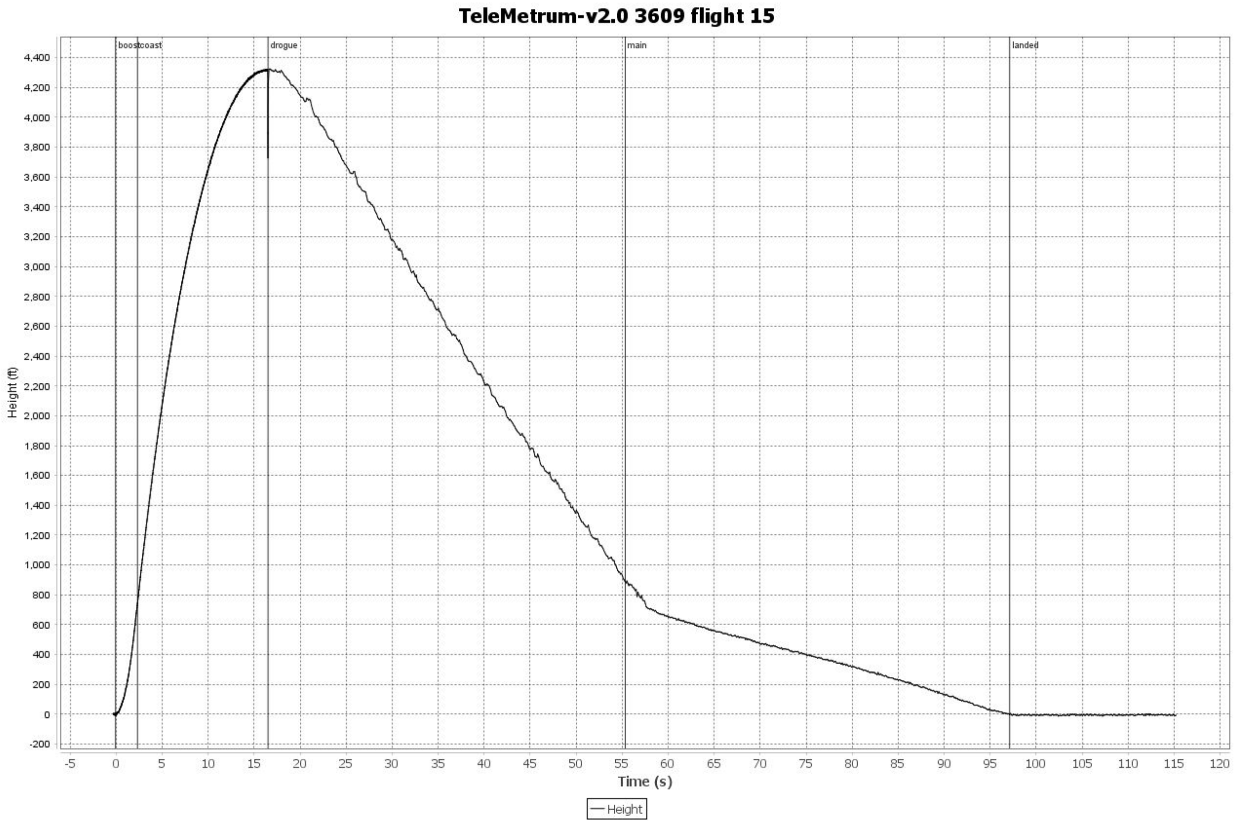
2. Flight Data

2.1. Data from Previous Flights

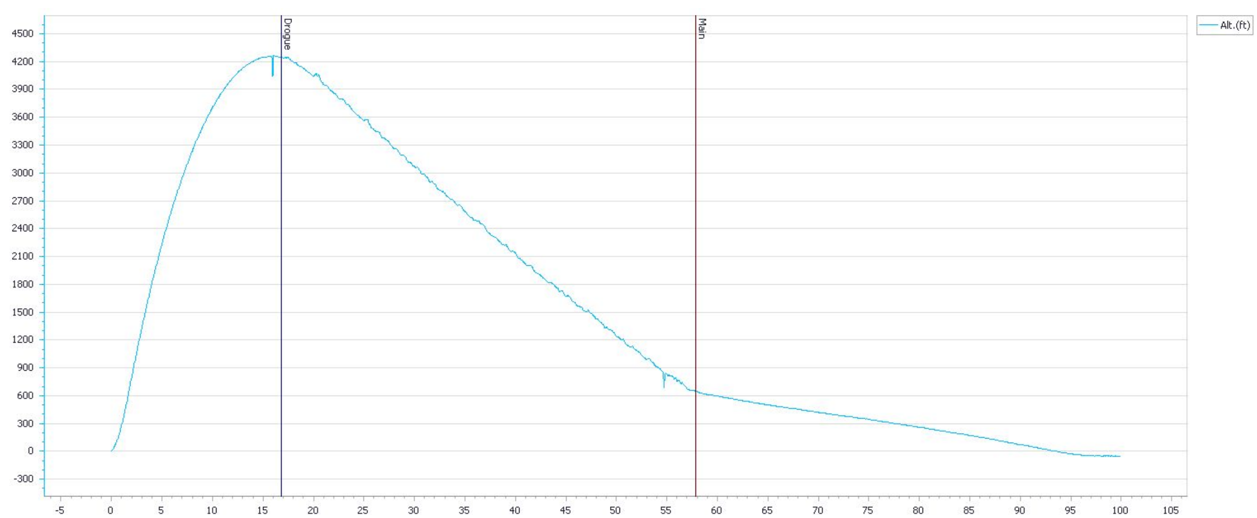
Flight on 02/25/2019

The weight of the launch vehicle before launch was 43.5 lbs. The apogees read were 4325 ft from the primary altimeter, and 4263 ft from the redundant altimeter.

Height AGL from Primary Altimeter - Telemetrum



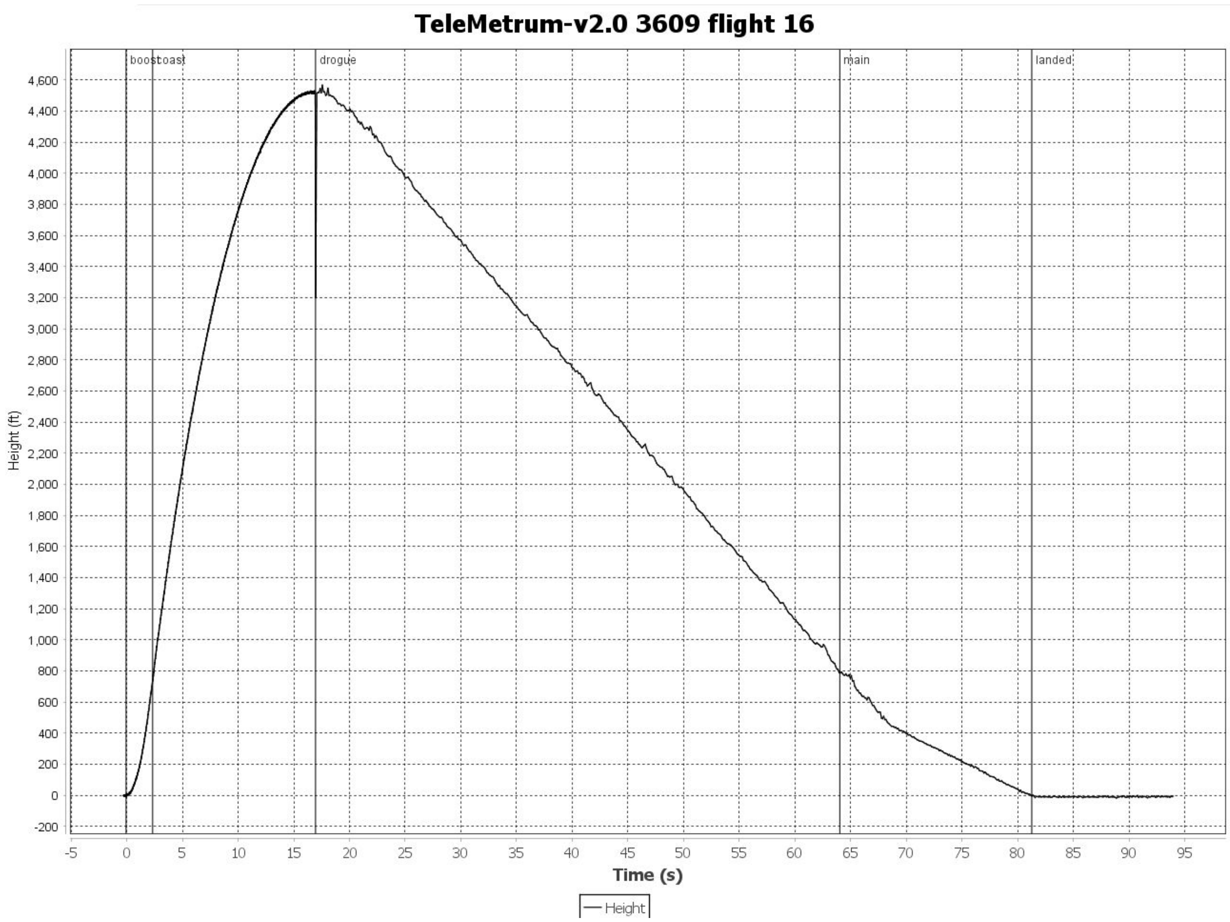
Height AGL from Redundant Altimeter - RRC3+ Sport



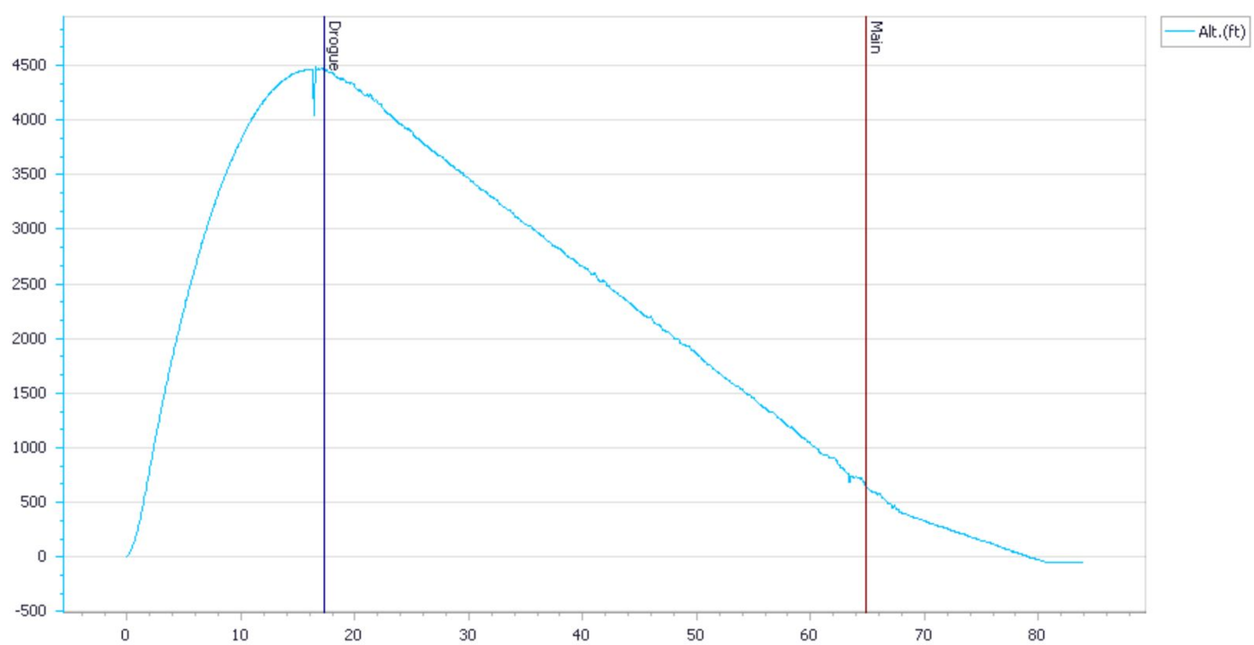
Flight on 03/17/2019

The weight of the launch vehicle before launch was 42.5 lbs. The apogees read were 4568 ft from the primary altimeter, and 4492 ft from the redundant altimeter.

Height AGL from Primary Altimeter (Telemetrum)



Height AGL from Redundant Altimeter (RRC3+ Sport)



2.2. Flight Anomalies and Mitigation

The height AGL data from both altimeters have an outlier data point at apogee that is a few thousand feet lower than its neighboring data points. It is reasoned that this is a result of a small amount of gases from black powder ejection charges entering the avionics bay. This is a non-issue, as the data in the height AGL vs time graphs clearly shows that the proper height AGL measurements are restored immediately after this outlier data point.

2.3. Changes To Airframe Since Last Flight

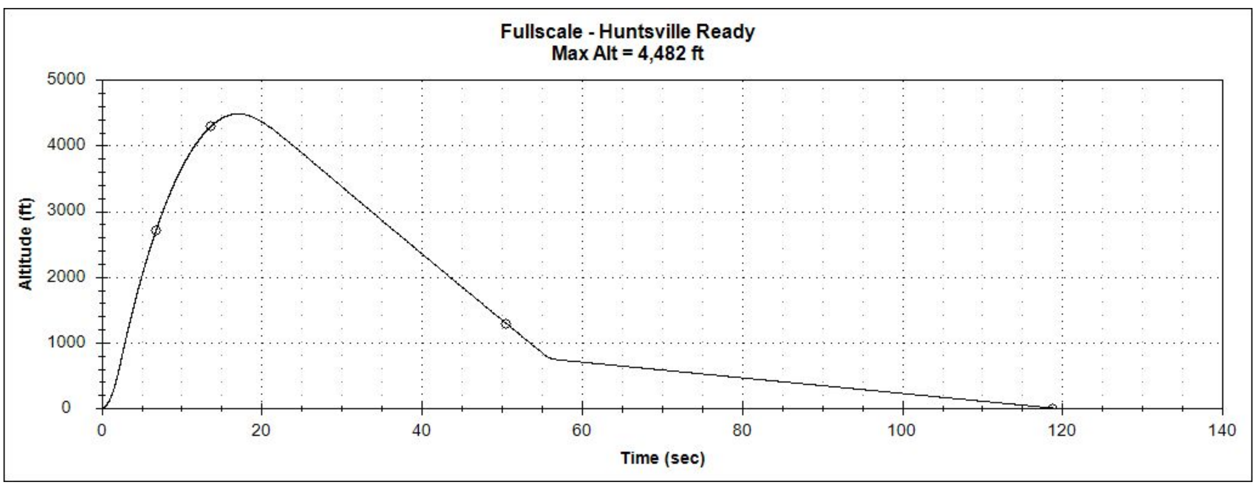
The team chose to spray paint the fins of the rocket with a gold color after the demonstration flight on 3/17/2019. Changes in the weight of the rocket is expected to be minimal. There were no other changes made.

2.4. Flight Simulations

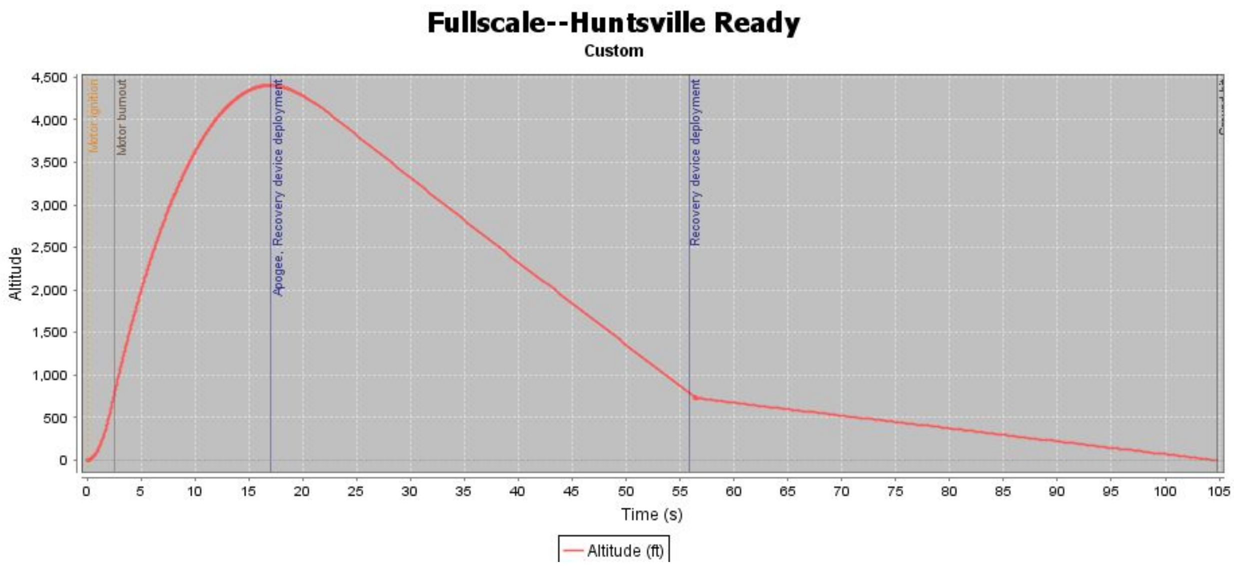
2.4.1. GLOW 43.5 lbs

2.4.1.1. Anchored Flight Predictions

2.4.1.1.1. Altitude Predictions (10 mph crosswinds)

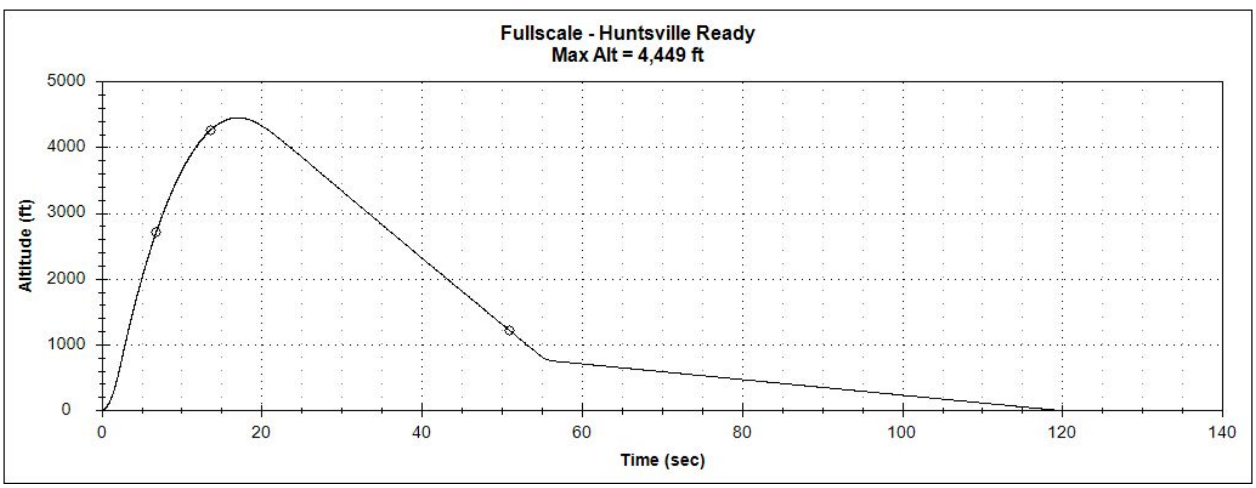


Altitude at a GLOW of 43.5 pounds reaches a maximum at 4482 ft AGL. This is well below the team's target altitude of 4950 ft, so the team is working on lowering the weight. The team has already successfully flown a prototype of a lighter weight, so there should be little reason that this section be needed. However, in the event that the rocket's weight increases, the data is here. Also shown is total flight time. This number is nearly two minutes. With an apogee time of only about 17 seconds, the descent time is over 100 seconds. Required is 90 seconds or less, so the team is not happy with this prediction. However, through our two test flights, flight time is significantly less than indicated. Though the reason for this difference is unknown, the team believes there will not be an issue at launch.

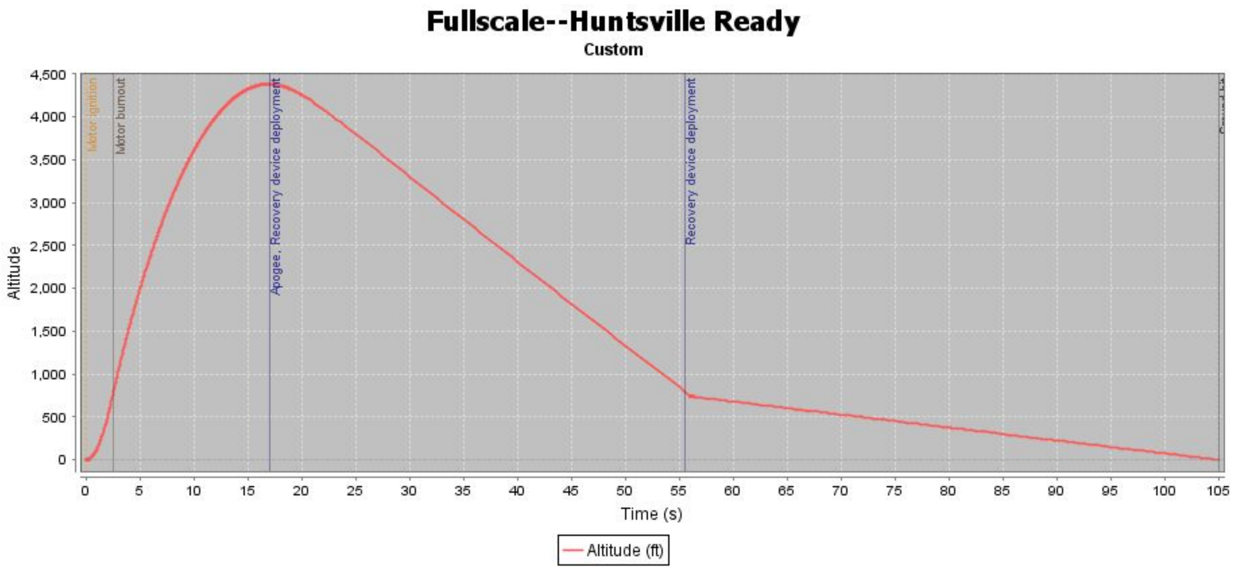


Shown above is the simulation of the flight from OpenRocket with a GLOW of 43.5 lbs and crosswinds of 10 mph. The apogee predicted from this simulation is 4404 ft, which is slightly lower than that of RASAero. Both the total flight time and time to apogee predicted by OpenRocket are similar to what is predicted by RASAero, with the total flight time estimated to be 105 seconds.

2.4.1.1.2. Altitude Predictions (15 mph crosswinds)

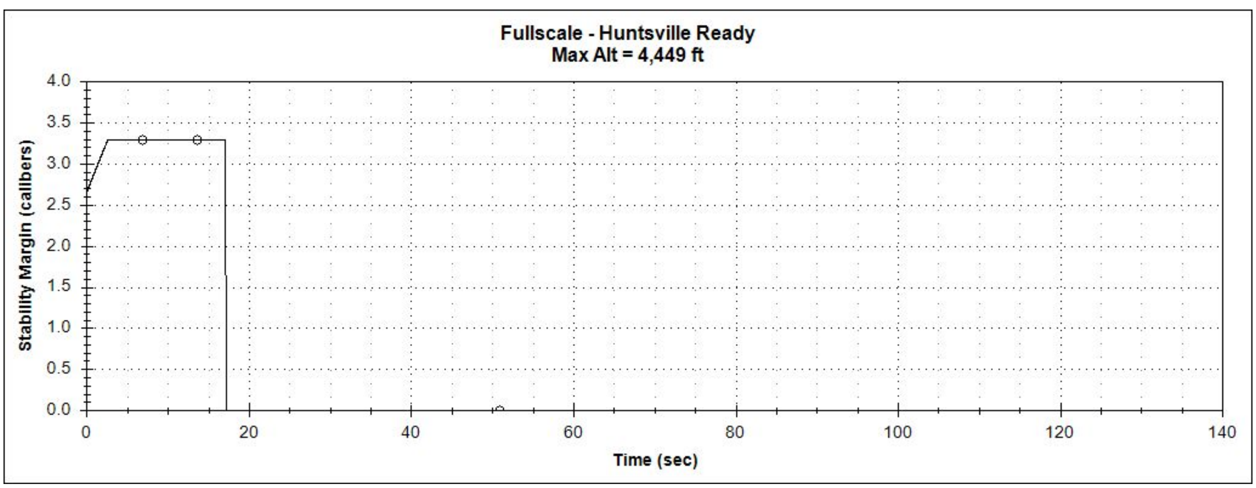


The figure above shows the graph of altitude versus time for 15 mph crosswinds. There is a maximum altitude of 4449 ft and flight time is just under two minutes. Time to apogee is only 17.1 seconds, so the descent time is approximately 100 seconds. This is slightly above the allowed time of 90 seconds for descent which worries the team, but changes can (and have) been made to prevent this from being as much of an issue.

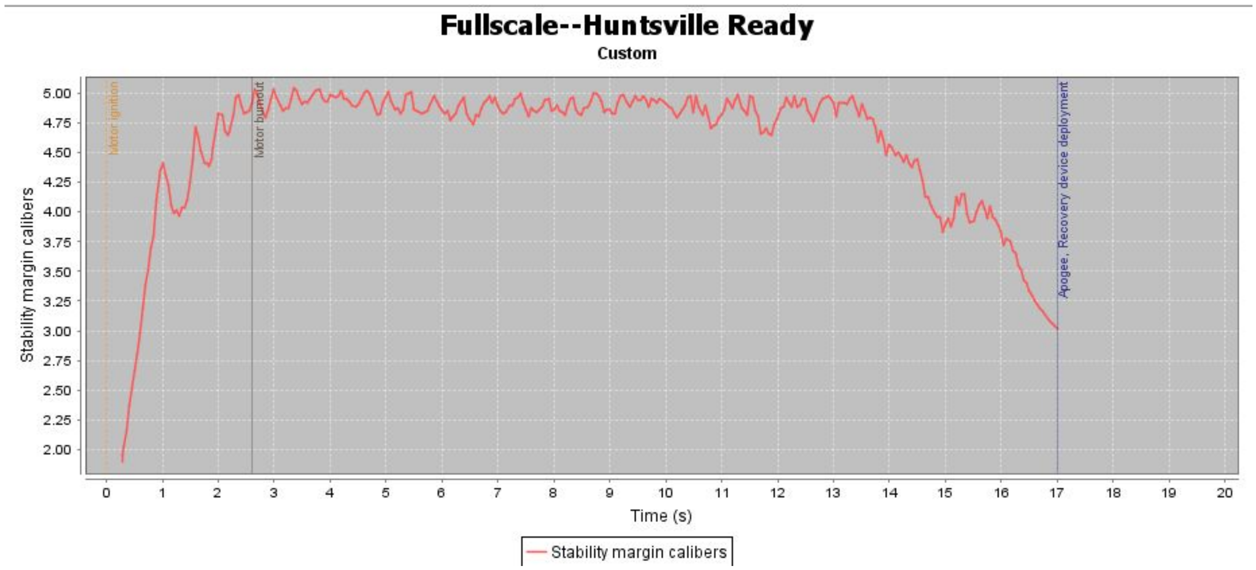


Above is the simulation from OpenRocket with a GLOW of 43.5 lbs and crosswinds of 15 mph. The predicted apogee from this simulation is 4382 ft, which is notably lower than that predicted by RASAero. However, the total flight time predicted by OpenRocket is 105 seconds, which is close to that predicted by RASAero.

2.4.1.1.3. Stability Margins

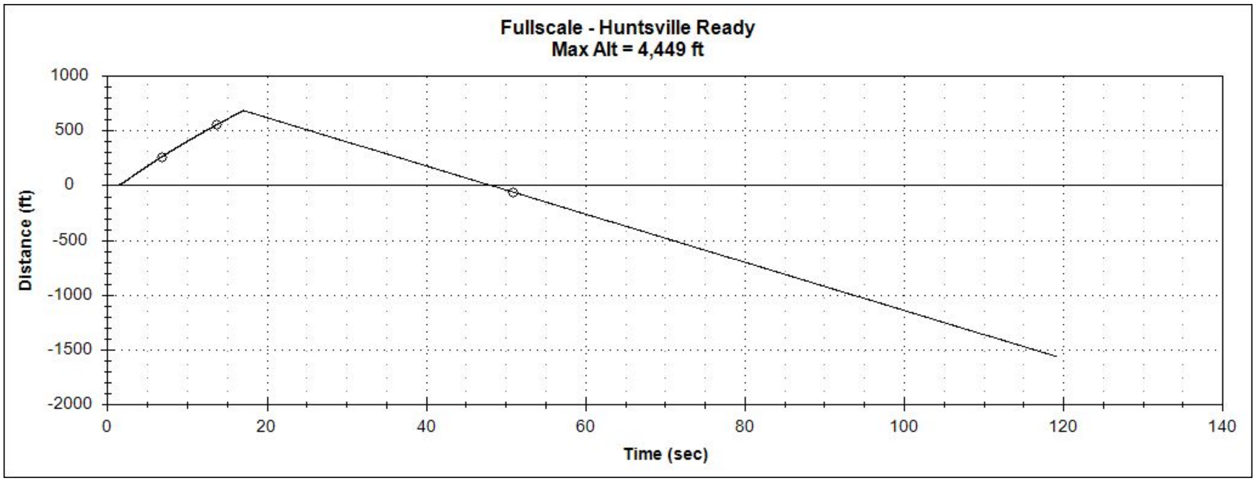


The above figure shows the stability margin of the rocket in calibers. Off the launch rail, there is a stability margin of about 2.6 calibers. This number increases to about 3.2 until apogee where the margin drops to zero.

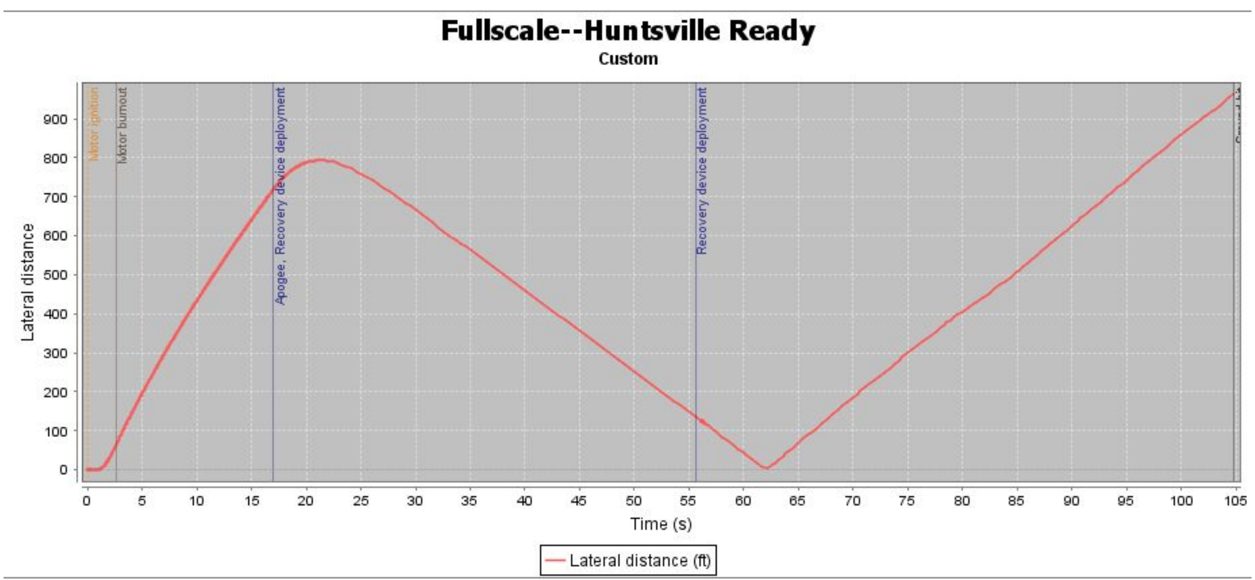


Shown above is the OpenRocket simulation of the stability margin of the rocket, measured in calibers. According to this simulation, when the rocket leaves the launch rod, the stability margin is slightly below 2 calibers, which is higher than that predicted by RASAero. The plot levels out at just under 5 calibers for the majority of the descent until the rocket reaches apogee.

2.4.1.2. Anchored Drift Predictions (15 mph crosswinds)



As shown in the figure above, the drift of the rocket will be approximately 2244.5 ft. This is not an easy number to see straight away due to the way the program calculates drift. RASAero uses displacement from the pad to show total drift, but as NASA has made clear, the drift distance measurement required is calculated from apogee to touchdown assuming the rocket travels straight up from the pad. In this graph, the rocket drifts "positively" until apogee at a distance of 681.1 ft from the pad (This number comes from a text file of all data points, not from simply guessing off the graph). The rocket touches down at a distance of -1563.4 ft. Therefore, total drift at a GLOW of 43.5 pounds could potentially yield a drift of 2244.5 ft. Though the team does not expect 15 mph sustained winds, the team also does not like this value.

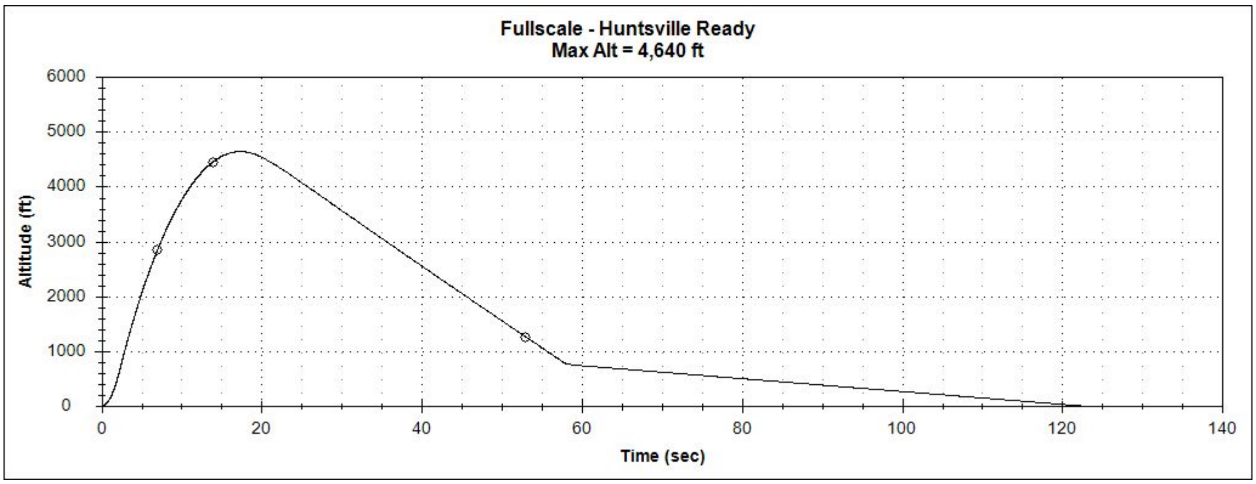


With crosswinds of 15 mph and a GLOW of 43.5 lbs, the total drift of the rocket is estimated by OpenRocket to be as much as 1800 ft, which close to that predicted by RASAero.

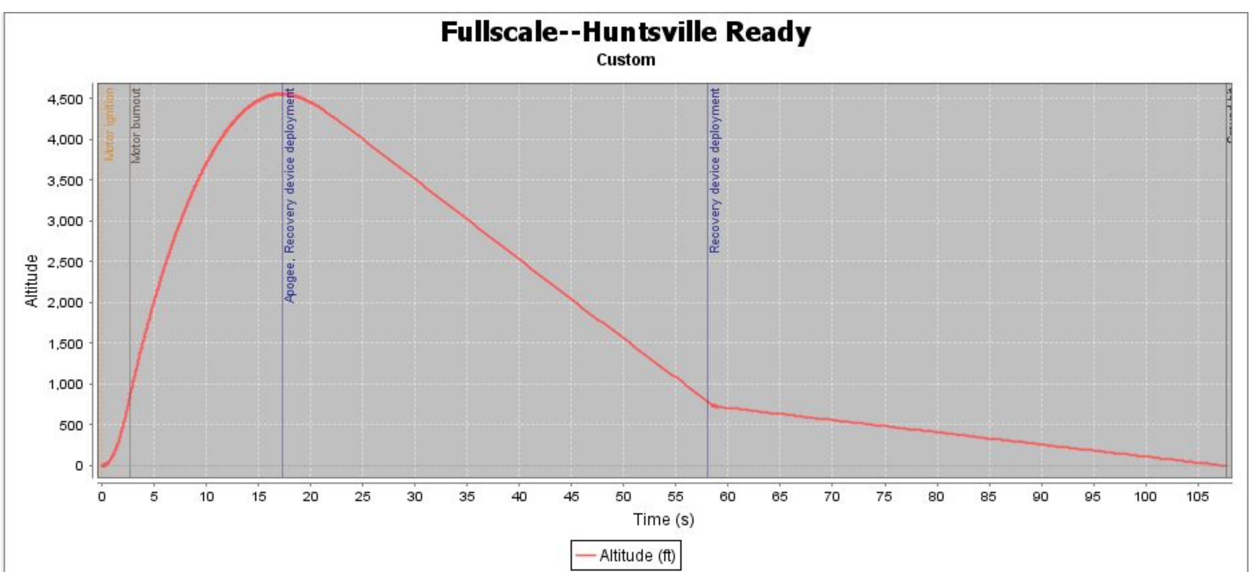
2.4.2. GLOW 42.5 lbs

2.4.2.1. Anchored Flight Predictions

2.4.2.1.1. Altitude Predictions (10 mph crosswinds)

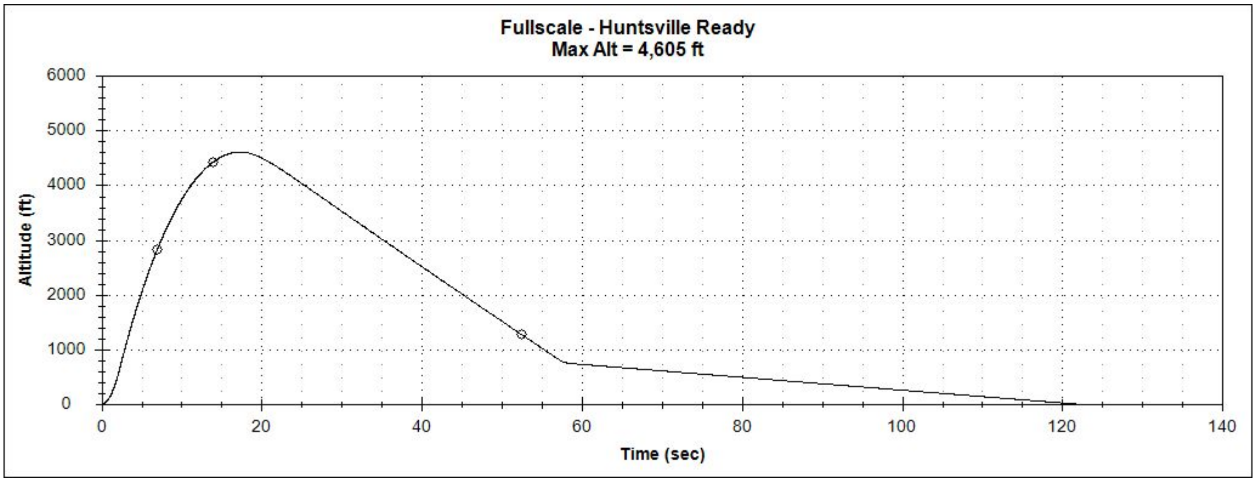


Shown above is the flight assuming a GLOW of 42.5 pounds with 10 mph crosswinds. The maximum altitude is 4640 ft, still below target altitude, but much closer. Losing one pound increases altitude by 158 ft. Also notice the total flight time. Loss of a pound increased the flight time while time to apogee was relatively the same, so time of descent is still over the requirement.

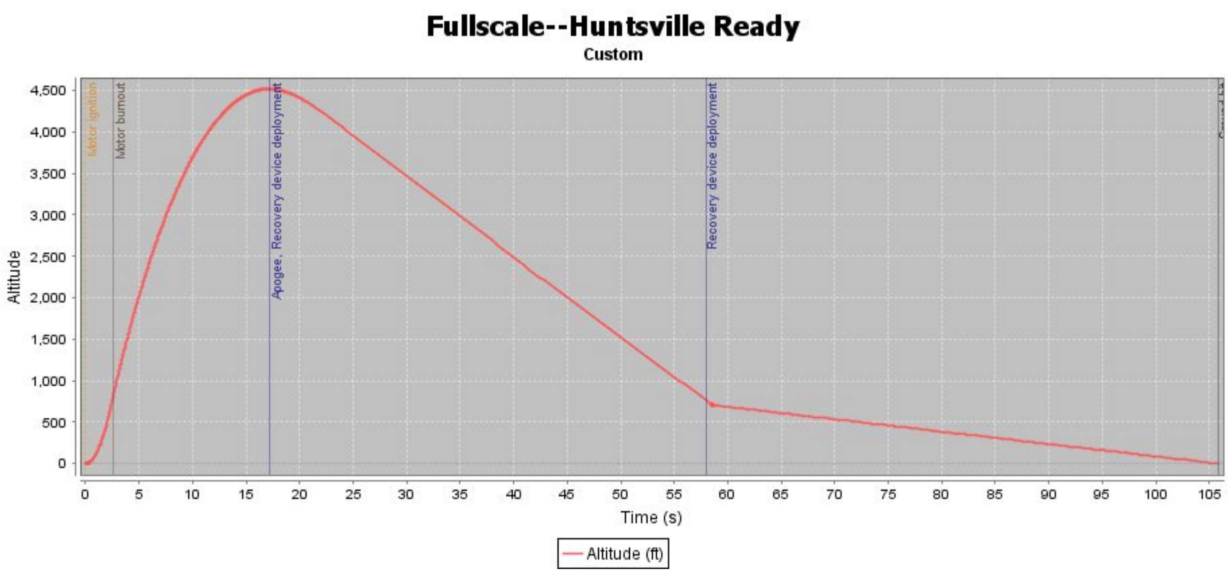


Above is the OpenRocket simulation with a GLOW of 42.5 lbs with 10 mph crosswinds. The predicted altitude from this simulation is 4556 ft, which is noticeably lower than the apogee predicted by RASAero. However, the flight and descent times were both similar to those predicted by RASAero.

2.4.2.1.2. Altitude Predictions (15 mph crosswinds)

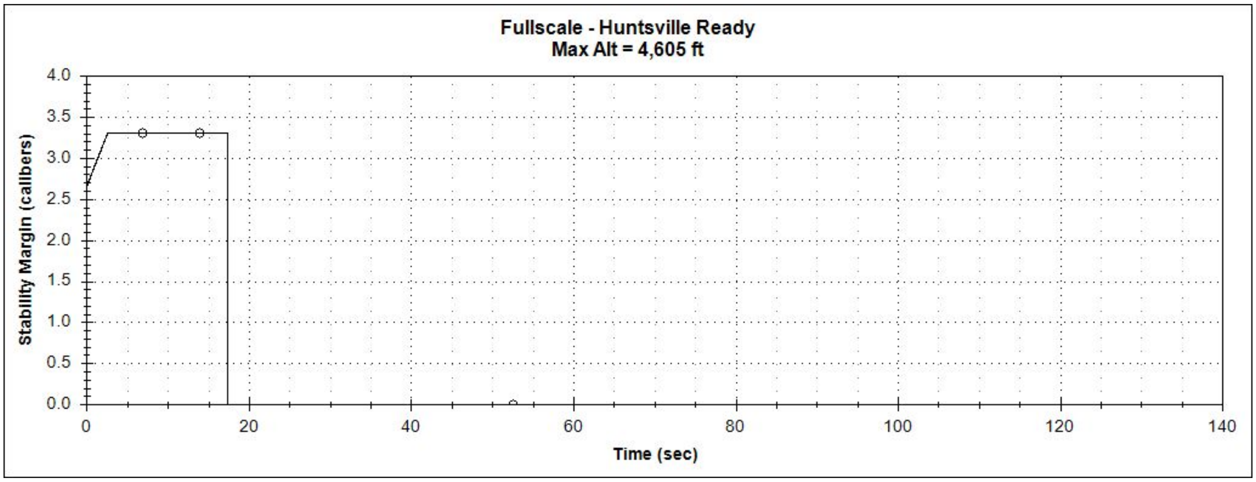


In this figure, the maximum altitude achieved is 4605 ft, still well below the target altitude of 4950 ft. Total flight time for this simulation is almost 122 seconds. With an apogee at around 17.3 seconds, there is once again a drift of approximately 105 seconds. The team does not anticipate a wind speed of 15 mph, but from experience, total flight time is much less than 120 seconds anyway. This may be a result of imperfect simulations or human error in input.

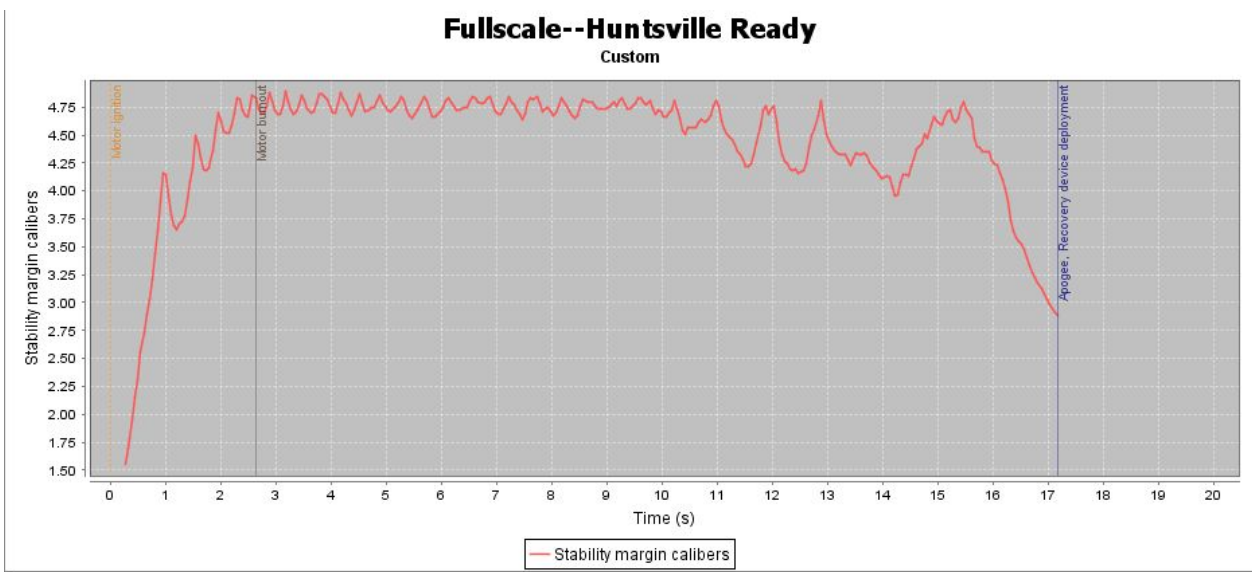


Above is the simulation from OpenRocket with a GLOW of 42.5 lbs and crosswinds of 15 mph. The predicted apogee from this simulation is 4522 ft, which is notably lower than that predicted by RASAero. However, the total flight time predicted is 106 seconds, which practically matches the time predicted by RASAero.

2.4.2.1.3. Stability Margin

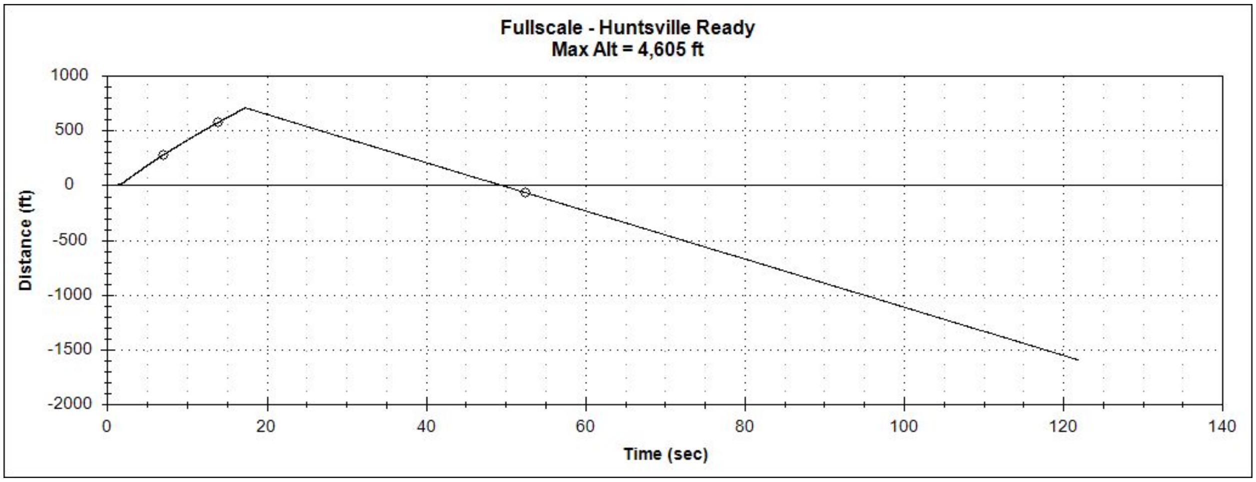


Stability margin does not drastically change with the one pound weight decrease and is similar to the graph shown and discussed in the previous sections.

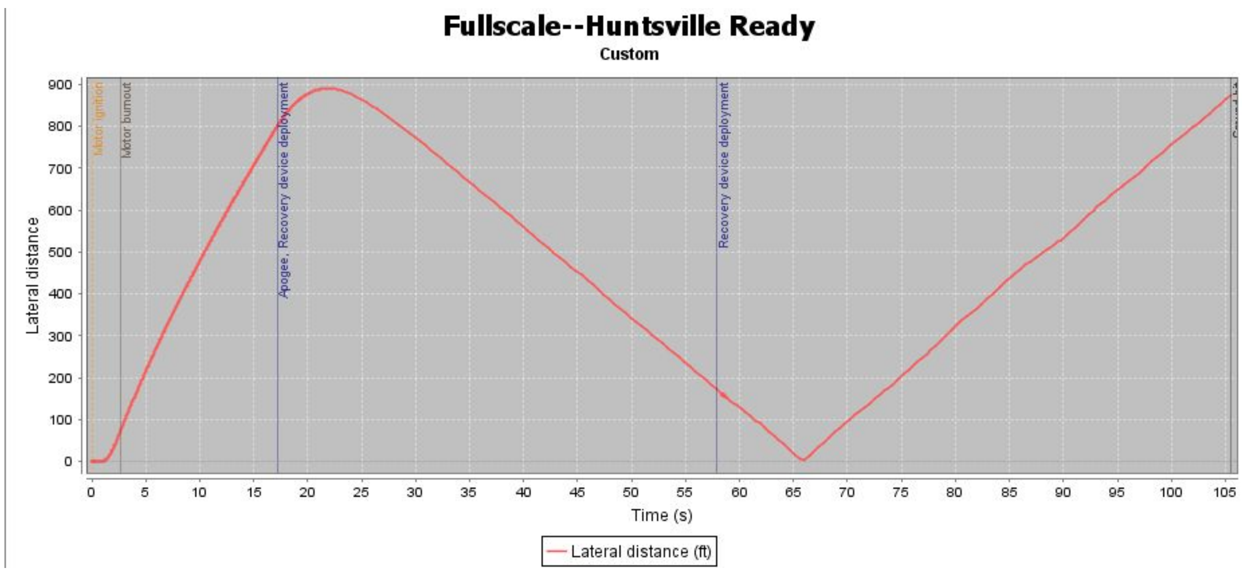


As shown in the graph above, the stability margin predicted by OpenRocket appears to change slightly, leveling out at approximately 4.75 calibers rather than 5. The rocket also appears to leave the launch rod with a lower stability margin of about 1.55 calibers, rather than just under 2.

2.4.2.2. Anchored Drift Predictions (15 mph crosswinds)



This figure shows the data for a GLOW of 42.5 pounds. Using the same method, the distance at apogee is 705.5 ft and the final value is -1594 ft. This gives a drift of 2299.5 ft. This suggests that lowering the weight will increase drift. Intuitively, this makes sense.

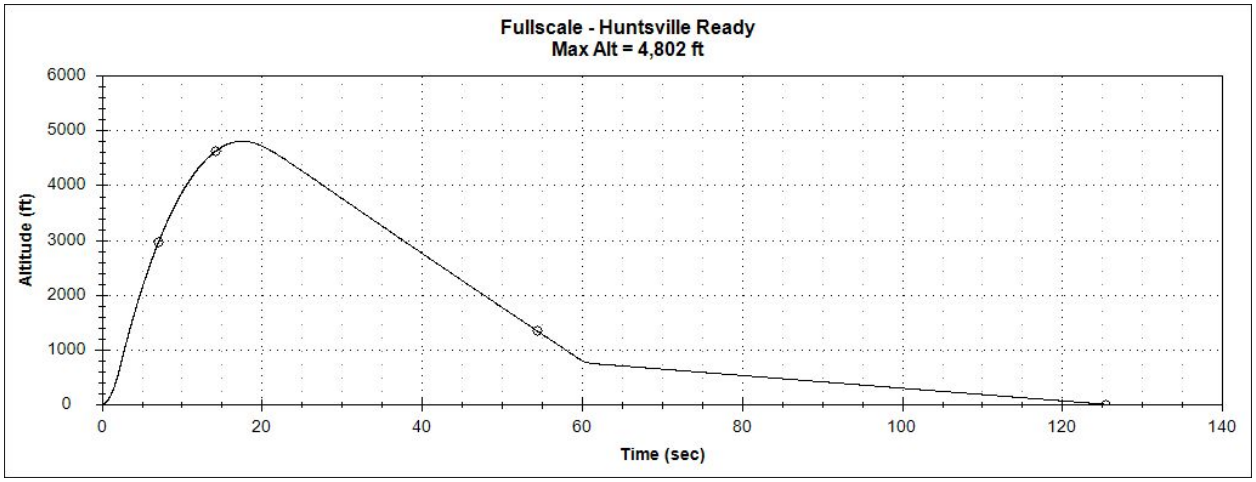


With the decrease in GLOW by 1 lb, the drift of the rocket was slightly increased, but not by a noticeable amount. OpenRocket still estimates the total drift distance of the rocket to be as much as 1800 ft.

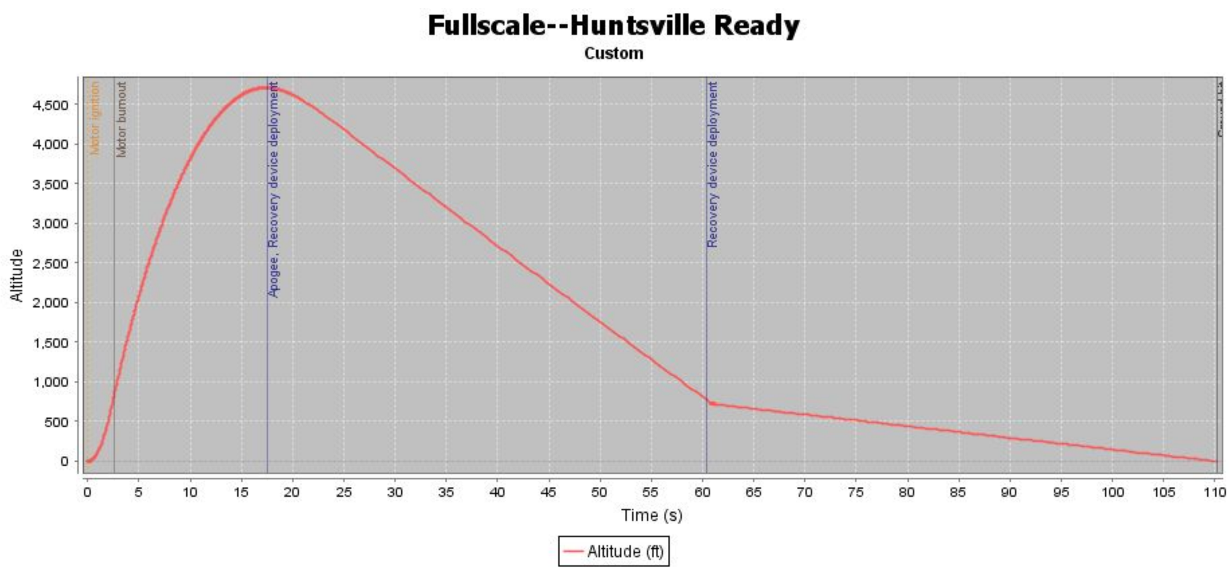
2.4.3. GLOW 41.5 lbs

2.4.3.1. Anchored Flight Predictions

2.4.3.1.1. Altitude Predictions (10 mph crosswinds)

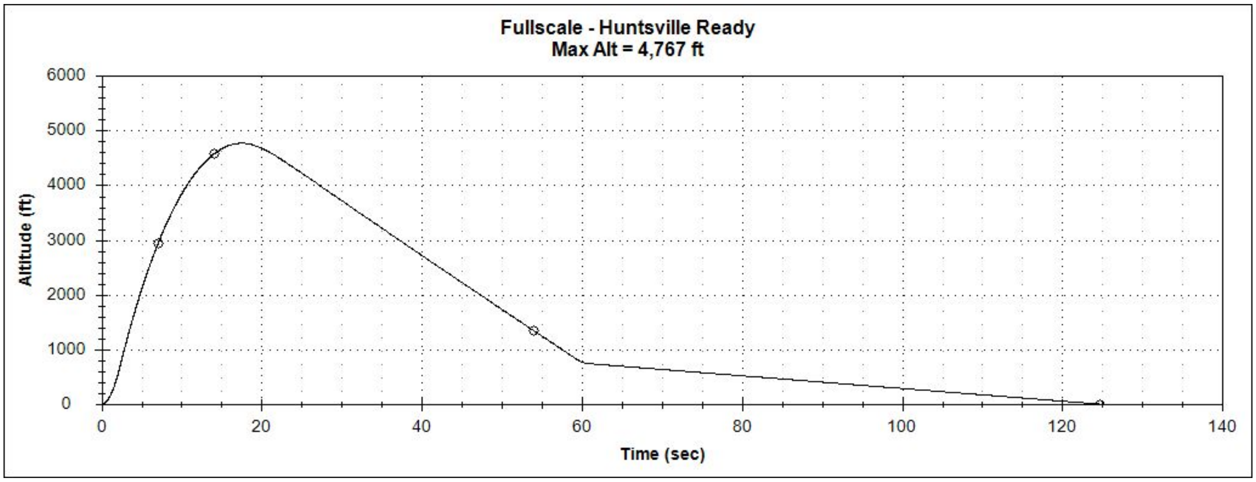


Final flight configuration will attempt to have a GLOW of 41.5 pounds. This will give the rocket a maximum predicted altitude of 4802 ft. This is still below the target altitude, but by less than 150 ft. This is a reasonable difference. However, the descent time continues to look like a problem. Historically, the rocket does not take this long to descend in similar wind conditions, so the team is not too concerned.

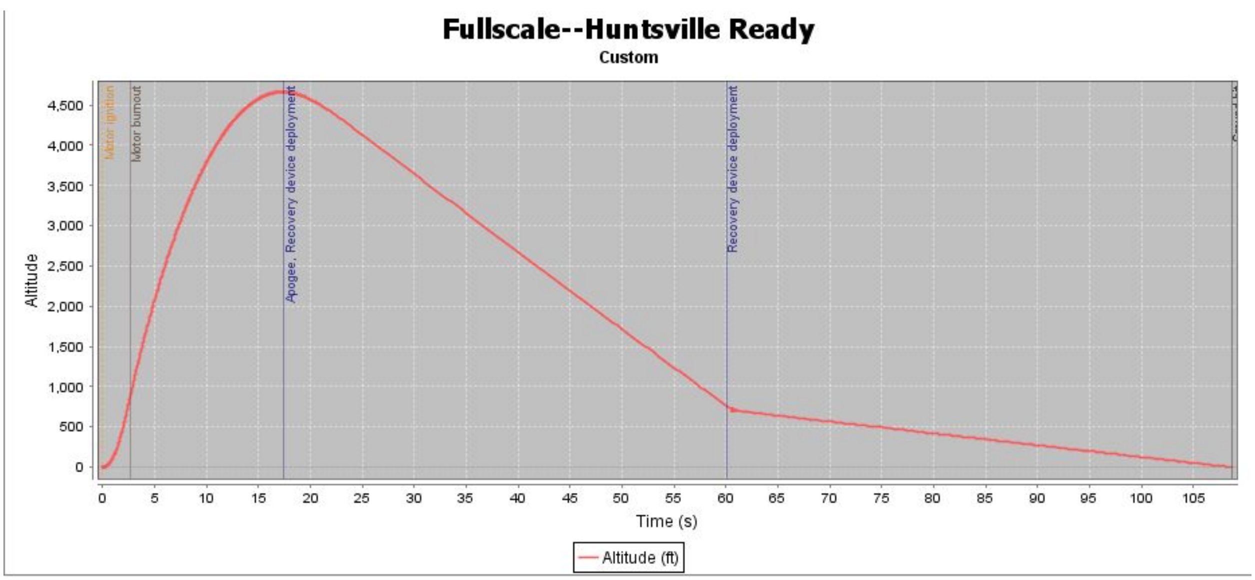


According to the OpenRocket simulation, the full scale rocket, with a GLOW of 41.5 lbs, will be approximately 4714 ft, which is slightly lower than the predictions from the RASAero simulation. However, the total flight time and the time to apogee predicted by OpenRocket are both similar to that from RASAero.

2.4.3.1.2. Altitude Predictions (15 mph crosswinds)

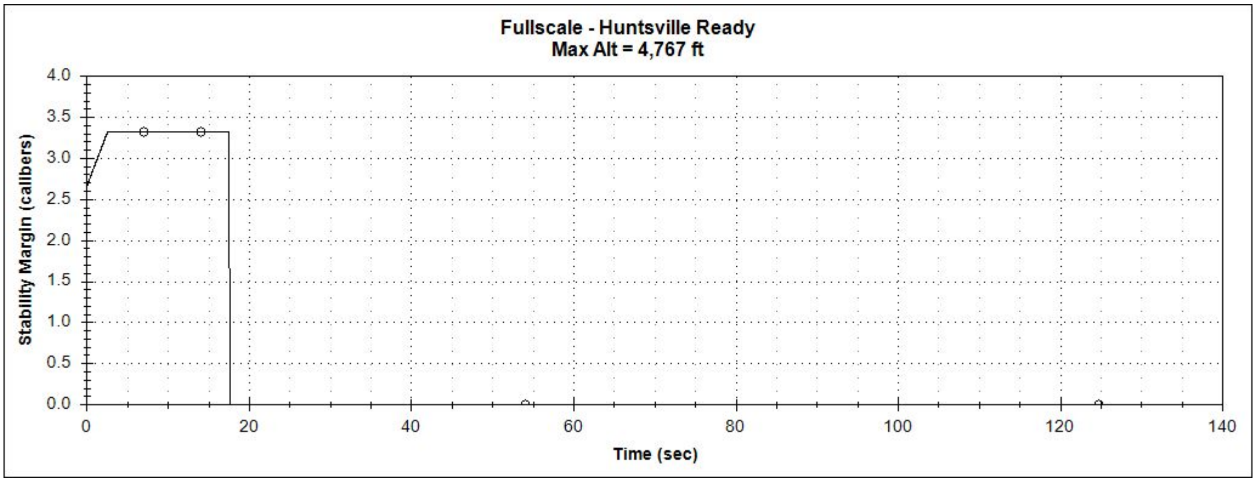


Altitude predictions for a final mass of 41.5 pounds will give a max altitude of 4767 ft. While this is still below the team's target altitude, it is an attainable weight and still within 5% of our target. This would still qualify as a team-derived flight success, so although the team would like to hit target altitude, settling for a 5% margin may have to do. Unfortunately, the time of flight is even longer than the previous weight. The team is confident that this number is inaccurate due to our two prior flights both being well below this number. Granted, the wind speed was slightly lower, but there was not enough of a difference to justify this large of a difference in flight time.

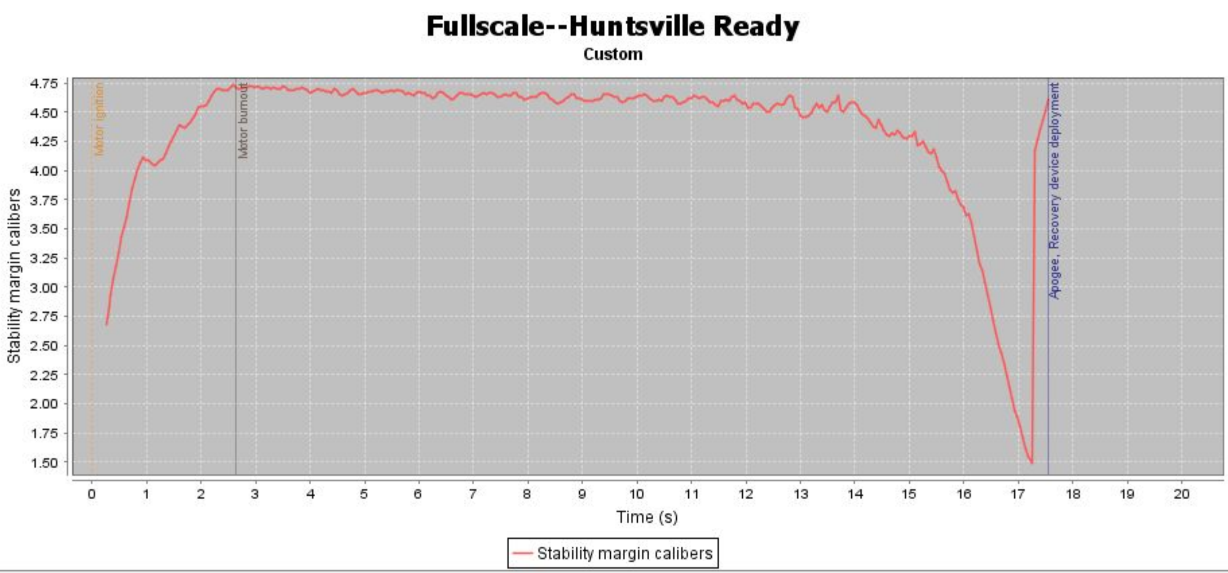


Shown above is the simulation from OpenRocket with a GLOW of 41.5 lbs and crosswinds of 15 mph. The predicted apogee from this simulation is 4664 ft, which is lower than that from RASAero. However, as with the other simulations, the total flight time is similar to that predicted by RASAero, being 109 seconds.

2.4.3.1.3. Stability Margin

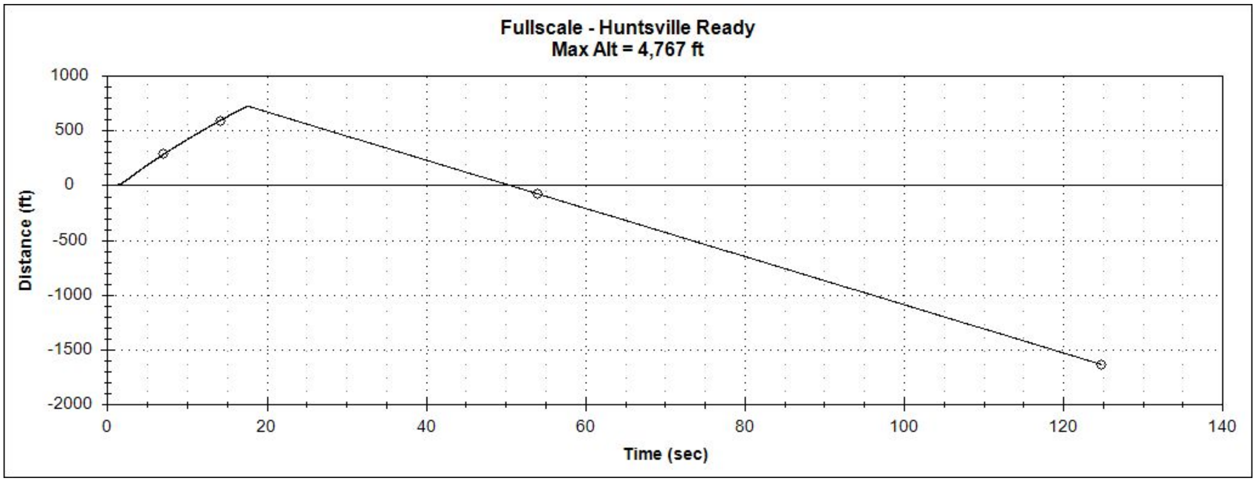


Again, the stability margin does not significantly change from that of the higher weights listed above. Stability margin is well within the range required plus a nice safety factor on top, so the team is happy with this value.

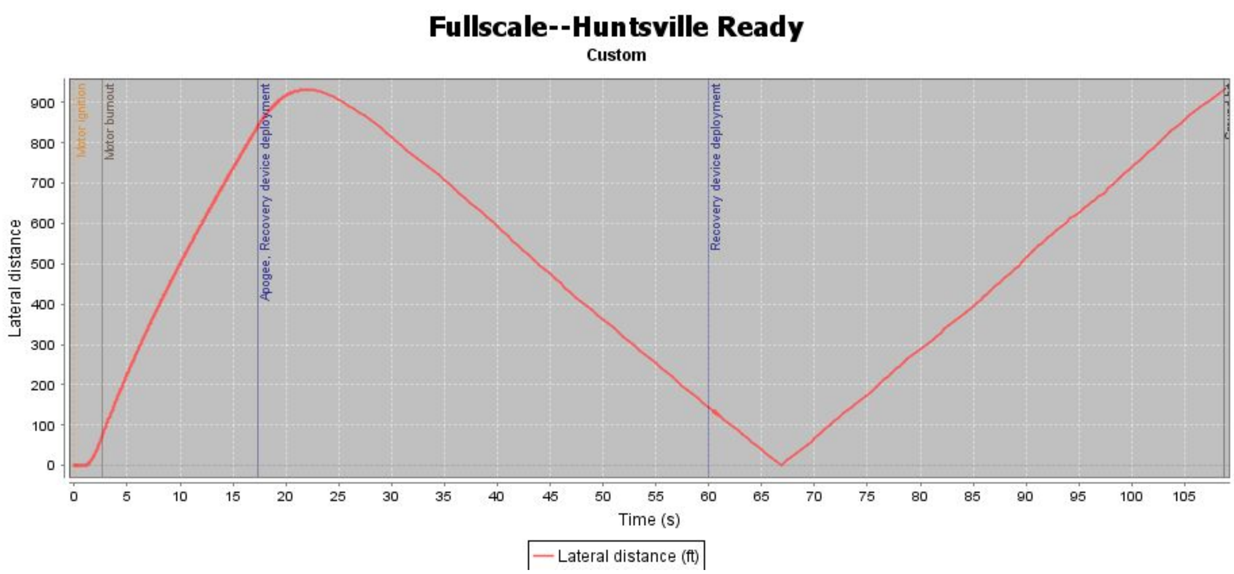


Again, the stability margin appears to have decreased slightly, leveling out just below 4.75, though the change between a GLOW of 42.5 lbs and 41.5 lbs does not seem to yield a significant change in the stability margin of the rocket.

2.4.3.2. Anchored Drift Predictions (15 mph crosswinds)



The final simulation for drift is shown above. Again using the same method, the drift will be calculated using an apogee distance of 723.3 ft and a touchdown distance of -1635.6 ft. Therefore, total drift will be 2358.9 ft. This number is frightening to the team. Since recovery is limited to a 2500 ft radius from the launch pads, the team is unsure the drift requirement will be satisfied in the event of 15-20 mph sustained winds. However, in lower wind speeds, the team has proven that the vehicle does not drift this much and are therefore confident in the rocket's ability to maintain this requirement.



With the GLOW of 41.5 lbs and crosswinds of 15 mph, OpenRocket yields a total drift distance of up to roughly 1900 ft. This is much less than that predicted by RASAero, and, as previously mentioned, does not seem to significantly change with the weight of the rocket.

2.5. Launch Vehicle Procedures

<u>Configure RRC3+ Sport</u>

Plug USB IO Dongle into computer using a working USB mini B cable (stock Missileworks cables are not reliable). Make sure USB IO Dongle dip switch is ON. On computer, launch mDACS.exe. In mDACS.exe, go to System Preferences, and select the Active COM port. May need to click Clear Active Port first. Go to RRC3 settings tab. Click RRC3 Host Connect. A 20 second timer will count down. Before the timer finishes, connect the USB IO Dongle to the RRC3+ Sport using the COMM port on both devices. Check all settings to make sure they are correct. Then, unplug the connector cable from the COMM port on the RRC3+ Sport. Wire the batteries. Connecting to the RRC3+ sport, red is positive, black is negative, and the 9V connector only goes on one way. Wire switch (set to OFF) and ejection charges to the RRC3, according to the Wiring Diagram below. Turn on RRC3+ Sport using the switch. A long 5 second beep will sound during startup. Listen for three beeps in a row. This indicates continuity on Main and Drogue. Turn the RRC3+ Sport off. When it's time to close avionics bay and it's time to launch: turn switch back on and make sure there are 3 beeps to indicate continuity on Main and Drogue. *Note: RRC3 orientation does not technically matter. However, the bay is designed with the RRC3 ejection charge terminal block facing down and the battery/switch terminal block facing up.*

<u>Configure Telemetrum</u>

Use a micro-usb cable to connect the telemetrum to a computer with AltOS installed. To recognise the telemetrum, the battery and switch must be connected. The battery will charge using the power from the computer's usb port. It may be necessary to leave the telemetrum plugged into the computer for a while to ensure the battery is fully charged. Open AltOS. A small window will appear. It is a good idea to delete all previous flights, as storage space on the telemetrum is very constrained. To do this, click Save Flight Data, and check the boxes to delete runs. Exit the window. Click "Configure Altimeter" and then turn on the Telemetrum using the switch. The Telemetrum should appear. Click on it and click select. *Note that if the teledongle antenna setup is connected, that will show up too. But you want to configure the Telemetrum.* Select all settings as desired. It is a good idea to set the flight log size at the largest possible, assuming the previous flights were cleared. TAKE NOTE OF THE FREQUENCY AND TELEMETRY BAUD RATE, AS WELL AS THE PAD ORIENTATION. Click save. Turn the altimeter switch to OFF. The pad orientation should be pointing down with the current design
On the Pad: (Use wiring diagram below as needed). Plug in LiPo battery into the battery port (red wire is positive and black wire is negative). Screw in switch wires into the appropriate slots. Screw in drogue and main e-match wires into the appropriate slots

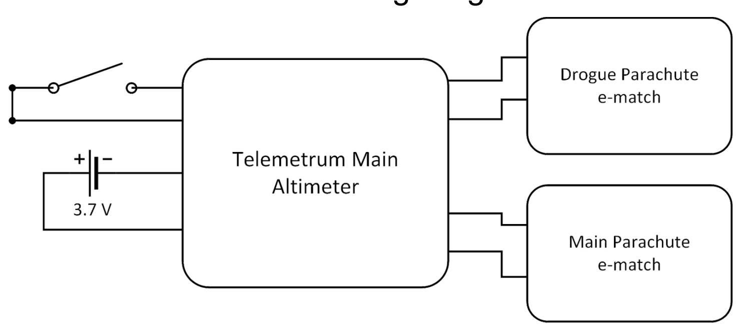
Before powering on the Telemetrum, ensure that it is in an upside-down orientation. Use the switch to power on the Telemetrum when the rocket is ready to launch. The Telemetrum should then emit the following sets of beeps:

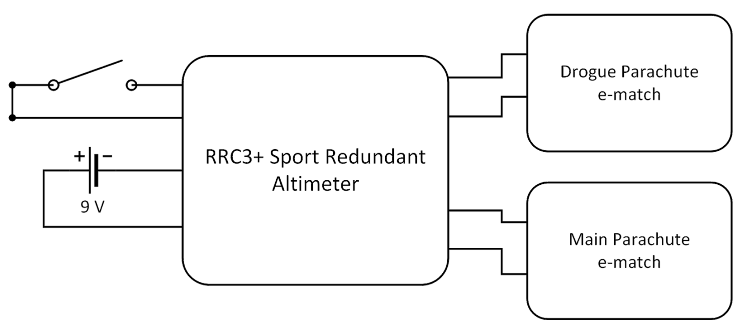
1. Four beeps, pause, one beep - Battery voltage
2. Dit, dah, dah, dit - Indicates pad mode; waiting for launch
    i. If only dit, dit - Indicates idle mode; ensure Telemetrum is in correct orientation
3. Dit, dit, dit - Continuity on both drogue and main e-matches
    i. If only brap - Indicates continuity on neither drogue nor main e-matches
    ii. If only dit - Indicates continuity on only drogue e-match
    iii. If only dit, dit - Indicates continuity on only main e-match
    iv. If warble - Storage is full; need to delete extraneous flights

<u>Set up the Teledongle</u>

Screw in the six purple rods, with the two shorter rods being on the top, and the rod with the teledongle attached being on the bottom. Connect the teledongle to the antenna. Connect the teledongle to the computer. Open AltOS. Select Monitor Flight and select the Teledongle. Set the frequency and baud to what was noted when the Telemetrum was configured.

Altimeter Wiring Diagrams



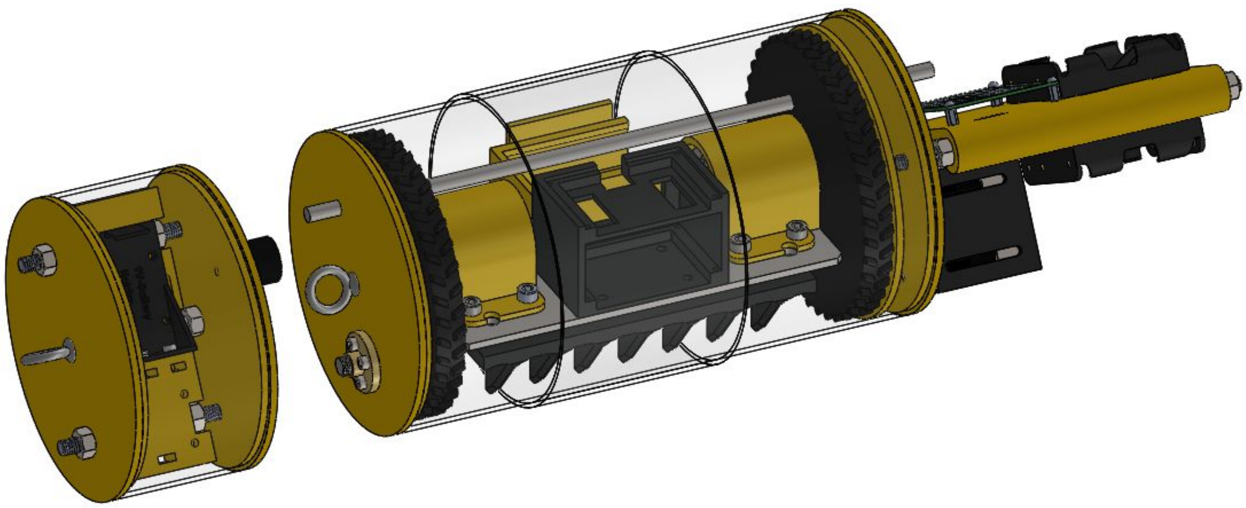


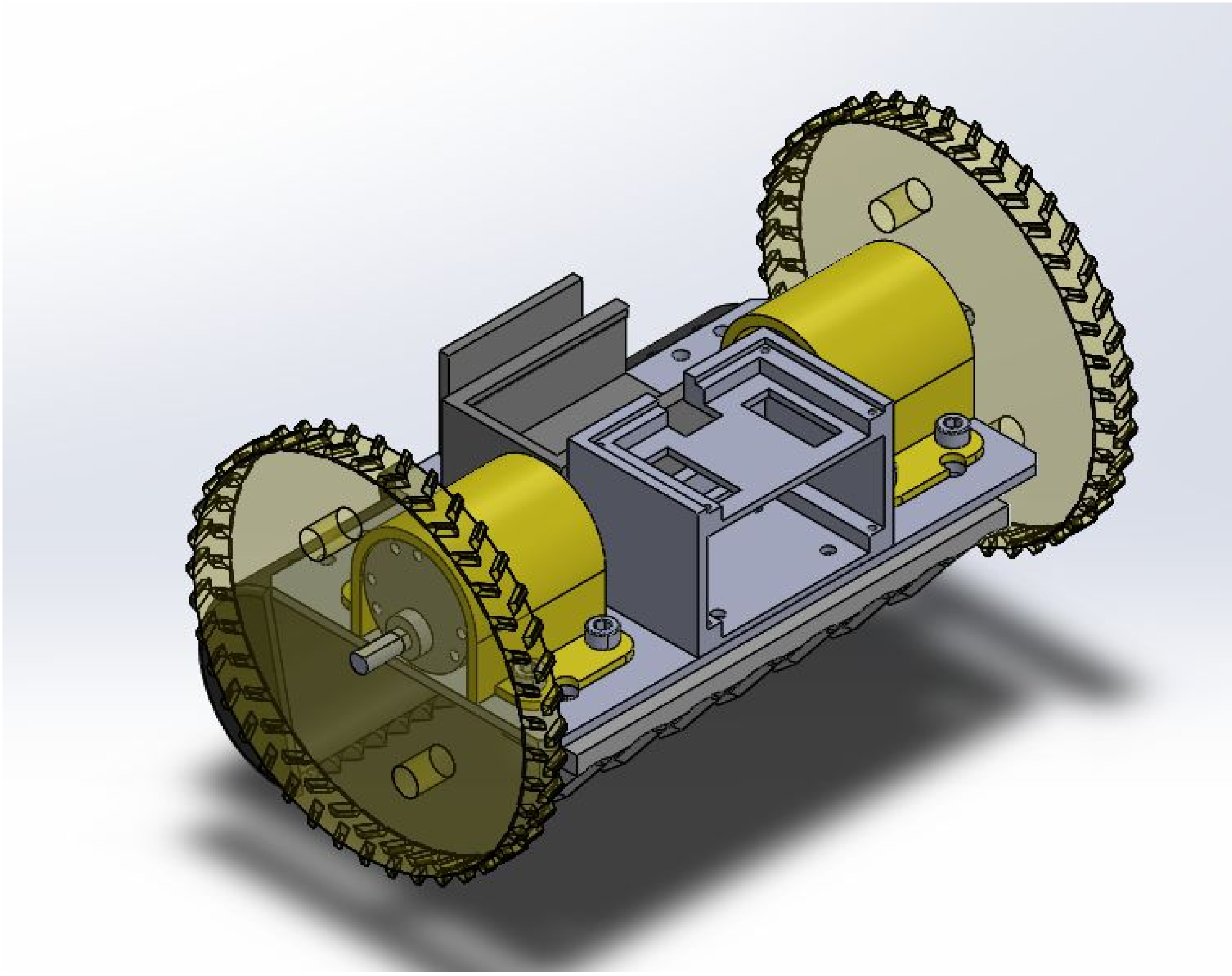
<u>Prepare Ejection Charges</u>

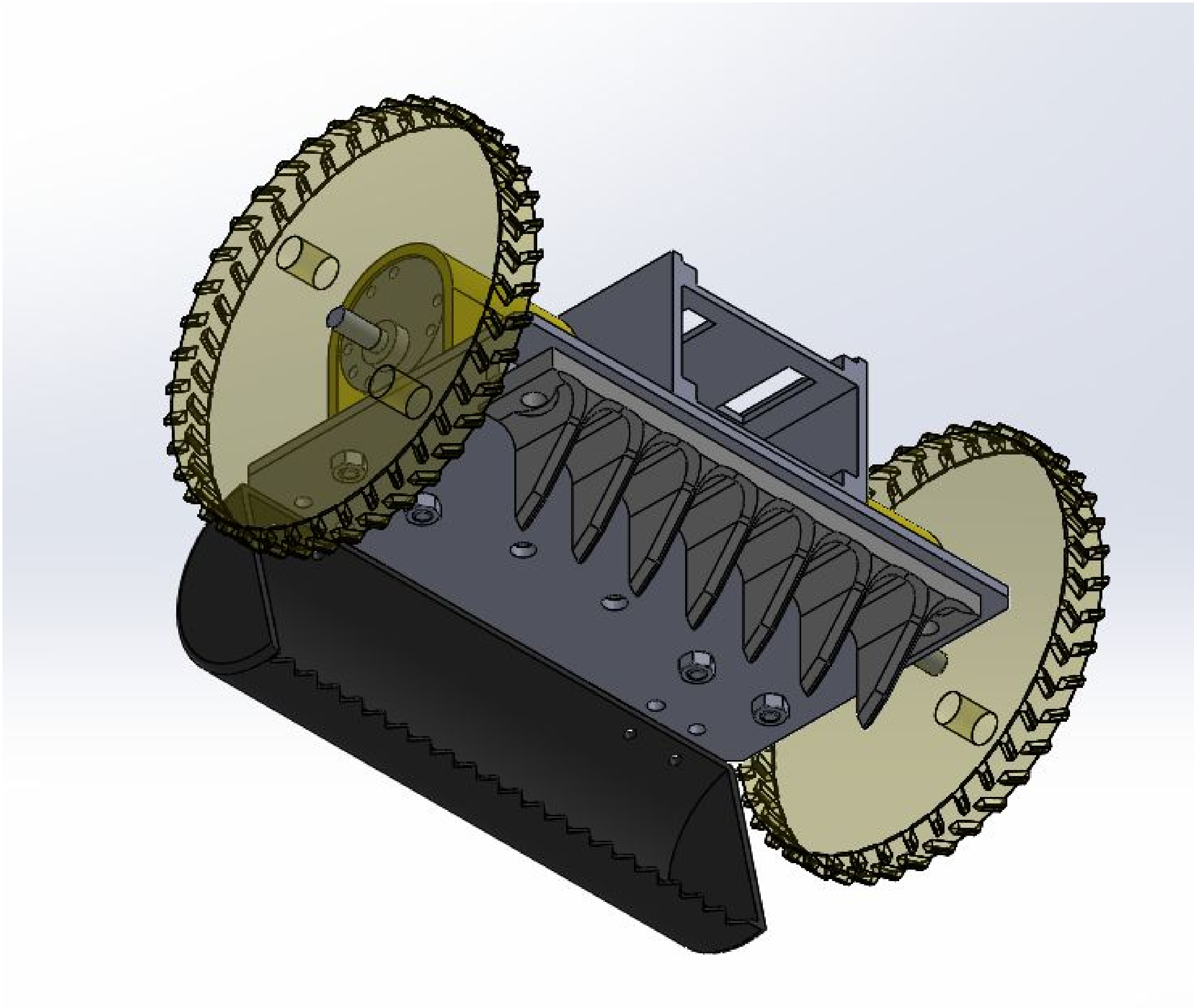
Note: Be very careful to not build up static electricity when preparing ejection charges. 4F black powder is very energetic and is a live ejection charge at any point after it is made. Cut off the finger of a disposable glove. Fill the fingertip of the glove with the amount of 4F black powder needed. Insert ejection charge into black powder. Close off the fingertip by tightly twisting the glove around the e-match wire and putting two zip ties around the twisted glove and wire. Truncate the zip ties. Feed the connection end of the ematch through the charge well and pull through so that the glove tip is inside the charge well. Pack the glove tip/black powder down into the charge well and pack dog barf on top. Seal the top of the charge well with tape.

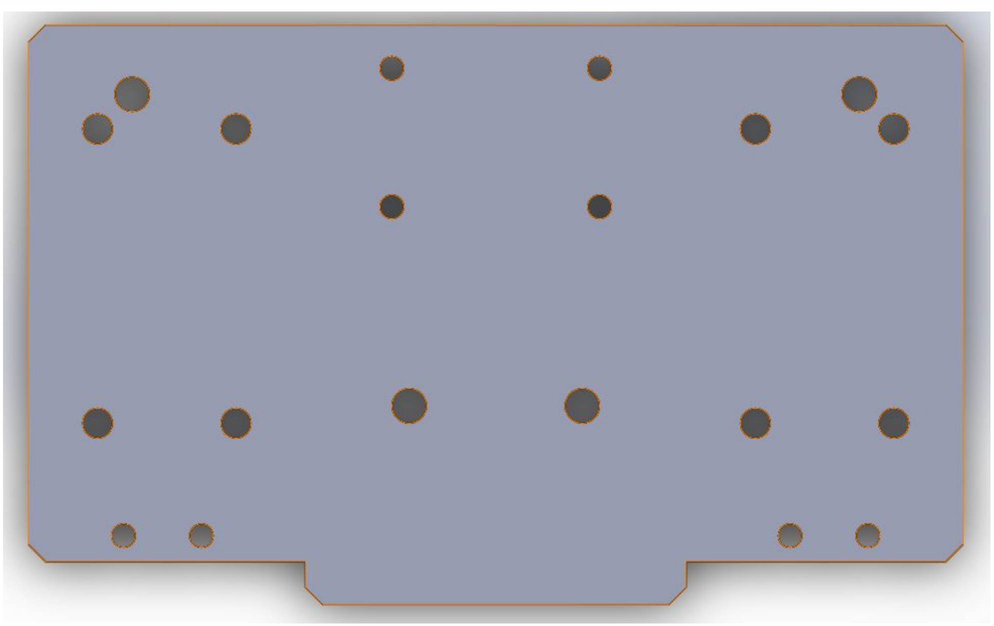
3. Payload In-Depth Summary

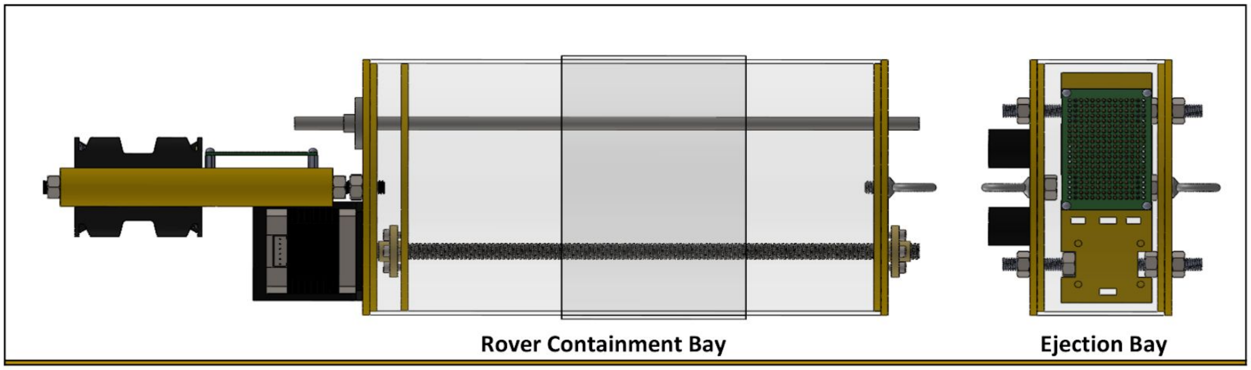
3.1. CAD and Step-By-Step Deployment CAD

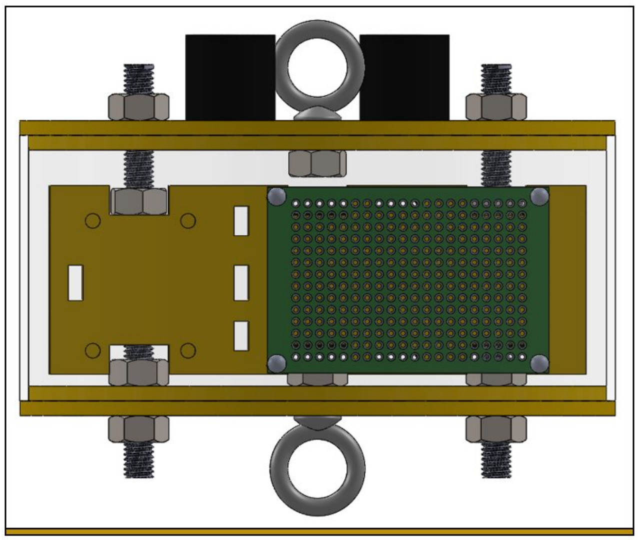


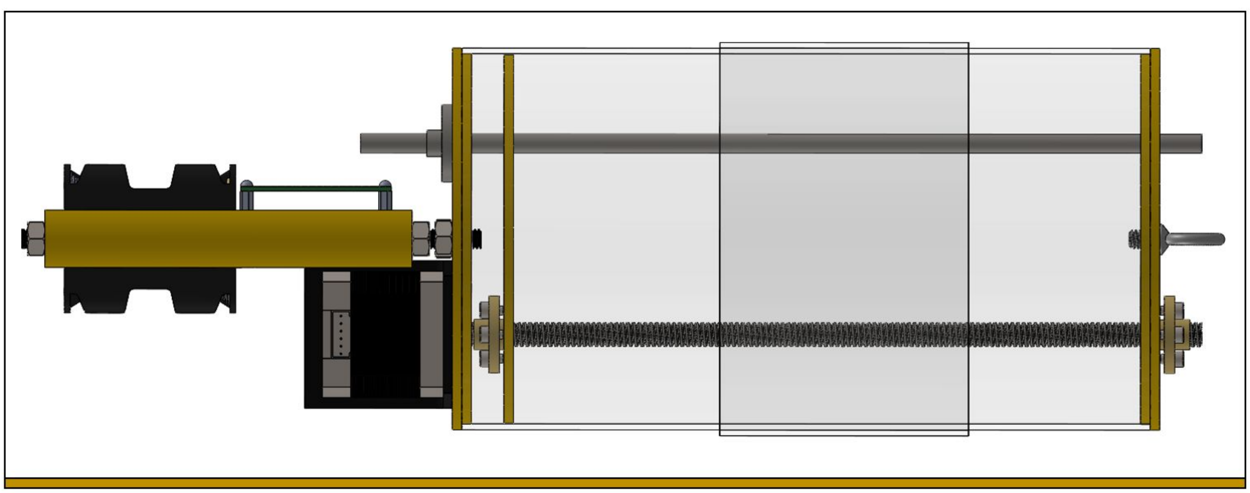


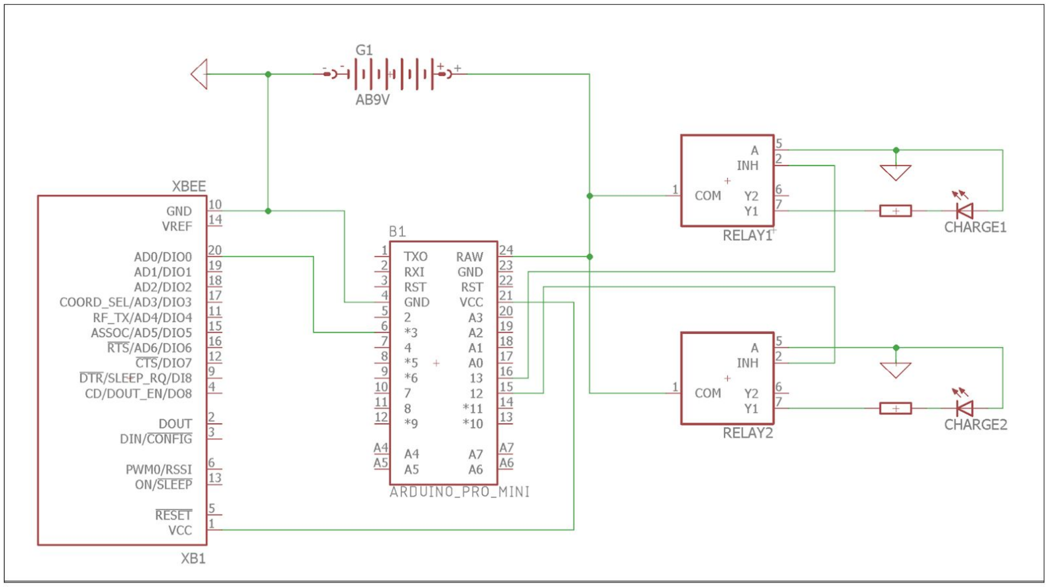





Rover Containment Bay
Ejection Bay



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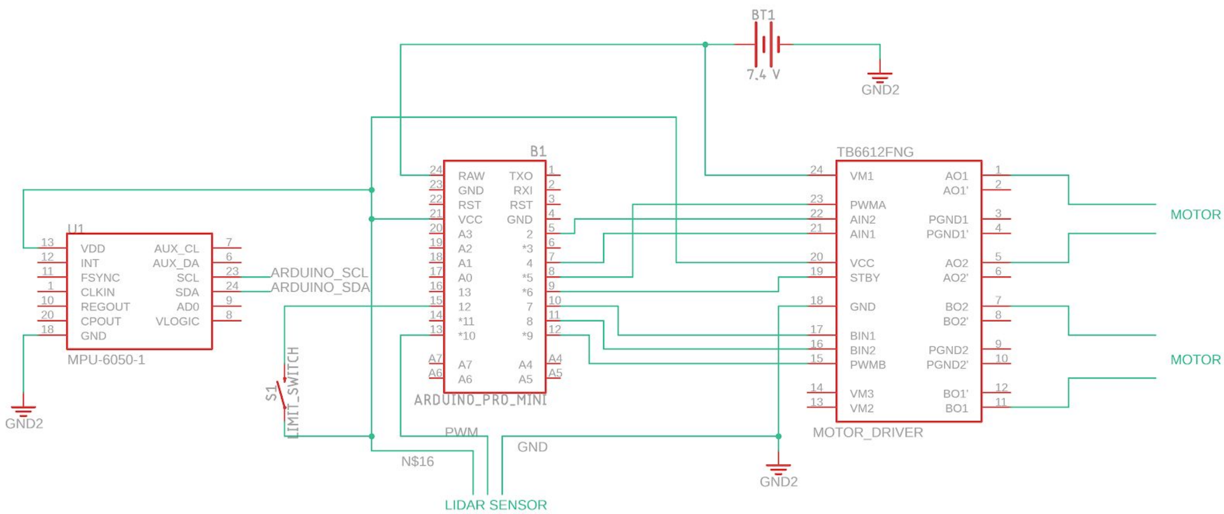
AB9V
XBEE
GND
VREF
AD0/DIO0
AD1/DIO1
AD2/DIO2
COORD_SEL/AD3/DIO3
RF_TX/AD4/DIO4
ASSOC/AD5/DIO5
RTS/AD6/DIO6
CTS/DIO7
DTR/SLEEP_RQ/DI8
CD/DOUT_EN/DO8
DOUT
DIN/CONFIG
PWM0/RSSI
ON/SLEEP
RESET
VCC
XB1
B1
TXO RAW
RXI GND
RST RST
GND VCC
ARDUINO_PRO_MINI
RELAY1
RELAY2
COM
INH
CHARGE1
CHARGE2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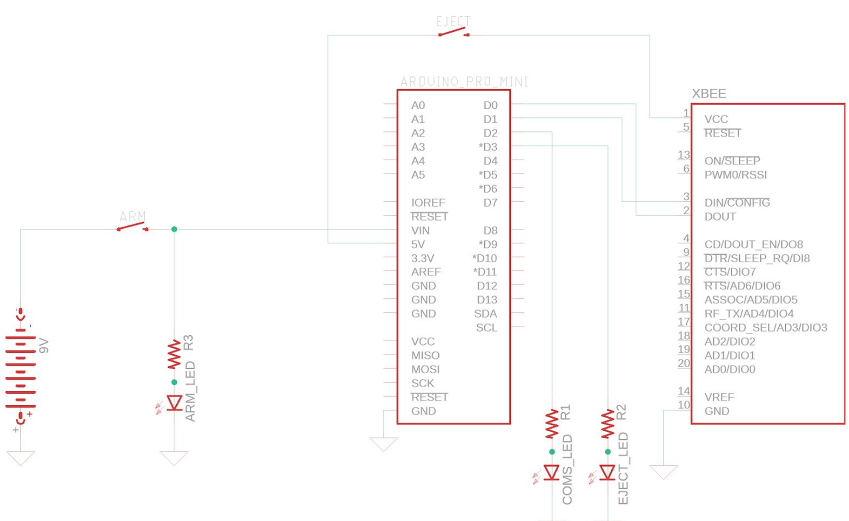
7.4 V
GND2
B1
TB6612FNG
U1
MPU-6050-1
ARDUINO_SCL
ARDUINO_SDA
S1
LIMIT_SWITCH
ARDUINO_PRO_MINI
MOTOR_DRIVER
MOTOR 1
MOTOR 2
PWM
GND
N$16
LIDAR SENSOR


EJECT
ARDUINO_PRO_MINI
XBEE
ARM
9V
R3
ARM_LED
R1
COMS_LED
R2
EJECT_LED

3.2. Transmitter Info

XBee Transmitters			
Brand	Xbee	RF Output Power (mW)	60
Model	Pro Series 1 (802.15.4)	Specific Frequency used by team (MHz)	2400
Handshake or frequency hopping? (explain)	Transmitters #1 and #2 are assigned 64-bit addresses in the manufacturing process. Each transmitter will be programmed to only send and receive data from the other transmitter. In this way, a basic handshake will be made between each transmitter.		
Distance to closest e-match or altimeter (in)	29.9		
Description of shielding plan:	Shielded boxing, short connections		

3.3. Payload Retention and Ejection

The Payload Retention System will serve to retain the rover within the launch vehicle during flight and protect the rover payload from any atypical flight forces. The retention and deployment subsystem consists of two distinct components: the Ejection Bay and the Rover Containment Bay. The Ejection Bay will control the ignition of black powder charges that will separate the Rover Containment bay from the rocket body which will create an opening for the rover to deploy from. The Ejection Bay will be fixed inside the upper airframe, and separate the Rover Containment Bay from the rocket's recovery system. The Rover Containment Bay is the primary component of the retention and deployment subsystem which will hold and deploy the rover. The Rover Containment Bay will have a section installed within the noseconse with the remaining section temporarily fastened to the upper airframe using shear pins to withstand any forces experienced during flight. The Rover Containment Bay and the Ejection bay will be attached to each other with a shock cord that will keep all rocket components connected even when the shear pins are sheared.

After a successful vehicle touchdown and upon receiving deployment instructions from the remote base station, the Ejection Bay will ignite its black powder charges and separate the Rover Containment Bay from the rocket body. Once separated from the rocket body, the Rover Containment Bay will have an opening that the rover will then be fully deployed from.

4. Safety

4.1. Briefings on Hazard Recognition/Avoidance and Launch Procedures

Prior to the first construction meeting, the team will hold a short briefing on basic launch vehicle construction safety in which all team members will be instructed on fundamental safety procedures (e.g. wearing protective eyewear during construction), as well as how to use lab equipment and recognize any potential hazards associated with it. In addition, the team will compose a checklist prior to all launches detailing the exact procedures that must be performed in order to ensure success and maximize launch safety. All inexperienced flyers will receive an additional briefing about basic launch safety (e.g. not standing immediately next to the launch pad as the launch control officer prepares to ignite the propellant situated on top of it).

Briefings will be carried out before major events and launches. A dedicated seminar during a team meeting will initially be provided to students on hazard recognition and accident avoidance to promote safety and keep students aware of the potential threats that exist. Historical and fictional examples will be generated to exemplify potential hazards and avoidance. Students will be required to sign a form acknowledging the potential threats as described at the seminar. Students must sign the form to ensure that safety standards are met and understood. The briefings and seminar will be made available throughout the group so that all members have permanent access. Dedicated pre-launch briefings will be presented and required to be acknowledged to attend a launch. Additional briefings and seminars will similarly be posted and required to ensure problems or concerns are addressed.

Briefings will cover the following topics and more:

- Lawful launch procedures which comply with FAA regulations, federal laws, and Purdue University policies
- What to do if the launch vehicle poses a threat at the time of launch
- What to do if the launch vehicle poses a threat during the flight
- What to do if the launch vehicle causes injury to a student or personnel
- What to do if the launch vehicle veers off the calculated course
- What to do in the case of unpredicted weather on the day of the launch

4.2. Caution Statements and Personal Protective Equipment Advisories

The safety officer will deliver a briefing on how to properly use the Personal Protective Equipment (PPE) this project necessitates. These necessary caution statements will be included before documented plans and procedures as a reminder of potential threats or concerns. All lab equipment will be labeled with the basic safety protocols associated with its use, including any PPE required to operate it. All hazardous materials will be stored in labeled containers.

The current established procedures for PPE, which will be updated throughout the course of the project, are as follows:

- All team members must secure loose hair and clothing and remove jewelry before participating in construction and fabrication processes or launches and before handling hazardous materials. Apparel should be metal-free and non-static producing.
- ANSI Z87.1-certified protective eyewear must be worn at all times during construction and fabrication processes, when handling hazardous materials, and during launches. Any safety glasses used must include a side shield.
- Thermal protection such as leather or canvas gloves must be used when working with hot objects. Such objects include, but are not limited to: recently-fired launch vehicle motors or objects which are being heated for construction or fabrication purposes. Team members must at the least wear cotton clothing for thermal protection.
- Proper NIOSH/MSHA-approved respiratory equipment must be worn in situations where airborne particle debris will be present as the result of a construction or fabrication process with limited ventilation.
- Measures must be taken to cover exposed skin when working with materials that are hazardous on contact such as epoxy. Nitrile rubber gloves and a lab coat or apron must be worn when working with these types of materials. Shoes that cover the entire foot must also be worn. In the case of a large spill or prolonged contact, boots must be worn. If clothing is soiled or contaminated, it should be removed ASAP.
- Ear protection must be worn when using equipment which creates a noise 85 decibels or louder. Earplugs or earmuffs should always be worn when operating power tools which create loud noises.
- Closed-toe shoes must be worn during all construction and fabrication processes.
- If using a machine with an instructor or teaching assistant, follow all instructions given both by this aide and the machine manual as to what PPE to use.

4.3. Facilities and Equipment

4.3.1. Zucrow Propulsion Labs

Zucrow Propulsion Labs is a facility with various research capabilities that encompass many disciplines within aeronautical and astronautical engineering. The team will be utilizing this facility (and more specifically the High Pressure Labs within Zucrow) to store hazmat materials such as the motors or other energetic devices (black powder, CO2 canisters, ignition supplies, etc.). The team will also be using the area to conduct deployment charge ground tests to ensure proper separation of the vehicle components at apogee and main parachute deployments. The team's contact for the site is Professor Scott Meyer, who is the Zucrow Managing Director, and is the only required personnel for the building. As a safety precaution to limit liability to team personnel, he will be the sole person with access into the secure areas where supplies will be stored in a safe and controlled environment. He will be available between 7 A.M. and 5 P.M.

Hours of Operation	7 A.M. - 5 P.M. or by appointment
Required Personnel	Scott Meyer for access, Safety Officer for safety
Necessary Equipment	Equipment specified by Scott Meyer and on-site instructions.
Safety Precaution	Limited access through Scott Meyer, climate controlled environment, and secured areas
General Use	Storage of potentially dangerous materials, such as high energy devices (motor, compressed gas, igniters, black powder, etc.)

4.3.2. Aerospace Science Labs (ASL)

The Aerospace Science Labs (henceforth referred to as ASL) is an annex attached to the Purdue University Airport that specializes in manufacturing and wind tunnel testing. It is also where Purdue SEDS has their storage area. Although the building is only publicly open between the hours of 7 A.M. and 5 P.M., the team will have full access around the clock thanks to Ben Walbaum, current Purdue SEDS president and Chris Nilsen who is last years president of the Purdue SEDS Executive Board and has a keypad code to the doors. The team will use this area for general assembly as it is where the majority of the team's parts, building supplies, and tools will be stored. The team will be utilizing basic manufacturing equipment such as drill presses, table saws, rotary tools, and vertical bandsaws. The team will also have access to construction equipment including adhesives, abrasives, craft knives, and common hand tools (pliers, screwdrivers, wrenches, taps, etc.).

Hours of Operation	Around the clock access with use of key
Required Personnel	Chris Nilsen for access, Safety officer for safety
Necessary Equipment	Drill presses, table saws, vertical bandsaws, adhesives, abrasives, and common hand tools
Safety Precaution	Team members must be briefed on proper safety precautions for using the ASL's equipment by the safety officer before being allowed to use the building's resources. PPE in the form of earplugs and safety glasses is available on-site.
General Use	Vehicle assembly, light manufacturing

4.3.3. Bechtel Innovation Design Center (BIDC)

The Bechtel Innovation Design Center (BIDC) is an advanced prototyping facility and machine shop which is located on campus and is available to all Purdue students. All students who enter the shop must take a series of online quizzes for each type of tool or machine they wish to use, and will be paired with a teaching assistant or Purdue employed machinist for the duration of their project. These rules, safety concerns, and safety protocols will be applied to all machining and safety for every location used by the team (Zucrow, ASL, etc.) to where all must be briefed before working with construction or operations. The BIDC is only open from 9 A.M. to 5 P.M. during the business week since a trained professional must always be present to minimize safety hazards. The team will use equipment such as sandblasters, mills, CNC's, paint booths, laser cutters, belt sanders, routers, and similar manufacturing machines at this facility for fabrication of custom or complex parts. All proper PPE will be worn in addition to the machinery having emergency protocols with emergency stop buttons and guards.

Hours of Operation	9 A.M. - 5 P.M.
Required Personnel	TA supervisor or Purdue employed machinist

Necessary Equipment	Sandblasters, mills, CNC’s, paint booths, laser cutters, belt sanders, routers, etc.
Safety Precaution	TAs or employed machinists must always be present when using machines, team members must take quizzes and undergo training before using machines
General Use	Fabrication of custom or complex parts

4.3.4. Purdue BoilerMAKER Lab

The Purdue BoilerMAKER Lab specializes in additive manufacturing. The team will be using their lab space and equipment in order to rapidly prototype parts. This can be done for testing tolerances and function, creating tool guides and jig assemblies, or creating mounting surfaces for the payload and electronics systems. The makerspace operates between the hours of 10 A.M. to 7 P.M. from Monday through Thursday and 10 A.M. to 4 P.M. on Friday, and is closed for the weekends. Due to the high temperatures associated with 3D printing, the team will be letting the lab assistants and technicians handle the machinery and parts as they are being produced. The team member who designs a part will then be responsible for going and retrieving the part from the lab.

Hours of Operation	10 A.M. - 7 P.M. M-Th, 10 A.M. - 4 P.M. Fr
Required Personnel	Lab assistants, part designer
Necessary Equipment	3D Printer, various types of plastic filament, CAD software, computer station
Safety Precaution	Lab assistants will handle the machinery and parts during production to avoid burns to the team members and will oversee the machines to ensure no problems arise
General Use	Rapid prototyping and development

4.4. Safety and Environment (Vehicle and Payload)

The seriousness of the risks discussed in this section will be evaluated by two criteria: the likelihood of an event to occur and the impact of the event should it happen or fail to be prevented. Categories of likelihoods and impacts are discussed below:

4.4.1. Likelihood of Event

Category	Value	Gauge
Remote	1	Less than 1% chance of occurrence.
Unlikely	2	Less than 20% chance of occurrence.
Possible	3	Less than 50% chance of occurrence.
Likely	4	Less than 80% chance of occurrence.
Very Likely	5	Greater than 80% chance of occurrence.

4.4.2. Impact of Event

Category	Value	Gauge
Negligible	1	Minimal injury, damage to equipment or facility, or environmental effects. Flight continues as normal.
Minor	2	Minor injuries, major reversible damage to equipment or facility, and minor environmental impact. Flight proceeds with caution.
Moderate	3	Moderate injuries, reversible failure, and reversible environmental impact. Flight is put on hold until effects are reversed.
Major	4	Potentially serious injuries, partial failure, and serious, reversible environmental effects. Flight is scrubbed or put on hold until system is removed.
Disastrous	5	Potentially life threatening injury, total failure, and serious, irreversible environmental damage. Flight is scrubbed or completely destroyed.

By cross examining the likelihood of an event with the impact it would have if it occurred, a total risk can be calculated which is detailed in the table below. The color code displayed is as follows:

- Green: Minimal risk
- Yellow: Low risk
- Orange: Medium risk
- Light red: High risk
- Dark red: Very high risk

4.4.3. Total Risk of Event

Category	Negligible	Minor	Moderate	Major	Disastrous
Remote	1	2	3	4	5
Unlikely	2	4	6	8	10
Possible	3	6	9	12	15
Likely	4	8	12	16	20
Very Likely	5	10	15	20	25

Risks that are above medium, as designated in orange to have higher safety importance with respect to likelihood and/or impact, must be signed off by the team lead, safety officer, and project manager. Hazards that have above a medium risk will be continuously designed to where the risk will be lowest. Since most risks occur during launch and it is at this time when probability for hazards to occur is expected to be highest, the mitigations and verifications will be strictly followed specifically and importantly at launches. Additionally, possible failures to the program according to the following analyses must be addressed ahead of time to where individuals are safe and the team continues to thrive. For the protection of individuals and the team, PPE will always be on and verified by team members for working on a task.

For all subsequent safety tables, the hazards, likelihood, severity, risk, mitigation, and verification will be considered, in addition to consideration of occurrence. Verification and mitigation will be different in that verification will to be to prove a control is in place while mitigation is the intended plan to control a situation. Final verifications will exist by showcasing design, analysis, testing, PPE/procedures, or another reference. These analyses shall help demonstrate the collective understanding of all components needed to complete the project and how risks/delays impact the project. Each verification will include strictly following the mitigation as a procedures/checklist in order to lower the risk. Verifications will use all information available and will constantly be improved to include more test data, design analysis, written procedures and checklists, and as-built configuration drawings. Similarly, verification will be done by testing, analysis, inspection, and demonstration with different criteria for design requirements or subsequent success. Verification by testing is the most rigorous way to verify as it is a planned method of checking for a specific parameter defined by a pass or fail criteria and involves collecting data and comparing it to an expected or predicted outcome. Verification by analysis relies heavily on data from previous studies or tests to create models and equations of the scenario and can be done through simulation, calculation, or survey of the system with a follow-up work to determine if it passes or fails. Verification by inspection of a system or subsystem can determine the condition and status of the system and is used if the result can be easily determine without calculation with a criteria and expectations. Lastly, verification by demonstration showcases the performance of a system or subsystem and implies that current success of a task implies future success of the same task but still with no guarantee.

4.4.4. Project Risks

The following hazards threaten the progress or completion of the project as a whole:

Hazard	Likelihood (Cause)	Severity (Effect)	Risk	Mitigation	Verification	Risk After
Improper Funding	3 (Lack of revenue)	5 (Inability to purchase parts)	15, High	Create and execute a detailed funding plan properly, minimize excessive spending by having multiple members check the necessity of purchases	Project lead shall keep track of budget to have an account of funding coming in and a timeline of what to have purchased, completed, or obtained by when; must have a plan B	High
Failure To Receive Parts	2 (Shipping delays, out of stock orders)	5 (Cannot construct and fly vehicle)	10, Medium	Order parts while in stock well in advance of needed date; attempt to use universal components dealt by multiple companies	Keep list of parts required and checklist for when purchased; set at minimum a week deadline to purchase components necessary before required and to make minute final adjustments in the remaining week	Medium
Damage to or Loss of Parts	2 (Failure during testing, improper part care during construction, transportation , or launch)	5 (Cannot construct or fly vehicle without spare parts)	10, Medium	Have extra parts on hand in case parts need to be replaced, follow all safety procedures for transportation, launch, and construction; attempt to use universal components dealt by multiple companies; keep parts secured in	Keep extra parts list and list of parts with potential of failure and delivery time to have time to fix or replace parts; check all shipping orders and ensure that extra parts are ordered; set at minimum a week deadline to purchase components necessary to core functionally before required; ensure after testing, construction, or	Low

				designated safe location	launch that parts are stored in the designated safe location as designated, and listed in the checklist	
Rushed Work	2 (Rapidly approaching deadlines, unreasonable schedule expectations)	4 (Threats of failure during testing or the final launch due to a lower quality of construction and less attention paid to test data)	8, Medium	Set deadlines which both keep the project moving at a reasonable pace and leave room for unforeseen circumstances; ensure at least two people are working to ensure safety and quality work	Keep team updated on all deadlines by maintaining effective communication; project lead enforces milestones and urges team to work proactively; have at least two people working with group checklist	Medium
Major Testing Failure	2 (Improper construction of the rocket, insufficient data used before creating the rocket's design)	5 (Damage to vehicle parts, possible disqualification from the project due to a lack of subscale flight data, an increase in budget for buying new materials, delay in project completion)	10, Medium	Only include reliable elements in the design which have been confirmed to work through prior designs or extensive mathematical and physical analysis	Follow safety measures in place to make sure failure does not occur in first place; have contingency plan to easily replace the components from spare components if failure occurs, as listed above; safety team will compare the construction with drawings / CAD models to verify construction quality	Medium
Unavailable Test Launch Area	2 (Failure to locate a proper area to launch subscale rockets for testing, failure to receive an FAA waiver for the test launch)	5 (Disqualification from the project due to a lack of subscale flight data)	10, Medium	Secure a reliable test launch area and FAA waiver well in advance of the dates on which test launch data is required; have team lead and Safety lead agree on mutual area	Make sure to secure multiple backup test launch areas in advance in case of unavailability of other launch areas or failure to receive an FAA waiver; project lead must present any related documents upon request for verification	Medium
Loss or Unavailability of Work Area	1 (Construction, building hazards, loss of lab privilege)	4 (Temporary inability to construct vehicle)	4, Low	Follow work area regulations and have secondary spaces available	Keep a list of backup work areas in case there is a need for a temporary work area (due to construction in primary work location)	Low

Failure in Construction Equipment	1 (Improper long-term maintenance of construction equipment, improper use or storage of equipment)	3 (Possible long-term delay in construction)	3, Low	Ensure proper maintenance and use of construction equipment and have backup equipment which can be used in case of an equipment breakdown	Keep equipment safe following proper protective measures to keep first the user safe and then the equipment; have backup construction equipment	Low
Insufficient Transporta-tion	1 (Insufficient funding or space available to bring all project members to launch sites or workplace)	3 (Loss of labor force, team members lose knowledge of what is happening with the project, low attendance to the final launch)	3, Low	Organize and budget for transportation early and keep track of dates on which large amount of transportation are needed	Have list of team members going and have list of maximum transportation amounts; make sure permanent funding exists for transportation; utilize an attendance roster well in advance before travel	Low
Design Flaw	2 (Program logic error, improper data entry, oversight)	5 (Inability to complete objectives or construct vehicle)	10, Medium	Collaborate and share design files for peer evaluation; only include reliable elements in the design which have been confirmed to work through prior designs or extensive mathematical and physical analysis	Make sure all sub team leads and responsible team members review design before assembly; have contingency plan to easily replace the components from spare components if failure occurs, as listed above; safety team will compare the construction with drawings / CAD models to verify construction quality	Medium
Lack of Communica-tion	3 (Members fail to keep other members updated on their personal progress and pertinent information they are aware of)	3 (Possible oversight of important deadlines or project aspects, possible delays to the project from a design which does not mesh well)	9, Medium	Encourage members to talk to each other about the project; have an organized group of subteams within the project and obtain updates from subteam leaders weekly	Employment of attendance tracking methods such as a sheet and utilization of electronic communications; use Google Docs and Slack to document attendance and ensure communication	Low
Inactivity	2 (Members are unable or unwilling to work)	5 (Low attendance, loss of team members, labor shortages,	10, Medium	Train all members to work in all areas necessary; have an organized group of subteams	Utilization of work time table; employment of attendance tracking methods such as a sheet and utilization of	Low

		inability to construct vehicle)		within the project and obtain updates from subteam leaders weekly	electronic communications; use Google Docs and Slack to document attendance and ensure communication	
Low Availability of Personnel	2 (Classes become extremely involved, other extracurricular s have events which cannot be skipped)	2 (Labor shortages, low attendance, specific responsibilities of absent team members are overlooked)	4, Low	Determine who has time to complete tasks and declare those members responsible, ensure the schedule and deadlines are known by all team members so they can work around them, have team members prevent their semester schedules from being too strenuous	Attendance; ensure new team members may join and help if personnel are unable to attend mandatory events, avoidable if mitigation is followed to where dates are determined by group members to ensure availability is not a significant issue	Low
Personnel Injury	2 (Members are unable to work)	5 (Temporary loss of team member and labor force)	10, Medium	Keep first aid kit on hand at all times and train all members to follow procedures	Ensure team members disclose injury to be attended to or call for additional assistance	Medium
Damage By Non-Team / Team Members	1 (Accidental damage caused by other workspace users)	4 (Extensive repairs necessary, delay in construction)	4, Low	Separate all components from other areas of the workspace as necessary, for organization, management, and safety concerns, in the designated area accessible only by team members to ensure in most safe and secure location that is unable to be inadvertently damaged	Ensure only team members as known can have access to components by following the mitigation as accessible to only members; ensure a lead is present to surveil; ensure storage location is in most safe and secure location that is unable to be inadvertently damaged by gently moving the launch components to ensure fixed or stable	Low
Improper Transit Availability	1 (No safe way to transport the	5 (Failure to launch)	5, Low	Organize rocket transportation well in advance;	Ensure transportation is set in advance and known to have transportation;	Low

for Rocket	subscale rockets or final rocket to the launch site)			ensure transportation can be sent to rocket location and capable of fitting rocket; fill out driver transportation form	ensure all drivers have filled out the necessary necessary form to ensure drivers are safe and permitted through the University to drive students and team members to launch sites and potentially design sites	
Damage During Transit	2 (Mishandling)	5 (Inability to fly rocket)	10, Medium	Protect all rocket components during transit; ensure rocket is secured at multiple locations to make sure no movement	Ensure rocket safety secured by testing movement of rocket secured at least two points; have teammate able to see and handle rocket in case error were to occur	Low
Calendar Conflicts	3 (Overlap with classes)	4 (Inability of team members to travel)	12, Medium	Inform professors and concerned persons about overlap ahead of time	Ensure professors are aware of calendar conflicts as documented once new semester starts and checklist or at least a week away	Medium
Failure to Plan for Breaks and Holidays	1 (Unreasonable expectations of team members)	1 (Slight delay in project progress)	1, Minimal	Do not expect a large amount of progress over breaks and holidays, as members will likely be busy and/or distanced from the designated workplace	Purdue Academic Calendar known in advance; ensure team leads are active over break and have longer meeting once break is over to complete what must have been completed	Minimal
Weather Delays	3 (Poor weather conditions during test launches, such as high wind speeds, ice and frost, or storms)	5 (Possible disqualification from the project due to a lack of subscale flight data)	15, High	Have multiple dates available on which test launches can be conducted in case of adverse weather conditions	Have backup date planned before with multiple days shared as workable	High

4.4.5. Personnel Hazard Analysis

The following hazards are threats to team members and bystanders presented by the project:

Hazard	Likelihood (Cause)	Severity (Effect)	Risk	Mitigation	Verification	Risk After
Assembly Malfunction	2 (Rocket destruction, splintering, etc.)	3 (Minor scrapes, splinters, bruising, abrasions, possible tripping over debris)	6, Low	Ensure instructions are followed and rocket is gently assembled in order to not break the rocket or injure personnel; wear appropriate PPE such as protective eyewear, gloves, face mask, and/or lab coat; follow any other rule set forth through Safety and written procedures and checklists;	Ensure verification by inspection with safety lead ensuring components are safe to assemble and that the assembler is supervised; strictly follow the mitigation and have a team lead assemble the rocket to ensure it is assembled correctly without possibility of other hazards	Minimal
Black Powder Incorrectly Measured	3 (Bad calculation or communicatio n	5 (Severe injury, death from unexpectedly large explosion)	15, High	Ensure with multiple calculations and measurements by at least three individual workers and at least one lead that correct measurement in addition to testing said amount in a secure area to ensure safe with test data; ensure labelled and secured; create a written procedure of how to measure the exact amount and try to use the same individual who measured the powder to repeat for later use with the safety lead continuously supervise	Strictly follow the mitigation and use testing and the written procedure of how to measure the exact amount; have the individual who measured the powder only handle the black powder if the individual possesses a low-explosives user permit and is supervised by the safety lead; guaranty PPE worn and checked during handling by a safety team member before and during use	Mediu m
Burns From	2 (Close	3 (Mild to	6, Low	Clean the	Ensure 200 feet border	Low

Motor Exhaust	proximity to launch pad)	moderate burns)		launchpad before use, ensure all members are wearing proper PPE for launch, ensure all team members are a minimum clear distance of at least 30 meters from the launch vehicle when launching and maintain minimum safe launch distances	be established after mounting of rocket onto launcher as compliance to NAR safety standards; prior PPE check must be done by a safety team member before ignition; Make sure area is evacuated and designated individuals are to recover components at a designated time when determined to be safe; no contact allowed without call out before use to make sure PPE worn	
Cuts or Lacerations from Damaged Rocket Components	3 (Sharp edges from damaged parts)	3 (Moderate cuts or lacerations to personnel retrieving the rocket)	9, Medium	Check the rocket for sharp edges before recovering, wear appropriate PPE when recovering; secure loose hair, clothing, and jewelry; wear appropriate PPE such as protective eyewear, gloves, face mask, and/or lab coat; brief personnel on proper construction procedures; follow rules set before use and by workshop requirements	Prior PPE check must be done by a safety team member before conducting recovery; rules must be known before to use in addition to mandatory supervision to ensure proper use and safety	Low
Contact with Airborne Chemical Debris	3 (Airborne particulate debris)	4 (Minor burns, abrasions)	12, Medium	Wear appropriate PPE such as protective eyewear, gloves, face mask, and/or lab coat; wash hands with water and soap; alert others that substances are in use before and during use; follow any other rule set forth through Safety	No contact allowed without call out before use to make sure PPE worn and area clear and avoid unless necessary; have two people minimum to make sure chemicals are secure and safely used; guarantee PPE worn at all times during manufacturing; call out prior to use for PPE	Mediu m

				and written procedures and checklists; wash with water and if direct contact, rinse eye with cool water for at least 15 minutes and get emergency	check to be completed by safety team	
Dehydration	3 (Failure to drink necessary amounts of water to remain hydrated)	4 (Exhaustion and possible hospitalization)	12, Medium	Ensure all members have access to water at launch; make sure backup of water for full mission; brief personnel on timeline and need for water	Mandatory water breaks will happen every hour; water must be brought or offered by team leads to any trip to ensure hydration	Low
Direct Contact with Hazardous Chemicals	3 (Chemical spills, improper use of chemicals)	4 (Moderate burns, abrasions)	12, Medium	Wear appropriate PPE such as protective eyewear, gloves and/or lab coat; wash hands with water and soap; alert others that substances are in use before and during use; follow any other rule set forth through Safety and written procedures and checklists; wash with water and if direct contact, rinse eye with cool water for at least 15 minutes and get emergency	No contact allowed without call out before use to make sure PPE worn and area clear and avoid unless necessary; have two people minimum to make sure chemicals are secure and safely used; guarantee PPE worn at all times during manufacturing; call out prior to use for PPE check to be completed by safety team	Mediu m
Dust or Chemical Inhalation	3 (Airborne particulate debris)	3 (Short to long-term respiratory damage)	9, Medium	Wear appropriate PPE of a respirator, safety glasses, and gloves; work in well ventilated and visible but isolated area	No contact allowed without call out before use to make sure PPE worn; PPE check must be done by a safety team member for dust mask; area must be away from others and be ventilated	Low
Electric	3 (Improper	4 (Possible	12,	Ensure labelled and	Strictly follow the	Mediu

Matches Misuse	use of equipment, static build-up, unexpected / accidental discharge)	explosion, destruction of electrical tools or components, possible severe harm to personnel)	Medium	secured; create a written procedure of how to setup to repeat for later use with the safety lead continuously supervising; ensure secured then secured properly directly before launch	mitigation and use testing and the written procedure of how to measure; guaranty PPE worn and checked during handling by a safety team member before and during use; follow checklist and ensure followed similarly to subscale	m
Electrocution	3 (Improper use of equipment, static build-up, unexpected / accidental discharge)	4 (Possible explosion, destruction of electrical tools or components, possible severe harm to personnel)	12, Medium	Give labels to all high voltage equipment warning of their danger; brief personnel on proper clean-up procedures and to wear appropriate PPE of gloves and ground; brief on proper construction procedures and to ground oneself when working with high-voltage equipment; follow rules set before use and by workshop requirements; turn off all construction tools when not in use	Guarantee no open electrical components; allow only one member to work on electrical components at a time with proper PPE and student supervising with prior PPE check; PPE check must be done by a safety team member before conducting construction; rules must be known before to use in addition to mandatory supervision to ensure proper use and safety	Mediu m
Entanglement with Construction Machines	2 (Loose hair, clothing, or jewelry)	5 (Severe injury, death)	10, Medium	Secure loose hair, clothing, and jewelry; wear appropriate PPE of secured hair, rolled up / short sleeves, no jewelry, and safety glasses	No contact allowed without call out before use to make sure PPE worn; make sure rules followed as set forth by machining rules and checked by personnel supervising	Low
Epoxy Contact	3 (Resin spill, resin contact during application or while drying)	3 (Exposure to Irritant)	9, Medium	Wear appropriate PPE such as gloves, face mask, and / or lab coats; wash with water and alert safety; work in well ventilated and visible but isolated area; have epoxy	No contact allowed without call out before use to make sure PPE worn; PPE check must be done by a safety team member; ensure epoxy cleanser, soap, and water accessible before epoxy use	Low

				cleanser, soap, and water available with use		
Eye Irritation	3 (Airborne particulate debris)	2 (Temporary eye irritation)	6, Low	Wear appropriate PPE such as protective eyewear, eye goggles or eye glasses; follow any other rule set forth through Safety and written procedures and checklists; wash with water and if direct contact, rinse eye with cool water for at least 15 minutes and get emergency medical attention and/or call 911	No contact allowed without call out before use to make sure PPE worn and area clear and avoid unless necessary; have two people minimum to make sure chemicals are secure and safely used; guarantee PPE worn at all times during manufacturing; call out prior to use for PPE check to be completed	Low
Falling Hazards	3 (Improper use of ladders, attempting to climb unstable objects)	4 (Bruising, abrasions, possible severe harm if falling into construction equipment)	12, Medium	Do not climb objects which are not ladders, when using ladders have another person present to stabilize the ladder	No contact allowed without call out before use to make sure PPE worn and area clear and avoid unless necessary; have two people minimum to make sure ladder is stabilized and held	Low
Heatstroke	3 (High temperatures on launch day)	3 (Exhaustion and possible hospitalization)	9, Medium	Wear clothing appropriate to the weather, ensure all members have access to water and a cold area to rest at launch; brief personnel on appropriate PPE of safety glasses and temperature to require short sleeve shirts	Team members must have necessary / adequate clothing, safety team will report violators to the project lead to decide if the violator should be dismissed to a colder area with enough space predetermined for entire group; water will be provided	Low
Hearing Damage	3 (Close proximity to loud noises)	4 (Long term hearing loss)	12, Medium	Wear appropriate PPE such as ear muffs when using power tools or explosive testing; brief personnel on proper PPE for	PPE check must be done by a safety team member before conducting construction or explosive testing; stay behind cover to avoid shock waves from	Low

				anywhere in vicinity of workshop	explosion testing; rules must be known before to use in addition to mandatory supervision to ensure proper use and safety	
Hypothermia	2 (Low temperatures on launch day)	3 (Sickness and possible hospitalization)	6, Low	Wear clothing appropriate to the weather, ensure all members have access to a warm area to rest at launch; brief personnel on appropriate PPE of safety glasses and temperature / wind chill to require warm clothes	Ensure people scheduled to attend have been mandatorily briefed on the temperature and rocket; ensure team members must have necessary / adequate clothing for sufficient warmth, safety team will report violators to the project lead to decide if the violator should be dismissed to a warmer area with enough space predetermined for entire group	Minimal
Kinetic Damage to Personnel after Launch	1 (Failure to take appropriate care around unburned fuel, post-landing launch vehicle explosion)	5 (Possible severe kinetic damage to personnel)	5, Low	Extinguish any fires before recovering, wait for motors to burn fully before recovering, wear appropriate PPE of safety glasses and gloves when recovering	Make sure area is evacuated and designated individuals are to recover components at a designated time when determined to be safe; no contact allowed without call out before use to make sure PPE worn	Low
Launch Pad Fire	3 (Dry Launch Area)	3 (Moderate Burns)	3, Medium	Have fire suppression systems nearby and use a protective ground tarp; follow relevant safety procedures when handling batteries, e-matches, and other potentially combustible materials	Make sure area is evacuated and designated individuals are to recover components at a designated time when determined to be safe; no contact allowed without call out and PPE; ensure PPE protocols are followed at all times;	Low
Injury from Ballistic Trajectory	3 (Recovery System Failure)	5 (Severe Injury, Death)	15, High	Keep all eyes on the launch vehicle and call “heads up” if	Make sure area is evacuated and individuals are	Medium

				needed	designated to recover components at a designated time when determined to be safe; no contact allowed without call out before use to make sure PPE worn	
Injury from Falling Components	3 (Failure to keep all components securely attached to the launch vehicle; result of improper staging constraints, part failure, or excessive vibration)	5 (Severe injury, death)	15, High	Keep eyes on the launch vehicle at all times; make sure all team members who cannot watch the launch vehicle have spotters nearby; alert others if the launch vehicle enters a ballistic trajectory; brief personnel on proper recovery to stay in cover until rocket is grounded and then for select designated group to recover the rocket	Make sure area is evacuated and designated individuals are to recover components at a designated time when determined to be safe; no contact allowed without call out before use to make sure PPE worn; ensure group is designated before launch and walks with partners to ensure to be aware and regard safety	Low
Injury from Fabrication	3 (Failure to keep all components securely attached, failure to wear proper PPE)	5 (Severe injury, death, cuts, burns, etc)	15, High	Wear appropriate PPE such as eye goggles, eye glasses, respirators, gloves, ear plugs, etc., wash with water; follow any other rule set forth through Safety and written procedures and checklists	PPE check must be done by a safety team member before conducting construction; team members must guarantee someone is there to watch and ensure safety	Low
Injury from Rocket Launch	3 (Explosion, rocket blast, falling components, etc.)	5 (Severe injury, death, cuts, burns, etc)	15, High	Follow all launch safety procedures, stay out of rocket safety circle, inspect rocket launch parts such as launch guide and motor casing, follow NAR/TRA safety code requirements, have first aid kit present	PPE check must be done by a safety team member before conducting launch; team members must guarantee someone is there to watch and ensure safety of each other; follow written procedures and checklists	Low

Injury from Navigating Difficult Terrain	2 (Uneven ground, poisonous plants, fast-moving water)	4 (Broken bones, infections, drowning, etc.)	8, Medium	Do not attempt to recover from atypically dangerous areas; brief personnel on proper recovery to stay in cover until rocket is grounded and then for select designated group to recover the rocket	Make sure to inform team on whether or not it is possible to recover the launch vehicle based off of identifying if terrain is dangerous and can be reached without inflicting harm; ensure group is designated before launch and walks with partners to ensure to be aware and regard safety	Low
Injury from Projectiles Caused by Jetblast	2 (Failure to properly clean launchpad, failure to wear proper PPE, failure to stand an appropriate listed distance from the launch vehicle during launch)	3 (Moderate injury to personnel)	6, Low	Clean the launchpad before use, ensure all members are wearing proper PPE for launch, ensure all team members are a minimum clear distance of at least 30 meters from the launch vehicle when launching and maintain minimum safe launch distances	Make sure area is evacuated and designated individuals are to recover components at a designated time when determined to be safe; no contact allowed without call out before use to make sure PPE worn; follow procedures to make sure launchpad clean and members past minimum distance	Low
Material Safety Data Sheet (MSDS) Availability	3 (Failure to share or secure MSDS)	5 (Injury to personnel)	15, High	Ensure team is briefed on material safety data sheets (MSDS) and that they are shared and available to the team; share through group drive and ensure have universal axis at all times including launch; notify before the purchase of any materials to make certain that there is a safety plan sufficient to address any new safety issues, to proactively identify and acquire any required PPE, and to compile and	All team members will be given a briefing on the plan to properly purchase, store, transport, and use hazardous materials by the safety officer; safety brief will provide knowledge of and access to MSDS for all potentially hazardous substances which will be used on the project and will ensure the use of proper PPE when handling hazardous materials; MSDSs are to be referred to when a hazard occurs in order to execute the most effective mitigation and ensure all safety concerns are	Low

				maintain all MSDSs and other safety information; all MSDSs are available to the team at all times and are required to be understood before working with potentially hazardous materials	addressed; all MSDSs are available to the team at all times and are required to be understood before working with potentially hazardous materials as to help increase awareness to reduce the potential for a hazard or likelihood of failure	
Physical Contact With Heat Sources	3 (Contact with launch vehicle parts which were recently worked with, improper use of soldering iron or other construction tools)	3 (Moderate to severe burns; extended fire)	9, Medium	Brief personnel on proper clean-up procedures, wear appropriate PPE such as shoes that cover the toes; brief personnel on proper construction procedures; follow rules set before use and by workshop requirements; turn off all construction tools when not in use, be aware of the safety hazard of parts which were recently worked with	PPE check must be done by a safety team member before conducting construction; rules must be known before to use in addition to mandatory supervision to ensure proper use and safety; guaranty no open heat sources / components; allow only one member to work on heat components at a time with proper PPE and student supervising; label hot components	Low
Physical Contact with Falling Construction Tools or Materials	3 (Materials which were not returned to a safe location after use)	5 (Bruising, cuts, lacerations, possible severe physical injury)	15, High	Brief personnel on proper clean-up procedures and to wear appropriate PPE such as shoes that cover the toes; brief personnel on proper construction procedures; follow rules set before use and by workshop requirements	PPE check must be done by a safety team member before conducting construction; rules must be known before to use in addition to mandatory supervision to ensure proper use and safety; make sure heavy tools only used with closed-toe shoes as designated by machining rules	Mediu m
Premature Ignition	2 (Short Circuit; misfire)	5 (Burns)	10, Medium	Prepare energetic devices (batteries, black powder, etc.) only immediately prior to flight; allow proper ignition to	Deemed unsafe to arm electronics until prior to ignition; allow no possibility of ignition until launch by keeping separately secured from	Low

				only occur on launch pad and otherwise avoid contact	team; no contact allowed without call out before use to make sure PPE worn	
Power Lines	2 (Launch vehicle Becomes Entangled In Lines)	5 (Fatal Electrocution)	10, Medium	Call the power company and stand clear until proper personnel arrive to inspect and/or fix	No contact allowed at all; call out when recognized to safely call power company for them to handle; ensure safety lead and team lead notified or present to confirm as set forth by designated recovery team	Low
Power Tool Cuts, Lacerations, and Injuries	3 (Carelessnes s)	4 (Possible Hospitalization)	12, Medium	Secure loose hair, clothing, and jewelry; wear appropriate PPE of safety glasses and face mask; brief personnel on proper construction procedures; follow rules set before use and by workshop requirements	PPE check must be done by a safety team member before conducting construction; rules must be known before to use in addition to mandatory supervision to ensure proper use and safety	Mediu m
Recovery Related Injury	2 (Uneven Ground, Poisonous Plants, Fast Moving Water)	4 (Broken Bones, Allergic Reactions, Drowning, etc.)	8, Medium	Do not attempt to recover from atypically dangerous areas; brief personnel on proper recovery to stay in cover until rocket is grounded and then for select designated group to recover the rocket	If equipment is to be recovered, ensure that area is safe and recovery can be done with little to no potential for harm; ensure group is designated before launch and walks with partners to ensure to be aware and regard safety	Low
Soldering and Wiring Electronics	3 (Airborne particulate debris)	3 (Short to long-term respiratory damage)	9, Medium	Proper NIOSH/MSHA-appr oved respiratory equipment must be worn in situations where airborne particle debris will be present as the result of a construction or fabrication process with limited	No contact allowed without call out before use to make sure PPE worn; PPE check must be done by a safety team member for dust mask; area must be away from others and be ventilated; must have safety supervision or previous experience as instructed through	Mediu m

				ventilation; work in well ventilated and visible but isolated area; have safety supervision or previous experience	building presentation and knowledge known before having access to soldering and wiring electronics	
Testing	3 (Improper contact with testing apparatus)	5 (Bruising, abrasions; moderate to severe burns; extended fire; possible severe hearing damage or other personal injury)	15, High	Brief personnel on proper setup procedures and wear appropriate PPE such as shoes that cover the toes; brief personnel on proper testing procedures; follow rules set before use and by workshop requirements; ensure all personnel be aware of the safety hazard	PPE check must be done by a safety team member before conducting testing; rules must be known before to use in addition to mandatory supervision to ensure proper use and safety; guaranty no open heat sources / components; allow only one member to work on heat components at a time with proper PPE and student supervising; label hot components	Mediu m
Tripping Hazards	3 (Materials not returned to a safe location after use, loose cords on or above the ground during construction processes)	4 (Bruising, abrasions, possible severe harm if tripping into construction equipment)	12, Medium	Brief personnel on proper clean-up procedures, tape loose cords or wires to the ground if they must cross a path which is used by personnel; leave better and cleaner than what was arrived at	Guaranty no hazards exist by following the manufacturing rules and mitigation; follow all rules set forth by safety and make sure all possible hazards are acknowledged and/or moved out of personnel access	Low
Unintended Black Powder Ignition	2 (Accidental exposure to flame or sufficient electric charge, improver handling or storage)	5 (Possible severe hearing damage or other personal injury)	10, Medium	Properly store, handle, and label containers storing black powder; only handle the black powder if the individual possesses a low-explosives user permit and is supervised by the safety lead	Keep ignition sources at least 50 feet away from fuel; prohibition of smoking or other potential ignition sources will be enforced by a safety team member; guaranty PPE worn and checked during handling by a safety team member before and during use	Mediu m
Workplace Fire	2 (Unplanned ignition of flammable	5 (Severe burns, loss of workspace,	10, Medium	Have fire suppression systems nearby,	Make sure workplace has updated fire safety protocol; in case of a	Mediu m

	substance, through an overheated workplace, improper use or supervision of heating elements, or improper wiring)	irreversible damage to project)		prohibit open flames, and store energetic devices in Type 4 magazines	fire, ensure that the workplace had updated fire suppression systems nearby	

4.4.6. Failure Mode And Effects Analysis (FMEA)

The following hazards are threats to the vehicle used in the project and its successful completion of the mission:

Hazard	**Likelihood (Cause)**	**Severity (Effect)**	**Risk**	**Mitigation**	**Verification**
Airframe Failure	1 (Buckling or shearing on the airframe from poor construction or use of improper materials, faulty stress modeling)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate materials according to extensive mathematical and physical analyses of the body tube, bulkheads, fasteners and shear pins, use materials such that the rocket is lightweight but has the proper structural characteristics to withstand rocket launch and forces within a safety factor, make use of reliable, standard building techniques as designated by the manufacturing facility, confirm analyses with test launches, make sure composite materials are not delaminated; recheck that airframe is sufficient for the described design requirements	Use a construction checklist which ensures mathematical analyses match physical analyses, if the airframe does not perform well in test launches perform another test launch with a new airframe design before converting to full-scale, and use the launch checklists to ensure both before and after launch that the airframe is in good condition
Inadvertent rocket motor or pyrotechnic initiation	2 (Miswired onboard avionics, poor design of onboard electronics, failure of avionics, launch relay box failure)	5 (Partial or total destruction of vehicle, potentially no failure)	10, Medium	Have multiple individuals and the team check that the avionics is designed properly and wired to NASA's standards, ensure the electronics have been previously used in similar application for comparison sake and to ensure that it has the opportunity to function properly	Ensure multiple individuals, or at least two, verify that the avionics is set up properly, ensure that multiple individuals monitor the launch initiation and ignition to ensure checklist is properly followed

Failure To Launch	2 (Lack of continuity)	1 (Recycle launch pad)	2, Minimal	Check for continuity prior to attempted launch, ensure launch pad is properly connect prior to additional matters or rocket setup; re-setup system or have alternative system	Ensure continuity checked by checklist, ensure officials agree that the setup is proper and will be sufficient for uninterrupted launch
Catastrophic rocket motor malfunction "CATO")	2 (Motor failure; motor defect, assembly error; improper igniter or positioning; improper cable length; improper storage of motor)	5 (Partial or total destruction of vehicle)	10, Medium	Inspect motor prior to assembly and closely follow assembly instructions; mathematically ensure and test that chamber pressure cannot exceed limits of motor hardware as assembled; ensure all team members are a minimum clear distance of at least 30 meters from the launch vehicle when launching and maintain minimum safe launch distances; teach team on handling and storage of motor procedures	Ensure all team members are still an appropriate distance of at least 30 meters from the launch vehicle when launching and maintain minimum safe launch distances; ensure team is taught on handling and storage of motor procedures before allowed to contact motor; ensure motor inspected by checklist during test runs and launch
Instability	1 (Stability margin of less than 1.00, stability margin less than design requirement)	5 (Potentially dangerous flight path and loss of vehicle)	5, Low	Measure physical center of gravity and compare to calculated center of pressure; ensure center of gravity and center of pressure theoretically yield a stable flight within the margin for the previously stated design requirement; ensure design is stable before manufacturing; if understable after, change the center of gravity to increase stability	Ensure construction checklist ensures the center of gravity has been measured and simulated and these measurements have been compared; these measurements should be made available to the entire team and checked before additional designing
Motor Expulsion	1 (Improper retention methods)	5 (Risk of recovery failure and low apogee)	5, Low	Use positive retention method to secure motor; ensure motor properly secured by Level 3 and LEUP holder; follow the previously tested motor procedures and/or external setup process	Ensure motor secured by checklist during test runs and launch; ensure properly mounted by Level 3 and LEUP holder and / or official
Premature Ejection	1 (Altimeter programming, poor venting)	5 (Zippering)	5, Low	Check altimeter settings prior to flight and use appropriate vent holes of four holes at every 90 degrees to ensure a symmetric intake of air for sensor readings; ensure ejection charges are properly	Ensure altimeter set by checklist during test runs and launch, ensure vent holes are present to allow for sensor readings

				timed and tested during ejection tests	
Fin Loss or Damage	1 (Poor construction or improper materials used, faulty aerodynamic modeling, damage after landing from previous flights)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate materials according to extensive mathematical and physical flight analyses, use materials such that the rocket is lightweight but has the proper structural characteristics to withstand rocket launch and forces within a safety factor, make use of reliable, standard building techniques as designated by the manufacturing facility, run stability tests, confirm analyses with test launches, check to make sure the fins are still in good condition before launches (especially if launching the same rocket twice), if using composites, make sure material is not delaminated	Use a construction checklist which ensures mathematical analyses match physical analyses, if fins do not perform well in test launches perform another test launch with new fins before converting to full-scale, and use the launch checklists to ensure both before and after launch that the fins are in good condition
Loss of Nose Cone	3 (Poor construction or improper materials used; improper active retention system)	5 (Partial or total destruction of vehicle)	15, High	Use appropriate materials according to extensive mathematical and physical flight analyses, use high powered building techniques and materials such that the rocket is lightweight but has the proper structural characteristics to withstand rocket launch and forces within a safety factor, make use of reliable, standard building techniques as designated by the manufacturing facility, run stability tests, confirm analyses with test launches, check to make sure the structure is still in good condition before launches (especially if launching the same rocket twice), if using composites, make sure material is not delaminated; ensure system is calculated to be properly retained with backup in case of failure	Ensure that nose cone is secured well before ejection during test runs and otherwise alter; ensure nose cone ejects as intended during ejection tests; ensure nose cone ejection method has no statistically no room for failure by the active retention system being calculated to only function when intended, or follow high safety factor with backup shock chord as to not lose the nose cone

Loss of Parachute	3 (Poor construction or improper materials used)	5 (Partial or total destruction of vehicle)	15, High	Use appropriate materials according to extensive mathematical and physical flight analyses, use high powered building techniques and materials such that the rocket is lightweight but has the proper structural characteristics to withstand rocket launch and forces within a safety factor, make use of reliable, standard building techniques as designated by the manufacturing facility, run stability tests, confirm analyses with test launches, check to make sure the structure is still in good condition before launches (especially if launching the same rocket twice), make sure no tears, punctures, holes, etc. are present	Ensure that parachute is secured well before ejection during test runs, otherwise alter to lower speed; ensure through multiple simulations that within the designed safety factor that the shock chord would not fail nor be destroyed during ejection, testing, or any other event during launch
Ejection Charge Failure	4 (Not enough power from black powder combustion, electrical failure)	5 (Ballistic trajectory, destruction of vehicle)	20, High	Ensure ground test charge sizes at least once before flight; ensure backup ejection charge of greater size than the first charge to be used to ensure ejection is successful; ensure ejection charges are properly timed and tested during ejection tests	Ensure test charge before final launch to ensure that charge does not fail; ensure ejection charge calculated by multiple individuals and cross checked with different methods
Altimeter Failure	3 (Loss of connection or improper programming)	5 (Ballistic trajectory, destruction of vehicle)	15, High	Ensure that all components are secured to their mounts and check settings before any test or launch; utilize multiple altimeters and strictly ensure altimeter checklist is followed	Ensure altimeter works with prior tests; ensure altimeter checklist is followed as previously tested to ensure functionality works as intended
Payload Failure	3 (Electrical failure, program error, dead battery)	4 (Disqualified, objectives not met)	12, Medium	Test payload prior to flight, check batteries and connections; ensure payload checklist is followed; ensure payload is tested before launch and on other random occasions to ensure system is functional and viable for the design requirements	Ensure that payload is fully functioning prior to flight by conducting tests; ensure payload checklist is followed as previously tested to ensure functionality works as intended
Heat	2 (Insufficient	4 (Excessive	8,	Use appropriate protection	Ensure (prior to final

Damaged Recovery System	protection from ejection charge)	landing velocity)	Medium	methods, such as Kevlar blankets, use appropriate materials according to extensive mathematical and physical flight analyses, use high powered building techniques and materials such that the rocket is unlikely to fail during heat and has the proper structural characteristics within a safety factor as designated by the manufacturing facility; make sure no, punctures, holes, etc. are present	launch) that proper materials are readily working and available in case heat damage occurs; ensure that recovery system is designed and calculated to not receive heat damage or non-negligible heat transfer
Broken Fastener	1 (Excessive force)	5 (Ballistic trajectory)	5, Low	Use fasteners with a breaking strength safety factor of 2 or higher safety factor set by the design requirement; test during testing including but not limited to ejection testing	Ensure by design and testing that fasteners are secure by following the mitigation in addition to running FEA simulations and generally testing the structural stability
Joint Failure	1 (Excessive force, poor construction)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate joint design according to extensive mathematical and physical flight analyses, make use of reliable, standard building techniques as designated by the manufacturing facility, confirm analyses with test launches; test during testing including but not limited to ejection testing	Ensure by design and testing that joints are secure by following the mitigation in addition to running FEA simulations and generally testing the structural stability
Centering Ring Failure	1 (Excessive force from motor, poor construction)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate centering rings according to extensive mathematical and physical flight analyses, make use of reliable, standard building techniques as designated by the manufacturing facility, confirm analyses with test launches; test during testing including but not limited to ejection testing	Ensure by design and testing that the centering rings secure by following the mitigation in addition to running FEA simulations and generally testing the structural stability
Motor Mount Failure	1 (Faulty motor or motor mount preparation, poor construction, damage to motor	5 (Partial or total destruction of vehicle, ballistic	5, Low	Use mathematical and physical analyses to ensure the motor mount works as planned, test the motor mount with subscale flights, check the	Ensure by design and testing that the motor mount secure by following the mitigation in addition to running

	mount)	trajectory)		motor mount for damage before flight, team members who prepare the motor must be supervised by at least one other team member	FEA simulations and generally testing the structural stability and rigidity
Component or Rocket Destruction Due To Drag Forces	1 (Poor construction or improper materials used)	5 (Partial or total destruction of vehicle)	5, Low	Use appropriate materials and high powered building techniques; use appropriate materials according to mathematical and physical analyses, make use of reliable, standard building techniques as designated by the manufacturing facility	Ensure that proper materials are being used to construct the vehicle securely, so that destruction due to drag forces does not occur
Airframe Zipper	2 (Excessive deployment velocity)	5 (Partial destruction of vehicle)	10, Medium	Properly time ejection charges and use an appropriately long tether; ensure through calculation completed by multiple individuals and cross checked to ensure proper sequence of events; test during testing including but not limited to ejection testing	Ensure by design, simulations, and testing that secure by following the mitigation in addition to running FEA simulations and generally testing the structural rigidity
GPS Lock Failure	2 (Interference or dead battery)	5 (Loss of vehicle)	10, Medium	Ensure proper GPS lock and battery charge before flight; ensure by following the checklist and ensuring secure by applying a force and simply checking	Verify that GPS lock and battery charge are properly secured by following the mitigation in addition to running FEA simulations and generally testing the structural stability
Excessive Landing Speed	3 (Parachute damage or entanglement, improper load, lower coefficient of drag for the parachutes than needed, lower surface area of the parachutes than needed)	5 (Partial or complete destruction of vehicle)	15, High	Properly size, pack, and protect parachute; ensure parachute properly rolled by checklist standards and ensure that proper parachute chosen by unique calculations from multiple individuals; use subscale flights to determine if the subscale parachutes were accurately sized	Ensure that parachute is well secured in on the aircraft and that it opens as planned; test the parachute before final launch via a drop test and by simply ensuring the parachute is unbroken
Battery Overcharge	3 (Unsupervised/undocumented charge)	3 (Destruction of battery)	9, Medium	Ensure batteries are documented and supervised if charging	Ensure alarms set and other individuals are aware batteries charging
Battery	2 (Landing	5 (Partial or	10,	Ensure design has sufficient	Ensure by design and

Puncture	damage)	complete destruction of vehicle)	Medium	distance / protection from outside, and motor, charges, and batteries; test during testing including but not limited to ejection testing	testing that secure from other systems or puncture by ensuring it is secured and away from moving components with protection to prevent puncture
Black Powder Ignition	2 (Accidental exposure to flame or sufficient electric charge)	5 (Partial or complete destruction of vehicle	10, Medium	Ensure design has sufficient distance / protection from outside, and motor, charges, and batteries; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	Ensure by design and testing that secure from other systems or puncture; ensure during testing that is isolated from individuals and is successfully accomplished with respect to the design requirements
Charge ignition close to motor	3 (Poor design location leads to damage)	5 (Partial or complete destruction of vehicle	15, High	Ensure design has sufficient distance / protection from motor, charges, and batteries; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	Independently ensure design is safe; ensure by isolated testing charge may work; ensure during testing that is isolated from individuals and is successfully accomplished with respect to the design requirements and mathematical modelling that sufficiently distant from critical rocket components such as the motor
Destruction of Bulkheads	1 (Poor construction or improper bulkheads chosen which cannot withstand launch forces, faulty stress modeling)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate materials according to extensive high-stress mathematical and physical analyses, make use of reliable, standard building techniques as designated by the manufacturing facility, run stability tests, confirm analyses with test launches	Ensure by design and testing that secure as ensured during simple checks, including during checklist, in addition to mathematical modelling and additional testing including ejection testing
Destruction of Nose Cone	1 (Poor construction, damage from previous flights, poor storage, or	3 (Lower rocket stability, possible deviations	3, Low	Check the nose cone for damage before and after each launch, choose a nose cone which is strong enough to withstand launch forces	Ensure by design and testing that secure as ensured during simple checks, including during checklist, in

	transportation)	from flight path)		according to mathematical and physical flight simulations, confirm choice of nose cone with subscale launches	addition to mathematical modelling and additional testing including ejection testing
Motor Tube Angled Incorrectly	1 (Poor construction, damage from previous flights, poor storage, or transportation)	3 (Lower rocket stability, rocket does not follow desired flight path well)	3, Low	Ensure proper measurements and alignments are made during construction, ensure there is no rush to attach the motor tube, double-check the alignment of the motor before each flight, test that the desired motor alignment is correct with subscale flights	Ensure by design and testing that secure as ensured during simple checks, mathematical modelling, and additional testing including ejection testing; ensure design is straight as manufactured by simply ensuring motor is perpendicular to airframe or as intended
Motor Tube Comes Loose	1 (Poor construction, damage from previous flights, poor storage, or transportation, faulty motor preparation)	5 (Ballistic trajectory, catastrophic destruction of vehicle)	5, Low	Check the motor and motor tube for damage before each launch, run mathematical and physical flight simulations to ensure the tube performs as planned, confirm simulations with subscale launches	Ensure by design and testing that secure as ensured during simple checks, including during checklist, in addition to mathematical modelling and additional testing including ejection testing
Premature Stage Separation	1 (Premature ejection, poor choice of shear pins or fasteners)	5 (Possible recovery failure and damage to or loss of vehicle, ballistic trajectory)	5, Low	Check altimeter settings prior to flight, use appropriate vent holes, and run thorough analyses to determine which types of shear pins and fasteners should be used	Ensure by design and testing that secure and that separation occurs strictly when desired, as ensured by the checklist that must be similarly strictly followed
Forgotten or Lost Component	3 (Carelessness with rocket components, failure to take note of inventory before attempting to launch)	4 (Rocket does not launch at the desired launch time)	12, Medium	Have spares for components which are small and easy to lose, have an inventory of all rocket parts to be checked before moving the rocket to a launch site	Ensure components are secured and follow checklist to ensure that all components that are necessary are accounted for and brought to launch, building, or other events
Poorly placed	2 (Carelessness with rocket	3 (Lower rocket	6, Low	Extensive, up-to-date, and detailed simulations and	Ensure by design and testing that secure

center of gravity	design, weight which was not considered in mathematical or physical analyses)	stability)		models of the rocket and its flight, adding and leaving room to add extra ballast as needed	during rocket design and that the proper verification is followed as listed
Poorly placed center of pressure	2 (Carelessness with rocket design, design aspects which were not considered in mathematical or physical analyses)	3 (Lower rocket stability)	6, Low	Extensive, up-to-date, and detailed simulations and models of the rocket and its flight, changing design aspects such as fin size as needed	Ensure by design and testing that secure during rocket design and that the proper verification is followed as listed; determined during design so ensure is a key fundamental step in designing the rocket
Premature Ejection	1 (Altimeter programming, poor venting)	5 (Zippering, possible recovery failure and damage to or loss of vehicle)	5, Low	Check altimeter settings prior to flight and use appropriate vent holes; test during testing including but not limited to ejection testing; ensure avionics properly set up as validated through testing and checklists	Ensure by design and testing that secure; ensure checklist is followed as to check for this failure mode that if it occurs the proper verification as listed will be followed
Ejection Charge Failure	4 (Not enough power, electrical failure)	5 (Ballistic trajectory, destruction of vehicle)	20, High	Ground test charge sizes at least once before flight; ensure tested multiple times to ensure ejection charge checklist is sufficient and that ejection charge is sufficient for stable ejection	Ensure by design and testing that secure; ensure checklist is followed as to check for this failure mode that if it occurs the proper verification as listed will be followed; ensure during testing that is isolated from individuals and is successfully accomplished with respect to the design requirements
Rocket Disconnects from the Launch Rail	2 (High wind speeds, failure to properly use the rail buttons, faulty rail buttons)	5 (Partial or total destruction of vehicle, ballistic trajectory which endangers personnel, onlookers,	10, Medium	Use mathematical and physical analyses to ensure the rail buttons are properly aligned and working as planned, double check the rail buttons are properly attaching the rocket to the launch pad before launch, test rail buttons with subscale flights)	Ensure by design and testing that secure; ensure checklist is followed as to check for this failure mode that if it occurs the proper verification as listed will be followed

		and property on the ground)			
Flightpath Interference	2 (Wildlife in the air, unforeseen obstacles such as a loose balloon)	4 (Minor to severe change in the vehicle's flightpath, possible ballistic trajectory)	8, Medium	Ensure there are clear skies above before launching, ensure an FAA waiver has been obtained for the designated launch area	Ensure launch site is designated and secure; ensure sky is clear during launch on day that is officially approved with the appropriate waver
Unplanned Amounts of Friction Between Rocket and Launch Rail	2 (Faulty setup of launch rail, faulty installation of rocket on launch rail, failure to properly lubricate launch rail as needed, weather conditions cause excess friction)	2 (Rocket does not follow the designated flight path well, lower maximum height)	4, Low	Set up the rail using instructions which come with the product, use lubrication on the rail as needed according to weather and rail type, ensure the rocket is properly installed on the launch rail	Ensure by design and testing that secure; ensure checklist is followed as to check for this failure mode that if it occurs the proper verification as listed will be followed; test via checklist
Failure to Ignite Propellant	1 (Faulty motor preparation, poor quality of propellant, faulty igniter, faulty igniter power source, damage to motor)	5 (Rocket does not immediately launch and is a considerable hazard until it is confirmed that it will not launch, changes to igniters or rocket required)	5, Low	Purchase propellant and motors only from reliable sources, team members who prepare the motor and igniters must be supervised by at least one other team member, determine if the igniters chosen work well during subscale testing	Ensure by design and testing that secure; ensure the area is properly thermally insulated and that there is an insignificant chance for a fire; ensure protection is sufficient by having official approval in addition to allowing no contact with flammable matter; ensure calculated heat transfer deemed insignificant
Propellant Fails to Burn for Desired Duration	1 (Faulty motor preparation, poor quality of propellant, damage to motor)	3 (Rocket does not follow the designated flight path well, lower maximum height, if drastic change in maximum height the ejection	3, Low	Purchase propellant and motors only from reliable sources, check the motor for damage prior to launching, team members who prepare the motor must be supervised by at least one other team member	Ensure by design and testing that secure; ensure the area is properly thermally insulated and that there is an insignificant chance for a fire; ensure protection is sufficient by having official approval in addition to allowing no contact with flammable matter; ensure

		charges for recovery may not deploy)			calculated heat transfer deemed insignificant
Propellant Burns Through Rocket Component s	1 (Faulty motor preparation, poor quality of propellant, poor construction, damage to motor, damage to propellant casing)	5 (Ballistic trajectory, catastrophic destruction of vehicle)	5, Low	Purchase propellant and motors only from reliable sources, check the motor for damage prior to launching, team members who prepare the motor must be supervised by at least one other team member, test propellant casing in subscale flights	Ensure by design and testing that secure; ensure the area is properly thermally insulated and that there is an insignificant chance for a fire; ensure protection is sufficient by having official approval in addition to allowing no contact with flammable matter; ensure calculated heat transfer deemed insignificant
Propellant Explosion	1 (Faulty motor preparation, poor quality of propellant, damage to motor)	5 (Ballistic trajectory, catastrophic destruction of vehicle, possible harm to bystanders)	5, Low	Purchase propellant and motors only from reliable sources, check the motor for damage prior to launching, team members who prepare the motor must be supervised by at least one other team member	Ensure by design and testing that secure; ensure the area is properly thermally insulated and that there is an insignificant chance for a fire; ensure protection is sufficient by having official approval in addition to allowing no contact with flammable matter; ensure calculated heat transfer deemed insignificant; ensure by structural analysis that if explosion were to occur that system would not become fragmented
Payload Computer Failure	3 (Electrical failure, program error, poor setup of wiring causes a connection to come undone, forgotten connection, battery failure)	5 (Disqualified, objectives not met, loss of electronic control)	15, High	Test payload prior to flight, check batteries and connections before flight; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	Ensure by design and testing that secure and that the electionics stay powered as intended and as previously calculated, including while in launch and testing conditions; ensure checklist is followed to ensure proper setup

Power Loss to Avionics Bay and/or Payload	3 (Faulty wiring, battery failure, poor setup of wiring causes a connection to come undone, forgotten connection)	5 (Disqualified, objectives not met, failure to correctly trigger ejection charges)	15, High	Test the reliability of the wiring and batteries through subscale flights, check batteries and connections before flight; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	Ensure by design and testing that secure and that the electionics stay powered as intended and as previously calculated, including while in launch and testing conditions; ensure checklist is followed to ensure proper setup
Improper Avionics and Payload Insulation	1 (Poor construction, damage to rocket body, avionics bay, or payload)	4 (Avionics bay and payload do not perform as planned, possible failure to trigger ejection charges at correct time, possible failure to meet mission objectives, possible recovery failure, possible ballistic trajectory)	4, Low	Take efforts to properly seal avionics and payload such as the use of putty, follow proper construction procedures, check the avionics bay, payload, and rocket body for damage before launch, check insulation of avionics bay and payload through test launches; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	Ensure by design and testing that secure; ensure the area is properly thermally insulated and that there is an insignificant chance for a fire; ensure protection is sufficient by having official approval in addition to allowing no contact with flammable matter; ensure calculated heat transfer deemed insignificant
Avionics Bay Fire	3 (Faulty wiring, battery failure, poor setup of wiring, adverse weather)	5 (May be disqualified if objectives are not met, possible failure to trigger ejection charges, damage to internal rocket components)	15, High	Thermal protection of avionics bay, do not overload avionics bay with wiring, only purchase avionics and payload equipment from reliable sources, check avionics bay and payload performance with test launches; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	Ensure by design and testing that secure and that fire would not occur during launch; ensure the area is properly thermally insulated and that there is an insignificant chance for a fire; ensure protection is sufficient by having official approval in addition to allowing no contact with flammable matter; ensure calculated heat transfer deemed insignificant
Human Error When	3 (Forgotten connection,	5 (Disqualified,	15, High	Leave reminders in multiple places to check that the	Ensure follow safety checklist to ensure

Arming Avionics and Payload	forgetting to activate avionics bay components or payload prior to launch)	objectives not met, failure to correctly trigger ejection charges)		avionics bay and payload are armed and ready before launch, follow launch checklists closely; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	properly armed; ensure continuity checked by checklist, ensure officials agree that the setup is proper and will be sufficient for uninterrupted launch; ensure during testing that arming works and that checklist is utilized to follow the proper steps
Arming System Failure	3 (Faulty arming system, faulty wiring, battery failure, poor setup of wiring causes a connection to come undone, forgotten connection)	5 (Disqualified, objectives not met, failure to correctly trigger ejection charges)	15, High	Ensure the avionics bay is successfully communicating with the team prior to flight, test arming system through test launches; check for continuity prior to attempted launch, ensure launch pad is properly connect prior to additional matters or rocket setup; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	Ensure by design and testing that secure; ensure continuity checked by checklist, ensure officials agree that the setup is proper and will be sufficient for uninterrupted launch; ensure during testing that arming works and that checklist is utilized to follow the proper steps; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
Poor Spacing Between the Ejection Charge and the Parachute	2 (Failure to properly consider the requirements of the recovery system, poor budgeting of space in rocket, failure to read instructions that come with parachute and/or ejection charges)	5 (Partial or total damage to the parachute, parachute does not launch from the rocket, possible recovery failure)	10, Medium	Read all instructions which come with the parachute and ejection charges, establish clear requirements of the recovery system early in the design process, run mathematical and physical analyses on the design of the rocket, ensure the parachute is spaced properly with subscale test flights; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements	Ensure by design and testing that secure and the stages separates during ejection tests and, prior to that, through mathematical modelling; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
Stage Fails to Separate	2 (Faulty ejection charge, excessive strength is used	4 (Rocket does not follow desired flight path,	8, Medium	Any team member who loads the ejection charges must be supervised by at least one other team member, examine	Ensure by design and testing that secure and the stages separates during ejection tests

	to hold stages together, altimeter failure)	possible ballistic trajectory, lower maximum height, damage to the rocket)		ejection charges for damage before launch, ensure proper functionality of the altimeters, ejection charges, and interstage joints and fasteners through test flights and mathematical and physical analyses, have a secondary ejection charge for each stage separation	and, prior to that, through mathematical modelling; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
Main Parachute Fails to Deploy	2 (Poor design of where parachute is in rocket, poor sealing of parachute chamber, poor loading of parachute, faulty parachute or ejection charge, altimeter failure)	5 (Main parachute does not slow down the rocket, recovery failure, ballistic trajectory)	10, Medium	Any team member who seals or packs the parachute chamber must be supervised by at least one other team member, examine parachute and ejection charges for damage before launch, run mathematical and physical analyses as well as subscale tests to ensure parachute is in the right position in the rocket, have a secondary ejection charge in case of emergency which is larger than the first	Ensure by design and testing that avionics properly set up for parachute to deploy; ensure by testing that checklist is sufficient to allow for parachute to deploy; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
Drogue Parachute Fails to Deploy	2 (Poor design of where parachute is in rocket, poor sealing of parachute chamber, poor loading of parachute, faulty parachute or ejection charge, altimeter failure)	5 (Drogue parachute does not slow down the rocket, recovery failure, ballistic trajectory)	10, Medium	Any team member who seals or packs the parachute chamber must be supervised by at least one other team member, examine parachute and ejection charges for damage before launch, run mathematical and physical analyses as well as subscale tests to ensure parachute is in the right position in the rocket, have a secondary ejection charge in case of emergency which is larger than the first	Ensure by design and testing that avionics properly set up for parachute to deploy; ensure by testing that checklist is sufficient to allow for parachute to deploy; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
Parachute Canopy Breaks or Tears	1 (Poor canopy materials, improper ejection of recovery system, damage from previous flights or transportation)	4 (Possible recovery failure, ballistic trajectory)	4, Low	Only buy parachutes from reliable sources, remove threats to parachute integrity from the parachute housing, test the recovery system through mathematical and physical analyses as well as subscale flights, check the recovery system for damage before launch	Ensure by design and testing that secure and test that after numerous ejection tests the shock cord and / or parachute do not become tangled or break; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design

					requirements
Parachute Shroud Lines Break	1 (Poor shroud line materials, improper ejection of recovery system, damage from previous flights or transportation)	4 (Possible recovery failure, ballistic trajectory)	4, Low	Only buy parachutes from reliable sources, remove threats to parachute integrity from the parachute housing, test the recovery system through mathematical and physical analyses as well as subscale flights, check the recovery system for damage before launch	Ensure by design and testing that secure and test that after numerous ejection tests the shock cord and / or parachute do not become tangled or break; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
Shock Cord Break or Disconnect	1 (Faulty shock cord, damage to shock cord, poor connection to the rocket)	5 (Parachute disconnect from the rocket, recovery failure, ballistic trajectory)	5, Low	Any team member who connects the shock cord to the rocket must be supervised by at least one other team member, check the shock cord for damage before and after flight, only buy shock cords from reliable sources, analyze the shock cord with test flights	Ensure by design and testing that secure and test that after numerous ejection tests the shock cord and / or parachute do not become tangled or break; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
Tangled Parachute or Shock Cord	1 (Faulty or damaged shock cord or parachute, poor packing of shock cord and/or parachutes, poor sizing of parachutes or shock cord, unstable or ballistic flight)	4 (Shock cord or parachutes may not fully achieve their goal, possible ballistic trajectory, possible failed recovery)	4, Low	Only buy parachutes and shock cords from reliable sources, any team member who seals or packs the parachute chamber must be supervised by at least one other team member, examine parachutes and shock cord for damage before launch, check performance of parachutes and shock cord in test flights, appropriately follow recommended sizings for shock cord and parachutes;	Ensure by design and testing that secure and test that after numerous ejection tests the shock cord and / or parachute do not become tangled or break; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
Parachute Comes Loose from Rocket	1 (Failure of recovery system mount on the rocket body, poor shroud line materials, improper ejection of recovery	5 (Recovery failure, ballistic trajectory)	5, Low	Only buy parachutes from reliable sources, test the recovery system through mathematical and physical analyses as well as subscale flights, check the recovery system for damage before launch, double check that the	Ensure that parachute is secured well before ejection during test runs, otherwise alter to lower speed; ensure through multiple simulations that within the designed safety

	system, damage from previous flights or transportation)			recovery system is properly mounted before launch	factor that the shock chord would not failure or be destroyed during ejection, testing, or any other event during launch
Heat Damage to Parachute or Shock Cord	1 (Not enough space given between ejection charge and parachute, poor insulation of parachute, poor parachute packing, faulty or poorly chosen ejection charge)	4 (Shock cord or parachutes may not fully achieve their goal, possible ballistic trajectory, possible failed recovery)	4, Low	Any team member who packs the parachute or ejection charges must be supervised by at least one other team member, use recommended sizing methods for ejection charges, confirm proper placement and packing methods of ejection charges and parachutes with test flights	Ensure by design and testing that secure; ensure checklist is followed to ensure proper steps are followed; ensure by calculation that heat transfer would not be significant to ignite the rocket
Parachute or Shock Cord Catch Fire	1 (Not enough space given between ejection charge and parachute, poor insulation of parachute, poor parachute packing, faulty or poorly chosen ejection charge)	5 (Shock cord or parachutes do not fully achieve their goal, possible ballistic trajectory, possible failed recovery, damage to internal rocket components)	5, Low	Any team member who packs the parachute or ejection charges must be supervised by at least one other team member, use recommended sizing methods for ejection charges, confirm proper placement and packing methods of ejection charges and parachutes with test flights	Ensure by design and testing that secure; ensure checklist is followed to ensure proper steps are followed; ensure by calculation that heat transfer would not be significant to ignite the rocket; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements
Fire	2 (Blast deflection insufficient, motor failure, hot igniter falls, on-ground ejection)	5 (Partial or total destruction of vehicle)	10, Medium	Clear out vicinity and have adequate blast deflectors by ensuring that only an insignificant amount of heat transfer would reach flammable matter, utilize fire blankets and maintain the previously listed distances	Ensure blast deflection is in place and is sufficient by having official approval in addition to no contact with flammable matter, and/or calculated heat transfer being deemed insignificant
Insufficient Landing Speed	3 (Improper load, higher coefficient of drag for the parachutes than needed, higher surface area of the parachutes	2 (Unexpected changes in flightpath and landing area, increased potential for	6, Low	Use subscale flights to determine if the subscale parachutes were accurately sized, use recommended and proven-to-work parachute sizing techniques	Ensure by design and testing that secure by following the mitigation in addition to running simulations and generally testing the landing speed by

	than needed)	drift)			individual unique calculations
Shock Cord / Parachute Stops Payload	3 (Shock cord stuck in payload or payload bay)	3 (Shock cord or parachutes may not fully achieve their goal and block payload)	9, Medium	Any team member who packs the parachute or ejection charges must be supervised by at least one other team member, use recommended sizing methods for ejection charges, confirm proper placement and packing methods of ejection charges and parachutes with test flights	Verification by testing and demonstration to ensure the shock cord and parachute may not get stuck; ensure by design and testing that secure; test during testing including but not limited to ejection testing to ensure sufficient design with respect to design requirements

4.4.7. Environmental Hazard Analysis

The following hazards are either threats to the project from the environment or threats to the environment from the project:

Hazard	Likelihood (Cause)	Severity (Effect)	Risk Before	Mitigation	Verification	Risk After
High Air Pressure	2 (Poor air pressure forecast)	4 (Premature drag separation)	8, Medium	Use appropriate amount of shear pins and vent holes	Keep records of the number of shear pins and vent holes included in the rocket in the safety section and double check that number with the number shown to be needed by testing and analysis	Low
Crowded Landscape	3 (Trees, brush, water, power lines)	5 (Inability to recover the rocket, obstacles that may be dangerous to personnel during recovery)	15, High	Launch only in designated areas that are generally open; if needed, angle rocket into wind as necessary to reduce drift	Follow strict designated areas as determined by launch officials and rocketry safety standards	Low

Collisions with Man-made Structures or with Humans	2 (Failure to properly predict trajectory, failure to choose an appropriate launch area isolated and safe (described in checklist))	5 (Damage to public property or private property not owned by the team, damage to team equipment, serious damage to team personnel or passerby)	10, Medium	Do not launch under adverse conditions which may affect the course of the rocket, run a large number of tests which analyze the rocket's trajectory mathematically and physically, choose a launch area which is not close to civilization, follow launch procedures closely	Run tests to analyze and estimate the rocket's trajectory so that the rocket's path is known to the team; do not launch rocket under adverse weather conditions and choose a launch location which allows for open space to avoid accidents	Low
Unstable Ground	2 (Poor choice of launch site, inclement weather creating mud or softening the ground)	3 (Personnel may slip or fall and damage equipment or themselves, launch pad may sink into the ground and cause an unexpected trajectory)	6, Low	A rigid system which can be used to support the launch pad, such as wooden planks (if needed to reduce their flammability, they may be wetted directly underneath the rocket), choice of a launch site which has rigid ground, observation of launch pad condition shortly before launch	Use designated launch areas as designated to which must strictly follow this rule to be approved	Low
Wildlife Contact with Rocket	1 (Failure to accurately predict trajectory, unexpected appearance of wildlife, poor choice of launch area)	4 (Damage to vehicle components, damage to wildlife, unexpected trajectory close to the ground)	4, Low	Launch in an open area with high visibility, be aware of the surroundings when choosing a launch area and launching	Ensure that the launch area is in a safe area where surroundings don't stand in the way of the launch or have a chance of getting damaged	Minimal

Wildlife Contact with Launch Pad	1 (Failure to monitor the launch pad, poor choice of launch area)	4 (Possible inability to launch the rocket, unpredicta ble launch behavior or trajectory)	4, Low	Have at least one team member monitoring the launch pad at all times, launch in an open area with high visibility, be aware of the surroundings when choosing a launch area and launching, if animals tamper with the launchpad do not launch	Ensure that the launch pad is in a safe area where surroundings don't stand in the way of the launch pad or have a chance of getting damaged by the launch	Minim al
High Humidity	3 (Climate, poor forecast)	1 (Rust on metallic component s, expansion of rocket component s and difficulty assemblin g the rocket because of this)	3, Low	Use as little metal as possible, apply rust prevention techniques, store the rocket indoors, choose a launch site with a desirable climate, choose not to launch if heat expansion makes assembly necessitate drastic adaptation	Ensure that launch site does not have any undesirable conditions; ensure that electronics are well protected and will not have contact with wet conditions; do not launch if there is rainfall	Minim al
Wet Conditions	3 (Climate, poor forecast)	3 (Threats to electronic performan ce, possible short circuit)	9, Mediu m	Choose a launch site with a desirable climate, read accompanying instructions for any electronics with regard to wet conditions, do not launch during rainfall which is more than a light sprinkle	Ensure that launch site does not have any undesirable conditions; ensure that electronics are well protected and will not have contact with wet conditions; do not launch if there is rainfall	Low
Dry Conditions	2 (Climate, poor long-term forecast)	3 (Increased chance of launch pad fire if there is dry brush present	6, Low	Clear all dry brush away from the launch pad area before launch, choose a launch area with a climate that is not often dry, do not launch	Ensure team is notified of all weather on day of launch or manufacturing to wear proper clothing; do not launch if too dry;	Minim al

		near to the launch pad)		if there is an unavoidable fire hazard present due to dry conditions	ensure mitigation is strictly followed due to weather notification	
Lightning	3 (Poor forecast)	4 (Threats to electronics and team personnel)	12, Medium	Do not launch during storms or attempt to launch if there is a storm approaching, check the forecast for the day in advance	Check the forecast days ahead of launching; in the event that there is a storm on launch day, do not launch	Low
High Wind Speeds	3 (Poor forecast)	4 (Inability to launch, excessive drift, unpredictable trajectory, destruction of parachute or damage to rocket parts, loose equipment blown away)	12, Medium	Angle into wind as necessary and abort if wind exceeds 20 mph	In the event that there are high wind speeds, angle the rocket to accommodate for the weather conditions; do not launch if wind speeds exceed 20 mph	Low
High Sun exposure	3 (Sunny day)	3 (Skin damage, eye irritation)	9, Medium	Ensure team is protected from the sun through shade and sunscreen to prevent UV light and/or the sun from causing a sunburn; ensure team has access to sunscreen; ensure team is aware of weather to bring sunglasses	Ensure team is notified of all weather on day of launch or manufacturing to wear proper clothing; ensure mitigation is strictly followed due to weather notification to prevent sunburn; with rocket and water, ensure sunscreen is provided from a lead; ensure protection area available to rest and avoid sun and	Medium

					stay in shade	
High Temperatures	3 (Poor forecast)	3 (Heat-related personnel injuries, failure in rocket structure, launchpad fires from overheated components or dry brush, excessive friction on the launch rail, especially if the heat is from sun exposure)	9, Medium	Ensure team is protected from the sun through shade and sunscreen and stays hydrated, choose a launch location with small amounts of brush, store the rocket in an area with regulated temperature	Ensure team is notified of all weather on day of launch or manufacturing to wear proper clothing; do not launch if weather above designed intent of rocket; ensure mitigation is strictly followed due to weather notification	Low
Low Temperatures	3 (Poor forecast)	3 (Cold-related personnel injuries, Frost on ground, ice on vehicle, clogging of vehicle ventilation, change in rocket rigidity and mass, higher drag force on rocket)	9, Medium	Ensure team is wearing appropriate clothing for extended periods of time in cold environments, keep the rocket at room temperature or bundled in materials which hold in heat, if ice appears anywhere on the rocket do not launch and return it to a warm location	Ensure team is notified of all weather on day of launch or manufacturing to wear proper clothing; do not launch if weather below designed intent of rocket; ensure mitigation is strictly followed due to weather notification	Low
Pollution from Exhaust	5 (Combustion of APCP motors)	1 (Small amounts of greenhouse gases emitted)	5, Low	Carpool to events to reduce pollution from exhaust in another way	Ensure team members with only high attendance may go, and be carpooled, to save energy	Low
Chemical	2 (Fuel	4 (Danger	8,	Do not launch if	Use designated	Low

Pollution to Water Sources	leakages, battery fluid leakages, launch too close to a water source)	of sickness to wildlife or humans which rely on the water sources)	Medium	the launching area is within 750 meters of a water source, check the rocket for leakages before launch	launch areas as designated to which must strictly follow this rule to be approved	
Pollution from Team Members	2 (Failed disposal of litter, improper cleanup procedures, members walk through important plantlife, farming fields, sod, etc.)	4 (Litter may degrade extremely slowly, wildlife may consume harmful litter)	8, Medium	Brief team members on proper cleanup procedures, foster a mindset of leaving no trace at launch sites, only the minimum number of required team members should retrieve the rocket	Follow societal standards and leave cite cleaner than was found; make sure disposable equipment is kept track of and guaranteed to remain at designated locations, not with retrieval	Minimal
Pollution from Vehicle	2 (Loss of components from vehicle, debris scattering from a crash or mid-flight explosion)	4 (Materials degrade extremely slowly, wildlife may consume the materials)	8, Medium	Properly fasten all components; ensure components that can fall off have low impact on environment and / or are biodegradabile	Follow MSDS protocols and fulfill design requirements and derived requirements while using no excess components	Medium

4.5. Launch Concerns and Operation Procedures

4.5.1. Final Assembly and Launch Procedures

4.5.1.1. Recovery Preparation

General Information:

- PPE required for all recovery and post-flight inspection procedures: ANSI Z87.1 safety glasses, leather or canvas gloves, closed-toe shoes or boots, and clothing which covers all exposed skin from the neck down.

- Do not attempt to recover the rocket from atypically dangerous areas, such as confined environments (especially woods) or uneven ground to avoid personnel injury from dangerous terrain
- If the rocket becomes entangled with power lines upon its return to the ground, call the power company and stand clear until proper personnel arrive to avoid electrocution hazards. Ensure launch officials (NASA, Indiana Rocketry Inc., or other launch officials) are aware of this concern in order to take the necessary precautions and procedures.
- Leave no trace of materials or other destruction during retrieval to minimize pollution from team members and to ensure the vicinity is safe and clean for future use by other teams or individuals

Preparation for retrieval:

- Ensure the rocket is being launched in an area which will not complicate retrieval; there should be an extremely minimal chance that the rocket will collide with personnel or onlookers, man-made structures, or wildlife, and the area which the rocket is expected to land in should not feature dangerous terrain or power lines.
- Carefully pack each parachute using the "burrito" technique to prevent shroud line tangling. The parachute is pinched at the four corners separated 90 degrees in the parachute, and then the shock cord is tucked into the parachute. From there, ensure the parachute is then folded as much as possible to reduce its size by then rolling it into a "burrito" with a smaller outside diameter than the airframe inner diameter. Any team member who packs the parachute or connects the shock cord must be supervised by at least one other team member who is using the safety checklists.
- Completely tighten all quick links, shear pins, screws, and motor retainers prior to flight to reduce the chance of parts falling from the rocket.

During retrieval:

- Before approaching the rocket, observe whether or not it seems there is still fuel present within. This may be recognized through an obviously incomplete launch with noticeable signs of unburned fuel, typically denoted by flames, smoke, and /or an explosion during flight. If unburned fuel is present, wait for the fuel to safely burn away. If the fuel is not burning away, clear the surrounding area of fire hazards while exercising extreme caution by going the direct opposite direction of the area with all available PPE worn in site, then ensure the motor is isolated and/or the fuel is safely disposed of by the proper authorities as determined by the launch officials. Fire protection services or a designated official may be needed for the accomplishment of this task.

- Double-check the area around the rocket before approaching to ensure there are no hazards from nearby terrain or man-made structures such as power lines.
- Extinguish any fires present to avoid burn hazards and care for the surrounding environment through fire retardant or provided extinguishers or water present at official launches.
- Double-check for sharp edges from damaged parts to avoid cuts or lacerations, especially before making physical contact with the rocket.
- Once the above points have been acknowledged appropriately in their entirety, and all post-flight inspection procedures have also been followed, the rocket may be prepared for transport.
- If the rocket was damaged enough during flight for parts to fall off, ensure these parts are also retrieved appropriately and securely with PPE and extreme caution so unwary passerby do not get involved with them. Ensure all known parts are accounted for and collected, and search the 10 meter radius of the rocket landing for other components. Apply the same safety procedures to each part as it would be with the rocket as a whole.
- Do not forget to also check the launchpad for damage, clean it, and take it down to prepare it for travel.

After retrieval:

- Double-check the rocket thoroughly for any damage which may have occurred during flight to avoid possible mishaps during the next use of the rocket.
- Replace/charge all batteries prior to or in between flights to ensure they are ready for the next use of the rocket.
- Securely attach all batteries to their electronics sled using both zip ties and electrical tape to ensure they are secure and will not be lost.
- Securely prepare the rocket and launchpad during transportation to prevent damage during the journey to the next destination.

4.5.1.2. Motor Preparation

Instructions regarding the chosen motor and its preparation will be supplied with the purchase of the motor. The preparation procedures defined by the supplier and the safety code must be followed word-for-word by team members when preparing the motor. If the motor is not prepared properly, the following hazards could occur:

- CATO (catastrophic failure)
- Fire or unexpected ignition
- Motor ignition failure
- Combustion instability
- Unpredicted launch time

- Unstable rocket flight
- Motor exits the rocket at ignition or during boosts

Before working with the motor, all team members must secure loose hair and clothing, wear closed-toe shoes, and remove jewelry. Team members must also wear ANSI 787.1-certified safety glasses with a side shield and heat-resistant leather or canvas gloves for protection in the case of an accident.

To accompany the supplier's instructions, general guidelines for motor preparation are as follows:

- Double check to ensure the motor is suitable for the desired flight profile and certified by NAR, Tripoli, or other certifying amateur rocketry organizations or groups.
- The motor casing should be insulated with a liner or similar material to prevent the motor casing or launch vehicle from melting or expanding due to excessive heat.
- Ensure the motor is unused, has not been tampered with in any way, and is being used for a purpose recommended by the manufacturer.
- Ensure the motor casing and nozzle are in good condition and have no defects or cracks.
- Check that the motor mount is secure, is in good condition, and will not deflect motor thrust.
- Ensure the use of a blast deflector to prevent the motor's exhaust from hitting the ground.
- Check the stability of the rocket after installing the motor.
- Ensure the nose cone does not fit too tightly into the body tube as this can cause the motor to be expelled by the ejection charge.

It is important to closely follow proper safety procedures and the manufacturer's instructions when preparing the motor, as doing so greatly reduces the chances of an accident. To ensure proper procedures are followed, two team members must supervise the preparation of the motor while filling out the pre-launch checklist. Additionally, this procedure is built into the checklist to ensure its correct completion in order.

4.5.1.3. Setup On Launch Pad

General Information and Requirements:

- PPE required for all launch setup procedures: ANSI Z87.1 safety glasses, leather or canvas gloves, closed-toe shoes or boots, and clothing which covers all exposed skin from the neck down.

- Ensure conditions are appropriate for launch before beginning setup. Check hazard analysis and contingency plans for all conditions which threaten the safety of the launch, such as lightning or excessive wind speeds.
- Have appropriate first aid materials, such as a first aid kit, and fire-fighting materials, such as a fire extinguisher, on hand to deal with a medical emergency or launchpad fire.
- Have a communication device with which to contact emergency personnel in the case of a launchpad fire or serious injury.
- Have a backup launching area and backup launch dates in case the planned launch area is unavailable for some reason. Doing this can prevent delays in retrieving launch data.

Before setup:

- Choose a launch site at which rigid ground is available to prevent personnel from falling and to prevent the launch pad from sinking and causing an unplanned trajectory.
- Choose a launch site which is greater than 750 meters from any water sources.
- Choose a launch site with high visibility and no threats, or officially-approved minimal threats, from and to passerby, wildlife, man-made structures, or dangerous terrain.
- Choose a day with weather such that the launch vehicle may successfully launch without concern of rain, snow, excessive winds, or other launch-hazardous weather conditions.

During setup:

- Ensure the ground is stable and even before placing the launch pad. If there are minor worries about unstable ground, place a rigid system which can be used for support underneath the launch pad, such as wooden planks. If there are serious worries about unstable ground, find a better launch site.
- At least one personnel member must be watching the launch pad at all times after placing it to ensure it does not change from its intended position and no wildlife or weather tampers with its condition.
- Ensure launch rails are not bent or twisted to prevent an unplanned or ballistic trajectory.
    - Inspect the launch rails to confirm that there are no abrasions or other damage to ensure the rocket starts in a vertical trajectory.
    - Unfold launcher legs and place the launchpad on firm ground.
    - Make sure said ‘firm ground’ is dry and has minimal amounts of dust to ensure a clean ignition.

    - Clear all obstructions and keep any flammable objects (barring the rocket itself) up to 100 feet away from the launcher.
- Ensure launchpad support struts are not bent, cracked, rusted, or showing other signs of damage to prevent an unplanned or ballistic trajectory.
- Ensure the launch rail is properly lubricated, if necessary, so all planned ejections occur and the rocket achieves the planned height and follows the planned trajectory with minimal friction to ensure a stable and unimpeded launch.
- Clean launchpad of any dust, pebbles, or anything that can turn into a projectile due to jetblast to prevent injury to onlookers.
- Double-check to ensure that the launch pad has not sunk from its intended position due to unstable ground.
- After observing the above safety precautions, carefully transport the launch vehicle to the launchpad without damaging it. Then, slide the launch vehicle onto the rail, ensuring it is firmly secured and all rail buttons are well-aligned and are properly attaching the rocket to the launchpad.
- Once the rocket is firmly attached to the launch rail, check it over at least two times for damage or leakages.
- Double-check that all batteries in the rocket are firmly secured and are at a desirable charge level to prevent payload or avionics bay failure, which can result in failure of the mission goals or failure to eject parachutes at the desired time.
- Make the necessary adjustments to the payload and the avionics bay to prime everything for performance during the launch. Ensure the rocket is structurally complete and that the deployment is executed as intended by its design and testing. Double-check that all connections have been properly made in the avionics bay and to the payload, that both the avionics bay and payload have not been damaged, and that the avionics bay and payload are thermally insulated since any of these issues can cause payload or avionics bay failure.
- Check to make sure the igniters have not been damaged in any way, are functional, and have been obtained from a reliable source and then attach the igniters to the rocket. This process must be done under the supervision of at least one other team member who is using the safety checklists.
- Double-check to make sure all components of the rocket are securely attached and fastened.
- If no damage is found on the rocket or launch pad, the rocket is securely attached to the launch pad and control systems, and the launch pad and control systems are in good condition, retreat to a safe distance and proceed with ignition procedures.

4.5.1.4. Igniter Installation

Before working with the igniters, all team members must secure loose hair and clothing, wear closed-toe shoes, and remove jewelry. Team members must also wear ANSI 787.1-certified safety glasses with a side shield and heat-resistant leather or canvas gloves for protection in the case of an accident.

The igniters used in this project will be supplied with the purchase of the chosen motor through the supplier. The installation procedures for the igniters will be defined by the accompanying instructions from the supplier using the appropriate PPE required of safety glasses and any other PPE deemed necessary. This requires the personnel with the Low Explosives User Permit (LEUP) and the Safety Lead in order to safely and securely setup the igniter. These instructions must be followed word-for-word by team members. If the igniters are not installed properly, the rocket may misfire or launch too early.

To accompany the supplier's instructions, general guidelines for igniter installation are as follows:

- Before approaching the rocket with the igniters, inspect the launch control mechanism to ensure it is disabled and not communicating with the rocket. For example, ensure any safety keys being used are removed before connecting the wires of the igniters to their clips.
- Inspect the igniter wires before installation to ensure they are not touching each other.
- Inspect the igniter clips before installation to ensure they are clean.
- Use an igniter plug/holder to keep the igniter in place once it is installed.

It is important to closely follow proper safety procedures and the manufacturer's instructions when installing the igniters, as doing so greatly reduces the chances of an accident. To ensure proper procedures are followed, two team members must supervise the installation of the igniters while filling out the pre-launch checklist.

4.5.1.5. Troubleshooting

If any step in these procedures and checklists is skipped, additional hazards that are not described in the instructions below may occur.

Construction:

- Machine failure: Consult online information, the machine manual, or any staff members who may work with the machine about how to fix the problem. Prepare an identical machine to use as a backup or a similar replacement to accomplish the same goal with potentially a longer manufacturing period while the machine is being fixed.

- Damage to, loss of, or failure to receive parts: Attempt to order new parts and have them sent through expedited shipping. Extra parts should be kept in storage in case an issue like this arises.
- Loss or unavailability of work area: If not done previously, select another work area and obtain permission to work in that area. Preferably, a secondary work area should be chosen and prepared prior to the occurrence of any emergency.

Vehicle Components:

- Rust or component expansion: Attempt to find suitable non-metal replacements for metal parts and store the rocket indoors. Consider that humidity might be the cause of the expansion.
- Part failure, loss, or damage: Run simulations through OpenRocket and RASAero of the rocket's flight as well as stability and load-bearing tests using FEA (Finite Element Analysis) and examine the affected area to determine how to improve the design of the rocket. Use spare parts to replace any lost parts or order new ones with expedited shipping if no spare parts are available.
- Poorly aligned motor tube: Realign the motor using a level, and do not rush the process. Double-check the alignment of the motor before all flights.

Ignition and Launch:

- Rocket does not launch when the electrical launch system is used: Remove the launcher's safety interlock or disconnect its battery and wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.
- Ignition failure: Ensure a physical connection exists between the ignition controller's power source and the ignitor. Check for dust or damage on the alligator clips. Ensure all pyrotechnic compound used is dry, has no dust on it, and is unburnt and undamaged. Make sure the fuel grain has no dust or moisture on or in it and is undamaged. Ensure proper motor packing procedures were followed.
- Loss or unavailability of launch area: If not done previously, select another launch area and obtain an FAA waiver for that area. Preferably, a secondary launch area should be chosen and prepared prior to the occurrence of any emergency.
- Rocket disconnects or is unstable on the launch rail: Ensure the launch rail buttons are properly aligned and working as planned, double check that the rocket was attached to the launch rail buttons using proper procedures, and

ensure that the rail itself was set up using instructions which came with the product.

Aerodynamics:

- Adverse effects (including undesired forces acting on the rocket and decreased velocity) from drag: Ensure the appropriate amount and locations of shear pins, fasteners, and vent holes are being used as determined by the design and testing and as described in the vehicle criteria section.
- Unpredictable trajectory: High wind speeds, mid-air collisions, or damage to rocket components may have caused this. Wait for wind speeds to lessen, ensure there are no obstacles in the flight path, and check all components of the rocket for damage.
- Instability: Measure the full-scale launch vehicle's physical center of gravity through balancing and compare it to the calculated center of pressure through simulated stability tests in RASAero and OpenRocket. If the physical center of gravity and the calculated center of pressure are not the same, make adjustments to ensure these quantities are the same. Make changes as necessary to increase the stability margin by adding ballast or slightly altering the fin geometry or fin size.

Avionics and Payload:

- Altimeter failure or loss of continuity: Between rounds, check and secure motor connections with alligator clips and masking tape. Double check altimeter settings. Check batteries and electronic connections to ensure they are working as planned.
- Loss of signal from GPS: Postpone flight and check the GPS unit, signal continuity, and batteries for problems before the next flight
- Arming system failure: Consult the manufacturer's instruction manual, ensure the system is undamaged, and communicate how to properly arm the system with the team before initiating the next flight.
- Overheating of avionics or payload: Ensure the avionics bay and payload are properly thermally insulated to prevent blistering. If they are not, take efforts to insulate them with a liner or similar material. Ensure the avionics bay and payload are not overloaded with wiring, as this can cause overheating and fire hazards.
- Mistimed, failed, or lack of ejection: Check altimeters for damage and ensure they are being run with proper settings. If everything is in working condition, check remaining ejection charges for damage and ensure they are being properly packed.

- Payload fails: Test the payload in general by inspecting its functionality and determining what is not working. If issue undetermined or persists, try launching on a different date or at a different location.
- Payload camera fails or takes poor quality pictures: Test the payload camera on the ground, double-check batteries and connections related to the camera, check the performance of the payload computer used by checking its batteries and connections, and double check that the rocket followed its planned flight path and was stable.
- Poor overall electronic performance: Test the reliability of the wiring and batteries. If doing so yields no results, weather (especially overly wet atmospheric conditions) or failure of other rocket components may have caused this. If the issue cannot be determined or persists despite adjustments, try launching on a different date or at a different location.

Recovery:

- Parachute deployment failure: Ensure proper parachute and ejection charge packing procedures are being followed, check that there was no damage to the parachute beforehand, ensure proper spacing between the ejection charges and parachutes, check for altimeter failure, and ensure there is no excessive velocity when the parachute system is being deployed. The recovery system mount for the parachute should also be examined to see if it is working as planned and is undamaged.
- Stage separation failure: Ensure faulty ejection charges are not being used, ensure ejection charges are being packed properly, double check the design of the rocket to ensure the strength of the bonds (made using shear pins, screws, or epoxy) holding the stages together is not excessive, and check for altimeter failure.
- Shock cord failure: Ensure the shock cord is of the proper size and is being packed properly, ensure the shock cord has been bought from a reliable source and is not damaged, and ensure any parachute which the shock cord may have been tangled in is the correct size for the rocket.
- Excessive or insufficient landing speed: Check parachutes for damage and ensure they are properly sized, packed, and protected from harm.

Personnel:

- Low / insufficient amounts of communication: Encourage members to talk to each other about the project, have an organized group of subteams within the project and obtain updates from subteam leaders weekly.

- Inactivity: Train all members to work in all areas necessary, track and encourage meeting attendance, encourage members to bring friends to meetings, improve communication.
- Low availability of personnel: Determine who has time to complete tasks and declare those members responsible, ensure the schedule and deadlines are known by all team members so they can work around them, and attempt to help team members prevent their semester schedules from being too strenuous by advising individuals on time management.
- Conflicts of important academic or personal events with team events: Talk to the parties concerned well in advance of the conflicting event to try and work out a change of date.
- Hypothermia: Call medical personnel immediately if hypothermia is suspected. Warm the person slowly, focusing on warming the chest area first as warming the limbs before the core may cause shock. Dry the person and remove wet clothing, if needed. Do not immerse the person in warm water and do not directly apply heat sources such as water bottles or heat packs to the person without first wrapping them in cloth. Give the person CPR if necessary and, if they are responsive, give them warm water to increase body temperatures. As body temperature rises, warm the person's head and neck as well.
- Heatstroke or heat exhaustion: Call 911 if the situation is serious, i.e. the affected person is being extremely unresponsive. Attempt to lower the body temperature of the affected person using cold water, ice, or cooling blankets. Get the affected person to a shaded or air-conditioned place, and give them water to hydrate.
- Physical injury: Call medical personnel immediately if the injury is serious. Attempt to slow any bleeding using cloth or a similar substance - if safety procedures have been followed, a first aid kit should be nearby. Treat the affected person for shock if the wound is of moderate severity or greater; however, be cautious of moving the affected person if it is believed that doing so could cause them more harm. If that is the case, the situation is best left to medical personnel and other individuals should not attempt to move the affected person unless officially designated.
- Electrocution: Immediately separate the person from the electrical power source by turning it off or, if that is not possible, standing on a non-conductive surface and using a non-conductive object (such as a wood-handled broom) to remove the person from the source. Do not touch the victim if he or she is still in contact with the electrical power source. Have someone call for emergency medical assistance immediately. Do not try to separate the person from a current if there is a feeling of a tingling sensation in the legs and lower body as this indicates the proximity to a high-voltage electrical power source. After removing the affected

person, do CPR if necessary and check for other injuries while waiting for medical personnel to arrive.

- Chemical contact: Shower the chemical off the affected area with water; if the chemical got in the eyes, apply water to the eyes, preferably with the use of an eyewash station. If a chemical was ingested, call the poison hotline immediately at (800) 222-1222. If a dangerous situation persists after washing the area with water, call 911 and again ensure that the launch officials are aware of the situation.
- Follow any other personnel safety concern as listed in the Personnel Hazard Analysis.

4.5.1.6. Post-Flight Inspection

General information:

- PPE required for all recovery and post-flight inspection procedures: ANSI Z87.1 safety glasses, leather or canvas gloves, closed-toe shoes or boots, and clothing which covers all exposed skin from the neck down.
- *Leave the avionics and payload* ***alone and armed*** *until otherwise mentioned. Ensure PPE mentioned above worn at all times until the end of cleanup.*
- Be aware that before beginning inspection, it is necessary for the competition that officials verify the results of the launch.
- Components of the rocket which have been damaged during flight may be dangerous to touch. Take extra care to observe the rocket closely before making physical contact with it, especially in the area which will be touched.
- Components of the rocket may also be hot to the touch for a small span of time after the fuel stops burning. Be aware of this and be sure to wear appropriate PPE of safety glasses and grab the rocket by the airframe if deemed not hot. If hot, wear the appropriate PPE of thermal-protective gloves before making physical contact with the rocket.

Exterior rocket inspection:

- Before approaching the rocket, observe whether or not it seems there is still fuel present within. If unburned fuel is present, wait for the fuel to safely burn away. If the fuel is not burning away, clear the surrounding area of fire hazards while exercising extreme caution, then ensure the motor is isolated and/or the fuel is safely disposed of; fire protection services may be needed for this task.
- After handling unburned fuel check the rocket for any missing parts. If there are missing parts, enforce the team’s best efforts to locate them in order to minimize pollution to the environment and to recover as much of the rocket as possible.

- Make sure all fasteners, joints, and shear pins are undamaged and secured in place and that each hole, including vent holes, is in the correct state as shown before launch. Ensure that none of the holes are cracked or otherwise damaged.
- Check the nose cone for damage such as cracks, holes, or warping.
- Check the body tube for damage. Look for any bending or twisting of the body tube and make sure there are no holes other than the ones necessary for the payload. Dry off the body tube of any water accumulated during flight, either from vapor or upon landing.
- Check the fins and any other aerodynamic surfaces for twisting or cracking.

Interior rocket inspection:

- *Leave the avionics and payload alone and armed* until the entirety of this list is completed.
- Ensure that all ejection charges were successfully and safely deployed. If ejection charges remain unfired in the rocket even though they should have gone off, exhibit extreme care when removing and disposing of them, ensuring that proper PPE is worn and no flammable objects are nearby. Remove and dispose of the rest of the ejection charges safely and with care as well.
- Verify that the recovery system was fully and successfully deployed and that it suffered no damage throughout the rocket's flight. Check to make sure there are no tears in the parachute, the shock cord and parachute shroud lines are in good condition, and the recovery system mount on the rocket is firmly secured and free of signs of stress such as cracks or torsion. Also, check the recovery system for signs of heat damage, as that means the packing methods being used are poor or the spacing between the recovery system and the ejection charges is incorrect.
- Check the motor for damage such as cracks or nozzle bending and check the centering rings and motor mount for signs of strain such as cracks or bending. Ensure the motor tube is still angled correctly and is tightly secured if the rocket is to be used again in the future.
- Check bulkheads for damage such as cracks, bending, or other visible data.
- Check the avionics bay and the payload for internal damage and failures. In the event of a hazardous material leak, such as that from damaged lithium ion batteries, notify fire personnel and clear the immediate area.
- Recover any data and footage from the flight; *only after* retrieving the data should the avionics and payload be disarmed. After disarming the avionics bay and payload, disarm the launch controller.

Pad inspection:

- Ensure the launch rails show no signs of damage, such as deformation, bending, cracks, breaks, or other catastrophic damage.
- Ensure the launchpad's support legs and struts show no signs of damage, such as cracks or deformities.
- Clean the pad of dust left by the rocket exhaust or any other dirt which has accumulated. Ensure this waste is disposed of safely in the proper disposal facilities or as determined by launch officials.
- Once the launch pad has been checked for damage and cleaned properly, it may be taken down and prepared for safe transportation.

The additional procedures for the payload and avionics are built into the checklist in order to ensure their completion in addition to it being in order. All launch components may be put for future reuse after careful transportation and inspection that all design criteria are still met and that no damage is present, other than possible visual damage other than that what would otherwise affect the performance of the rocket.

4.6. Checklists

4.6.1. Pre-Launch Checklist

General Safety:

- ❏ Ensure that at least two people simultaneously are using the checklist and following all procedures to prepare for launch included but not limited to a team lead in order to successfully complete a step or to witness and sign off verification of a step
  - If only one person has the checklist, there is more chance that something is misinterpreted or missed, leading to failure
- ❏ Ensure safety protection glasses are worn at all times for full duration of the launch
- ❏ Ensure that a trained Range Safety Officer is present
- ❏ Have first aid equipment and at least one phone available for use nearby
- ❏ Designate a "rapid response" person or persons to be the one(s) to perform duties such as call for an emergency or administering basic first aid
- ❏ Designate spotters to keep track of the rocket's descent and to point out its location to the rest of the team and spectators as it falls
- ❏ Have adequate fire suppression equipment including but not limited to fire extinguisher, fire retardant, or fire blanket available for use nearby
- ❏ If conditions at launch are dry enough to deem it necessary, a fire blanket must be placed under the pad

- ❏ Prep payload (more in-depth instructions, if necessitated, are included in payload section)
    - ❏ Plug wired connections to battery on rover
    - ❏ Calibrate the accelerometer
    - ❏ Check XBee connection to stepper motor
    - ❏ Setup and install payload bay on rocket
        - ❏ Setup ejection charges
        - ❏ Setup shear pins
    - ❏ Make sure limit switch is flush with the payload bay for arming the rover
    - ❏ When rover is armed the LED on the arduino blinks 1/s (If NOT armed the LED will be constant)
- ❏ *Prep avionics and reloads* (more in-depth instructions, if necessitated, are included in avionics section)
    - ❏ Setup teledongle
        - ❏ Screw in the six purple rods, with the two shorter rods being on the top, and the rod with the teledongle attached being on the bottom
        - ❏ Connect the teledongle to the antenna
        - ❏ Connect the teledongle to the computer
        - ❏ Open AltOS
            - ❏ Select Monitor Flight and select the Teledongle
        - ❏ Set the frequency and baud to what was noted to the Telemetrum configuration
    - ❏ Setup RRC3+ Sport
        - ❏ Plug USB IO Dongle into computer using a working USB mini B cable
        - ❏ Make sure USB IO Dongle dip switch is ON
        - ❏ Launch mDACS.exe
        - ❏ In mDACS.exe, go to System Preferences, and select the Active COM port (if does not function, may need to click Clear Active Port first.)
        - ❏ Go to RRC3 settings tab
        - ❏ Click RRC3 Host Connect
            - ❏ A 20 second timer will count down
            - ❏ Before the timer finishes, connect the USB IO Dongle to the RRC3+ Sport using the COMM port on both devices
        - ❏ Check all settings to make sure they are correct. Then, unplug the connector cable from the COMM port on the RRC3+ Sport.
        - ❏ Avionics now prepped until on the pad
    - ❏ Setup Telemetrum

- ❏ Use a working micro-usb cable to connect the telemetrum to a computer with AltOS installed
- ❏ To recognise the telemetrum, the battery and switch must be connected
  - The battery will charge using the power from the computer's usb port. It may be necessary to leave the telemetrum plugged into the computer for a while to ensure the battery is fully charged
- ❏ Open AltOS
  - ❏ A small window will appear: It is a good idea to delete all previous flights, as storage space on the telemetrum is very constrained. To do this, click Save Flight Data, and check the boxes to delete runs, and then exit the window.
- ❏ Click "Configure Altimeter" and then turn on the Telemetrum using the switch
  - ❏ Select the telemetrum
    - ❏ *Note that if the teledongle antenna setup is connected, that will show up too if needed*
- ❏ Select all settings as desired
  - ❏ It is a good idea to set the flight log size at the largest possible, assuming the previous flights were cleared
- ❏ TAKE NOTE OF THE FREQUENCY AND TELEMETRY BAUD RATE, AS WELL AS THE PAD ORIENTATION
  - ❏ Click save and temporarily turn the altimeter switch to OFF
  - ❏ The pad orientation should be pointing down with the current design
- ❏ Require verification and recheck of this list to ensure all steps have been completed or the system may not work and the rocket fails

❏ Ensure that the avionics are initially disarmed as previously checked and that an "arm before flight" reminder is in use

General Rocket Construction:

- ❏ Ensure computer simulations have already been run of the rocket in its current construction state before launch to analyze both normal and ballistic scenarios
- ❏ Check that all fins and lugs are secure and aligned
- ❏ Check that the body tube is in good condition without cracks or other failures whereas it may be flown
  - ❏ Ensure there are no cracks or other signs of damage

- ❏ Check that the recovery system is in good condition, is functional, is securely installed, and is strong enough to withstand recovery loads
    - ❏ Check that shock cords are securely attached and are not cracked, burned, or frayed
    - ❏ Check that shroud lines are not burned or tangled
    - ❏ Check that all hardware, such as snap swivels and screw eyes, is in good condition and secure
    - ❏ Check that parachute protection is installed properly and is in good condition
- ❏ Check that the electronics bay is in good condition, is functional, and is securely installed
    - ❏ Have each altimeter checked the **night before** the flight
    - ❏ Ensure the altimeters are properly installed
    - ❏ Check that the electronics bay is properly vented and that wires do not cover any ports
    - ❏ Check that the drogue and main wiring are in good condition
    - ❏ Check that all electronics bay hardware and electrical connections are secured against acceleration forces
    - ❏ Ensure the battery or batteries being used are charged and in operational condition, and secure battery positions with masking tape
    - ❏ Check that the ejection charges are properly set up
    - ❏ Close and secure the electronics bay
- ❏ Check that the motor and ejection system are in good condition before installation
- ❏ Ensure the proper motor and ejection system have been selected for the desired flight profile and that they are certified by NAR, Tripoli, or other amateur rocketry organizations or groups
- ❏ Check the reload motor for proper build-up, paying special attention to the motor being centered
- ❏ Install the black powder ejection system
    - ❏ Payload ejection charges
        - ❏ Cut off the finger of a disposable glove
        - ❏ Fill the fingertip of the glove with the 2 and 3 gram amount of 4F black powder needed
        - ❏ Insert ejection charge into black powder
        - ❏ Close off the fingertip by tightly twisting the glove around the e-match wire and putting two zip ties around the twisted glove and wire
            - ❏ Truncate the zip ties

        - ❏ Feed the connection end of the ematch through the charge well and pull through so that the glove tip is inside the charge well
        - ❏ Pack the glove tip/black powder down into the charge well and pack dog barf on top
        - ❏ Seal the top of the charge well with tape and foil
    - ❏ Avionics ejection charges
        - ❏ Cut off the finger of a disposable glove
        - ❏ Fill the fingertip of the glove with the 4 and 5 gram amount of 4F black powder needed
        - ❏ Insert ejection charge into black powder
        - ❏ Close off the fingertip by tightly twisting the glove around the e-match wire and putting two zip ties around the twisted glove and wire
            - ❏ Truncate the zip ties
        - ❏ Feed the connection end of the ematch through the charge well and pull through so that the glove tip is inside the charge well
        - ❏ Pack the glove tip/black powder down into the charge well and pack dog barf on top
        - ❏ Seal the top of the charge well with tape
    - ❏ Verify and ensure the ejection charge is properly installed, and is the proper amount according to the table at the end of this checklist
- ❏ Check that the motor mount is secure, is in good condition, and will not deflect motor thrust
- ❏ Install motor
    - ❏ Ensure setup strictly by LEUP holder and Level 3 certification following instructions provided by manufacturer and by following the steps in the motor preparation
    - ❏ Ensure that motor properly inserted into rocket and securely attached
    - ❏ Ensure that the motor is properly installed

Flight Check:

- ❏ Check the nose cone and any stage or payload couplers for a secure and proper fit
- ❏ Check that the motor is securely installed
- ❏ Check for continuity, resistance, and cracks or flaws in the pyrogen of the igniters so that all igniters must touch the propellant, have adequate electrical current flowing to them as determined by the motor specifications, and have no shorts by being fully inserted
- ❏ Ensure thrust symmetry in case of clustering or mass imbalance

- ❏ Check that staging delay is less than one second
- ❏ Ensure that the rocket's center of gravity is in its expected position with respect to the rocket's geometry and with respect to the rocket's center of pressure
- ❏ Perform manufacturer's checking instructions on the avionics
- ❏ Check that shear pins are installed, including for the main parachute compartment
- ❏ Ensure drogue ejection will not cause main parachute to deploy

Pad Distance:

- ❏ Ensure only the minimum number of personnel are at the pad to prep for launch
- ❏ Ensure barriers are in place to keep spectators away from the launch area
- ❏ Ensure all team personnel and spectators are a safe distance from the pad based upon NASA or other officials approval and the attached minimum safe distance table)

Pad Installation:

- ❏ Ensure the launch controller is disarmed prior to installing the rocket onto the pad
- ❏ Ensure the launch pad is stable and is an adequate size for the rocket being used as determined by the rocket parachute sizing equation
- ❏ Ensure that enough electrical current will reach the igniters of the rocket
- ❏ Verify that the igniter clips are clean
- ❏ Ensure that the launch rail and rocket are clean to verify that the rocket moves smoothly on the launch rail
  - ❏ Install the rocket on the launch rail and verify that this is true
- ❏ Ensure that the igniter clips are secure them to the pad
- ❏ Install igniter into motor by following igniter procedure instructions
- ❏ Connect launch leads to motor igniter
- ❏ Arm the avionics system once the rocket is on the pad:
  - ❏ Checklist for the RRC3+ Sport avionics system
    - ❏ Wire the battery
      - ❏ Connecting to the altimeter, red is positive, black is negative, and the 9V connector only goes on one way. Set the switch to OFF, wire the switch and ejection charges to RRC3+ Sport, according to the Wiring Diagram below.
    - ❏ Turn on RRC3+ Sport using the switch
      - ❏ A long 5 second beep will sound during startup.
    - ❏ Listen for three beeps in a row
      - ❏ This indicates continuity on Main and Drogue

        - ❏ Turn the RRC3+ Sport off: When it's time to close avionics bay and it's time to launch: turn switch back on and make sure there are 3 beeps to indicate continuity on Main and Drogue
        - ❏ Ensure that the systems are all turned on
    - ❏ Telemetrum
        - ❏ Plug LiPo battery into the battery port with the red wire as positive and black wire as negative
        - ❏ Screw in switch wires into the appropriate slots
        - ❏ Screw in drogue and main e-match wires into the appropriate slots
        - ❏ Before powering on the Telemetrum, ensure that it is in an upside-down orientation
        - ❏ Use the switch to power on the Telemetrum when the rocket is ready to launch
        - ❏ Ensure the telemetrum emits the following sets of beeps:
            - ❏ Four beeps, pause, one beep - Battery voltage
            - ❏ Dit, dah, dah, dit - Indicates pad mode; waiting for launch
                - ❏ If only dit, dit - Indicates idle mode; ensure Telemetrum is in correct orientation
            - ❏ Dit, dit, dit - Continuity on both drogue and main e-matches
                - ❏ If only brap - Indicates continuity on neither drogue nor main e-matches
                - ❏ If only dit - Indicates continuity on only drogue e-match
                - ❏ If only dit, dit - Indicates continuity on only main e-match
                - ❏ If warble - Storage is full; need to delete extraneous flights
        - ❏ Require verification and recheck of this list to ensure all steps have been completed or the system may not work and the rocket fails
    - ❏ Close the avionics bay

Flight Trajectory:

- ❏ Ensure the launch and the flight will not be angled towards any spectators
- ❏ Know the expected performance of the model: double check that the rocket will not fly higher than its permitted clearance waiver
- ❏ Check cloud bases and winds and make sure the skies around the launch area are clear
- ❏ If needed, use a wind speed indicator to avoid launching during extremely windy intervals

- ❏ Ensure there are no obstructions or hazards in the launch area

4.6.2. Launch Checklist

- ❏ Ensure that safety glasses are worn
- ❏ Ensure that the procedures for troubleshooting and procedures are followed and have been read
- ❏ Ensure that at least two people are using this checklist to observe the launch
- ❏ Ensure the stability of the model is being monitored
- ❏ Ensure rocket trajectory is being tracked during flight. Be aware of tilt or drift from mass/aerodynamic imbalance, wind, or other sources
- ❏ **Do not turn off the altimeters and ensure that all avionics and payload are in the proper state for launch**
- ❏ Ensure that spectators and vehicles are in the crosswind (perpendicular to the wind) positioning to ensure that the rocket will not unsafely drift in that vicinity
- ❏ Ensure that the launch pad is being monitored after takeoff in case any dangers arise at the pad
- ❏ Ensure all passerby and spectators are aware of the launch

Beginning the Launch:

- ❏ Shortly before the countdown, give a <u>loud</u> announcement that the rocket will be launched
    - ❏ If too loud or otherwise applicable to the situation, use a PA system
- ❏ Ensure that all spectators are aware of the launch and are safely positioned
- ❏ When launching, give at least a <u>loud</u> 5-second numerical countdown followed by shouting “launch”
- ❏ Ensure that the recovery system is successfully deployed
- ❏ Carry out a safe recovery of the model
- ❏ Call a loud “Heads up” (If needed, sound an air horn) in the case of any rockets approaching the prep area or spectators and ensure all see the incoming rocket
    - ❏ If somebody cannot see the rocket, ensure everyone points at it as it descends
- ❏ Monitor the flight path, using binoculars if necessary
- ❏ Make sure whoever is responsible for recovery is kept fully aware of the status of the rocket (failed to launch, nominal in-flight, mid-air failure, returning for recovery, etc.)
- ❏ Communicate launch progress effectively to NASA or other relevant officials

In the case of a misfire:

- ❏ Wait a minimum of one minute unless officially notified otherwise

- ❑ Disarm launch controller and avionics by following the same steps as below by simply turning off systems or as safely determined dependent on the failure
- ❑ Remove failed igniter and motor if officially deemed feasible

- ❑ **Ensure rocket has successfully landed**
- ❑ Ensure permission by NASA or other official range safety officer to deploy payload
    - ❑ Turn on “Power” switch on control box and verify
    - ❑ Flip the “Arm” switch and verify by checking frequency of blinking LED
    - ❑ At the moment further permission is provided by the official, press “Eject” button and verify the LED turns solid
    - ❑ Hold for 30 seconds
    - ❑ Hit “Deploy” button

4.6.3. Post-Launch Checklist

- ❑ Ensure that PPE worn as required for all recovery and post-flight inspection procedures, including but not limited to: safety glasses, leather or canvas gloves, closed-toe shoes or boots, and clothing which covers all exposed skin from the neck down
- ❑ *Leave the avionics and payload **alone and armed** in their current state until otherwise mentioned*
- ❑ Follow post-flight inspection procedures
- ❑ Double check that there are no hazards which have gone unnoticed during the launch before approaching the launch pad or the rocket for clean-up
    - ❑ If there are hazards, notify emergency personnel
- ❑ Let NASA or other launch officials verify the results of the launch, if necessary
- ❑ Double check that all necessary data from the avionics bay has been retrieved
    - ❑ Record weather data for determining additional characteristics for calculation
- ❑ Disarm the avionics by simply turning off the avionics
- ❑ Disarm the launch controller
- ❑ Place cap on launch rods, if necessary
- ❑ Take down the launch pad, if necessary
- ❑ Retrieve the main rocket body and all components which may have landed separately
    - ❑ Check for any failed ejection charges
    - ❑ Safely disable / remove all ejection circuits and remove any non-discharged pyrotechnics

4.7. Plan for Compliance with Laws

Each team shall provide a plan for complying with federal, state, and local laws regarding unmanned rocket launches and motor handling (specifically, 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, NFPA 1122 “Code for Model rocketry”, NFPA 1127 “Code for High Power Rocket Motors”). The project team will follow regulations listed in NFPA 1127 and CFR 27 Part 55 and will store all motors, black powder, and other flammable materials in a Type 4 Magazine. These materials will only be removed immediately prior to flight. All launches will be conducted in an area with an active FAA waiver that extends beyond 5,623 feet, the projected altitude of the launch vehicle. All team members present at these launches will closely follow the NAR High Power Rocket Safety Code and the safety agreement, which both encourage lawful rocketry.

Hazard	Likelihood (Cause)	Severity (Effect)	Risk	Mitigation
Damage of Property	Low	High	Legal Repercussions	Insurance
FAA Violations	Low	High	Legal Repercussions	Adhere to regulations
NAR/TRA Violations	Low	High	Legal Repercussions	Adhere to regulations
OSHA Violations	Low	High	Legal Repercussions	Adhere to regulations
Personal Injury	Low	High	Legal Repercussions	Individual / independent calculations and safety protocols / preparedness

With this, the Safety Officer will be in charge and share the responsibility with the Team Leader to inform the team of any laws and regulations listed above in additional to any that may apply set by the NAR/TRA.

4.8. Plan to Purchase, Store, Transport, and Use Hazardous Materials

Some of the materials that will be used on this project require extreme care and caution. Team members will be reminded and required to have knowledge of the safety rules based on storage, transport, and use of the hazardous materials by use of Material Safety Data Sheets (MSDS).

Hazardous materials used on this project include but are not limited to black powder, fiberglass, epoxies and other adhesives, ammonium perchlorate composite propellant, pre-made rocket motor igniters, and compressed carbon dioxide. Hazardous materials will be stored off-site, within the Zucrow Labs research facilities adjacent to the Purdue University Airport.

The Team Lead or Safety Officer will be notified and engaged before the purchase of any materials to make certain that there is a safety plan sufficient to address any new safety issues, to proactively identify and acquire any required PPE, and to compile and maintain all MSDSs and other safety information. Additionally, certain members of the team working on the project currently hold a Low Explosives User Permit (LEUP), and these are the members who will handle the acquisition, transportation, and storage of the hazardous materials involved in this project.

All team members will be given a briefing on the plan to properly purchase, store, transport, and use hazardous materials by the safety officer. This safety brief will provide knowledge of and access to MSDS (Material Safety Data Sheets) for all potentially hazardous substances which will be used on the project and will ensure the use of proper PPE when handling hazardous materials. The MSDS are to be referred to when a hazard occurs in order to execute the most effective mitigation and ensure all safety concerns are addressed. All MSDS are available to the team at all times and are required to be understood before working with potentially hazardous materials as to help increase awareness to reduce the potential for a hazard and likelihood of failure.

As fiberglass will be a primary component of the rocket and a hazard most team members will be working with, the team will be required to properly use the PPE of safety goggles, dust masks, and gloves at all times when cutting, sanding, and painting to prevent dust from entering any orifices primarily including any eyes or lungs. All proper clothing will be worn including pants and closed-toe shoes to prevent injury to the legs from any objects.

4.9. Team Safety Statement

The following statement will be printed out for all team members to sign:

As a member of the Purdue Space Program Student Launch (PSP-SL) team, I agree to:

1. Adhere to any and all relevant local, state, and federal laws and regulations.
2. Adhere to the NAR High Power Rocket Safety Code.
3. Comply with all instructions given to me by the Safety Officer and by the Range Safety Officer.
4. Wear appropriate personal protective equipment whenever constructing or operating the launch vehicle.
5. Understand the hazards of each material or machine I plan to use or operate.
6. Never misuse the materials or equipment I will work with in this project for any reason.
7. Acknowledge that the Range Safety Officer will inspect the launch vehicle prior to all flights.
8. Acknowledge that the Range Safety Officer reserves the right to approve or deny the flight of the launch vehicle for any relevant reason.
9. Acknowledge that my team will not be allowed to fly if it does not comply with each of the aforementioned safety regulations.

My signature confirms that I have read and understood the aforementioned agreements. I recognize that any violation of these agreements may result in being unable to participate in Project Walker or the PSP-SL program. I recognize that although the safety team is in charge of overall safety, I am individually responsible for remaining safe and following the rules set forward by these statements.

Name____

Signature____ Date______________