# The Terra Nova Project
# Final Readiness Review

NASA University Student Launch Flight Readiness Review

Florida State University - Panama City
4750 Collegiate Dr
Panama City, FL 32405

March 9th, 2026

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# Figures and Tables

# Acronym Bank

**ATF –** Bureau of Alcohol, Tabacco, Firearms and Explosives

**CAD** – Computer Aided Design

**CAM** – Computer Aided Manufacturing

**CDR** – Critical Design Review

**CFR** – Code of Federal Regulations

**CNC** – Computer Numerical Control

**DDS** – Digital Design Studio

**EMI** – Electromagnetic Interference

**FAA** – Federal Aviation Administration

**FAMU** – Florida Agricultural and Mechanical University

**FMEA** – Failure Modes and Effects Analysis

**FRR** – Flight Readiness Review

**FSU** – Florida State University

**GCSC** – Gulf Coast State College

**HAUS** – Habitat for Agricultural Utilization Study

**HOL** – Holley Building

**HPR** – High Powered Rocketry

**ICT** – In-Circuit Testing

**InSPIRE -** Innovation, Sustainability, and Preeminent Research & Education

**LRR** – Launch Readiness Review

**NAR** – National Association of Rocketry

**NASA** – National Aeronautics and Space Administration

**NFPA –** National Fire Protection Association

**OSHA** – Occupational Safety and Health Administration

**PC** – Panama City

**PCB –** Printed Circuit Board

**PDF** – Payload Demonstration Flight

**PDR** – Preliminary Design Review

**PHA** – Preliminary Hazard Analysis

**PhD** – Doctor of Philosophy

**PLA** – Polylactic Acid

**PLAR** – Post Launch Analysis Report

**POC** – Point of Contact

**PPE** – Personal Protective Equipment

**RAM –** Rocketry & Mechatronics

**RSO** – Registered Student Organization

**SDS** – Safety Data Sheet

**SEARS** – SouthEast Alabama Rocketry Society

**SAIC** – Science Applications International Corporation

**STEM** – Science Technology Engineering and Math

**TRA** – Tripoli Rocketry Association

**UAS –** Unmanned Aircraft System

**USLI –** University Student Launch Initiative

# 1. Summary of FRR Report

## 1.1. Team Summary

| Team Summary | |
|---|---|
| **The Terra Nova Project** | 4750 Collegiate Dr. Panama City, FL 32405 |
| Elizabeth Gildersleeve – Mentor | |
| NAR #: 119990<br>HPR Certification Level: Level 2 | Email: Elizabeth.gildersleeve00@gmail.com<br>Phone: (850) -775-8483<br>FSU PC Mechanical Engineering Alumni |
| Final Launch Week Plans: | Planning to attend NASA Launch Week |

## 1.2. Launch Vehicle Summary

| Launch Vehicle Summary | | | | |
|---|---|---|---|---|
| **Primary Motor/Competition Launch** | **Secondary Motor** | **Dry Total Mass:** | **Total Wet Mass:** | **Burnout Mass:** |
| L2200G-0 | L1420P-R | 46.25 lb | 56.75 lb | 51.2 lb |
| **Rail Size** | **Target Apogee** | **Ballast Weight** | **Total Length** | |
| 12 ft 1515 rail | 4900 ft | 2 lb | 120.75” | |
| **Launch Vehicle Sections:** | **HAUS Section** | **Avionics Section** | **Propulsion Section** | |
| Landing Mass: | 15.9 lb | 14.5 lb | 16.8 lb | |
| Landing Section Lengths | 46.69” | 60.5” | 26” | |
| External Lengths | 39.75” | 60.5” | 20.5” | |
| **Drogue Parachute** | **Main Parachute** | **Altimeter** | **Black Powder** | **$CO_2$ Canisters** |
| Fruity Chutes 15” Compact Elliptical Parachute | 120” Fruity Chutes Iris Ultra Compact Parachute | Altus Telemetrum | Estimated < 0.1g. Located In Avionics Bay. | 25 and 38 oz canister for drogue separation / 38 and 45 oz canister for main deployment |
| **Proj. Descent Rate (Landing)** | **Drogue** | **Reefed Main** | **Full Main** | **Reefing-Line Cutter** |
| 15.5 ft/s<br>Deployment at Apogee. | 120 ft/s Descent Rate. Deployment at 1000 ft. | Deployment at 1000 ft. | Deployment at 650 ft. | Deploys Main at 650 ft |

## 1.3. Payload Summary

The title of the HAUS (Habitat for Agricultural Utilization Study) is the Terra Inquisitor meaning “Earth Searcher”. This is a perfect indication of the mission of the payload, the Terra Inquisitor is a mechanically deployed, ground-operating experimental system designed to autonomously collect and analyze soil following launch and recovery. After landing, the payload separates from the launch vehicle using a non-energetic lead-screw-driven mechanism compliant with NASA safety requirements. Once deployed, the payload collects 60ml of soil using a linkage system and drilling auger, measures soil pH, storing all data onboard for post-flight analysis. The payload is fully self-contained and designed to remain functional after exposure to launch, recovery, and landing loads.

# 2. Changes made since CDR

## 2.1. Recovery

The primary recovery change since the CDR is the redesigning of the reefing bay. Initially this system used a container housing the electronics used for the reefing system, which was attached to the RMS eyebolt (on the aftmost bulkhead). This design has since been changed to use a PETG plate that fits around the motor tube between the aftmost bulkhead and the forward centering ring. This change was made to improve structural integrity of the system and to better pressurize the components as to not read the separation pressurization as loudly.

## 2.2. Payload

The have been multiple modifications to the design of the systems of the payload due to more completed testing of the systems. These modifications are detailed in the Changes to Payload Design. These include modifications to mounting holes for the chassis, the inclusion of steel rods, splitting the chassis into to sections for printability and implementation of steel rods, modifications to the separation mechanism, modification of the coupler link, inclusion of bearings for all links and mounting locations of idler wheel assemblies for the track systems, modifications to the soil container assembly, and modifications to the water tank assembly.

## 2.3. Project Plan

Following the unsuccessful recovery of our Full-Scale Flight on February 21st, we pushed our second flight till March 14th or schedule permitting March 21st to allow our team more time to run failure analysis. We also changed direction as we are now going to submit the FRR Addendum.

We also made several changes to our derived requirements and handbook requirement verifications per conversations with the NASA Team following our CDR.

# 3. Vehicle Criteria

## 3.1. Launch Vehicle as Constructed

### 3.1.1. Separation Locations

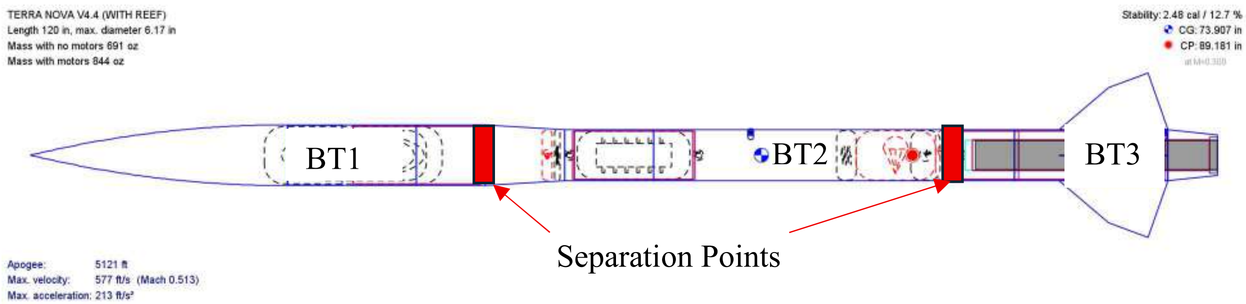



***Figure 3.1 Separation Points***

The separation Points of the Terra Nova vehicle are as shown in the image above. The drogue separation will occur by separating body tubes 1 & 2 (BT1 & BT2) +1s from apogee. The main separation will involve separating body tubes 2 & 3 (BT2 & BT3) at 1000 ft.

### 3.1.2. Energetic Locations

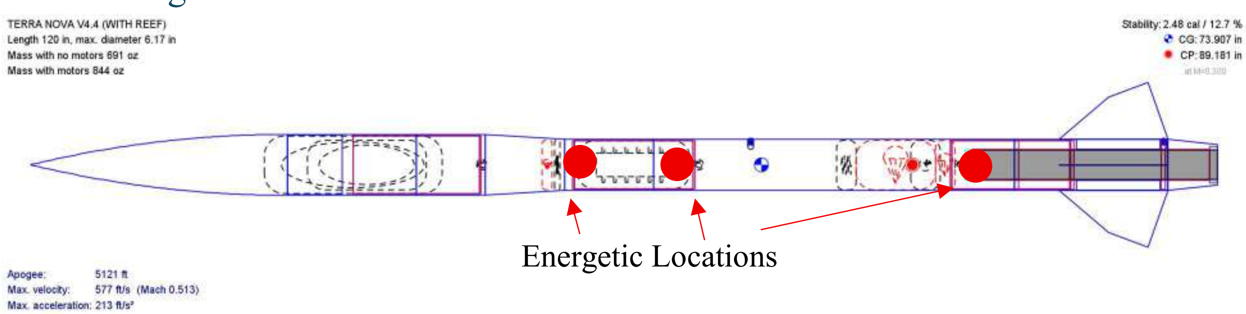



***Figure 3.2 Energetic Locations***

The locations of energetic materials to be contained within the Terra Nova vehicle are as shown in the image above. Black powder will be stored within contained metal components including the four TR Eagle $CO_2$ ejection devices and the Mako line cutter device. Each one of these devices uses minimal material, and the blast within is contained within each component.

## 3.2. Structural Elements

### 3.2.1. Nose Cone

The nose cone of any rocket is a key component. The Terra Nova implements an ogive nose cone with a fineness ratio of 4:1. The nose cone was purchase from Loc Precision due to its light weight. The drawing below details the as received nose cone dimensions.

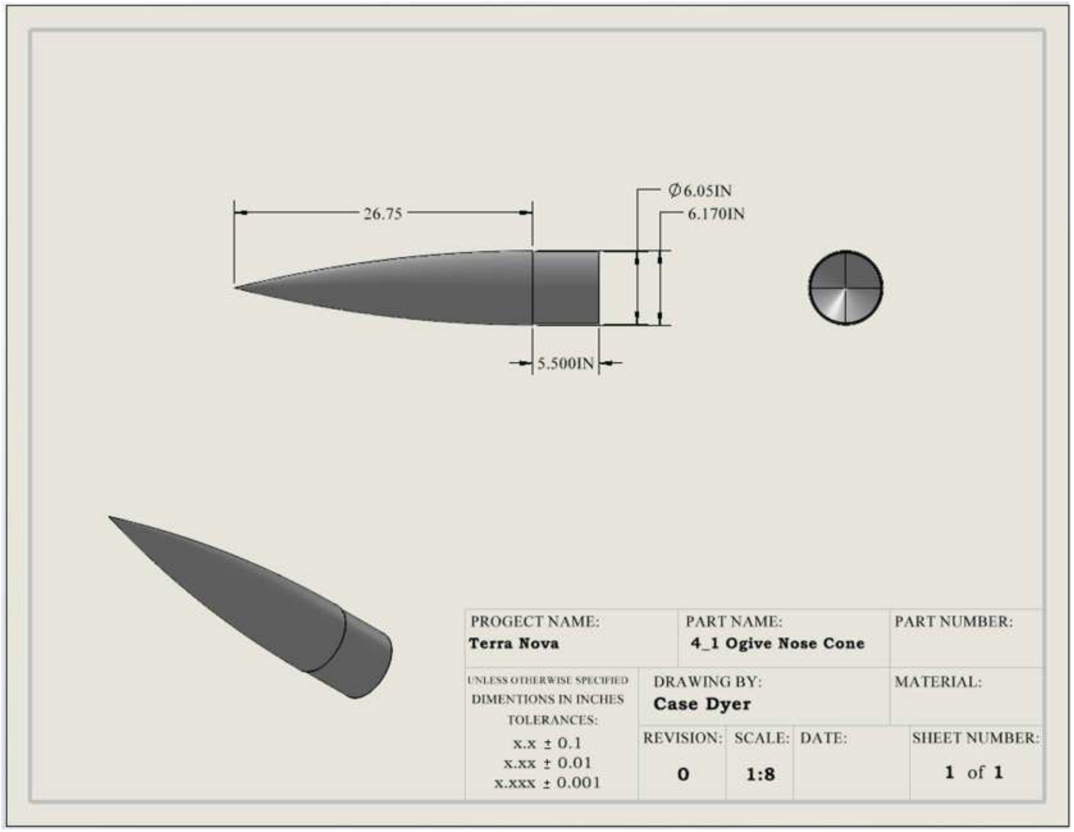



*Figure 3.3 Ogive 4:1 Nose Cone*

### 3.2.2. Airframe

The airframe of the Terra Nova rocket consists of fiberglass body tubing purchased from Wildman Rocketry. This material was chosen for the final construction because of its high strength and rigidity combined with low weight. This material is commonly used in rocketry making it a fairly straightforward option. Below are the detailed drawings of all body tubes as constructed:

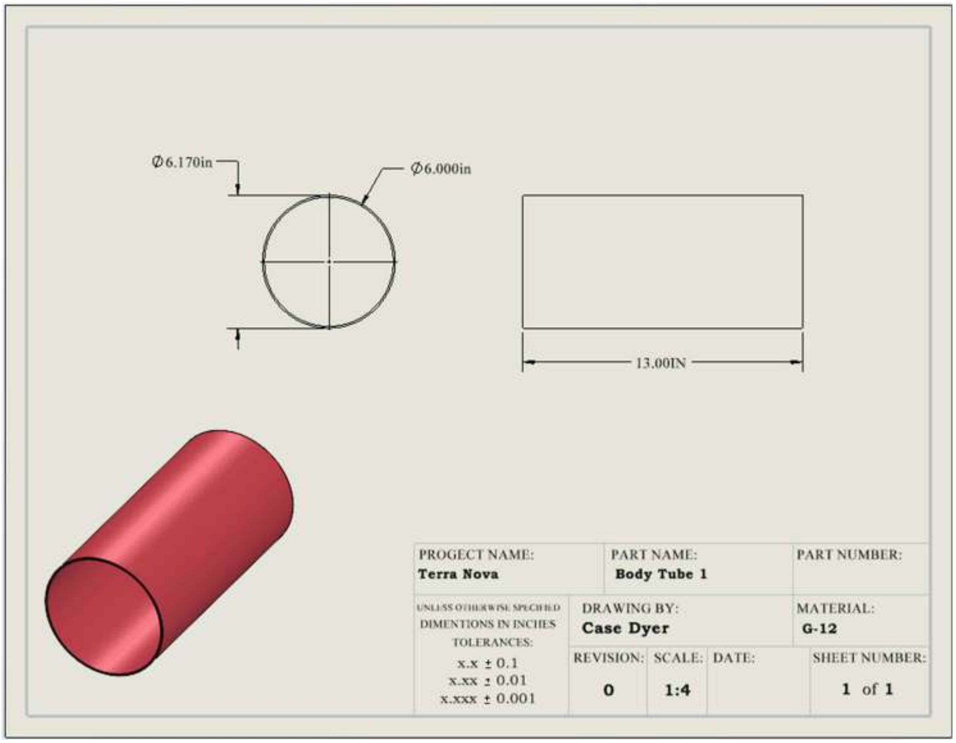



***Figure 3.4 Body Tube 1***

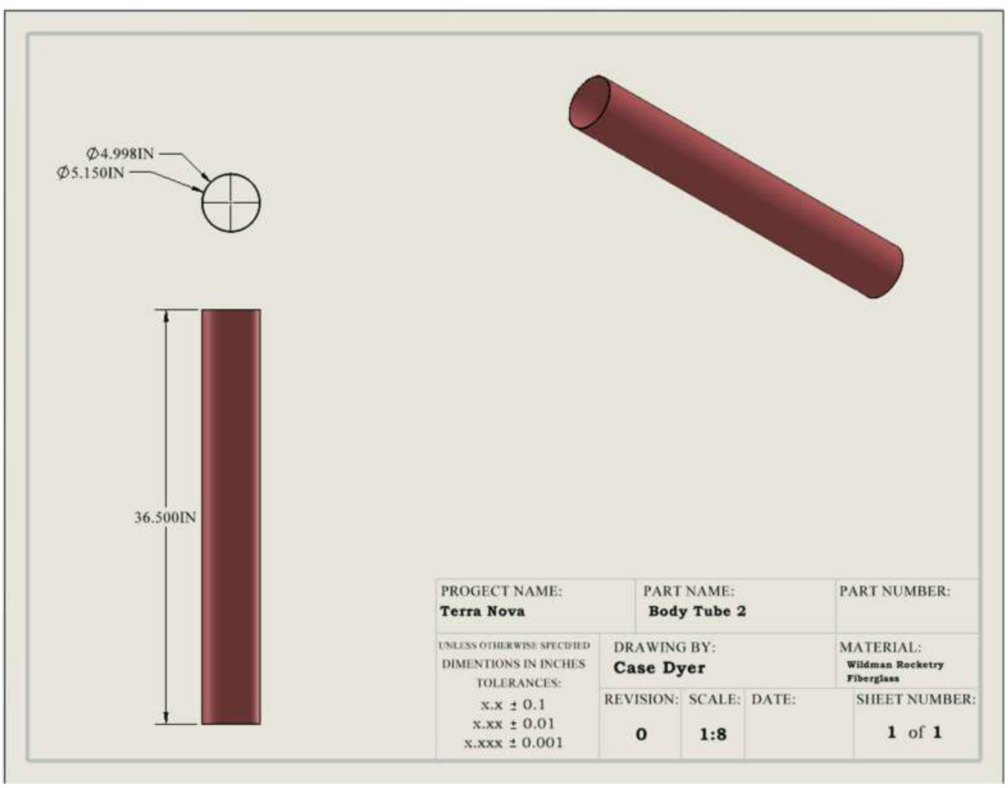



***Figure 3.5 Body Tube 2***

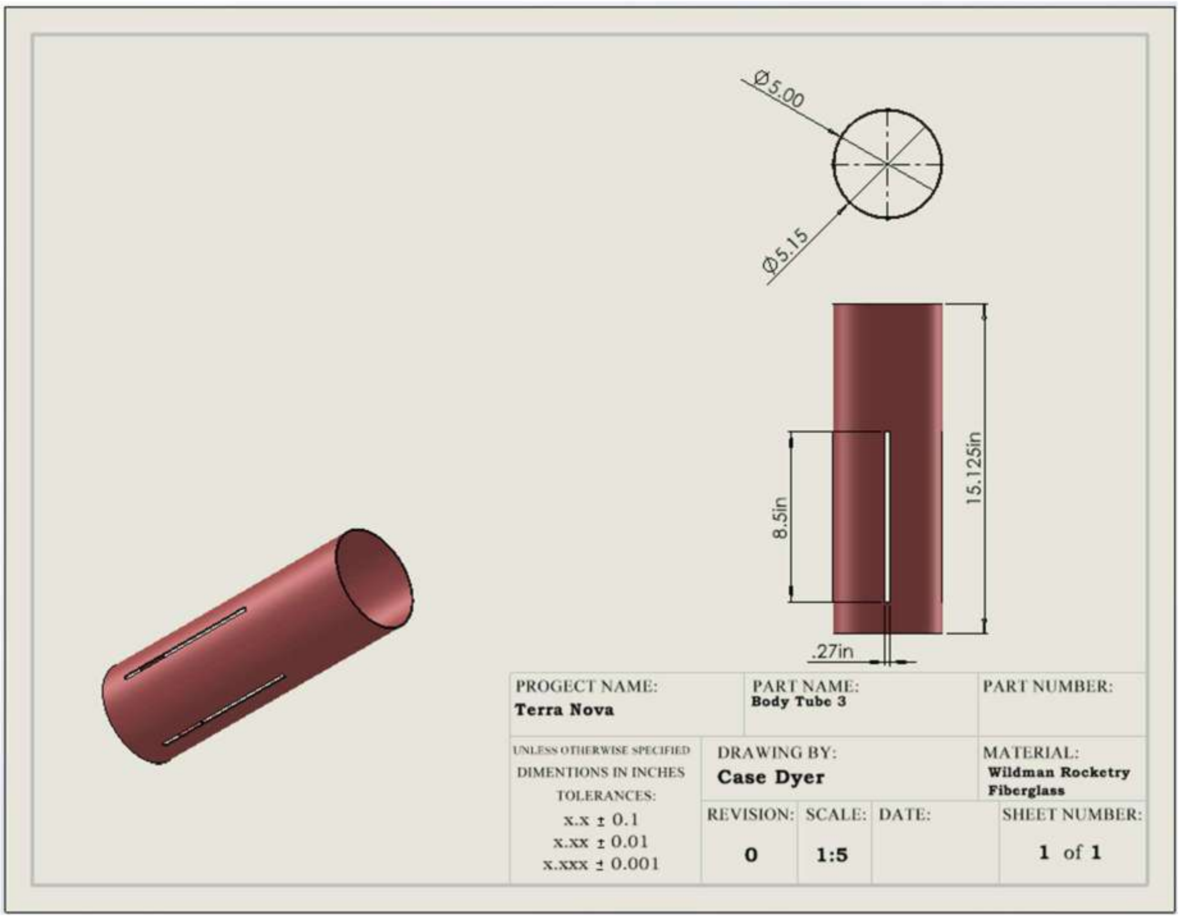



*Figure 3.6 Body Tube 3*

### 3.2.3. Couplers

All couplers were made of fiberglass and purchased from Wildman Rocketry. The as constructed drawing of the couplers are as below. It should be noted that it was required by the NASA handbook that all couplers for separating sections be at least 2 times the diameter of the rocket. The Terra Nova team specified that all coupler for separating sections be 2.125 times that of the Inner diameter of the rocket section being coupled. As can be observed in all drawings, the specified criteria are met.

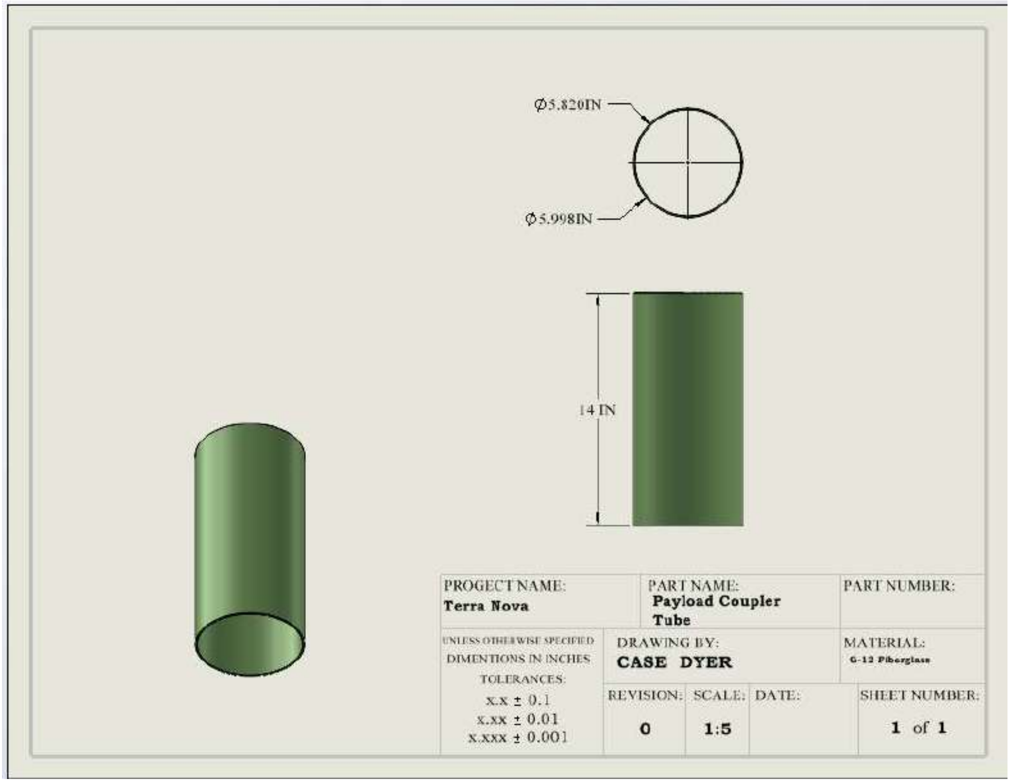



*Figure 3.7 HAUS to Upper Transition Coupler*

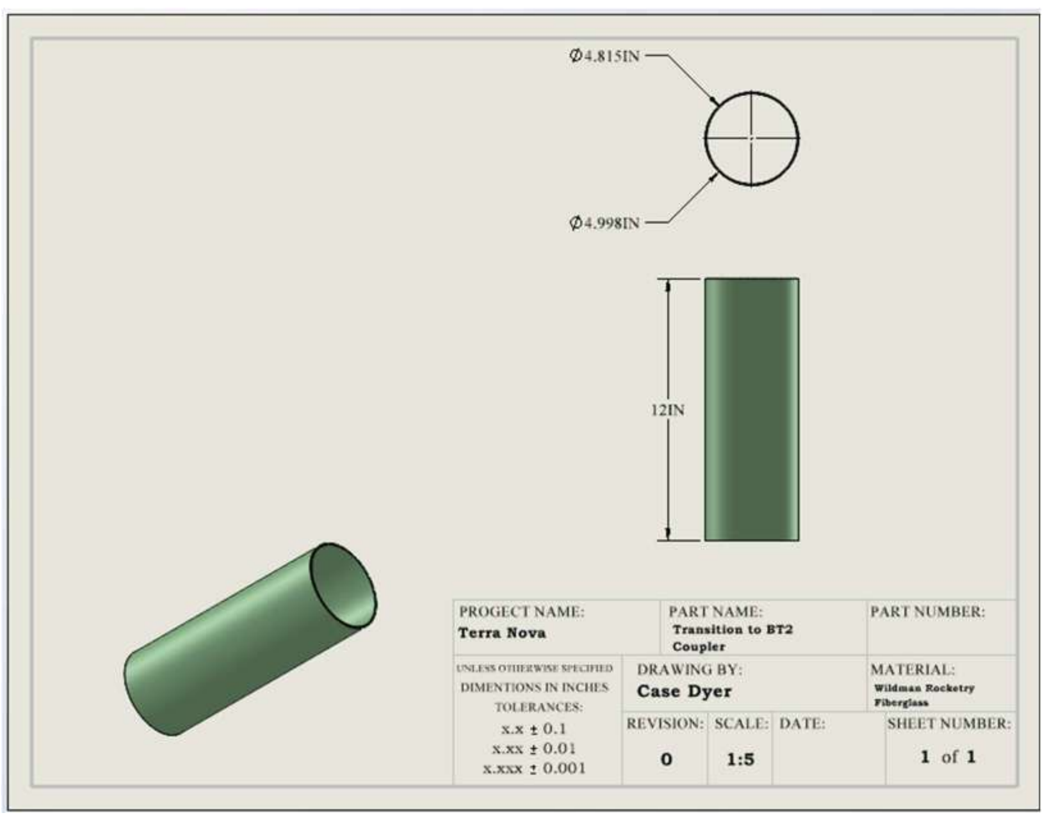



*Figure 3.8 Lower Transition to Body Tube 2*

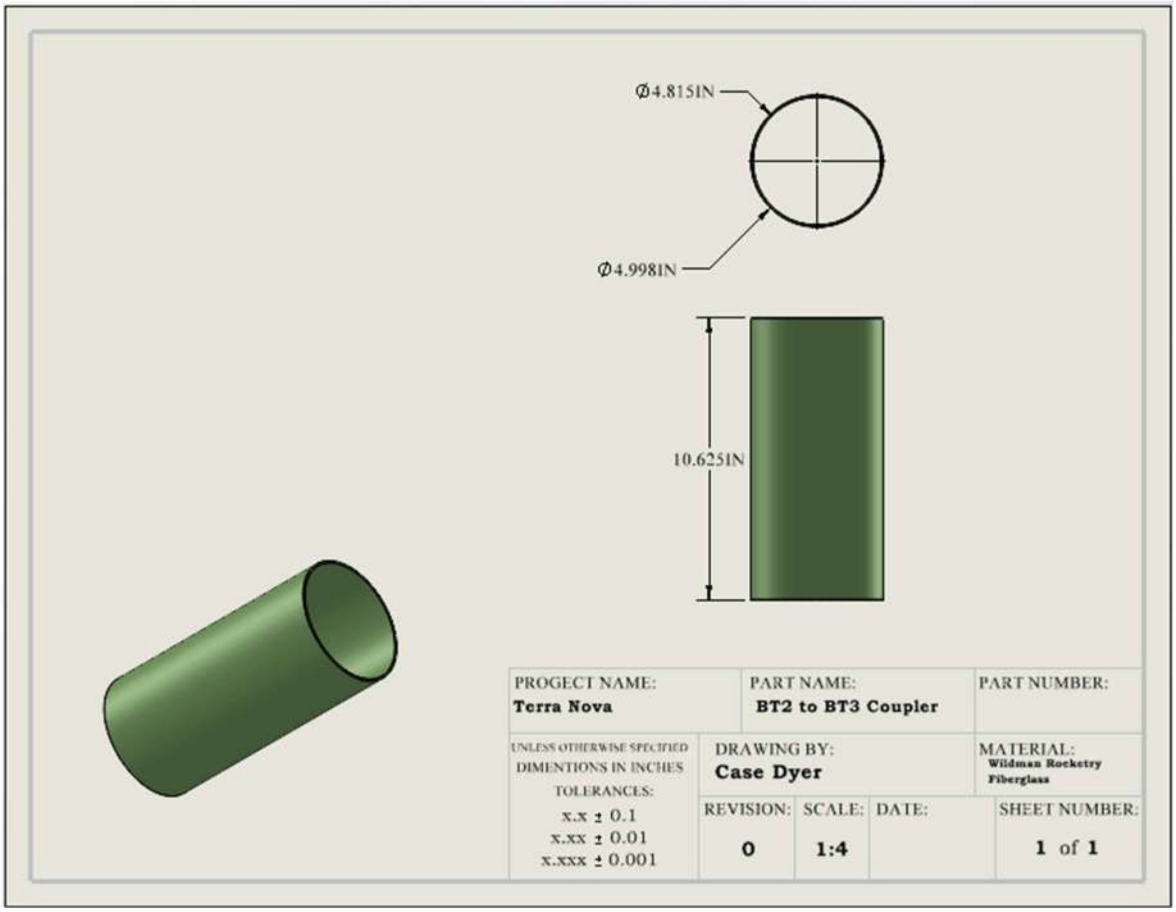



*Figure 3.9 Body Tube 2 to Body Tube 3 Coupler*

### 3.2.4. Fins

The fins of the Terra Nova vehicle are also made from fiberglass. Sheets of the proper thickens were purchased and stenciled to be cut. The freeform design of our fins was not commercially available, and thus had to be fabricated in-house. Below is a detailed drawing of the as constructed fin design.

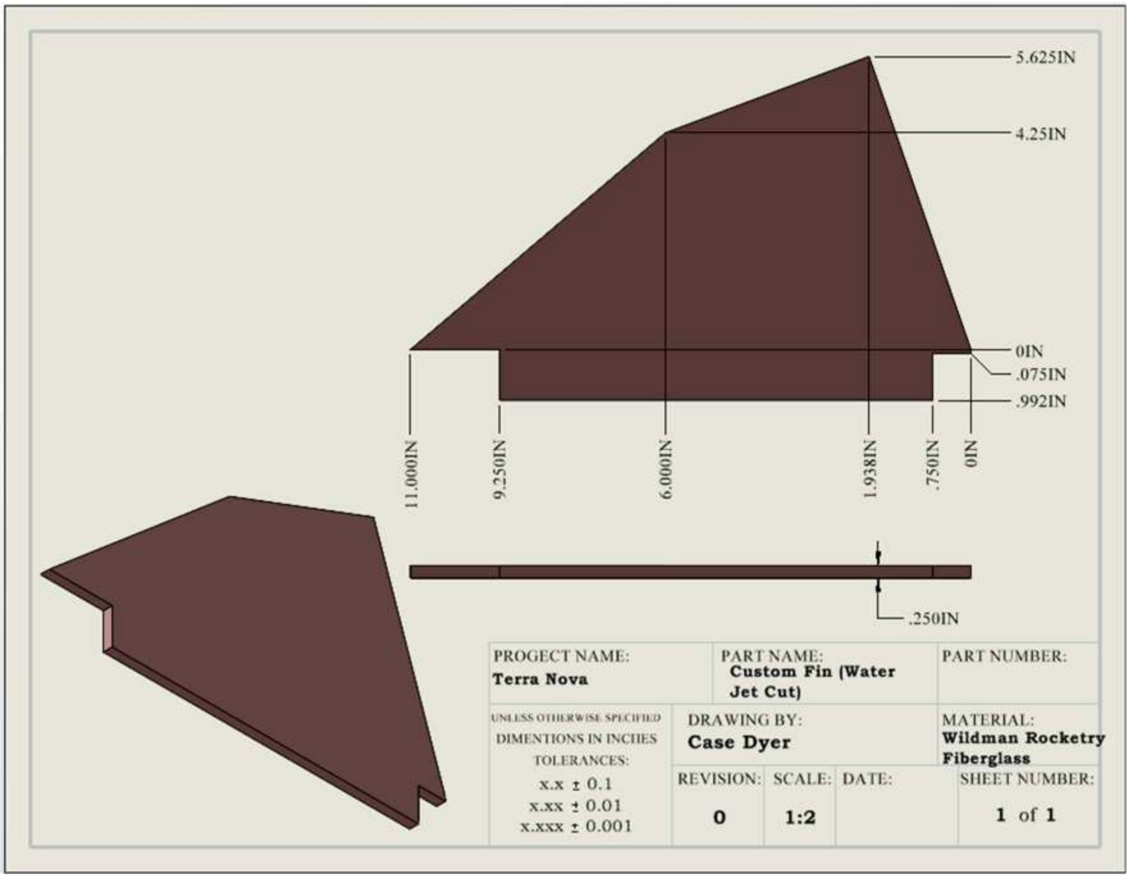



*Figure 3.10 Custom Fins*

### 3.2.5. Bulkheads

The bulkheads for the Terra Nova rocket will be constructed from Inconel 718 and be 3/16" thick. This will be achieved with help from Meritech Machining, a local industry partner. In exchange for conducting materials testing on their new additive manufacturing techniques, they will supply us with the printed parts we need for the full scale. While tensile testing has not yet been conducted, torsional properties have been tested and converted to tensile properties using Von Meses theory. A deducted 283,000 psi can be assumed to be the material's tensile yield strength for calculations. Given the larger bulkhead area of 28.27 $in^2$, the force required to rupture would be just over 8,000,000 pounds. This selection is certainly overkill, though it will complete our derived goal of using additive manufacturing in our design. It also removes bulkhead failure from the picture completely, since other components would fail long before the bulkheads even yield.

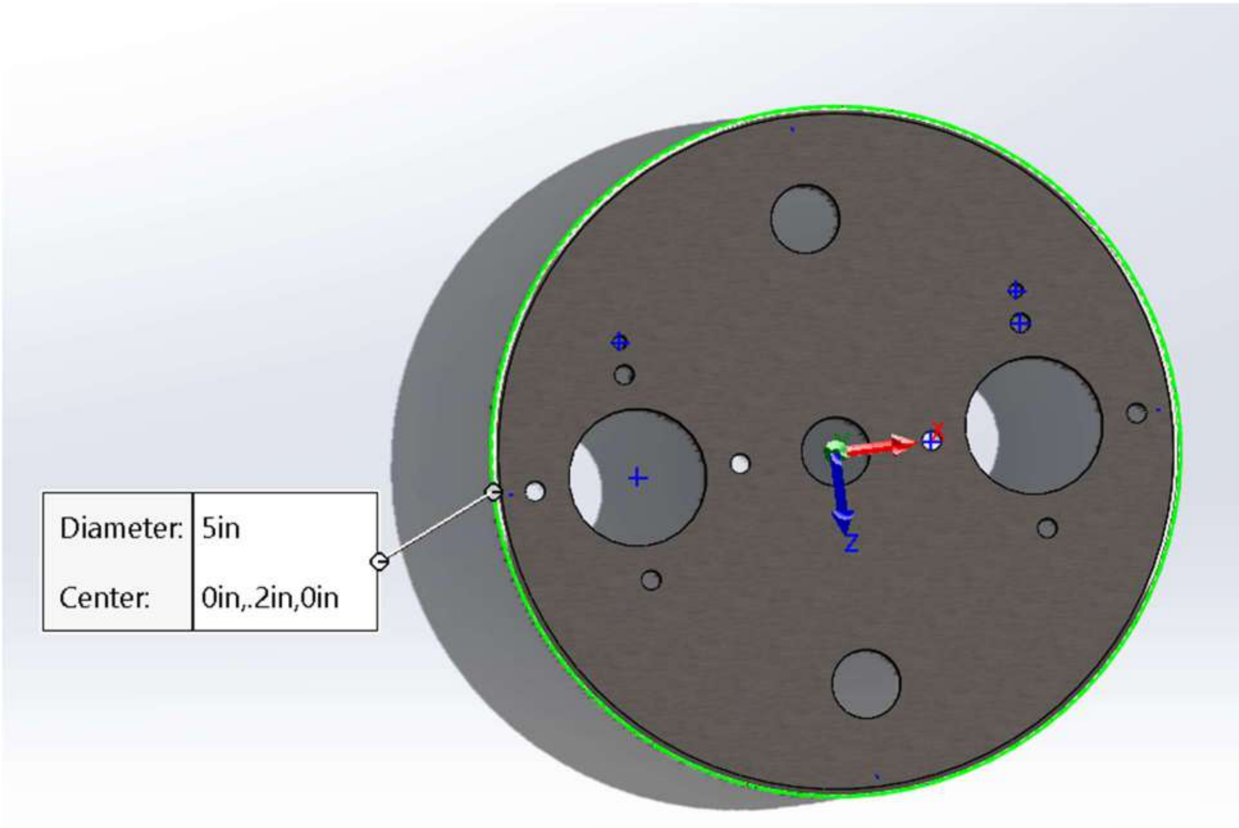



*Figure 3.11 Avionics Bulkhead*

### 3.2.6. Attachment Hardware

4-40 shear pins have been selected for separating points, using 4 for both separation points. These 4 shear pins combine to provide an estimated 152 lbs. of shear resistance to be overcome by ejection. The set screws selected are stainless steel ½" #10 screws, with a yield strength of roughly 450 ksi. This material will provide sufficient strength well above any requirements of this project and has been tested in flight.


*Figure 3.12 4-40 Shear Pins*

*Figure 3.13 Stainless Steel #10 Screws*

## 3.2.7. Transition

The transition within our airframe from 5”-6” moving forward from the tail up to the nose was done to reduce aerodynamic drag and increase style. It is made entirely from fiberglass fabric reinforce with cured resin. A PETG mold was printed to be used for shaping, and the fiberglass resin was applied slowly and carefully over the course of a few days. The final product was then sanded down to achieve the proper finish. The as constructed transition is a below:


*Figure 3.14 Transitional Airframe*

### 3.2.8. Boat-Tail

The original idea of the boattail came from one of our school's previous teams: the Daedalus project, though we included it in our design to reduce pressure drag at the base of the vehicle. There was no commercially available boattail that fit our needs, so we asked the help of one of our sponsors, Coastal Machining, to manufacture the part for us. The as constructed component is as below:

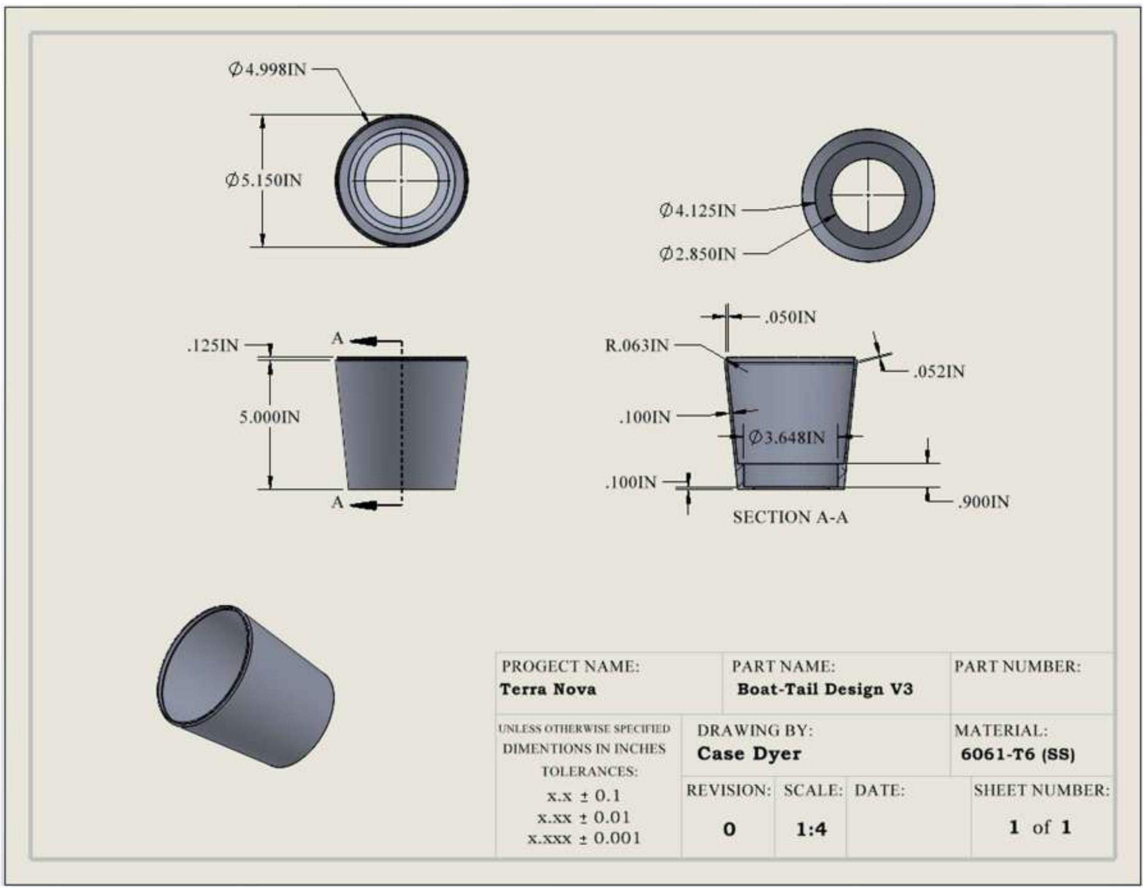



***Figure 3.15 Transitional Airframe***

### 3.2.9. Avionics Retention

The avionics plate will house all components and be contained within the AV coupler and between two bulkheads. This plate fits snugly within the 12" coupler and leaves just enough room for the bulkheads to be applied. Electrical components including computers and switches are held in via screws, while the power supplies are securely zip-tied to the plate.

### 3.2.10. Reef Retention

The reefing bay is housed on the motor tube, just beneath the aftmost bulkhead. Friction is the primary securing method, though the bulkhead and centering ring would prevent any movement if it were possible. Because of the tight fit and location of the motor, screws could not be used to retain electrical components. To counter this, zip ties are used for all component retention in this bay.

## 3.3. Construction

### 3.3.1. Construction of HAUS Section

The term “HAUS Section” in this case means the forwardmost separating section of the rocket. This section consists of a fixed 6” airframe and the nosecone. Upon receiving the fiberglass nosecone ordered, we found the construction quality was poor and required additional reinforcement from the remaining material used to fabricate the transition. The nosecone had multiple voids and air pockets that could potentially be locations of catastrophic failure. Thus, to resolve these voids portions of the fiberglass were cut with a razer to open the void locations, than epoxy was used to fill the void. Then the cut back portion of the fiberglass would be pushed back into the void filled with epoxy to regain some rigidity of the fiberglass cloth

The nosecone is attached to the fixed airframe via a mechanical separation mechanism that allows these two components to separate upon landing for payload deployment.

### 3.3.2. Construction of Body Tube 2

The term “body tube 2” in this case means the middle separating section of the rocket. This section consists of a fixed and transitional airframe connected by the avionics coupler. Beginning with the construction of the avionics bay, a 12” coupler was chosen to house the AV plate and components which was closed off from the rest of the vehicle via two bulkheads (1 on each side). To make the AV bay accessible, 4 stainless-steel #10 screws are used to attach either side of the bay to the transition and fixed airframes.

To set this in place, proper holes needed to be drilled for the screws to fit. Due to human error, this requires the coupler to be in a specific orientation to be attached, though this works in the benefit of the team as it helps maintain a consistent orientation for the entire system. This construction also required drilling through the coupler and airframe to allow the flight computers to read pressure changes as elevation changes.


Upon connection of these components, a coupler is needed to attach BT1 & BT2. This coupler is attached to the fixed airframe via epoxy resin as it does not need to be removed for any reason. A bulkhead is also epoxied on the other end of this coupler to attach eyebolts for recovery.

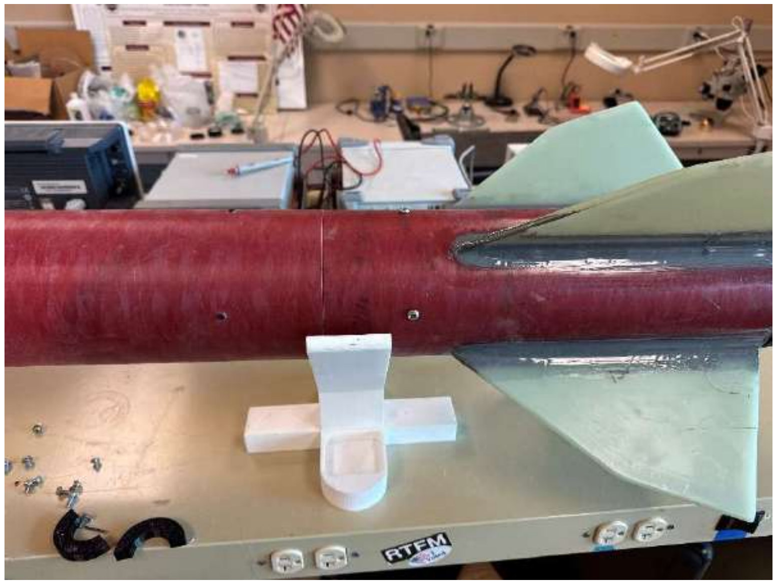
### 3.3.3. Construction of Body Tube 3

The term "body tube 3" in this case means the aftmost separating section of the rocket. The construction begins with that of the motor tube. This component uses a carboard tube just large

enough to fit our RMS, as well as epoxying 3 PETG centering rings along its length in strategic locations. The forwardmost centering ring is not critical in exact location, but the other two serve to hold the fins in place, so they must be precise. Once these were set in place, the fins were filleted via the same epoxy internally to provide extra structural integrity for those components. Also epoxied to the bottom is a threaded ring to both secure the RMS in place and provide an attachment point for the internally threaded boattail.

The fins were epoxied internally to the motor tubing and the centering rings as well as externally to the airframe of the rocket. This was to ensure the fins were as rigidly fixed to the rocket as possible. Especially after the experience of our teams very first subscale launch, it was deemed critical by our team to ensure these fins can handle all possible forces applied during flight. Below is the epoxied internal fin assembly. The fins were held in place on top and bottom using 3D printed fin guides.

The Airframe tubing was then cut to its appropriate length, and slotted so that it the motor tube (with fins attached) could be inserted into the airframe. These slots were not the most precise cuts, so they required additional sanding and the epoxy fillets covered for any geometric inconsistencies. Once the cuts were finished, the motor tube could be inserted and epoxied in along the outside radius of the centering rings, and the external epoxy fillets on the fins. The boattail could then be threaded on once the RMS was inserted.




The final consideration in the construction of BT3 is the insertion of the coupler to attach it to BT2. Since the reefing bay is housed beneath the bulkhead on this coupler, it needed to be removable. To compensate for this, 4 stainless-steel #10 screws were used to attach the coupler to the airframe, while the bulkhead was set via epoxy. Holes were also drilled in this area to allow the flight computers to read pressure changes.

### 3.3.4. Assembly of the Vehicle

The assembly of the entire vehicle requires the proper assembly of each individual section and connecting them with 4 4-40 shear pins. These pins allow a secure connection between each section that can be ruptured at each desired separation event. At the first assembly, holes were drilled for these shear pins.

### 3.3.5. Differences from other Models

This current vehicle is a result of a changing design throughout the entire process. The overall scope of the design has not changed, but a few modifications deserve mention. These modifications include the design of the reef bay and the use of internal fillets when setting the fins.

The original reef bay concept was a container housing the necessary computers & support components attached to the RMS eyebolt. This has been changed to a cylindrical plate set around the motor tube to allow proper sealing and a more secure design.

The use of internal fillets was a subtle addition to the original design that increases the strength of the fin attachment to the airframe.

## 3.4. Launch Vehicle Recovery System

### 3.4.1. Recovery CONOPS

The Recovery system for the Terra Nova rocket will have two separation events: one at apogee and the other at 1000 ft. Both events will be initiated via $CO_2$ ejections, with the drogue event using a 25g cartridge and the main event a 38g cartridge. The drogue and main events will use 38g and 45g $CO_2$ cartridges, respectively. The drogue deployment will use a 15" fruity chutes parachute with a $C_d$ of 1.5. This chute will reach an estimated terminal velocity of 152 ft/s. After the main event, a 120" Rocketman parachute with a $C_d$ of 2.2 will be deployed, reefed to a 30" diameter. This phase is estimated to fall at a rate of 52 ft/s. The reefing line will be attached to a Mako line cutter, with redundant matches wired to two separate altimeters. At 650 ft, these devices will initiate, severing the reef line and allowing the parachute to expand to its full 120" diameter. In this phase of recovery, the vehicle is estimated to descend at 16 ft/s, which will impact the ground with less than 65 ft-lbs of energy. This meets both the NASA requirement and our derived goal. Additionally, the descent time from apogee to ground projects at 76.18s, also meeting both the NASA requirement and our derived goal of 80s. The purpose of the reefing system is to create a stable transition between the small drogue and large main without causing accelerations large enough to damage the airframe or other load bearing components.

## 3.5. Structural Elements

### 3.2.2.1 Inconel Bulkheads

The bulkheads for the Terra Nova rocket will be constructed from Inconel 718 and be 3/16" thick. This will be achieved with help from Meritech Machining, a local industry partner. In exchange for conducting materials testing on their new additive manufacturing techniques, they will supply us with the printed parts we need for the full scale. While tensile testing has not yet been conducted, torsional properties have been tested and converted to tensile properties using Von Meses theory. A deducted 283,000 psi can be assumed to be the material's tensile yield strength for calculations. Given the larger bulkhead area of 28.27 $in^2$, the force required to rupture would be just over 8,000,000 pounds. This selection is certainly overkill, though it will complete our derived goal of using additive manufacturing in our design. It also removes bulkhead failure from the picture completely, since other components would fail long before the bulkheads even yield.

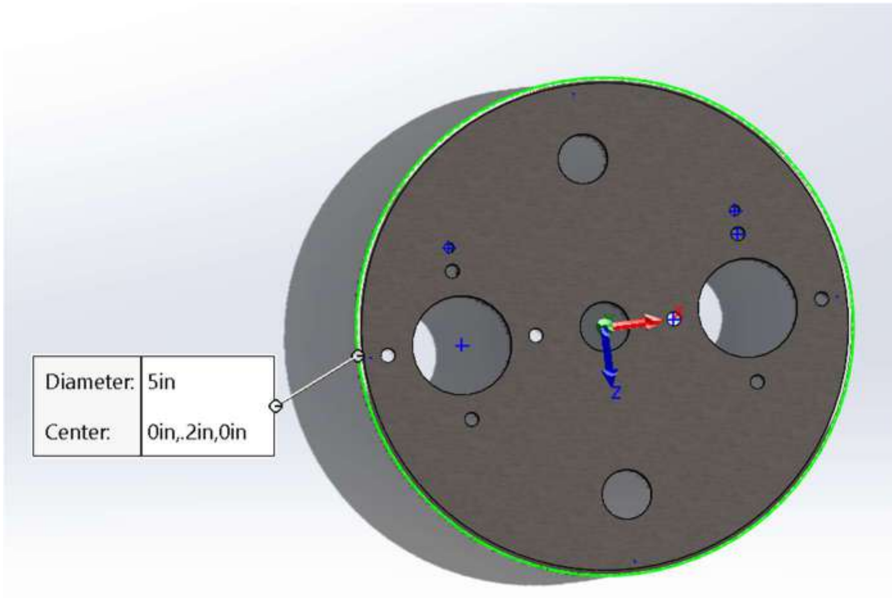



*Figure 3.16 Avionics Bulkhead*

#### 3.2.2.2 Vehicle Section Attachments

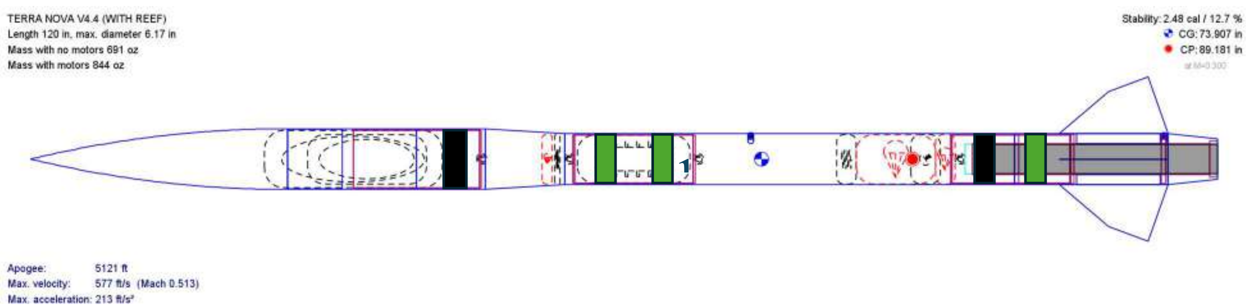



*Figure 3.17 Attachment Points*

The figure above provides the locations of all attachment points on the vehicle. The green marks represent the use of screws not intended to fail, with the black marks showing the location of shear pins. 4-40 shear pins have been selected for separating points, using 4 for both separation points. These 4 shear pins combine to provide an estimated 152 lbs. of shear resistance to be overcome by ejection. The set screws selected are stainless steel ½” #10 screws, with a yield strength of roughly 450 ksi. This material will provide sufficient strength well above any requirements of this project and has been tested in flight.


*Figure 3.18 4-40 Shear Pins*

***Figure 3.19 Stainless Steel #10 Screws***

## 3.5.1. Anchor Points

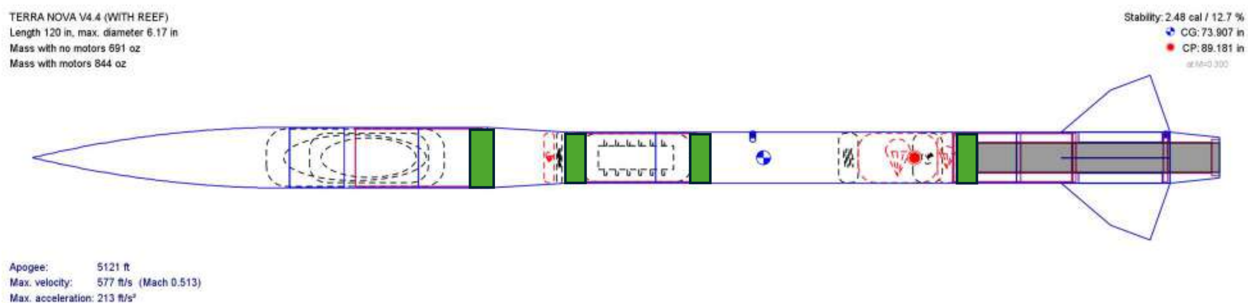



***Figure 3.20 Anchor Points***

The figure above shows the locations of all anchor points in the vehicle. 3/8" Steel Eyebolts are used for the forward eyebolt (connected to body tube 1) and both eyebolts on either side of the avionics bay (attaches to the avionics bulkheads), with the furthest aft eyebolt attached to our Aerotech 755120 RMS. All eyebolts are made from stainless steel and have a yield strength of roughly 450 ksi. These eyebolts will be capable of withstanding a static tensile force of 168750 lbs, which is well above the requirements of this mission.

***Figure 3.21 3/8" Stainless-Steel Eyebolts***

## 3.5.2. Shock Cord

***Figure 3.22 Paramax Paracord***

The shock cord selected for this vehicle is The Paracord Store's PARAMAX Paracord with a tensile strength reported at 1200 lbs at a ¼" diameter. This strength has been confirmed up to 1000lbs, which is the capacity of the load cell on the tension tester at FSUPC's Materials Lab. The sizing of this cord will follow the rule of thumb of 4x the rocket length, coming out to 40 ft, or 480 inches.

### *3.2.2.5 Supplementary Cord*

***Figure 3.23 Paracord 550***

The selected supplementary cord for this vehicle is The Paracord Store's Paracord 550 with a tensile strength of 550 lbs at a 3/32" diameter. This strength has been confirmed past its reported strength, up to 650 lbs via the tension tester at FSUPC's Materials Lab. The term supplementary cord is defined by this team as a cord used for any purpose other than a shock cord. In the final design, this cord will be used to reef the main parachute and attach the drogue parachute to the forwardmost eyebolt. It is required to attach the drogue because the swivel ring is too small to fit the selected quicklinks. Both uses have been successfully demonstrated in flight.

## 3.6. Electrical Elements

### 3.6.1. Telemetrum Flight Computer


***Figure 3.24 Telemetrum Flight Computer***

The Telemetrum flight computer by Altus Metrum uses a barometric altimeter to detect pressure changes and determine the altitude throughout flight. It also uses an accelerometer to detect launch, apogee, and landing, as well as recording velocity and acceleration data throughout flight. It is capable of data transmission and GPS and will provide location tracking during flight. The purpose of this computer in the vehicle build is to control events for both separations and the reef event while also collecting telemetry to be analyzed post flight. This computer will act as the primary initiator for all events.

### 3.6.2. EZ Mini Flight Computer

***Figure 3.25 EZ Mini Flight Computer***

The EZ Mini flight computer will act as the redundant initiator for all events including both separations and the reef event. While it does not employ an accelerometer or transmission capabilities, the barometric altimeter is sufficient for its event initiation specific role.

### 3.6.3. Screw Switch

***Figure 3.26 Screw Switch***

As specified by NASA, any avionics systems cannot be active prior to the rocket reaching the launch pad. This requires a method that can turn on the AV systems after the vehicle has been assembled and prepared for launch. We have selected a screw switch to do this. It is located on the center of the AV plate and is accessible by an open hole on the airframe. A long screwdriver can reach this switch and turn it until continuity is confirmed by the flight computers. It should be noted that the avionics bay must be in a specific orientation to reach the screw switch. This same method will also be used to arm the flight computers in the reef bay.

### 3.6.4. Power Supply

All electronic devices will be independently powered by 9V LiPo Batteries. This includes the Telemetrum & EZ Mini in the Avionics Bay, as well as the Telemetrum & EZ Mini in the Reef Bay. All computers will have their own dedicated battery.

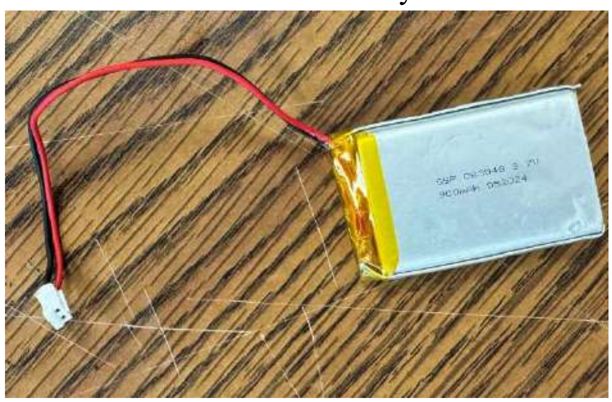


***Figure 3.27 9V LiPo Battery***

### 3.6.5. Event Initiation

With each event being electronically initiated, E-Matches will be used to ignite the black powder charges contained within the Avionics Bay's 3 TR Eagle $CO_2$ Ejection devices and the Reefing System's Mako line cutter. All E-Matches used in the Terra Nova Project are commercially available and purchased from Chris' Rocketry.

***Figure 3.28 E-Match***

### 3.6.6. Interference

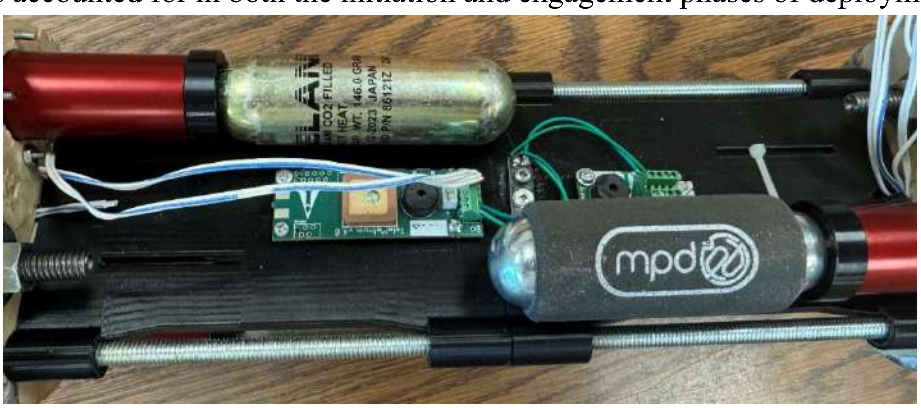
The Telemetrum flight computer is configured to transmit at a frequency of 435.050 MHz and a power of 40mW. Operating in the 70 cm band requires the Technicians Class Amateur Radio

License, which the Terra Nova Project's Electrical Officer obtains. Using a directional antenna with a clear line of sight, 40 mW is an acceptable power level to maintain contact with the launch vehicle, while not interfering with the altimeter readings. This has been shown through comparisons of altimeter readings placed at staggering distances from transmitting objects during flight. While low power transmitters are being used, the avionics bay is shielded from transmitting devices by the Inconel bulkheads that surround it.

The nature of the recovery system allows for the avionics bay to become pressurized for small periods of time during recovery events. This is observed in the telemetry data as quick dips in altitude readings, immediately followed by accurate readings once the bay pressure evens out. These readings would be cause for concern, however through testing and previous launches, it is clear the Telemetrum is able to discern these inaccuracies from true recovery event conditions.

### 3.6.7. Avionics Bay

Implemented into the Avionics Bay is a dual-redundancy feature to ensure proper deployment. Two independently powered flight computers will initiate both the main and drogue events to ensure a malfunction with one does not impact the recovery sequence. While the TR $CO_2$ devices have shown incredible consistency throughout testing, two devices will be used for each deployment with sufficient force to create separation independently. While the redundant computer systems will ensure electronic success, the possibility exists that a device could be jammed, improperly packed, or randomly malfunctioning. This dual-redundancy feature ensures that failure is accounted for in both the initiation and engagement phases of deployment.




***Figures 3.29 & 3.30  Avionics Bay Dual-Redundancy Showcase***

### 3.6.8. Reef Bay

***Figure 3.31 Reef Bay***

The reef bay is an assembly similar in objective and makeup to the avionics bay. It will use the same combination of a Telemetrum and EZ Mini flight computer to engage the reef event. This bay is cylindrical in design to be placed on the motor tube, between the aft bulkhead and forward centering ring. The two computers will both be wired to the Mako line cutter to sever the reefing line along the skirt of the main parachute, allowing it to open to its full 120” diameter prior to landing.

## 3.7. Event Engagement

### 3.7.1. TR Eagle CO2 Ejection Device

The TR Eagle $CO_2$ Ejection device is composed of two main components and event engagement occurs in 3 phases. The base component houses a black powder charge, a firing pin, and a spring, while the top component is threaded both to attach to the base component, and to house the $CO_2$ cartridge. Phase one occurs at the event initiation stage, where the flight computer sends a signal to ignite the E-Match and thus the contained black powder charge within the TR device. Phase two begins after the ignition, where the force created by the charge overpowers the spring holding the firing pin back. This pin is then driven into the nozzle of the $CO_2$ cartridge, rupturing the seal. Once the seal is open, phase three involves the release of the $CO_2$ and separation of the respective vehicle sections.

***Figure 3.32 TR Eagle $CO_2$ Ejection Device***

### 3.7.2. Mako Line Cutter

Being made by the same company (Tinder Rocketry) the TR Mako operates very similarly to the Eagle, though no $CO_2$ is involved. The device consists of 3 main components being the base, firing pin, and main cylindrical body. The base of the device houses the contained black powder charge and has openings for two e-matches to be slotted inside. The firing pin is housed within the main cylindrical body, and while no spring is present, the pin fits nicely so that it does not slide down the body prior to event engagement. The device is initiated by the ignition of e-matches and black powder, which creates a force to drive the firing pin down the cylindrical rod where the line to be cut is threaded. While this pin is not sharp, it "pinches" the line along the opening it is threaded through to create a concentrated shear force and sever the line.

***Figure 3.33 Mako Line Cutter***

### 3.7.3. Drogue Event

The drogue event will see the separation of body tubes 1 & 2, as well as the deployment of the drogue parachute. Per NASA guidelines, this event will occur at apogee with a +1 second margin for the primary event, and a +2 second margin for the redundant event. This event will be initiated by the Telemetrum and AZ Mini flight computers, sending a signal to their respective TR Eagle $CO_2$ devices. The amount of $CO_2$ to be used for this separation will is determined by the Ideal Gas Law:

$$PV = nRT$$

Where the number of moles "n" is set via standard sizes of commercially available $CO_2$ cartridges and will ideally pressurize the internal volume "V" of the rocket to a pressure "P". All calculations assume room temperature. This pressure will then be correct to gauge pressure and applied to the bulkhead surface area and estimate a force to be compared with the strength of the shear pins on the vehicle, represented by the following equation.

$$F = (P_{inner} - P_{outer})A$$

For this first event, a 25g $CO_2$ canister has been deemed sufficient to consistently create separation through calculations and deployment tests. The empty volume of the transitional section is difficult to calculate, so it will be estimated to be a 6" diameter cylinder. This method creates a larger reference volume, and thus an overestimate of the $CO_2$ required. Taking the internal volume of this section to be 169 $in^3$ and the cross-sectional area of the bulkhead to be 28.27 $in^2$, the force exerted by the 25g cartridge can be calculated.

$$F_{Dep1} = 1730\ lbf$$

The selected combination of 4 shear pins for this section will require at least 159 lbf to fail, so this selection is justified. A 38g Cartridge will be used as redundancy if the first event fails, creating the following theoretical force.

$$F_{Dep\ ,Redundant} = 2817\ lbf$$

### 3.7.4. Main Event

The main event will see the separation of body tubes 2 & 3, as well as the deployment of the main parachute in its reefed configuration. The primary event will occur at 1000ft, with the redundant event at 950ft. This event will be initiated by the same Telemetrum and EZ Mini as the drogue event, signaling the two remaining TR Eagle $CO_2$ devices. Using the same process as in the previous section, the mass of $CO_2$ can be selected via the Ideal Gas Law.

$$PV = nRT$$

Just as before, the number of moles "n" is defined by commercially available $CO_2$ canisters, the internal volume of the section is set to the variable "V", and the resultant pressure "P" will be corrected to gauge pressure and used to calculate the estimated force on the bulkhead in the following equation.

$$F = (P_{inner} - P_{outer})A$$

The internal volume of this section is taken to be 486.95 $in^3$ and the cross-sectional area of the bulkhead in this section is 19.64 $in^2$. A 38g cartridge has been selected for this separation, and the estimated opening force at room temperature is as follows.

$$F_{Dep2} = 483\ lbf$$

The selected combination of 4 shear pins for this section will require at least 159 lbf to fail, so this selection is justified. A 48g $CO_2$ cartridge will be used as redundancy if the first event fails, netting the following estimated force.

$$F_{Dep2,Redundant} = 620\ lbf$$

### 3.7.5. Reef Event

The reef event will initiate the TR Mako line cutting device to sever the main parachute reefing line. The primary event will be initiated at 650 ft, with the redundant event at 600 ft. The main parachute will be attached to the RMS Eyebolt contained in body tube 3, and the reef bay will be located aft of the related bulkhead, and forward of the first motor tube centering ring. A Telemetrum flight computer will handle the primary event and an EZ mini will initiate the redundant event. For both events, a 200” e-match will be wired from the body tube up to the skirt of the parachute where the Mako is located. The Mako will then cut the reefing line and allow the main parachute to expand from the restricted 36” diameter to its full 120” diameter.

## 3.8. Parachutes & Descent

### 3.8.1. Parachute Selections

The selected Drogue Parachute for the Terra Nova Project is a 15” Elliptical Parachute that is commercially available and purchased from Chris’ Rocketry. Prior to deployment, this parachute will be housed in Body Tube 2 (the midsection of the vehicle), between the Avionics Bay and the base of Body Tube 1. The Drogue Parachute will be attached to a stainless steel eyebolt on the bulkhead at the aft of Body Tube 1, just behind the payload and nosecone. This parachute is specified by the manufacturer to have a $C_d$ of 1.5-1.6, so all calculations/simulations regarding this chute have used a $C_d$ value of 1.55.

***Figure 3.34 Fruity Chutes 15” Elliptical Parachute***

The selected Main Parachute for the Terra Nova Project is a 120” Parachute purchased from Rocketman Parachutes, with a specified $C_d$ of 2.2. Prior to deployment, this parachute will be housed in Body Tube 2 (the midsection of the vehicle), aft of the Avionics Bay and forward of Body Tube 1. The Main Parachute will be attached to the eyebolt built into the RMS system used to house the vehicle’s motor.

*Figure 3.35 Rocketman 120” High Performance Parachute*

### 3.8.2. Main Parachute Reefing

The main parachute reefing system is intended to ease the transition from the 15” drogue and the 120” main by decreasing its effective open diameter to 36” for a short period of time. This method will decrease the largest opening force from 4700 lbs to 470 lbs, significantly decreasing the shock loading on the bulkheads, shock cords, and airframe. This will be done by attaching ½” Brass grommets along the skirt of the parachute and running a 117” line of paracord through all the loops. This length of cord was defined as the circumference of a 36” circle, which is the intended diameter of the parachute in its reefed configuration. Since the drag force is a function of area, the diameter of these areas was back calculated in order to properly simulate this phenomenon in OpenRocket. The need for this system is created by the small 15” drogue selected to increase descent speed during the drogue phase transitioning to a large 120” main parachute to land the rocket within the NASA specified impact energy requirements. The transition from the reefed main to open main will be initiated by the Mako line cutter previously discussed in this report.

## 3.9. Failure Modes

### 3.9.1. Previous Recovery Failures

Throughout the course of this project, several recovery failures have been recorded and analyzed to provide us valuable data allowing us to adjust the design to prevent future failures. The first major failure was the initial subscale launch, which used PETG 3D printed bulkheads at a 20% infill. This design oversight led to the immediate destruction of the bulkheads upon parachute opening, and the rocket fell to the ground with no recovery device. This decision was made to showcase the full-scale’s Inconel bulkheads, and the design was changed to plywood for the second subscale launch.

Another recovery failure saw the reefing system initiated early after the pressurization from the $CO_2$ expansion created an increase in pressure that the reefing computer read as a lower altitude. This altitude decrease was enough to reach its programmed threshold, so the main parachute was at its full diameter upon opening. Several methods to create better seals and responses throughout the rocket were implemented, including the use of a Telemetrum flight computer for the system, and epoxy/hot glue to create permanent and temporary seals throughout the vehicle.

The third major recovery failure came in the first full-scale launch, where the wire fed from the reefing computer (Telemetrum) to the Mako line cutter was severed before the event was initiated. This was likely due to a lack of length in the wire which applied load to a component not intended to withstand loading.

A final fourth significant recovery error also occurred in the first full-scale launch, where the main parachute deployed shortly after the drogue parachute and significantly earlier than was intended. An investigation is still ongoing as to why this happened, though no verdict has been reached. Despite this, we have ruled out several theories as to why this happened. Initially the idea was that the avionics setup was wired improperly, though upon recovery, this was shown to be false. A computer failure was also ruled out as telemetry data shows that all events initiated at correct timing. All four of these major recovery failures brought us data on how to improve the design of the vehicle, which have been implemented into the final design to make it as safe as possible.

## 3.10. Identified Failure Modes & Mitigation

Several predicted failure modes must be identified and discussed to decrease the chances of failure during flight. Improper match wiring/computer failures are the most significant failure modes, though barometric verification and detailed checklists have been implemented to ensure proper assembly of the AV bay. Shock cord/bulkhead failure should be discussed, but given the strength of these components, it is the most unlikely failure mode to which the airframe would be greater concern for failure. The most significant failure mode is presented in the reefing system. While our first full-scale flight demonstrated that a failure to cut the reef line will bring the rocket down at a speed that will not damage the airframe, it will most certainly exceed NASA's specified impact energy requirements. The primary failure mode for this system is a failure/rupture of the match wire, preventing initiation altogether. All other failure modes involve the same avenues as other recovery failure modes discussed prior.

## 3.11. Mission Performance Predictions

### 3.11.1. Flight Profile Simulations

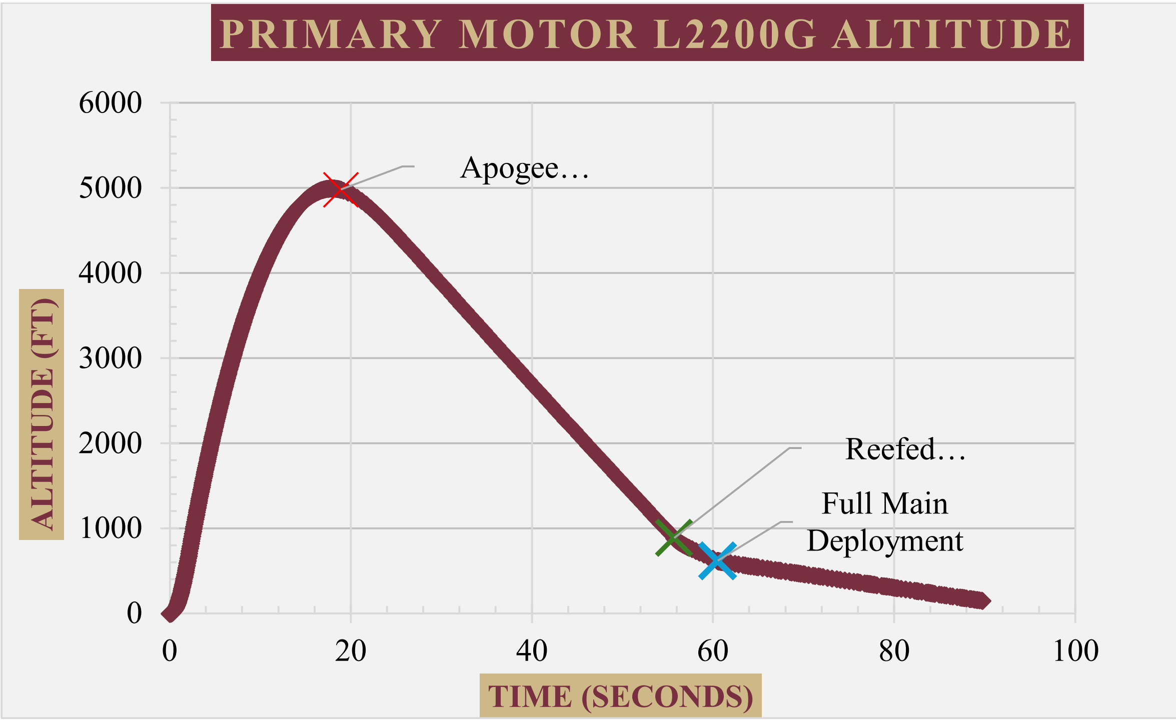



***Figure 3.36 Primary Motor Altitude Performance***

The projected altitude using OpenRocket simulations comes to 5008 ft, though our target apogee is 4900 ft. During our VDF launch attempt, we saw the rocket reach roughly 100 ft above the projection, so our simulations will mark this recorded error to potentially account for real-world discrepancies.

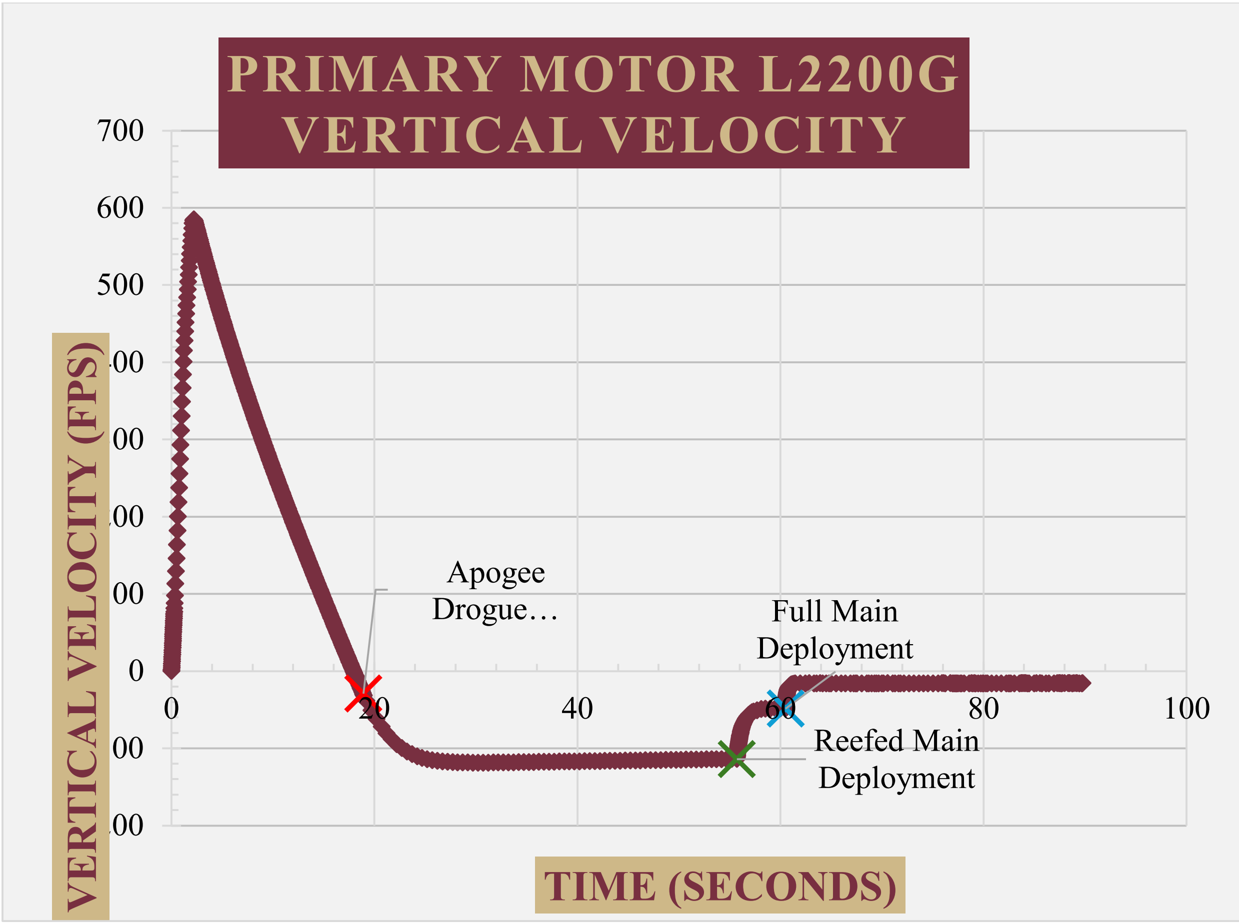



*Figure 3.37 Primary Motor Vertical Velocity Performance*

During ascent, the vehicle will reach a maximum velocity of just under 600 ft/s. After apogee, the vehicle will descend under the drogue at a simulated 152 ft/s, under the reefed main at a simulated 52 ft/s, and under the full main at a simulated 15.5 ft/s.

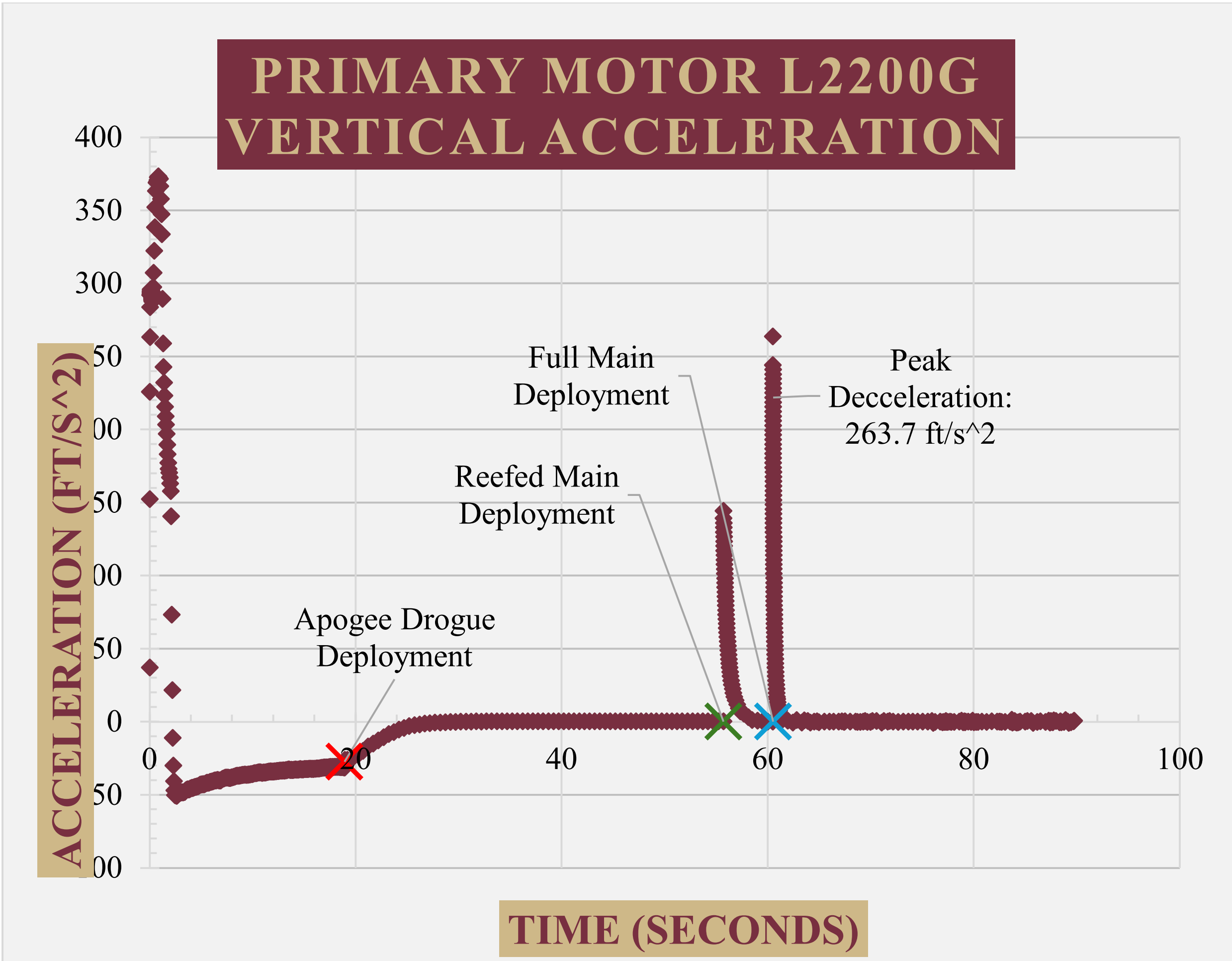



*Figure 3.38 Primary Motor Acceleration Performance*

The peak acceleration during flight will occur during the deployment of the full main at 263.7 ft/s$^2$. This acceleration will create an instantaneous force of 386.58 lbf, which is well within reason for the strength of airframe & recovery components.

Figure 3.38

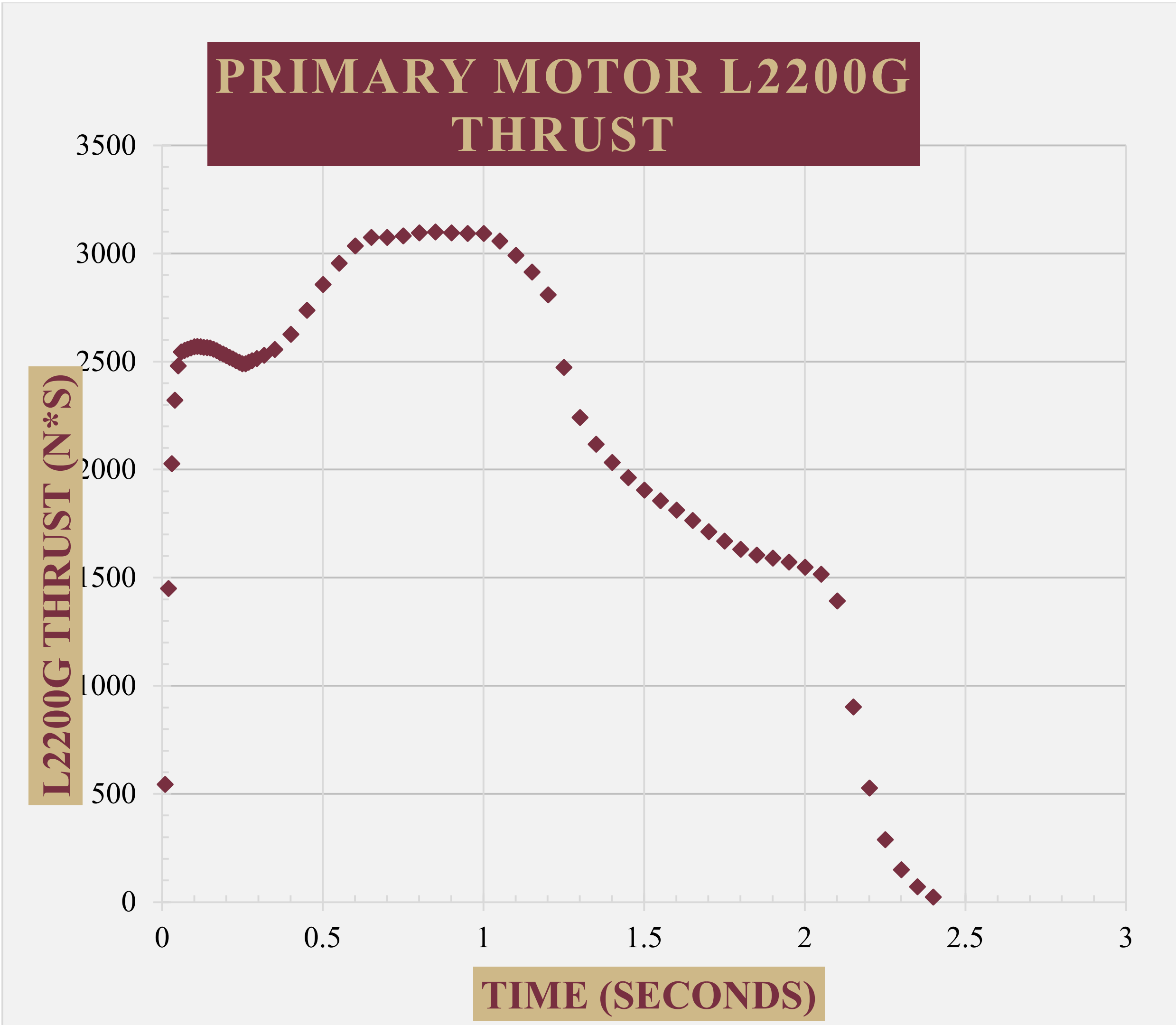



*Figure 3.39 Primary Motor Thrust Performance*

During flight, the vehicle will achieve a maximum thrust of roughly 3150 Ns provided by the primary selected L2200G motor.
Figure 3.39

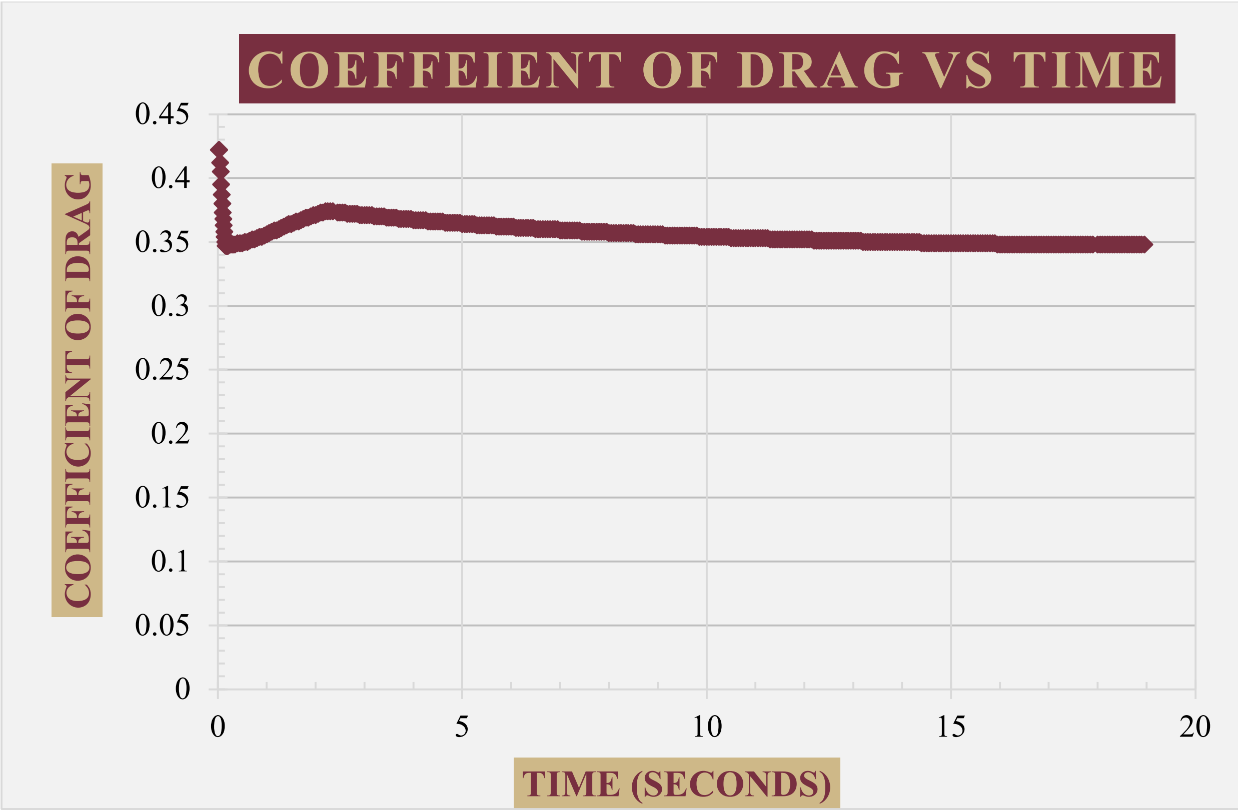



***Figure 3.40 Primary Motor Drag Performance***

### 3.11.2. Load Verification

To ensure the system is capable of withstanding flight, the deployment forces during recovery will be examined since these cause the highest accelerations for the launch vehicle to withstand. Firstly the peak deceleration experience by the rocket can be seen in Figure 3.38 Primary Motor Acceleration Performance at 263.7 $\frac{ft}{s^2}$. The mass of the rocket after burnout is 51.2 lb or 1.59 slug. Thus, the produced force on the recovery hardware is 419 lbf. The stress in the I-bolts an be calculated using ***Eq. 3.1***. As the I-bolt has a 3/8" diameter, the cross-sectional area is .110 $in^2$. Using these parameters the resulting stress in the eye bolts is 3.79 ksi. According to the supplier, this eye bolt has a safe working load of 1300 lbf. This equates to a Safety factor of 3.10.

$$\sigma_N = \frac{F}{A}\ (psi) \qquad \textbf{Eq. 3.1}$$

Now to examine the stress the bulkheads can withstand, the primary concern for the bulkheads is not that they fail in tension, but shear. Thus, to calculate the shear stress in the bulkheads ***Eq. 3.2*** will be used. This equation is true for bulkheads due to their very thin thicknesses and thus the shear experience through the bulkhead is very close. The stress concentration factor k will be implemented due to the many holes in the avionics bay bulkheads. For this estimation k will be assumed to be equal to 11. This is based on the worst stress concentration factor determined for a circular geometry under shear. The area parallel to the force V is equal to the thickness times the diameter of the bulkhead, the cross-sectional area is $\frac{3}{16} * 4.988 = .935\ in^2$. The resulting stress is 4.93 ksi. The minimum yield strength determined for Inconel 718 in its un-heat-treated state from testing was 84.1 ksi. Thus, the safety factor for the bulkheads is 17.1. This seems very high, however due to the uncertainty the area calculation due to the many large holes in the design, and the off-centered location of the I-bolt. This safety factor is deemed permissible based on the limitations of the calculation methodology employed. Also the reported minimum yield was determined from torsional testing which is a non-standard test and thus variance of determined strengths is expected.

$$\tau_{avg} = k\frac{V}{A}\ (psi) \qquad \textbf{Eq. 3.2}$$

### 3.11.3. Stability

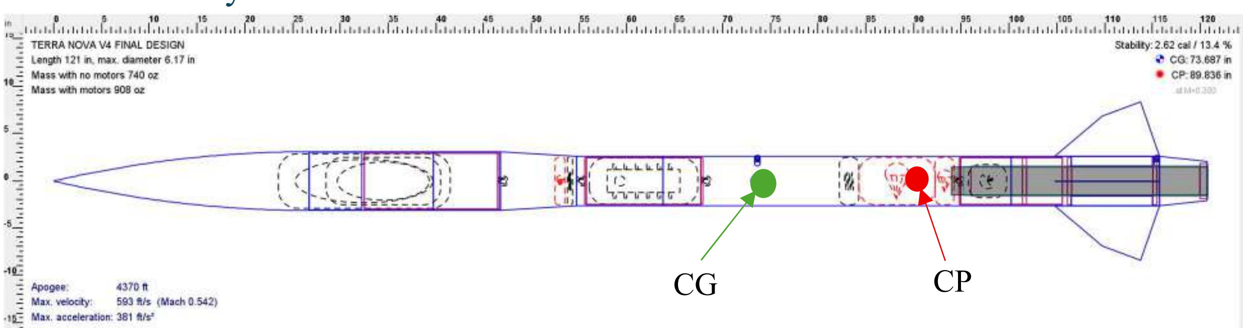



*Figure 3.41 Stability*

The vehicle as designed has a stability of 2.62 Cal, and its CG and CP locations are 73.687” & 89.836” aft of the forwardmost point on the vehicle, respectively. The stability over time can be observed in Figure 3.42 Primary Motor Stability Performance.

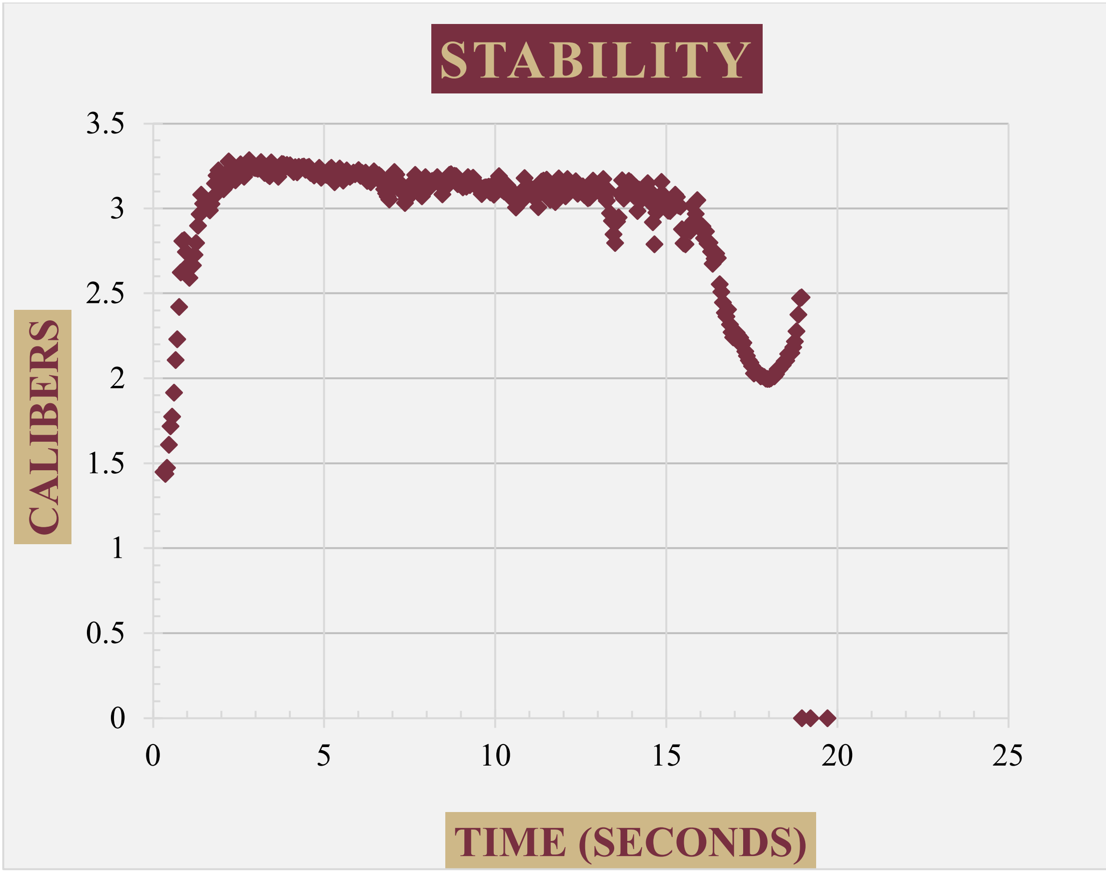



*Figure 3.42 Primary Motor Stability Performance*

### 3.11.4. Descent

The descent rates of this vehicle are calculated with the assumption that the rocket is static relative to the flow of air around it. This creates a model stating that the rocket will drift with the velocity of the wind, making descent drift a function of total descent time and wind speed. Two sets of calculations will be done to include the descent rates and drift both with and without the reefing system to compare the effects of both systems.

The governing equation for this phenomenon is the drag force equation. Assuming a very small transient phase allows the calculations to be done in a static environment. If the drag force of the parachute is equal to the weight of the rocket, the descent velocity under each parachute can be calculated with the following equation.

$F_d = \frac{1}{2} C_d \rho A v^2$Using this equation, the following descent rates under both recovery concepts can be seen below, with the total descent time being calculated by dividing each respective altitude range by its descent rate. It should be noted that these calculations do not include the drag of the rocket body in their calculations, so actual descent rates are likely slower.

| | With Reef System | Without Reef System |
|---|---|---|

| | | |
|---|---|---|
| Drogue Descent Rate | 152 ft/s | 152 ft/s |
| Reefed Main Descent Rate | 50 ft/s | N/A |
| Main Descent Rate | 15.5 ft/s | 16 ft/s |
| Total Descent Time | 76.18s | 71.22s |

Also to be considered is the drift due to wind, calculated as described above.

| Wind Speed | 0 ft/s | 5 ft/s | 10 ft/s | 15 ft/s | 20 ft/s | 25 ft/s | 30 ft/s |
|---|---|---|---|---|---|---|---|
| With Reef | 0 ft | 381 ft | 762 ft | 1142.7 ft | 1524 ft | 1905 ft | 2285 ft |
| Without Reef | 0 ft | 356 ft | 712 ft | 1068 ft | 1424 ft | 1781 ft | 2137 ft |

### 3.11.5. Impact

Perhaps the most important single metric in this recovery system is the impact energy of the vehicle upon landing. NASA specifies that the heaviest independent section of the vehicle should land with no more than 75 ft-lbs of energy, with bonus points being rewarded for landings less than 65 ft-lbs of energy. The impact energies can be calculated via the following equation and will be tabulated below. The calculations will use the landing velocity presented in the previous section

$$E = \frac{1}{2}mv^2$$

| | HAUS Section | Avionics Section | Propulsion Section |
|---|---|---|---|
| Section Mass | 0.495 slug | 0.450 slug | 0.521 slug |
| Impact Energy | 55.75 ft-lbs | 58.11 ft-lbs | 62.59 ft-lbs |

In this model, the heaviest section lands with just under 63 ft-lbs, meeting both mandatory and bonus requirements. Prior to launch, an exact measurement of each section’s weight will be conducted again, and these calculations will be repeated. In the event that the true launch weight does not meet the impact energy requirements, weight reduction modifications will be made to accommodate requirements.

# 4. Payload Criteria

## 4.1. Terra Inquisitor CONOPS

The Terra Inquisitor is a rover-like vehicle capable of being deployed from the launch vehicle, the Terra Nova, upon the safe landing of the craft. This rover is deployed by the usage of a Mechanical Separation device that uses a stepper motor to drive a gear system of worm gears, worm wheels, and power screws to remove the nose cone of the launch vehicle, push the payload out of the housing coupler, and then rotates the assembly into the correct orientation for final depositing the payload onto the ground. The Terra Inquisitor then turns from the rocket and begins conducting its soil collection via an auger drilling assembly and a linkage system. The Linkage system rotates the auger into a vertical drilling position and then drives the auger assembly down into the ground. The auger will pull the soil into the auger head assembly during the linkage downward driving stage and then once the linkage reverses its motion to reposition the auger head assembly back into the payload chassis, the drilling head reverses its rotation direction to expel the soil into the collection container. Due to limitations of motion for the linkage system, the Terra Inquisitor will need to conduct the full drilling and evacuation cycle 20 times to collect the required soil quantity by the Terra Nova team of 60ml. Between each cycle of drilling, the Terra Inquisitor will activate its tracks to drive it forward for a new drilling location. After 4 iterations of the drilling cycle, the Terra Inquisitor testing systems will add water to the container, check the volume of soil collected, test the soil for pH, test the soil temperature, and store all data to its on-board SD card memory.

## 4.2. Changes to Payload Design

As further testing has been conducted, there have been necessary changes to the payload design. All changes involved minor corrections in which primary dimensions, form, and function remained the unchanged. Modifications include:

1. Slight adjustments to Chassis design to reduce interference of linkage as well as additional mounting holes. These holes were necessary base on the changes in other components.
2. Chassis was split into to sections for the printers available to be able to produce the design, thus the chassis was split into forward and aft sections.
3. Addition of steel structural rods to Chassis. During testing of the track systems, due to the tension of the tracks, the side of the payload would deflect out of shape, rods incorporated to prevent such deflections as well as providing consistent assembly methodology between the forward and aft section of the payload Chassis
4. Addition of bearings to all link joints. Testing proved that linkage could not fluidly move without the implementation of bearings or looser tolerances at the joints. However, the looser tolerances caused the linkage to perform poorly, thus bearings were implemented at all joining locations of the linkage for at least one of the links joint to ensure fluid and low friction motion.

5. Modification of link joining methodology. Space between all the linkages became a more obvious problem the more testing and assembly required of the payload system, thus rethinking the joining methodology was necessary to be able to fully assemble linkage and ensure minimal interference between other links as well as other component within the payload.
6. Adjustment of the shape of the coupler link to allow the slot link to rest on it when linkage is in the soil ejection phase. This is also because the linkage was not fully capable of rotating the slotted link to the horizontal position. However, base on the design of the drilling head, the weight causes the link to rotate, but this rotation was farther than desired. Thus, the implementation of a physical limit.
7. A sting was attached to the end of the drilling head and to the shaft of the crank to help the drill assembly to rotate from the horizontal position to the vertical position.
8. Modification to auger design based on limitations of linkage vertical drilling motion. Auger was modified to a simple continuous pitch till the pointed tip. This ensures soil the soil being drilled will not get pushed out of the way but pulled into the drilling head assembly even from the tip of the auger.
9. The motor mount for the track system was modified to incorporate the bearing block for the idler gear between the linkage and the actuation servo. The motor mount also now provides securing for the servo motor. The initial design of inserting it into the chassis was insufficient to hold the servo in place and thus the motor mount was modified to incorporate other older designs as well as to solve the problem of the servo retention.
10. Idler wheel assembly to chassis was modified to use bearings for attachment to payload chassis. This is due to the inaccuracies of the 3D printed chassis due to print orientation as well as overall print complexity and size. Bearings incorporated to ensure proper alignment and retention of idler wheel assemblies.
11. Idler wheel guide pins modified to be with a circular geometry and made of steel due to the weakness and unreliability of the 3D printed tabs as well as their continual inability to be inserted into the chassis due to warping of the chassis during printing.
12. Soil container modified based on modification of idler wheel due to new retention method of the idler rotator shaft causing more space within the chassis. This additional space then allows for the various needs of the STEMnauts abord. As well as relocation of sensors to the top of the container.
13. Drill head coupler design modified to fit the correct screws and to be able to retain the lower coupler from being ejected by the spring tension.
14. Slotted guide link modified to have more material to ensure proper strength as well as better mounting to the payload ground location

## 4.3. Overall Design

It should be noted that due to the fabrication methodology of 3D printing all designs resulted within a few thousands of the originally designed component. In addition to this, due to the nature of fabrication, some locations of surfaces would measure the exact desired dimension while other locations may be a few thousands off. An example of this is any hole for assembly hardware. These holes would often have a range of measured diameters including the actually desired diameter; thus, the reported diameter was largest diameter measured. **Figure 4.1** below details all subsystems included in the payload design.

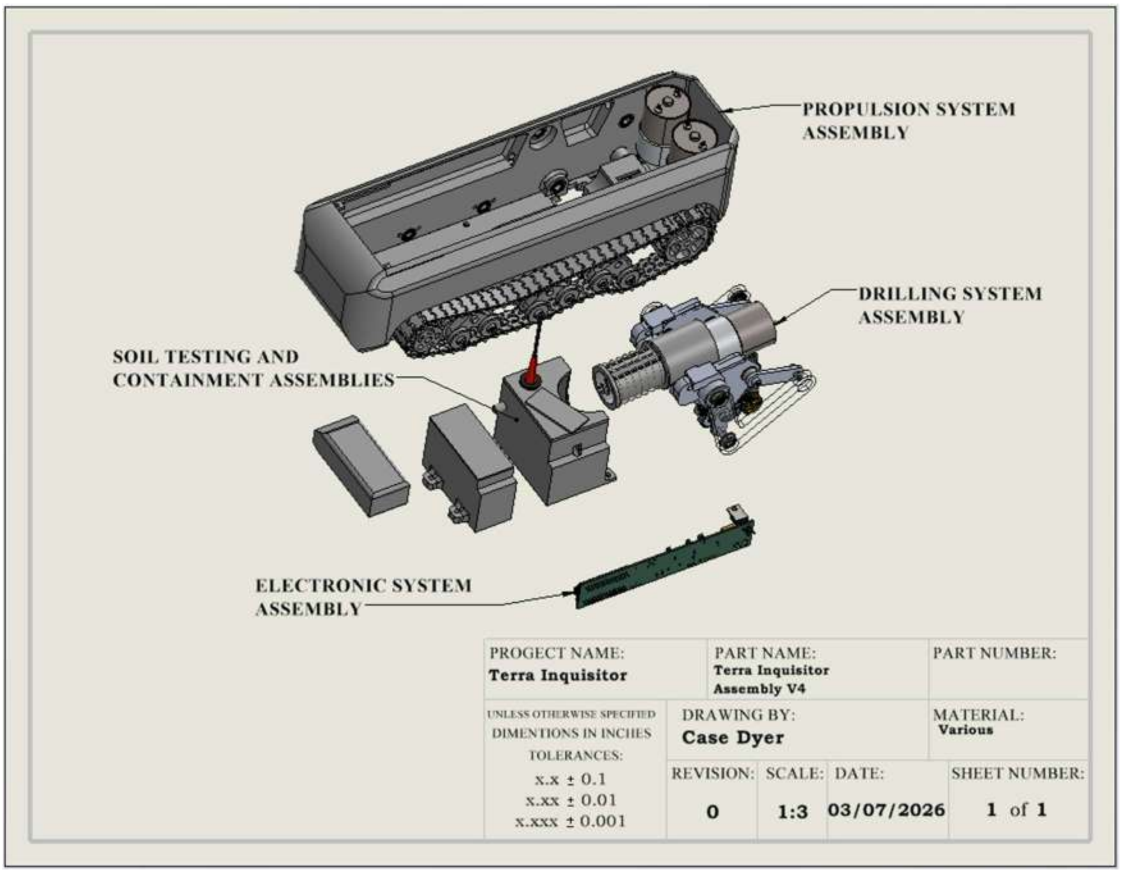



***Figure 4.1 Terra Inquisitor Full-Assembly***

## 4.4. Propulsion System Overview

The payload propulsion system is made up of three primary systems, the track systems, the motor and gearing systems, and the chassis. In total, it comprises of 18 unique component designs with a total of 372 components. The vast majority of being in the track system requiring 126 track pads and pins per side. The vertical Pololu 4271 motors drive the tracks through a system of crossed helical gears held within proper alignment by the motor mount. Each track system includes two driving sprockets, a front and rear sprocket, and three idler wheel assemblies. The rear sprocket is the driving sprocket of the system. The idler wheel assemblies ensure Terra Inquisitor has proper clearance from the ground, was well as providing small motions to help the track to mold to the terrain being traversed to improve traction. There have been two changes in the propulsion system design since the CDR. One, the mounting methodology of the idler wheel assemblies to the chassis of the Terra Inquisitor. This change was implemented due to the inaccuracies of 3D printing as wheel as a more rigid fixture for the connecting shafts of the idler wheel assemblies. Secondly, the design of the motor mount. The motor mount design was changed due to provide proper mounting for the Pololu motors as well as adjusting the mounting holes design for the interface between he chassis and the motor mount. Additionally, the motor mount was modified to provide securing for the linkage servo motor and also to incorporate the bearing block for the idler gear of the linkage system. **Figure 4.2** details the payload propulsion system design.

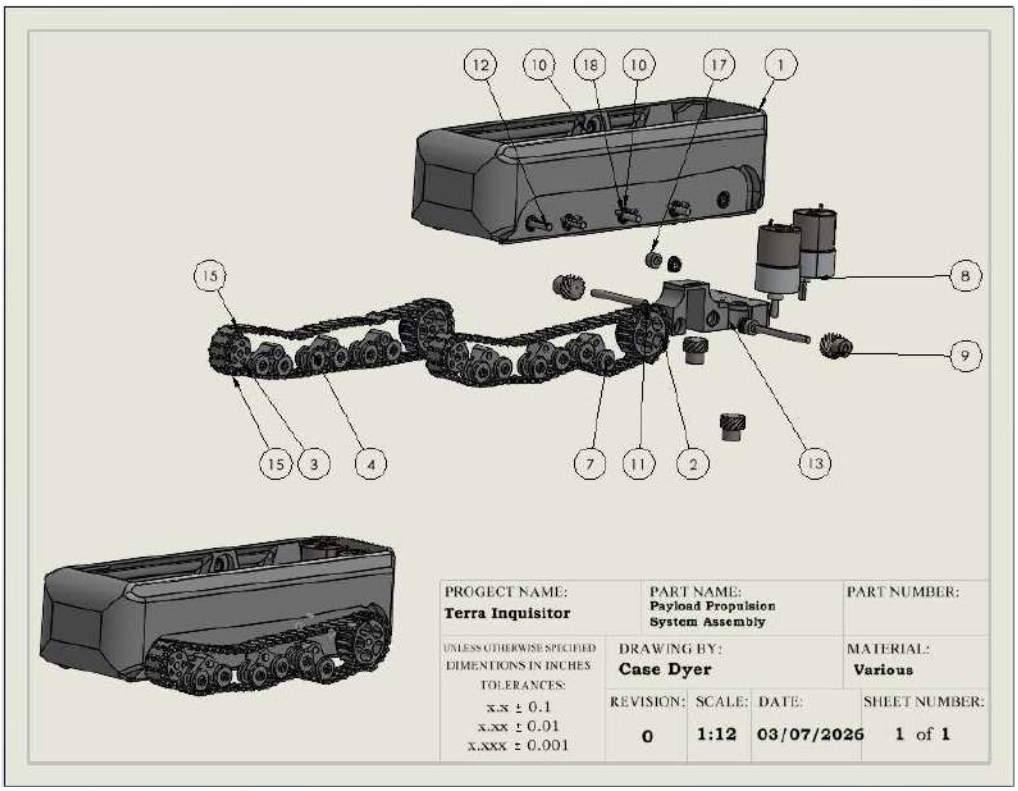



***Figure 4.2 Propulsion System Assembly***

## 4.5. Drilling System Assembly

**Figure 4.3** is the linkage drilling system implemented by the Terra Inquisitor. This systems is one of the unique designs of the Terra Nova team, featuring a parallel linkage system to achieved the desired horizontal and vertical motions based on the motion of a four-bar linkage with an attached slider and slider guide. This design also includes the drilling head assembly for retaining soil withing its lower and upper coupler during the drilling stage which is then expelled into the soil container. In addition to achieving these motions, this linkage provides mechanical advantage to the servo motor during the vertical drilling motion thus aiding the auger in drilling the soil. There have been multiple design modifications to this system since the CDR. Initially the design did not include bearings for all joints, only the joints mounted to the ground link had bearings. However, upon the completion of more performance tests, it was proven necessary to add bearings for all joint pairs. Meaning that for any joint between two separate links, one link has a bearing integrated into its design to allow fluid and rotationally constrained motion. Without these bearings the design either could not rotate due to inner frictional forces or was too loss and would fall apart or bend and twist out of the desired plane of motion. The coupler linkage was modified to provide a resting location for the slotted link during ejection of collected soil. Some

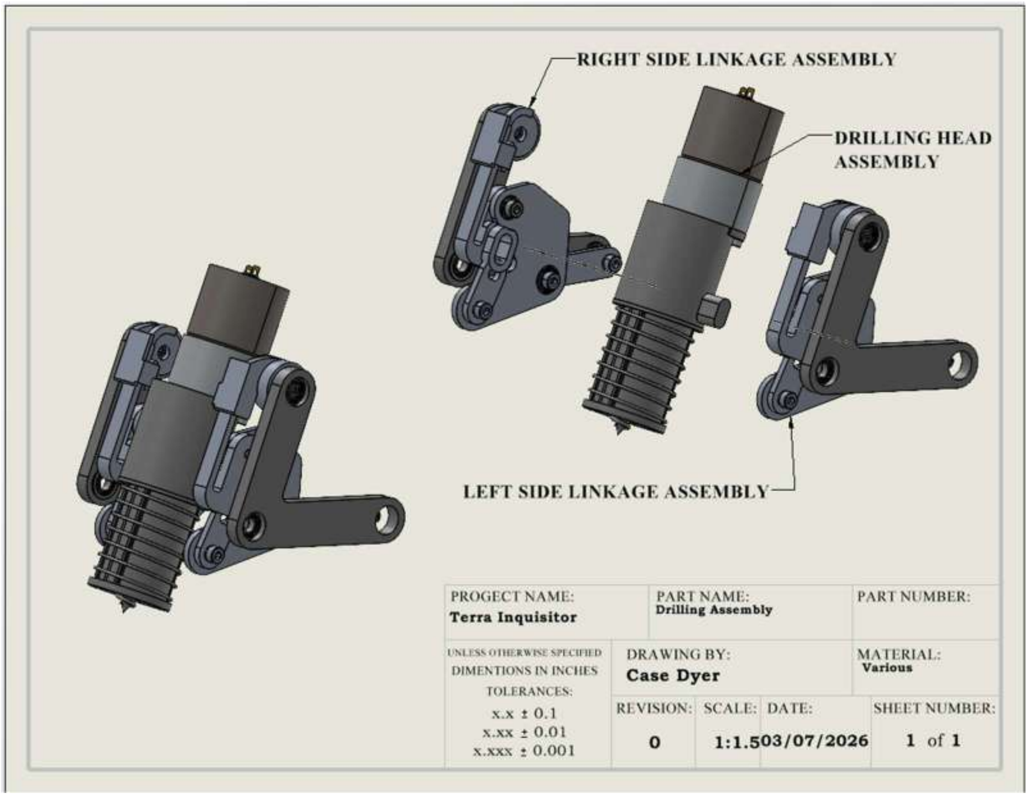



***Figure 4.3 Drilling System Assembly***

of the joints were modified to ensure no interference between the linkage and surrounding components. Finally, the Auger head assembly was modified through the addition of a retainer ring to ensure the lower coupler would not self-eject due to the spring forces but rather ensure consistent covering for the auger to pull up all drilled soil. The auger design upon further testing was also modified due to the limitations of the motion of the linkage. The linkage can only drive the drill into the soil for an inch and this to maximize on drilled soil the auger was modified to no longer taper the flighting of the auger till the end, rather it has a consistent flighting size till the pointed tip of the auger to ensure all soil contacted can be pulled into the lower coupler of the drilling head assembly.

**Figure 4.4** further details the linkage assembly implemented in this design with is various bearings, M4 bolts, threaded shafting, and different link designs. It should be noted that this is only displaying the right side of the linkage, the left side is the exact same overall design with only the slotted guide and the slotted link being mirrored.

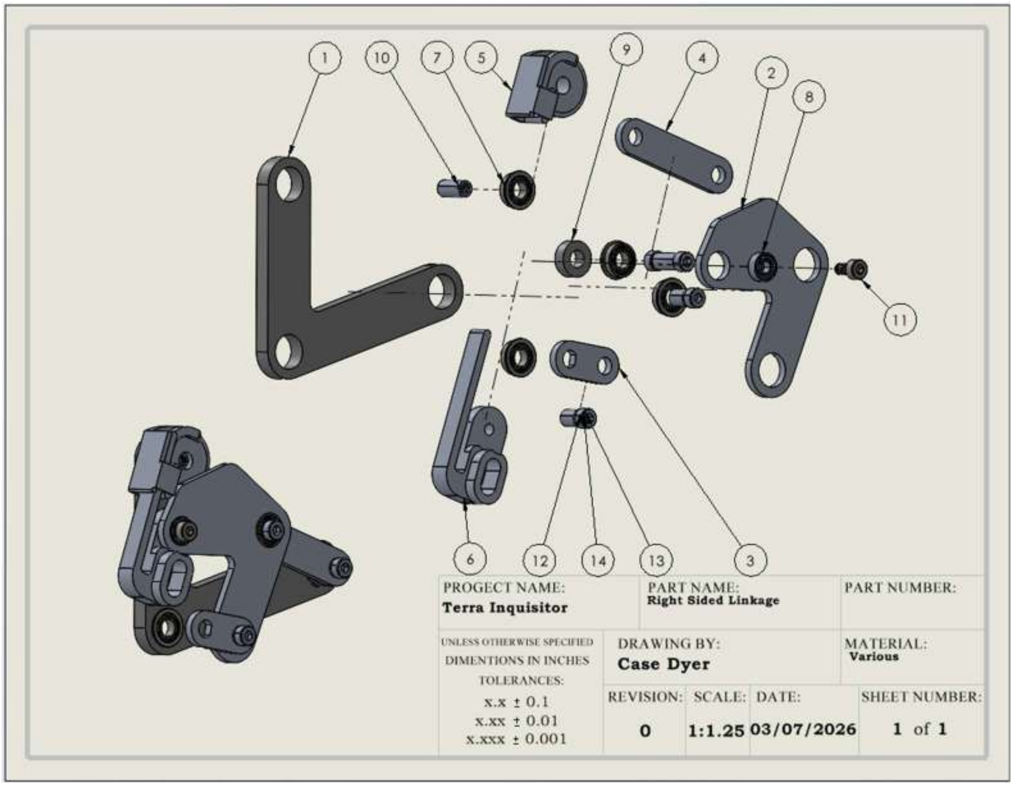



*Figure 4.4 Right Side Linkage Assembly*

**Figure 4.5** further details the drilling head assembly implemented in this design with its various M3 bolts, Pololu 4741 drilling motor, and more.

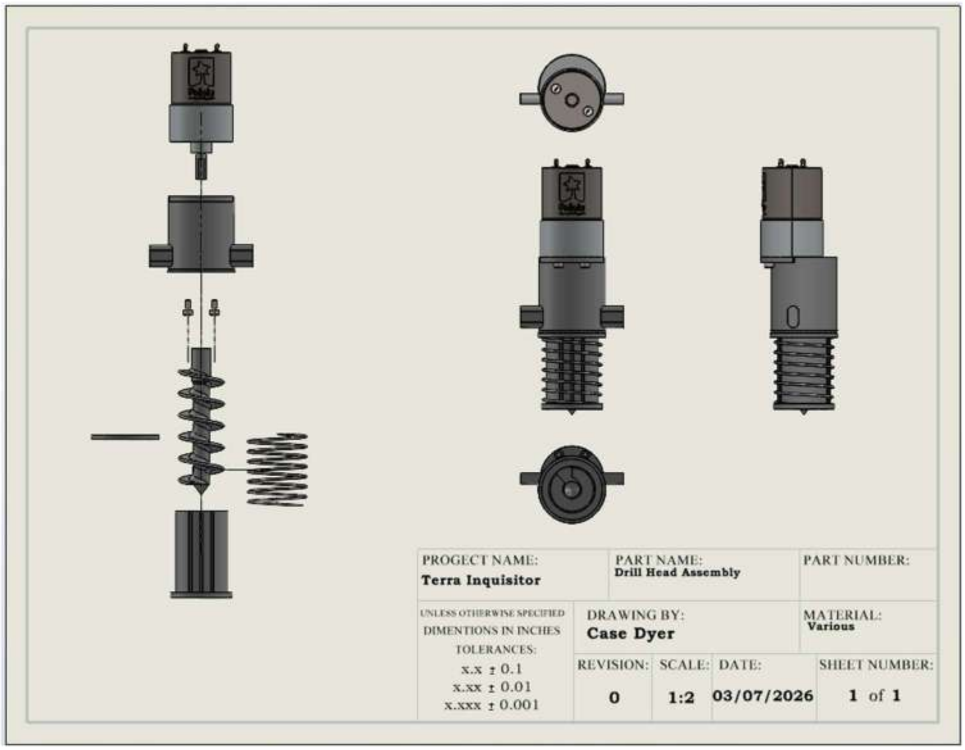



***Figure 4.5 Drilling Head Assembly***

## 4.6. Soil Container and Testing Assembly

**Figure 4.6** details the soil container and testing equipment assembly. This assembly includes the pH sensor, the temperature sensor, the ultrasonic sensor, the soil container, and the soil container lid. Since the CDR there have been a few necessary modifications: moving the mounting location for the sensors, including two different sensors, the ultrasonic (UT) sensor and the temperature sensor. The UT sensor has been included instead of the weight sensor due to many complications and failures what have arisen due to the attempted implementation of the weight sensor. Thus, due to the inclusion of this different sensor, the mounting locations had to be modified. In addition to this, the soil sensor was repositioned to be placed at the top of the container instead of its side. The soil container was modified due to the changes in the propulsion system allowing a more uniform design and space optimization within the payload chassis.

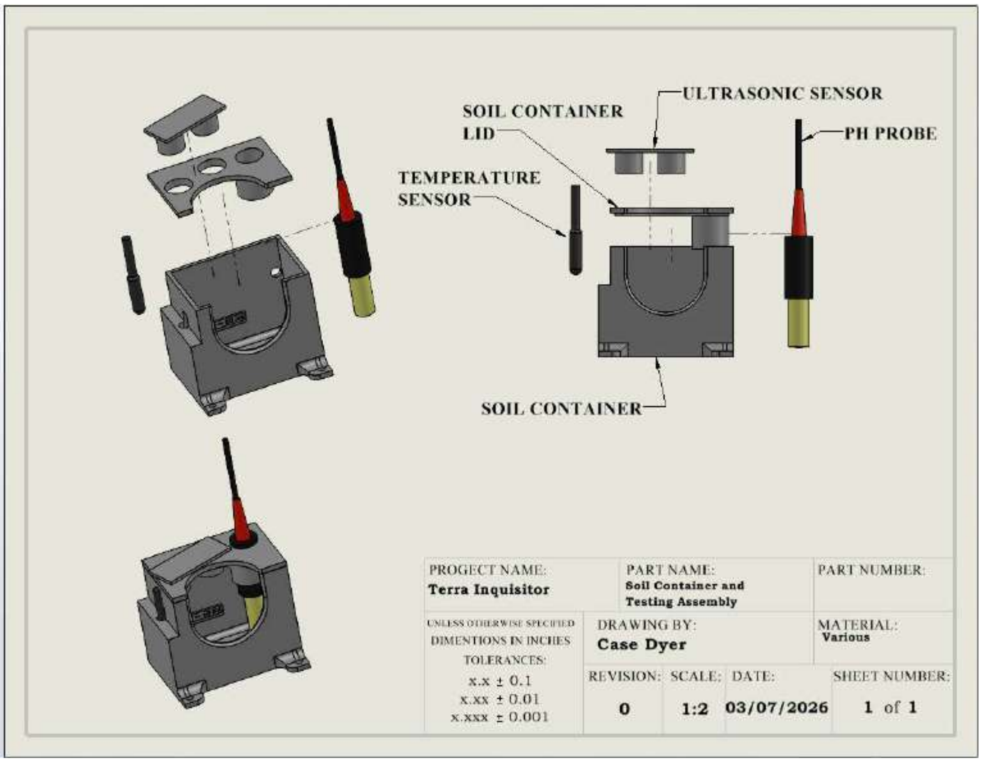



*Figure 4.6 Soil Container and Testing Assembly*

## 4.7. Water Tank and Pump Assembly

**Figure 4.7** details the water tank and pump assembly. This assembly includes water tank lid, water tank, and submersible pump. Since the CDR, there have been some modifications to the design of the water tank and pump assembly. The water tank design was modified due to the change in the design of the soil container to optimize space for the STEMnauts and mounting locations for the tank to the chassis of the Terra Inquisitor.

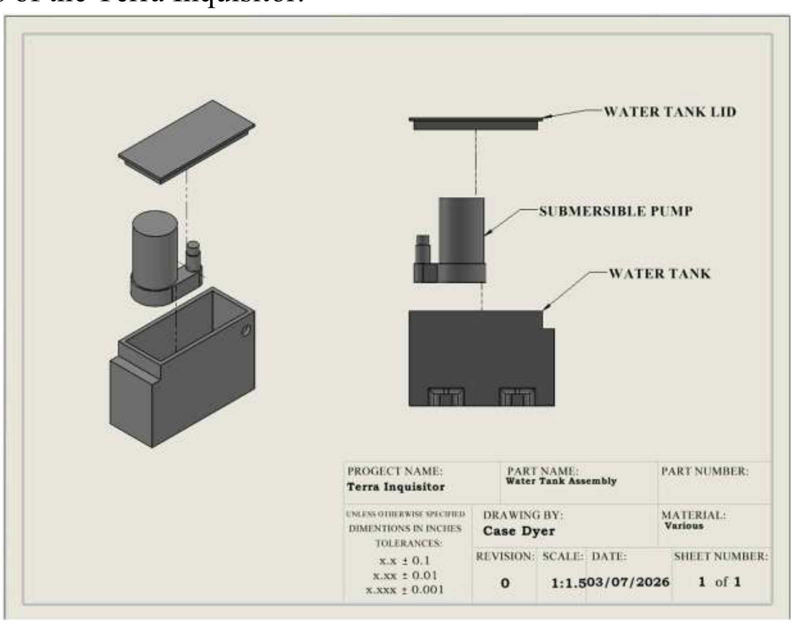



*Figure 4.7 Water Tank and Pump Assembly*

## 4.8. Payload as Constructed Drawings

### 4.8.1. Chassis as Constructed

The chassis design has been modified based on further testing of the system. The primary changes to the chassis are addition of bearings for all Idler Wheel assembly attachment locations, additional mounting holes, steel rod supporting, and track system clearance addition for the rear sprocket. All these changes were deemed necessary due to their effects on the ability of the Terra Inquisitor to achieve it mission as safely as possible. All components need to be able to be properly secured. The chassis must be rigid enough to support the loads of flight and all loads caused by its own systems. The images and drawings below detail the as constructed and tested design of the chassis as well as the design modifications to the chassis to ensure it is capable of fulfilling its mission. For the printing and insertion of the supporting steel rods the payload chassis print had to be sectioned into two sides, the front and aft sections of the chassis. They are be held in place by the steel rods and the tension provided by the track systems.

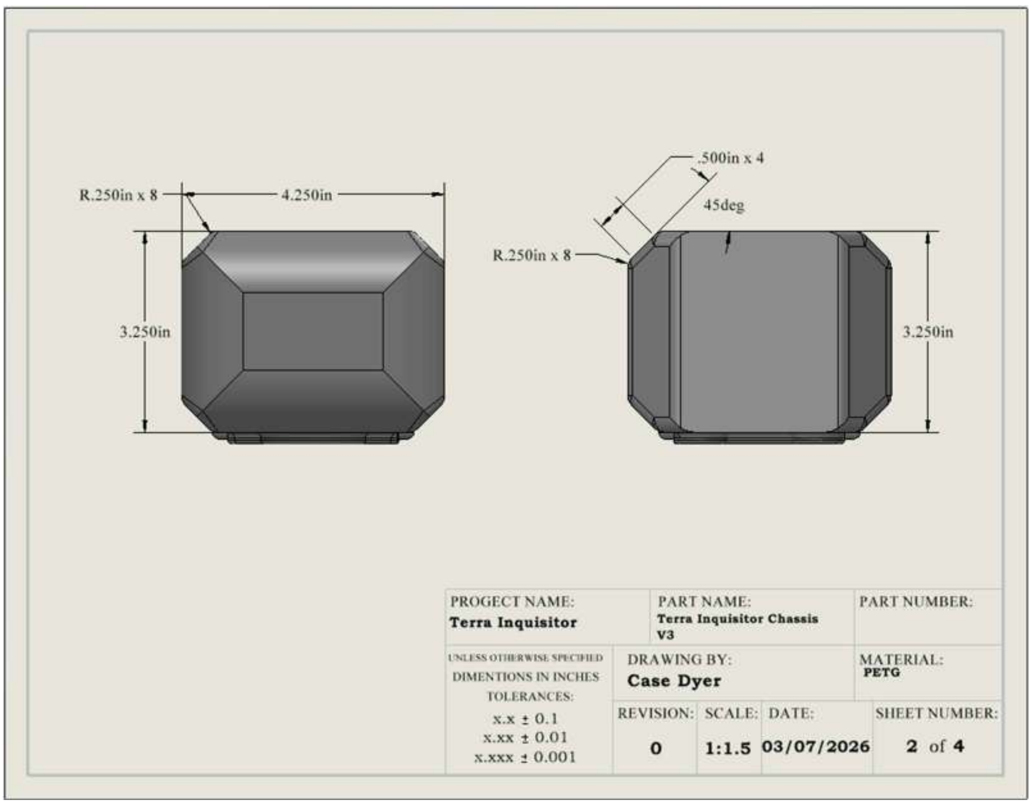



*Figure 4.8 Chassis Front and Rear Views*

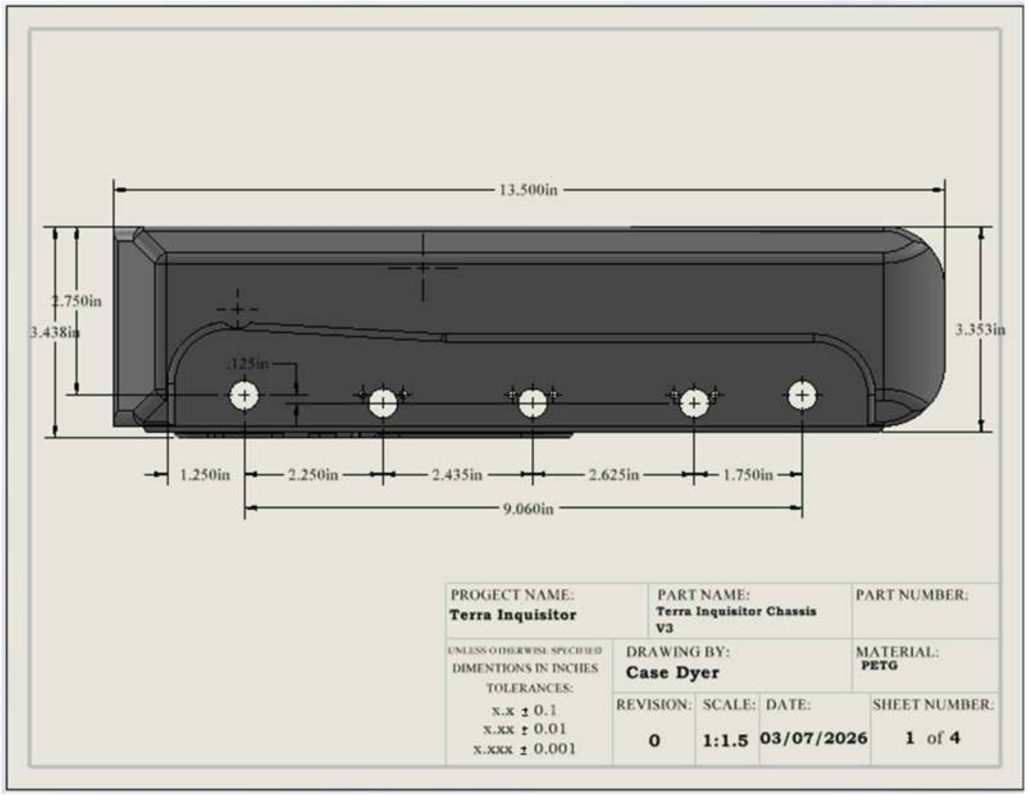



*Figure 4.9 Chassis Side View*

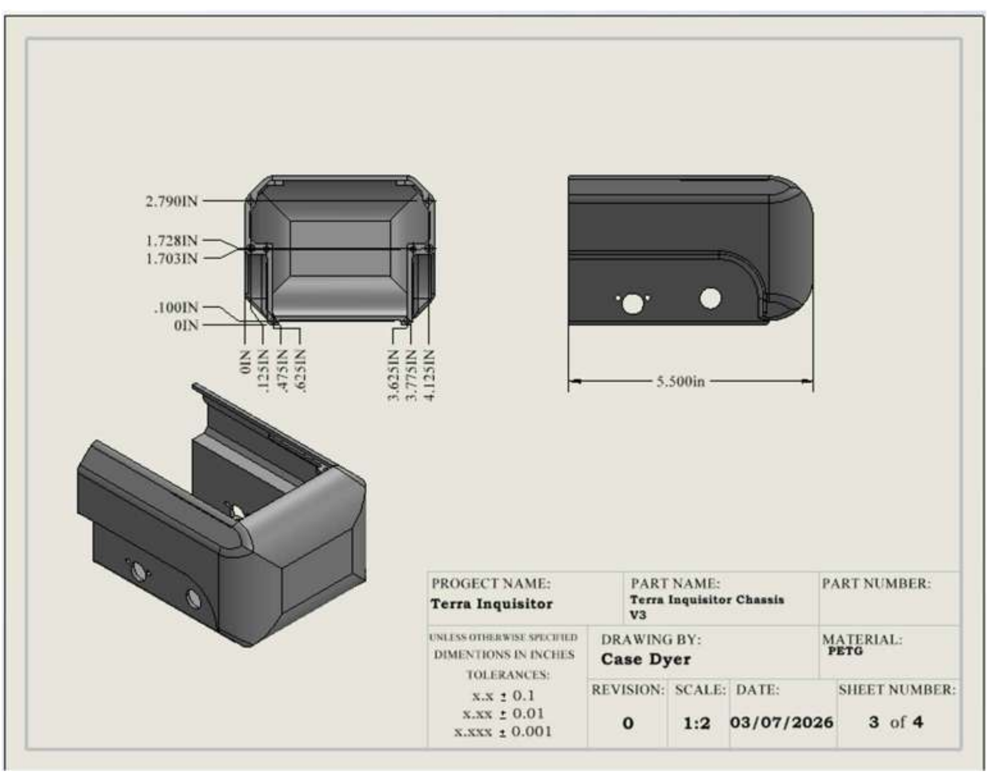



*Figure 4.10 Chassis Front Section*

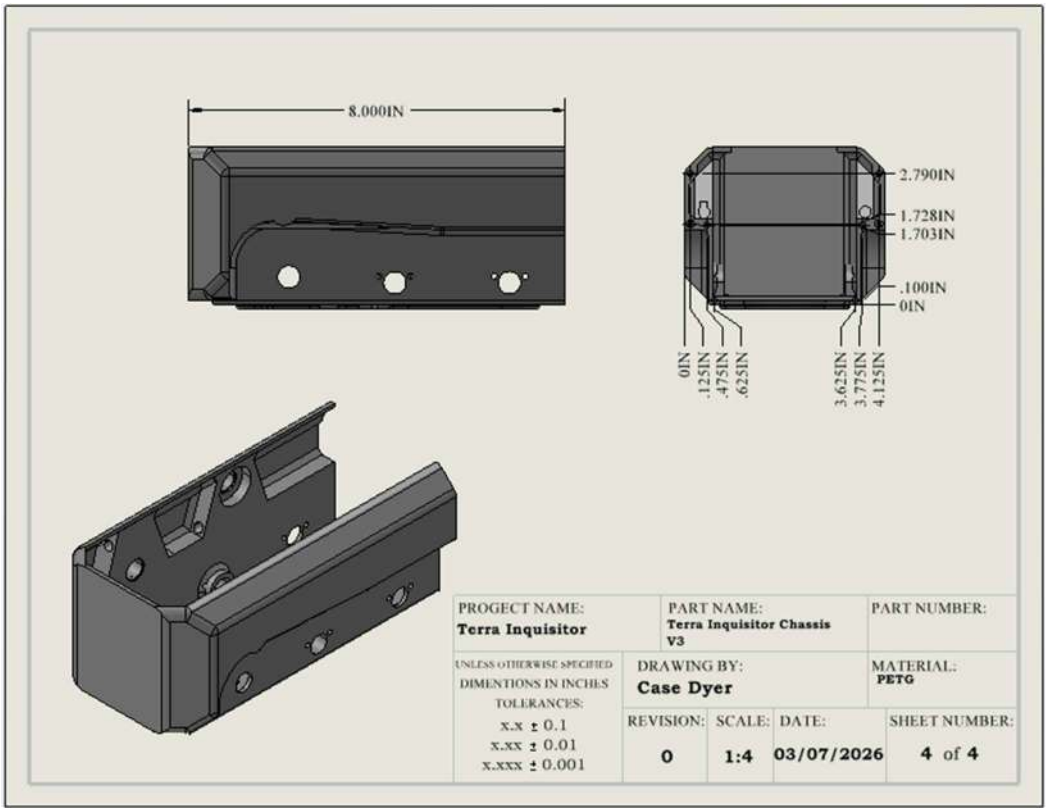



***Figure 4.11 Chassis Rear Sectioned View***

### 4.8.2. Propulsion System as Constructed

The propulsion system of the Terra Inquisitor detailed in Error! Reference source not found. entails two tracks powered by two Pololu 37D motors with a gear ratio of 19:1. The track system includes the tracks themselves as well as the front sprocket (**Figure 4.13**) and rear sprocket (Figure 4.14), and three idler wheel assemblies (Figure 4.15) for each side. Below are detailed drawings and images of the as constructed components and any necessary comments on the components. The image below is of the payload propulsion system fully constructed.

Figure 4.8 details the as constructed motor mount that was made via 3D printer.

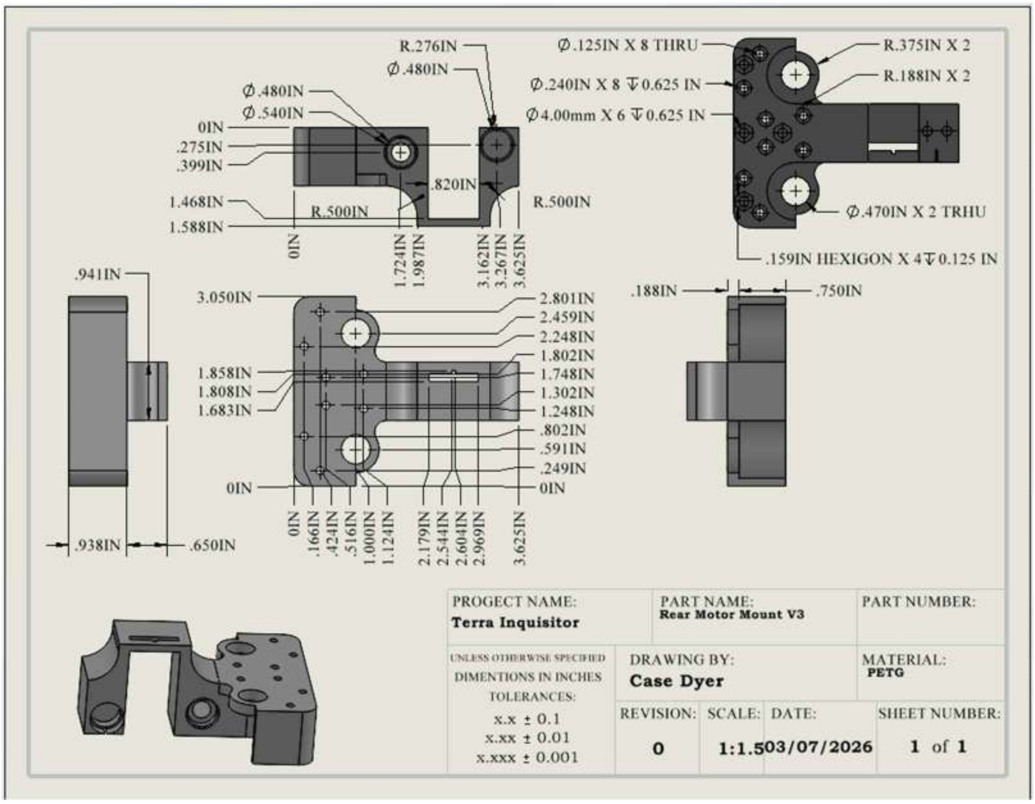



*Figure 4.12 Track Drive Motor Mount Detailed Drawing*

The below picture further details the as constructed condition of the Motor Mount.

The front sprocket as constructed design is detailed below as well as in the additional image of the as printed condition.

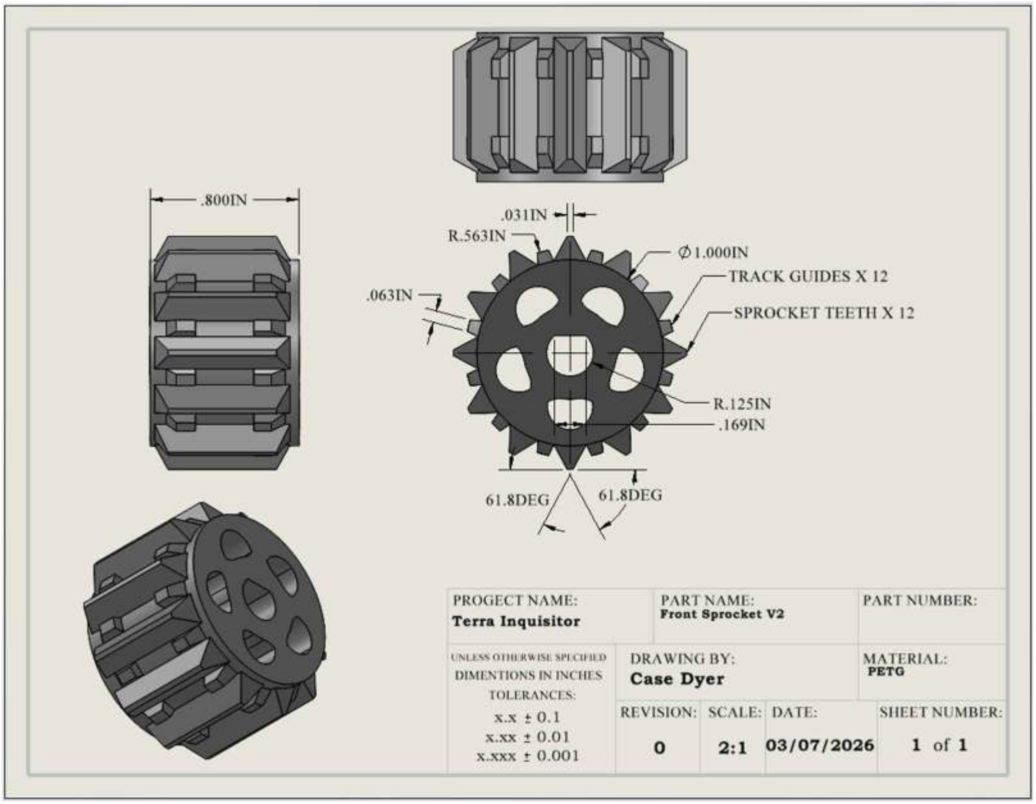



*Figure 4.13 Front Sprocket Detailed Drawing*

The rear sprocket was printed as detailed below in the drawing an also the as built image.

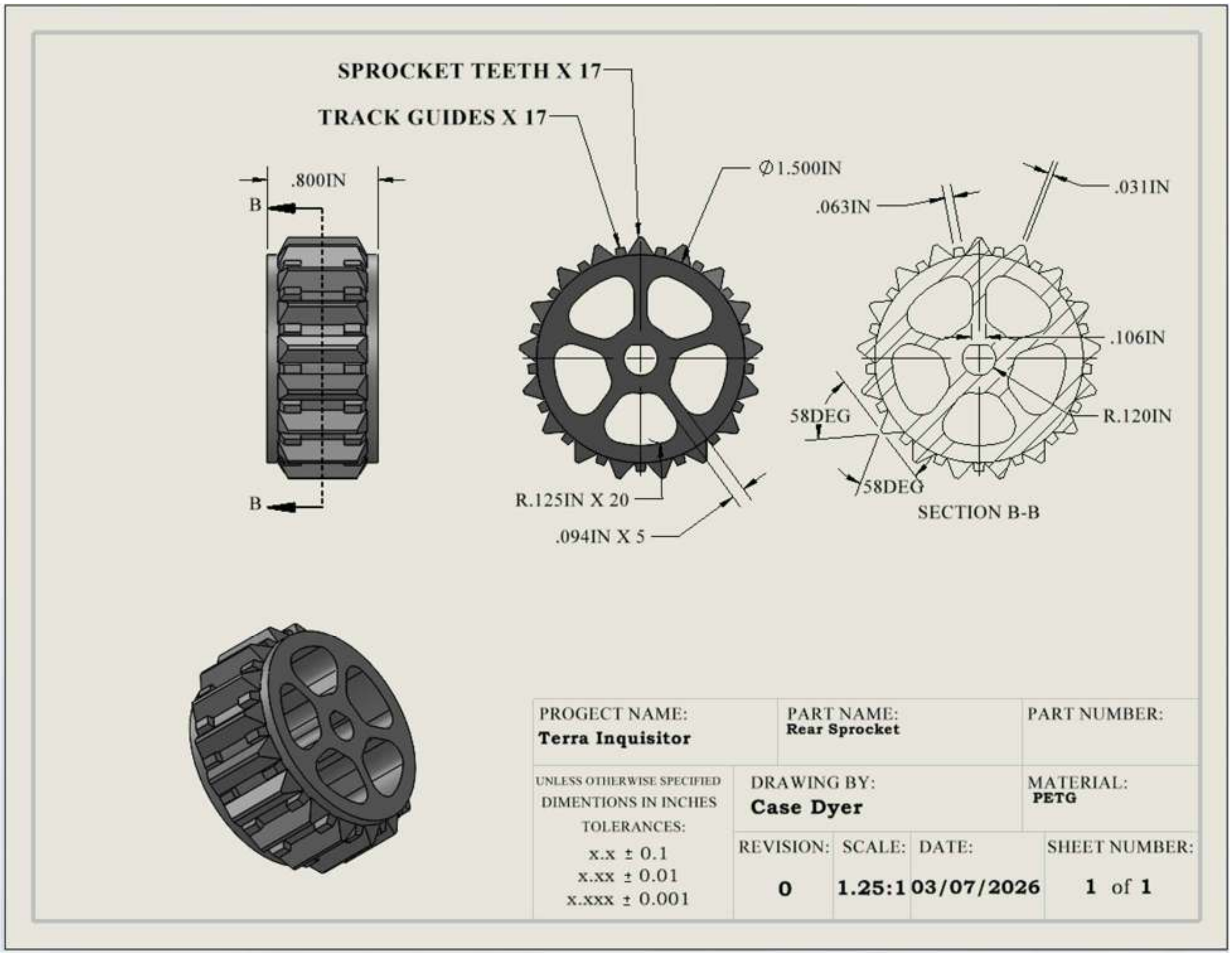



*Figure 4.14 Rear Sprocket Detailed Drawing*

The idler wheel assembly is detailed below in **Figure 4.15** through **Figure 4.17**. Below is a drawing of the overall assembly of the idler wheel with all for unique components that comprise the design, the M4 screws, Idler Wheels (**Figure 4.16**), 4mm Bearings, and Wheel Rotator (**Figure 4.17**.). The image below the drawing depicts the "as printed" state of the Idler Wheel Assembly.

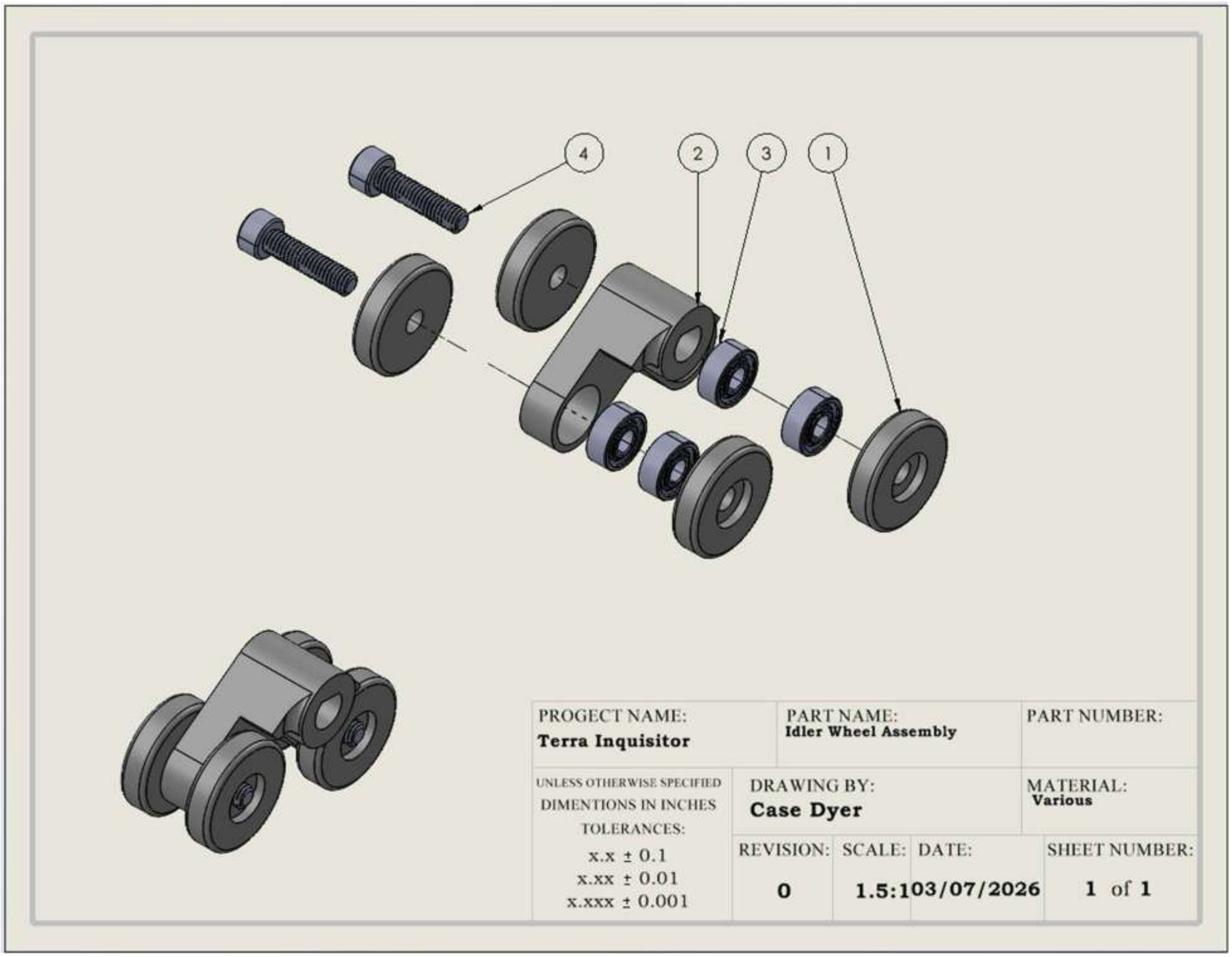



*Figure 4.15 Idler Wheel Assembly*

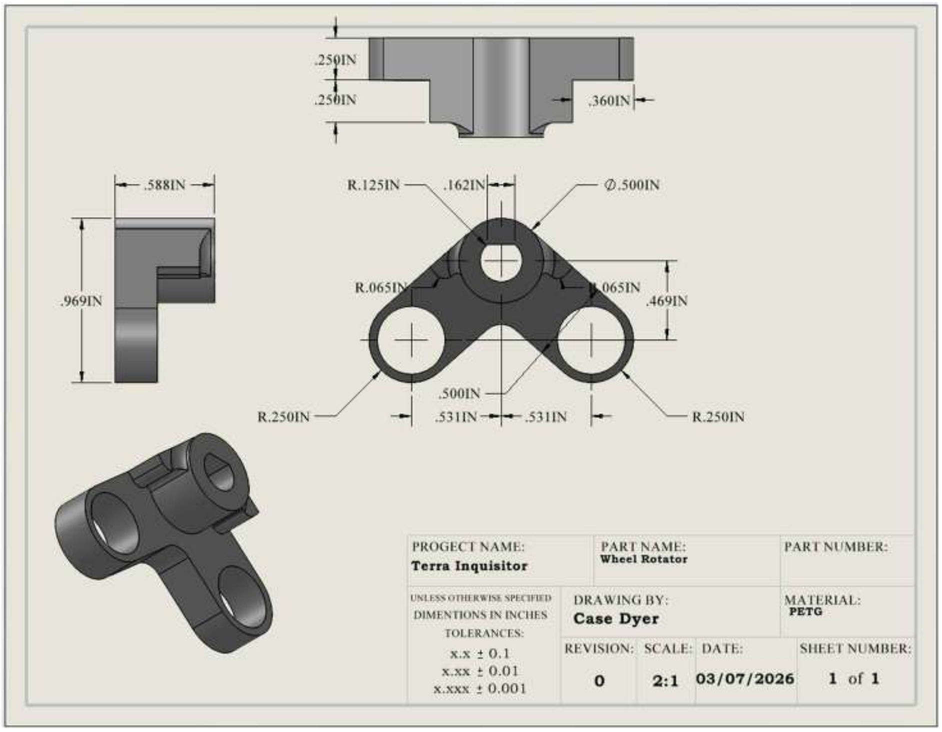



*Figure 4.16 Wheel Rotator Detailed Drawing*

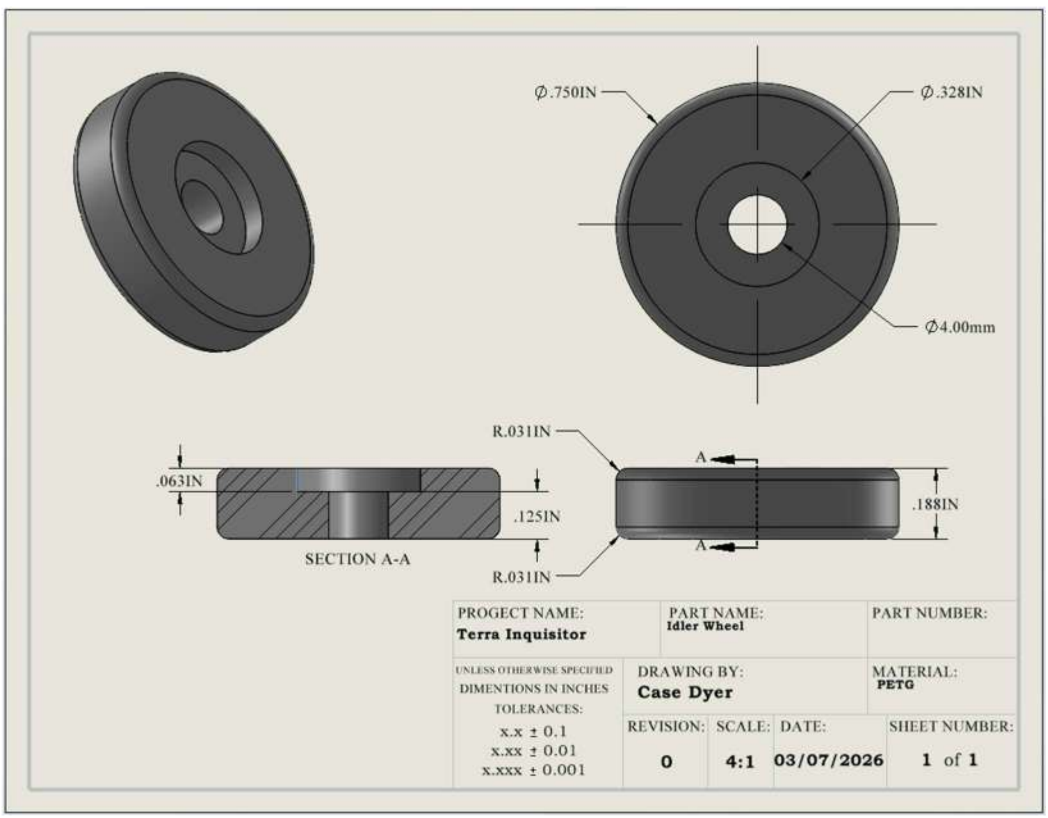



*Figure 4.17 Idler Wheel Detailed Drawing*

## 4.8.3. Drilling System as Constructed

The drilling system assembly comprises of a commercially purchased spring and M3 screws with the custom designed Upper Coupler (**Figure 4.18**), Lower Coupler (**Figure 4.19**), Upper Cover Cap (**Figure 4.20**), and Auger Drill Bit (**Figure 4.21**). The final image is of the system fully integrated and after significant usage for testing.

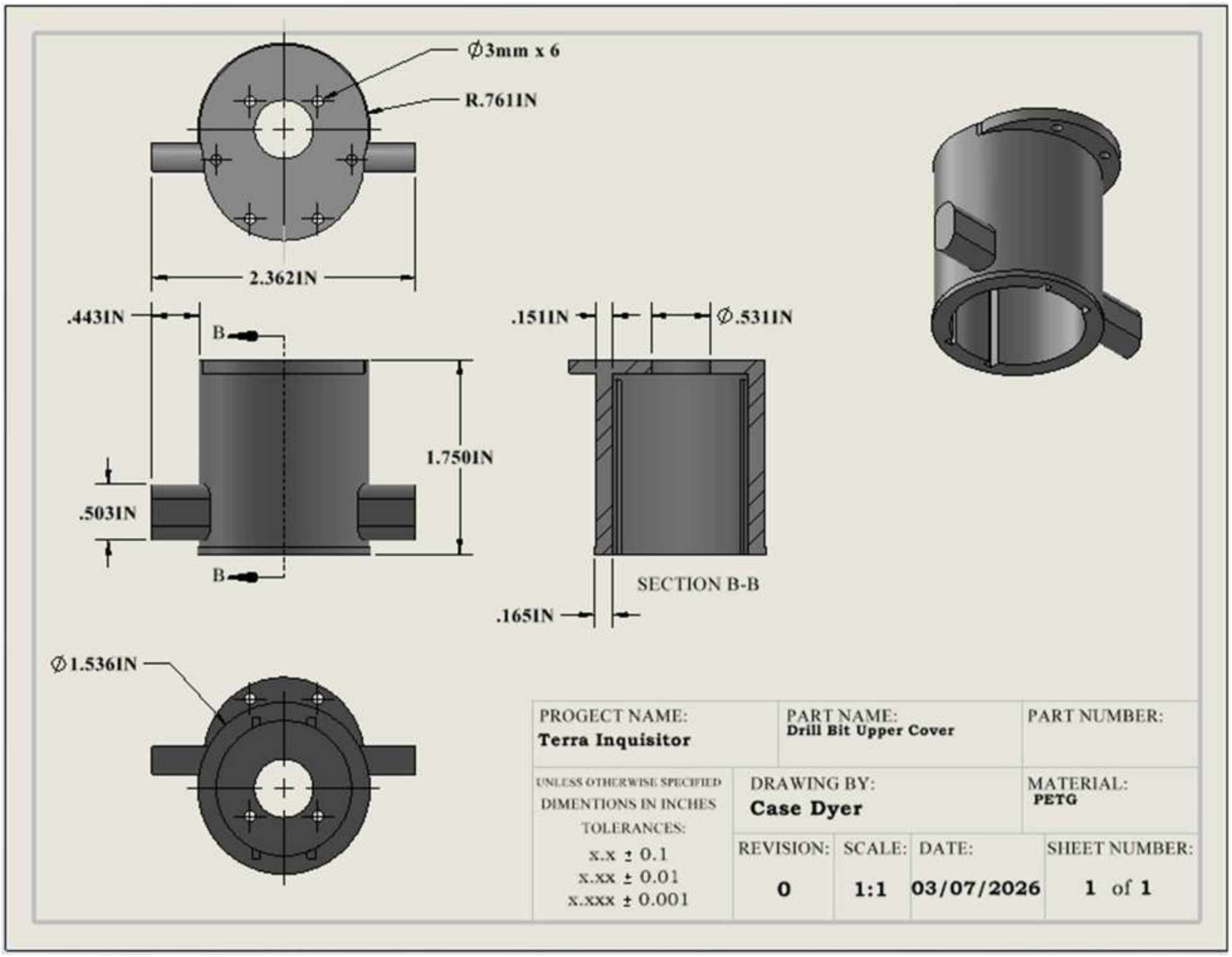



*Figure 4.18 Upper Coupler Detailed Drawing*

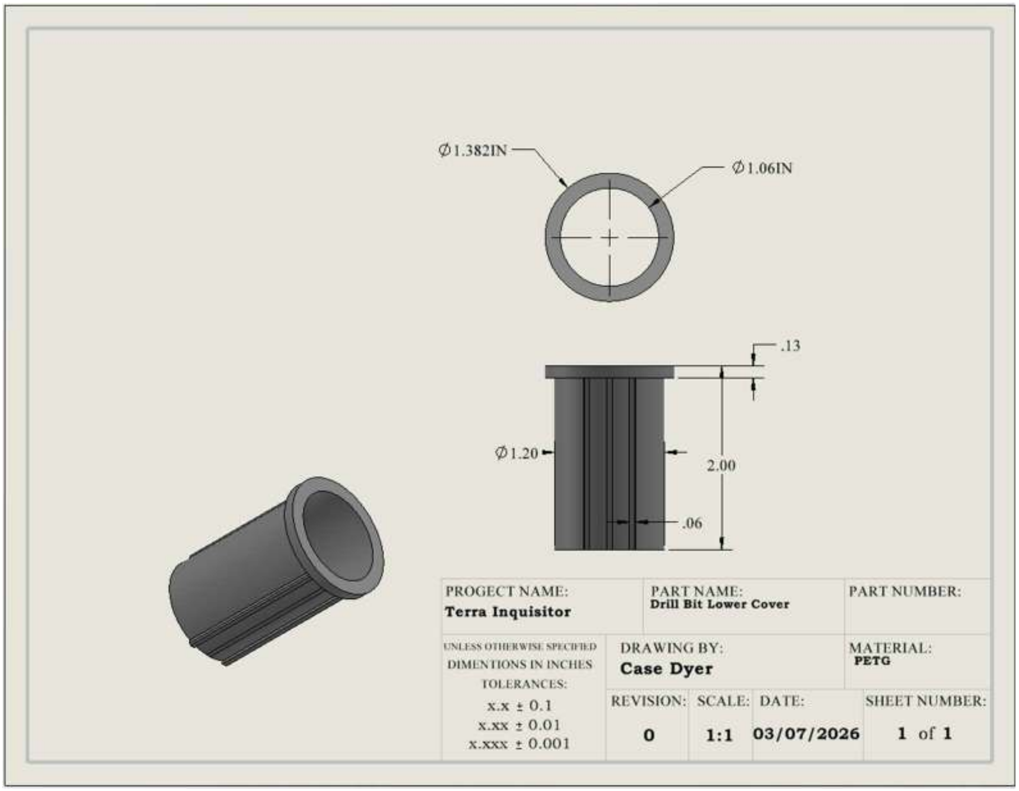



*Figure 4.19 Lower Coupler Detailed Drawing*

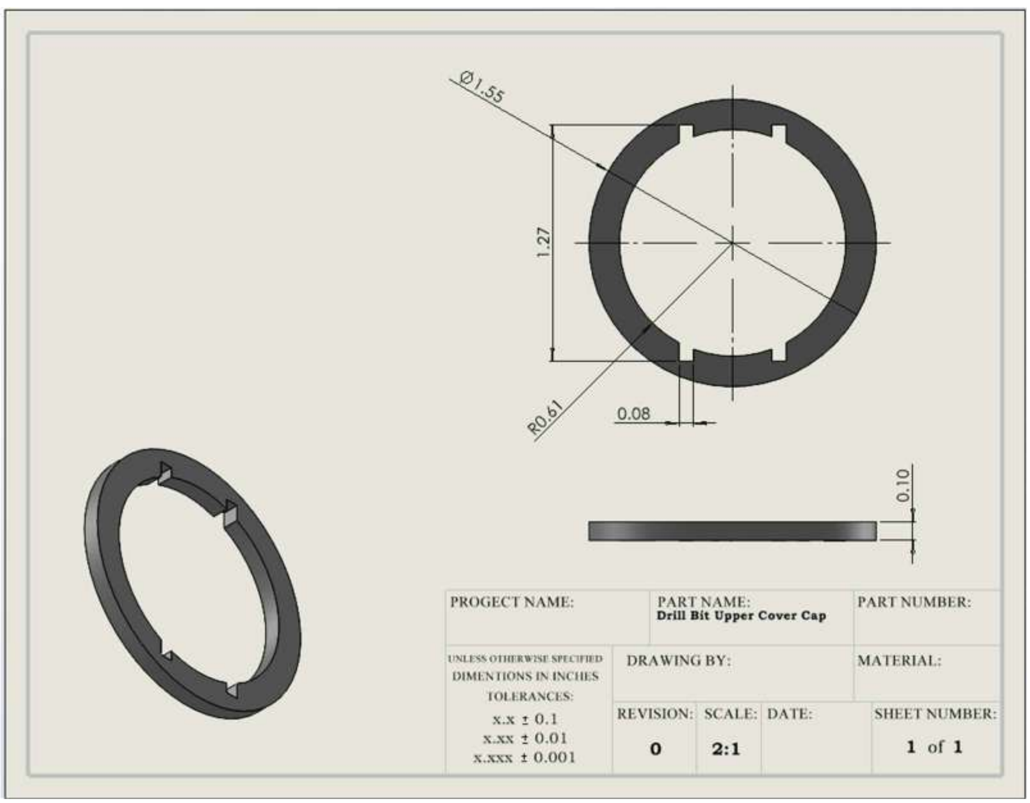



*Figure 4.20 Upper Coupler Cap Detailed Drawing*

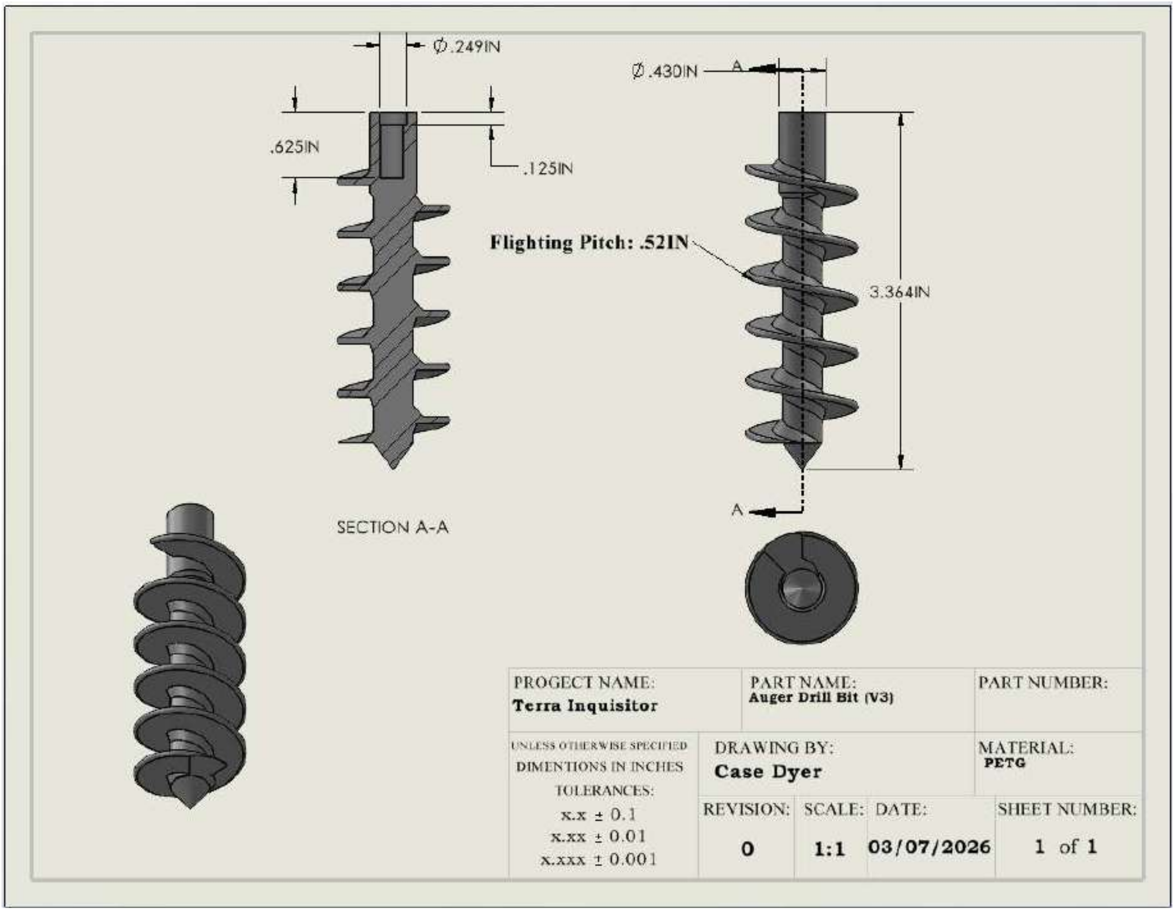



*Figure 4.21 Auger Drill Bit Detailed Drawing*

## 4.8.4. Soil Collection and Containment Components

Below are the detailed as constructed drawings of the components for the soil collection, containment and testing. This includes the linkage system and all its components, the soil container, soil container lid, water tank, and water tank lid.

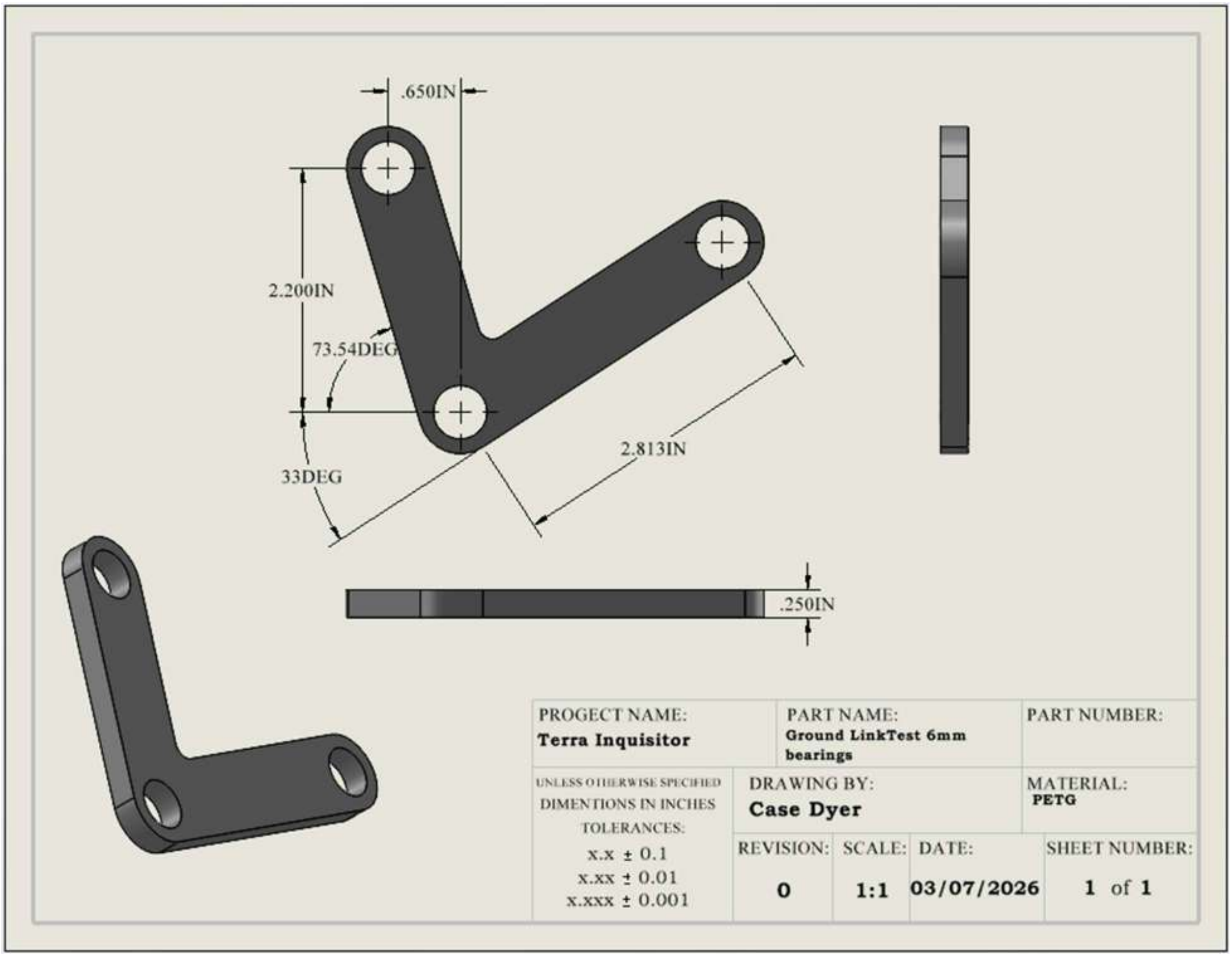



*Figure 4.22 Representation Ground Link Detailed Drawing*

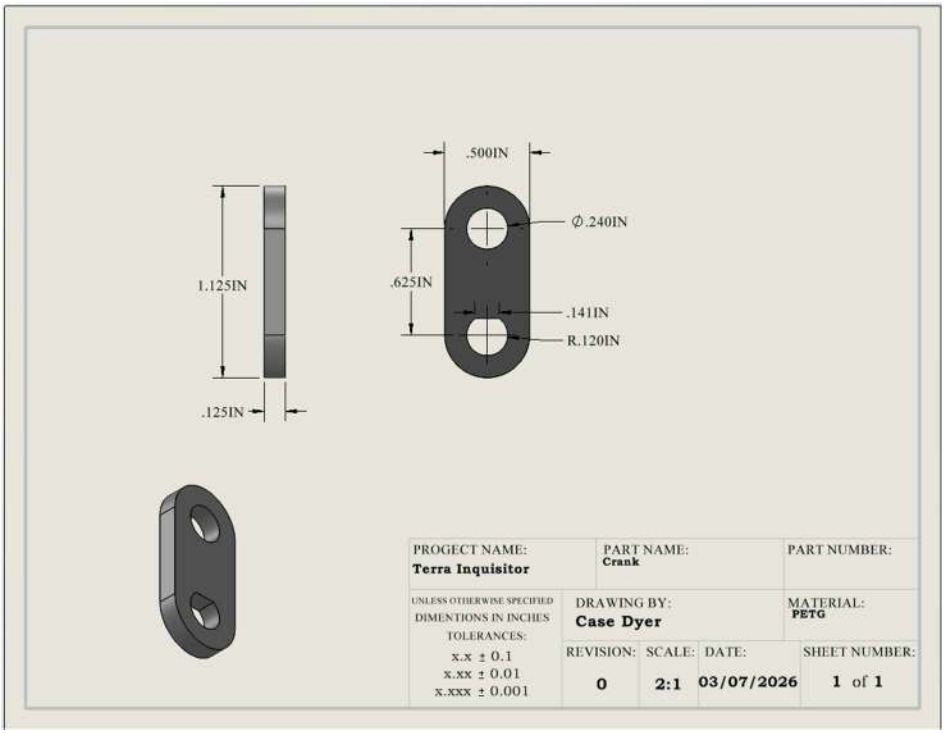



*Figure 4.23 Crank Link Detailed Drawing*

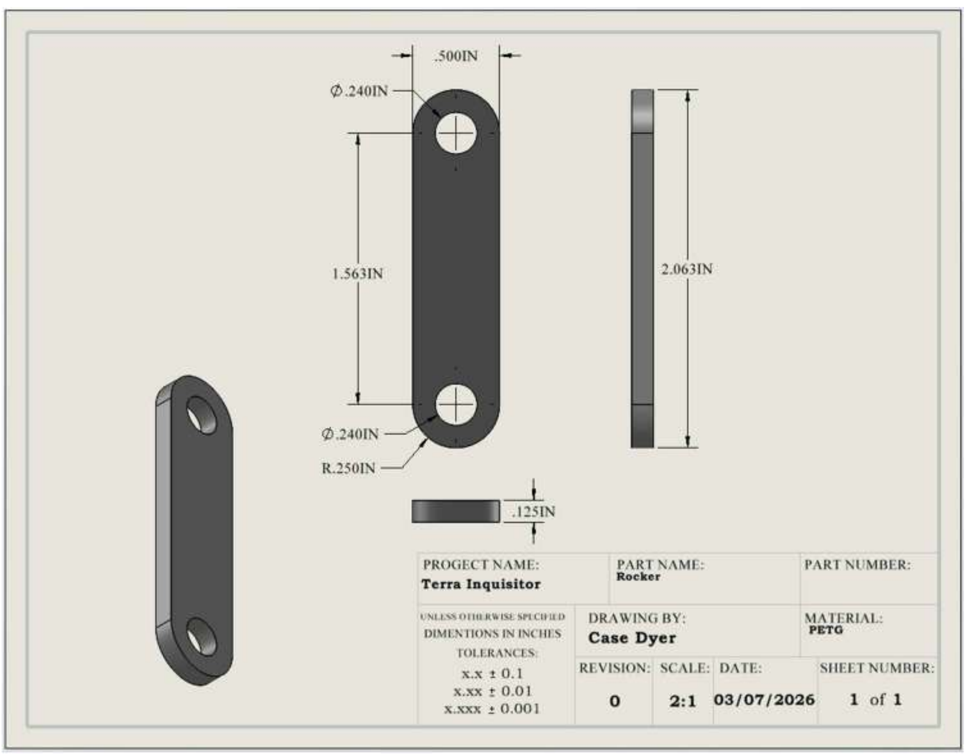



*Figure 4.24 Rocker Link Detailed Drawing*

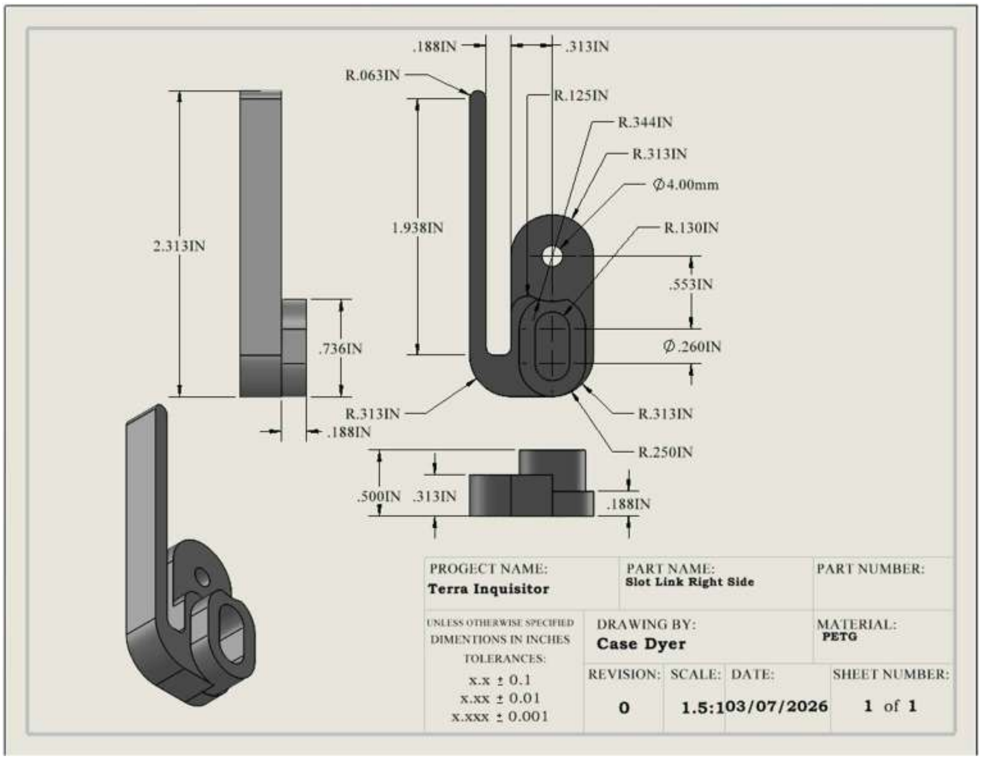



*Figure 4.25 Right Side Slot Link Detailed Drawing*

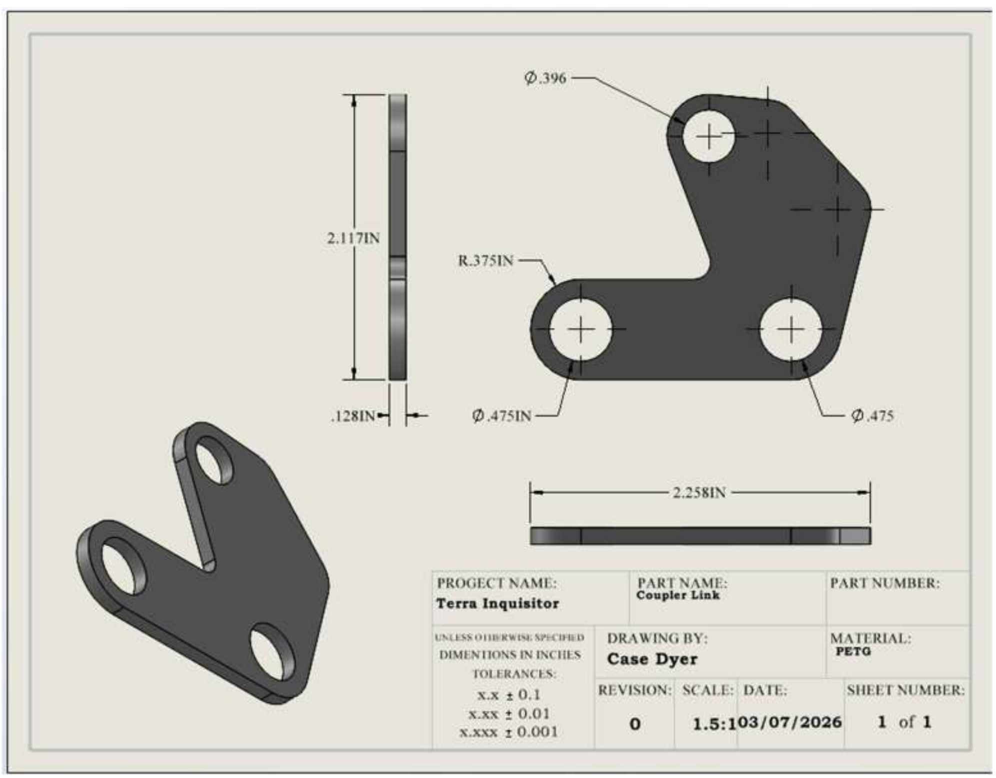



*Figure 4.26 Coupler Link Detailed Drawing*

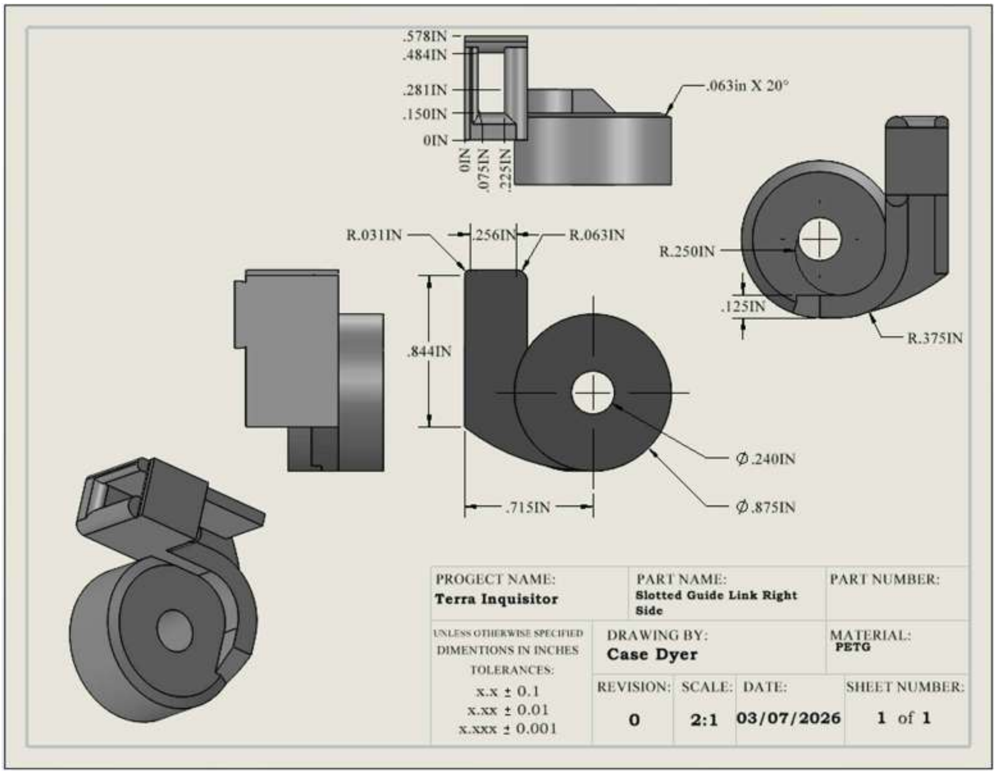



*Figure 4.27 Right Side Slot Link Guide Detailed Drawing*

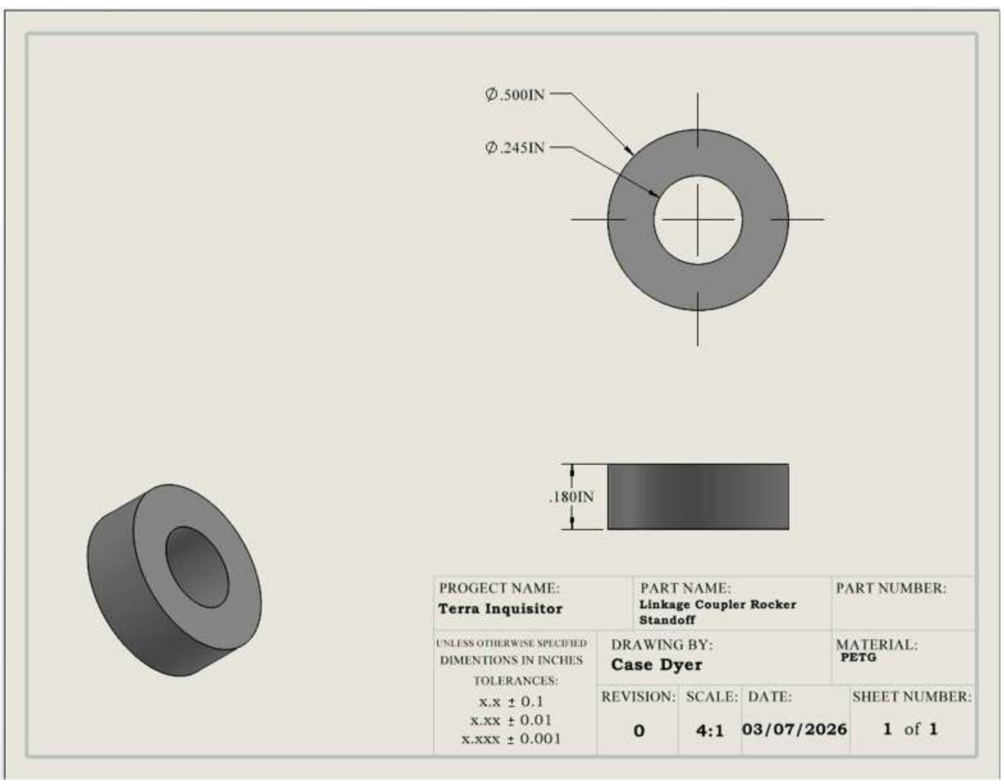



*Figure 4.28 Coupler to Rocker Standoff Detailed Drawing*

The image below is of the linkage system fully constructed.

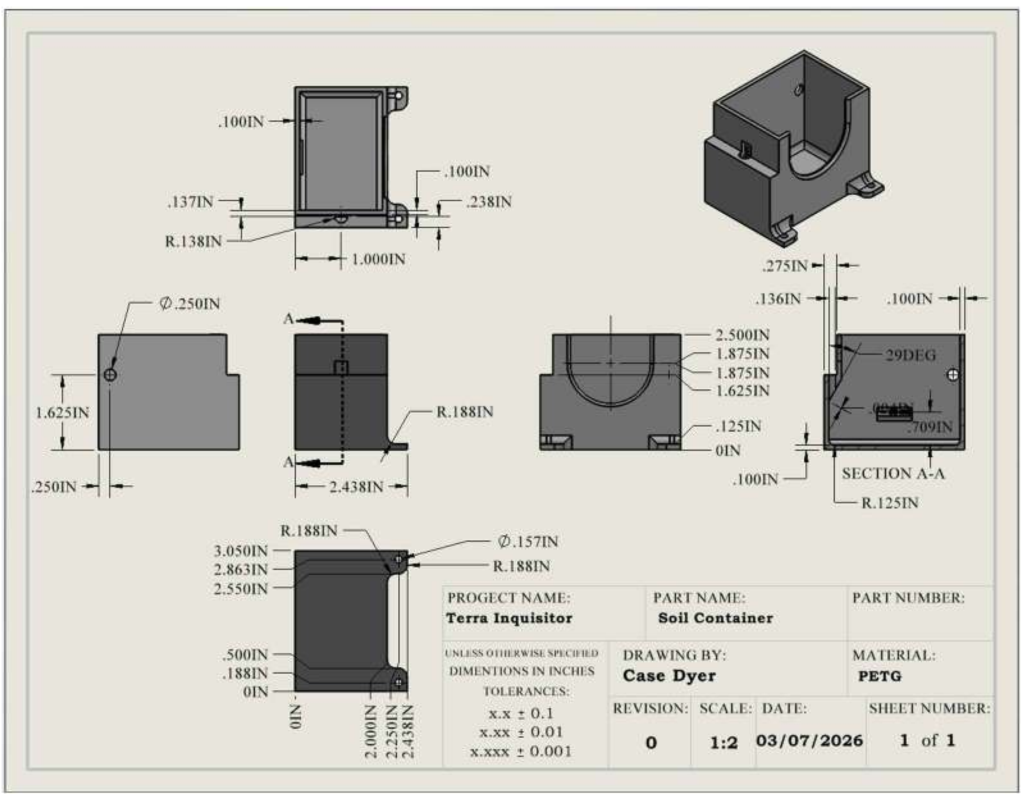



*Figure 4.29 Soil Container Detailed Drawing*

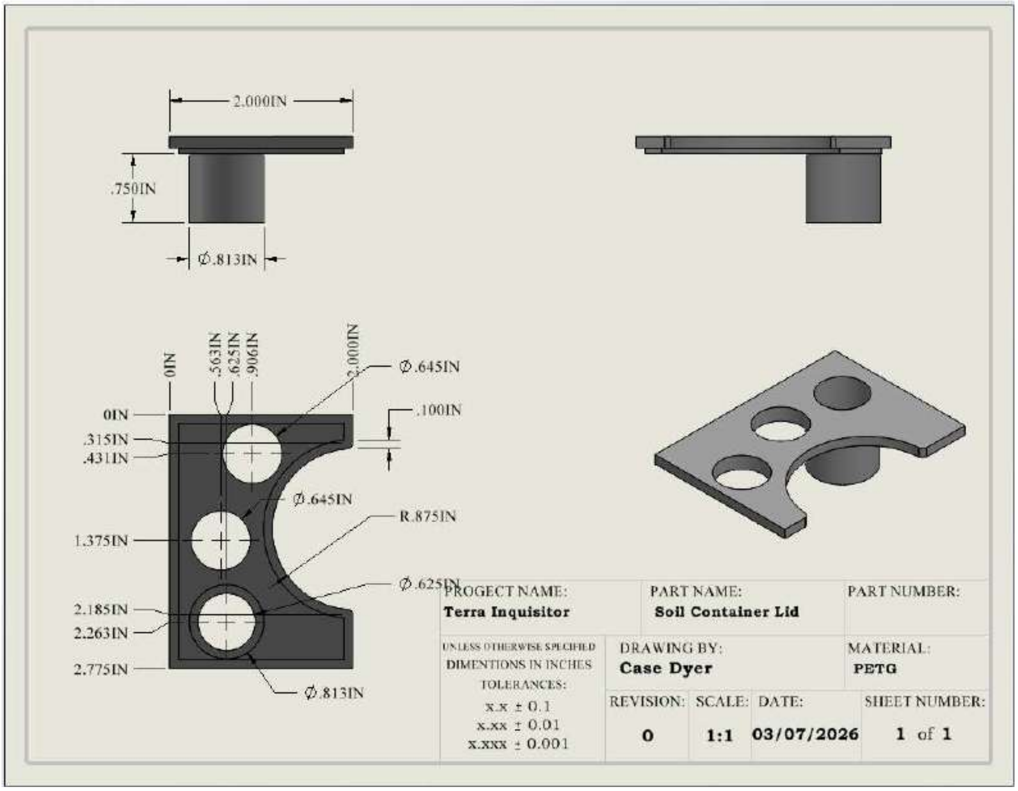



*Figure 4.30 Soil Container Lid Detailed Drawing*

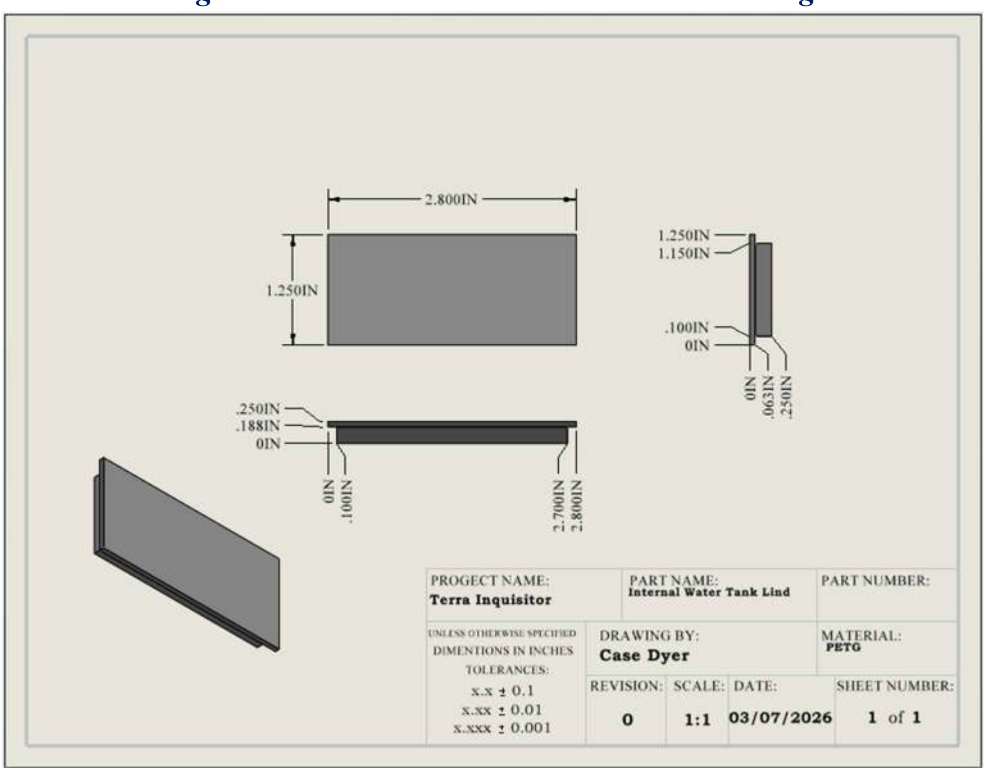



*Figure 4.31 Water Tank Lid Detailed Drawing*

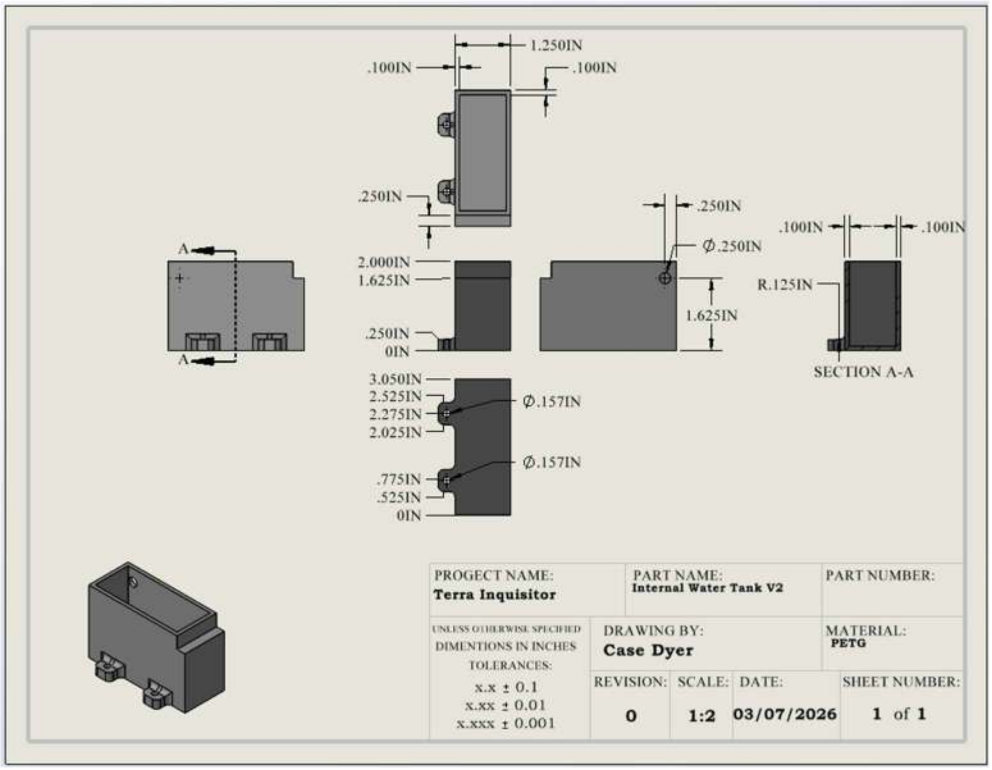



***Figure 4.32 Water Tank Detailed Drawing***

## 4.9. Mechanical Separation as Designed

The Separation mechanism has had a couple of changes since the CDR to allow locking for during flight and to allow more space for the Payload to fit in the Body Tube 1.

The payload is made to only deploy after landing to fulfill the HAUS mission objective while putting safety and rule compliance first. We created a purely mechanical separation and deployment system because energetics are not allowed for payload deployment. The system creates exit clearance, removes the nose cone, and positions the payload for release in a controlled, repeatable way using a motor-driven lead screw assembly.

A geared lead screw system is powered by a stepper motor, which translates rotational motion into linear translation. The HAUS payload is retained and supported until deployment while the nose cone is pushed forward off the airframe by this linear translation.

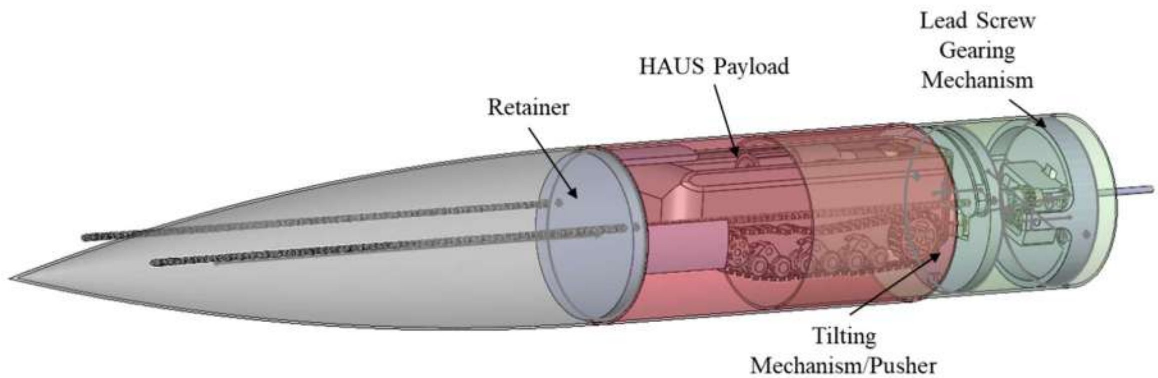



***Figure 4.29 Separation Mechanism Assembly***

<u>Retainer and Pusher Assembly</u>

**Function:** Nose cone removal + payload retention and positioning
The retainer is rigidly attached to the nose cone, while the pusher is located just aft of the payload. As the lead screws advance, the retainer and pusher translate together, generating a controlled axial force that:

1. Pushes the nose cone off the body tube to open the forward bay, and
2. Maintains positive retention of the HAUS payload until deployment is initiated.

**Material:** PETG was selected for its ease of fabrication and sufficient stiffness

<u>Tilting Mechanism</u>

**Function:** Create clearance for payload exit
Once the nose cone is removed, the payload must have enough clearance to exit the airframe reliably. The tilting mechanism is designed to open the payload bay to ensuring a clear deployment path.

**Operation:**
The tilting mechanism is held in the closed position while constrained by the body tube. After separation, the mechanism becomes unconstrained and a spring-loaded arm rotates outward, driving the system to the designed deployment angle.

**Spring selection rationale:**

The team selected nickel-plated extension springs (spring steel construction) with a maximum safe force of 11.5 lbf and a maximum deflection of 2.4 in. This provides sufficient stored energy to rotate the arm through the required travel range, achieving repeatable deployment to the target angle while also being commercially viable.

**Design impact:**

If testing shows under-rotation, binding, or inconsistent deployment angle, design changes include spring rate adjustment, hinge friction reduction, arm geometry revisions, or addition of mechanical hard-stops to lock the final angle.

***Figure 4.30 Tilting Mechanism***

Lead Screw Gearing Mechanism

**Function:** Provide controlled, repeatable actuation force

The lead screw mechanism is powered by a NEMA 17 stepper motor with a rated torque of 2.65 in*lbf. The motor drives a mirrored geartrain that synchronizes the lead screws and increases available torque to the actuation system.

**Geartrain behavior:**

The gear layout is configured such that the input gear drives an output gear with large torque multiplication. This results in increased torque at the lead screws, improving reliability under friction and misalignment loads while preserving the stepper motor's controllability. The utilization of worm gears were used as it does not allow rotation without the stepper motor, securing the system.

**Design impact:**
If deployment force is insufficient or motion is inconsistent, the team can adjust motor current limits, screw pitch, or introduce additional alignment constraints (guides/bushings).

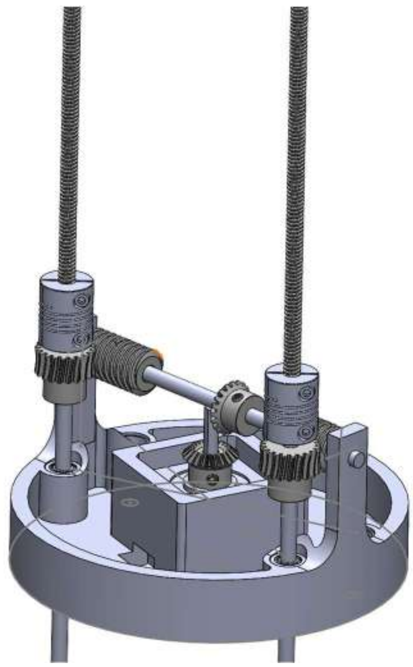


*Figure 4.31* **Lead Screw Gearing Mechanism**

## 4.10. Electrical System Design

The Terra Nova Electrical System has several non-negotiable tasks defined by its mission and mechanical construction of the rover itself. The electrical system must provide the payload with means to:

- Power motors
- Test soil
- Log data
- Detect loss of contact with launch vehicle

This is a broad view of what the design of the electrical system strived to accomplish. To do this, many other requirements were developed and met through the initial design, testing, and redesign of the system. Due to the nature of the payload design, many aspects of the electrical system were design from the "bottom-up". This is due to the specific size, weight, and mechanical power parameters introduced in the mechanical design. These parameters often required specific electrical devices, such as motors, to be chosen and implemented. Summarizing the electrical design involves exploring the individual systems that it requires, broken across several electrical schematics, concluding in the final design of the physical PCB that was designed using KiCad software.

The task of the electrical system listed above can be further broken down after consideration of the final design of the rover. The Terra Inquisitor required two DC motors for lateral movement, and one for drill rotation. A stepper motor was also required for the rotation of the linkage that positions the drill. The selected soil test of the Terra Inquisitor was the pH test. The final design implemented a pH probe and required the soil container to be filled with water upon the addition of soil for sensor accuracy. The required task of logging data includes recording the pH readings along with timestamps for each reading. Temperature data is a necessary addition to these values that improved pH value accuracy. The electrical systems supporting requirements will be defined in detail below.

### 4.10.1. Power System

The Terra Inquisitor utilized a 3s Lithium Polymer battery, with a capacity of 1350mAh and a discharge rating of 80C. 3s batteries have a fully charged voltage of 12.6V and a nominal voltage of 11.1V.

The Terra Inquisitor electrical system accepted this voltage range and stepped it down to two more power rails. The rails include a 7.5 V and a 5 V rail, used to power other subsystems that will be discussed in further detail later in this report. To step the voltage down to these levels, the voltage regulation system utilized both a 7.5V buck converter, the D24V22F7, and a 5V linear regulator, the LM1117T.

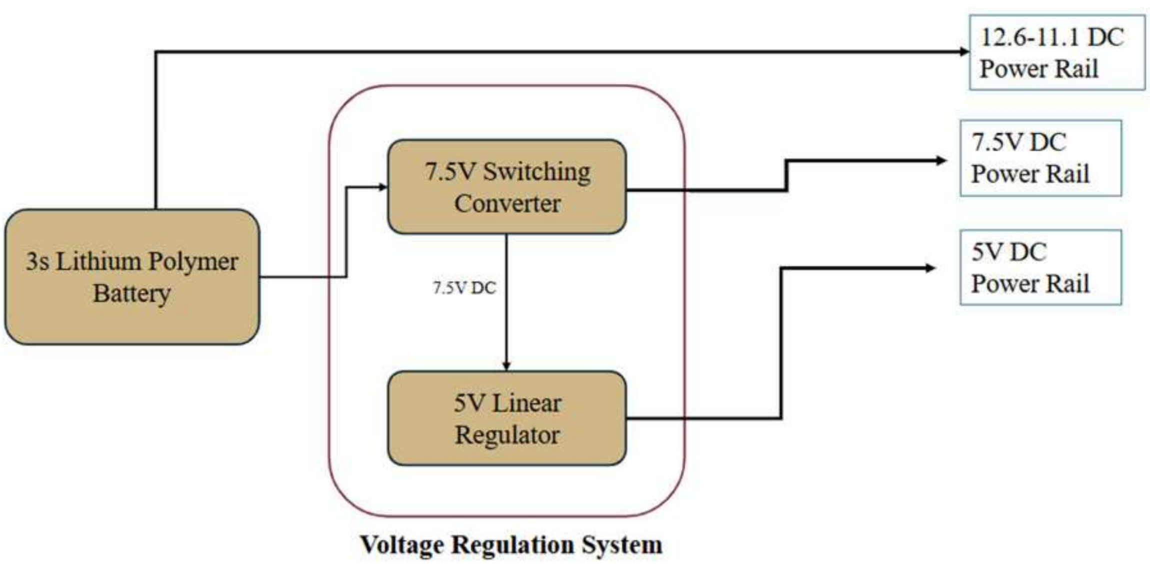



*Figure 4.32 Power System Diagram*

The D24V22F7 has an input voltage range of 8-36 V and a typical maximum output current rating of 2.4 A. The LM1117T has a 15 V maximum input voltage and a maximum output current rating of 800mA, at which it has a dropout voltage of only 1.2 V. In the final design of the electrical system, filtering capacitors were placed for near inputs and outputs of power regulations devices. A 10 A fuse was also implemented for circuit protection.

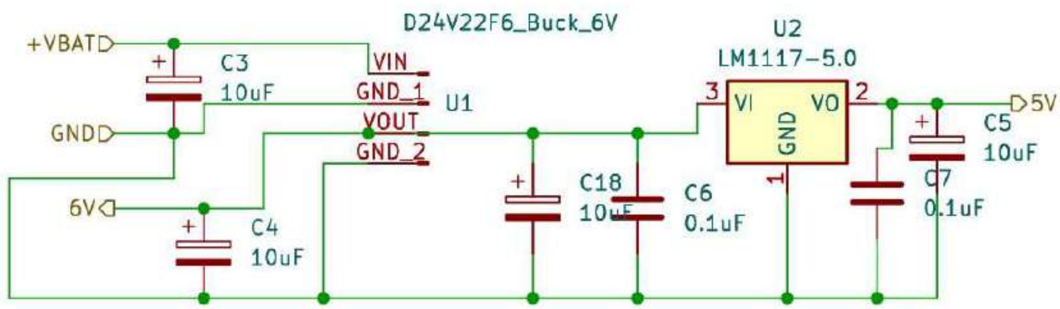



*Figure 4.33 Power System Schematic*

The figure above shows the final design of the voltage regulation system. Note the incorrectly labeled buck converter and 6V rail. The final design swaps an identical 7.5 V buck converter in the place of the 6 V buck converter shown above. The 6 V converter was part of the initial design and swapped after testing.

## 4.10.2. Control/Sensor System

An Arduino Nano Every controls every aspect of the Terra Inquisitor throughout the mission. The system is completely automated, meaning once it is powered on, the Terra inquisitor will be able to detect which stage of the mission it is in and maneuver through each stage on its own. This development board was selected due to its necessary hardware and ease of programming, which was vital through the development and testing stages out the Terra Inquisitor. Some of the main tasks of the control system include:

- Realizing and initiating mission stages
- Controlling movement of rover
- Processing sensor input
- Logging mission data

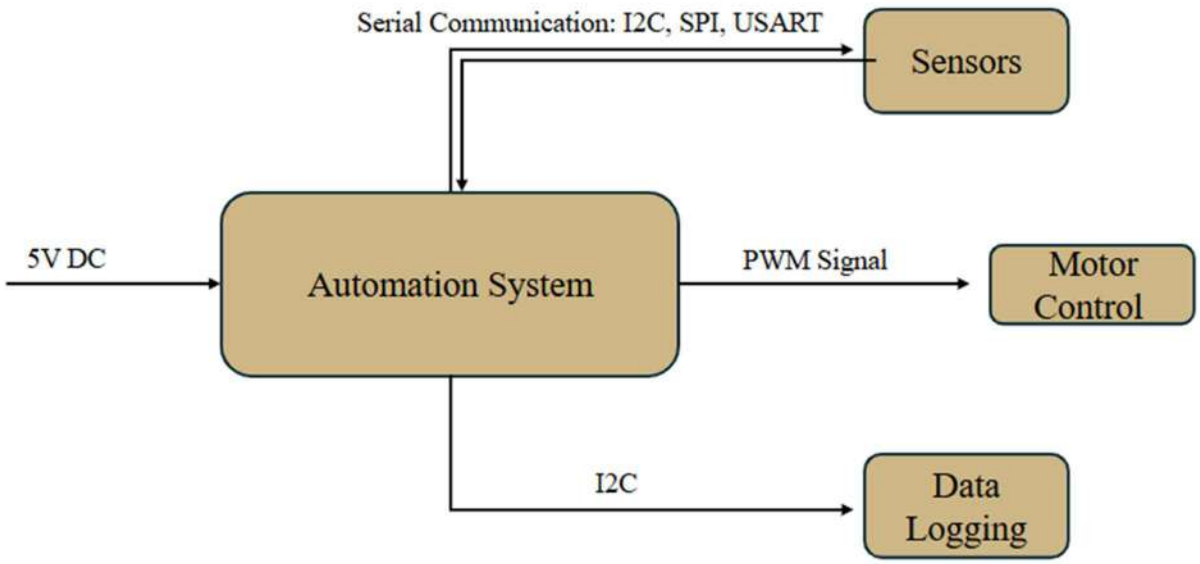



***Figure 4.34 Control System Diagram***

This is the general concept of the control system for the Terra Inquisitor. The figure above displays the required input of 5 V to power the development board, as well as various communication protocols and control signals that the control system will use to accomplish its tasks. In the Terra Inquisitor electrical system, the development board is powered through its 5V power pin where it bypasses its own on-board regulator. The Arduino Nano Every consistently pulls 10-15 mA when plugged into the Terra Inquisitor.

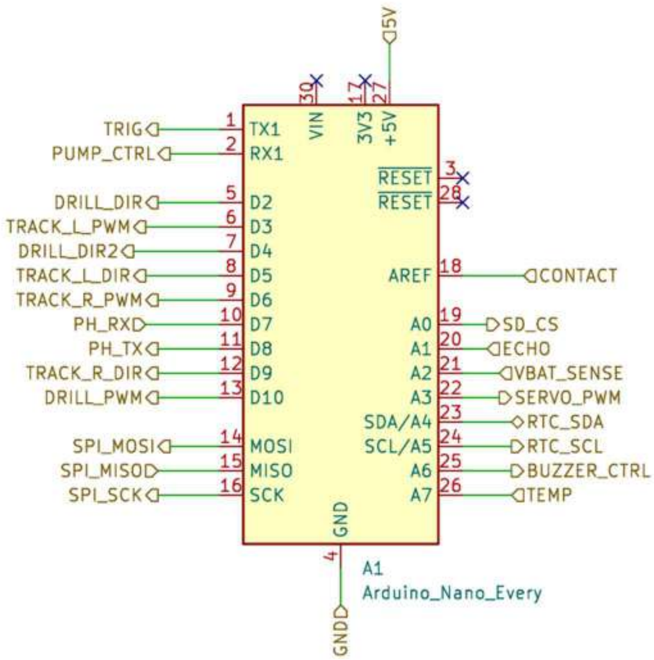



***Figure 4.35 Control System Schematic***

Visible above are the many signals the control system uses to operate the various subsystems of the Terra Inquisitor. These include serial communication protocols such as USART, SPI, and I2C, an analog input that is fed into the on-board ADC, and digital input and output signals coming from sensors and controlling motors.

One of the most important signals to the mission is the signal coming from the pH sensing circuit. The pH test is critical to the success of the mission. The Terra Inquisitor utilizes the EZO pH circuit in its design, which can connect directly to a pH probe and relay the pH readings to the development board using USART. The EZO pH circuit can easily calibrate itself with access to buffer solutions of known pH. The pH probe used in the final Terra Inquisitor design is the Atlas Scientific Mini Lab Grade pH Probe. This probe was integrated easily into the mechanical design of the rover due to its small size.

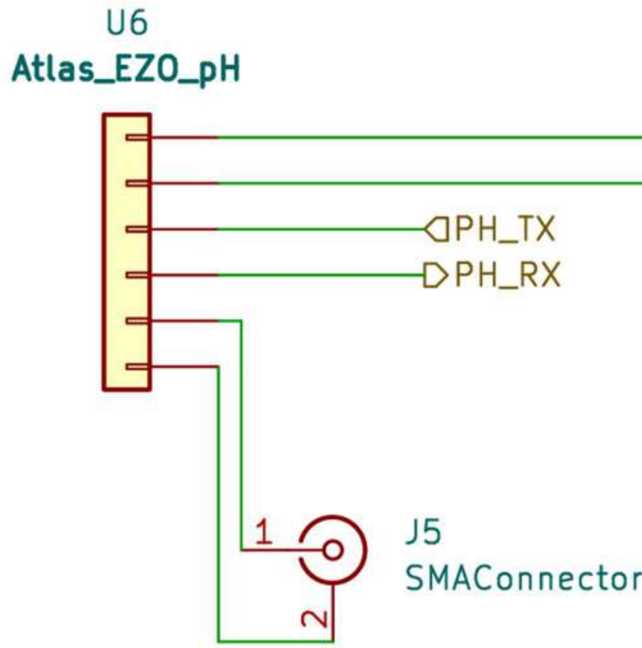



*Figure 4.36 pH Circuit Schematic*

The schematic above shows how the EZO circuit and pH probe are implemented into the electrical design. The two unlabeled signals near the top of the module are the 5V and GND inputs responsible for powering the circuit. The TX and RX signals are responsible for USART communication between the pH circuit and Arduino Nano. These signals are also visible on the schematic of the development board. An SMA connector connects the pH probe to the Terra Inquisitor PCB and allows for easy attachment and removal.

Along with data about the pH of the soil from the pH probe, a temperature sensor will take the temperature of the soil so that a post-mission adjustment can be made to the pH values for better accuracy. The sensor being used is the DS18B20. This model is completely sealed so that it may be submersed in the soil sample. This sensor has a 3-5.5V input voltage range, making it perfect for the 5 V power rail, and it communicates via a 1- Wire interface.

The pH and temperature data will be combined with time stamps from a real time clock module. The RTC module being used is the DS3231 RTC Module. This module utilizes I2C to communicate with the Arduino.

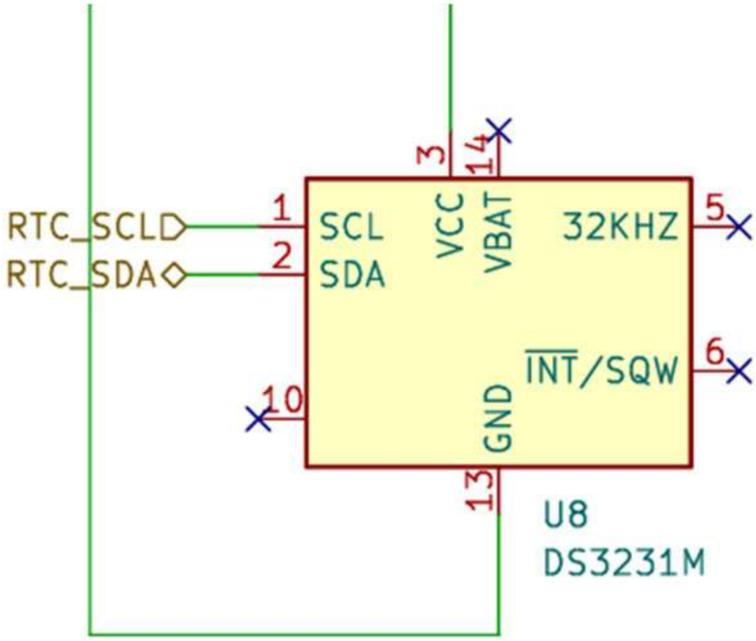



***Figure 4.37 RTC Module***

Figure 4.19 displays the integration of the RTC module into the electrical system. The module required 5V power supplied by the 5V power rail. As described, the I2C communication bus is seen on the left side of the symbol, showing the unidirectional clock signal and bidirectional data signal.

Another critical sensor for automating the Terra Inquisitor is an ultrasonic sensor that measures distance. This sensor is placed on top of the soil containment vessel where it measures the height of the soil in the container. This is to verify that 60ml of soil has entered the container before completing the mission.

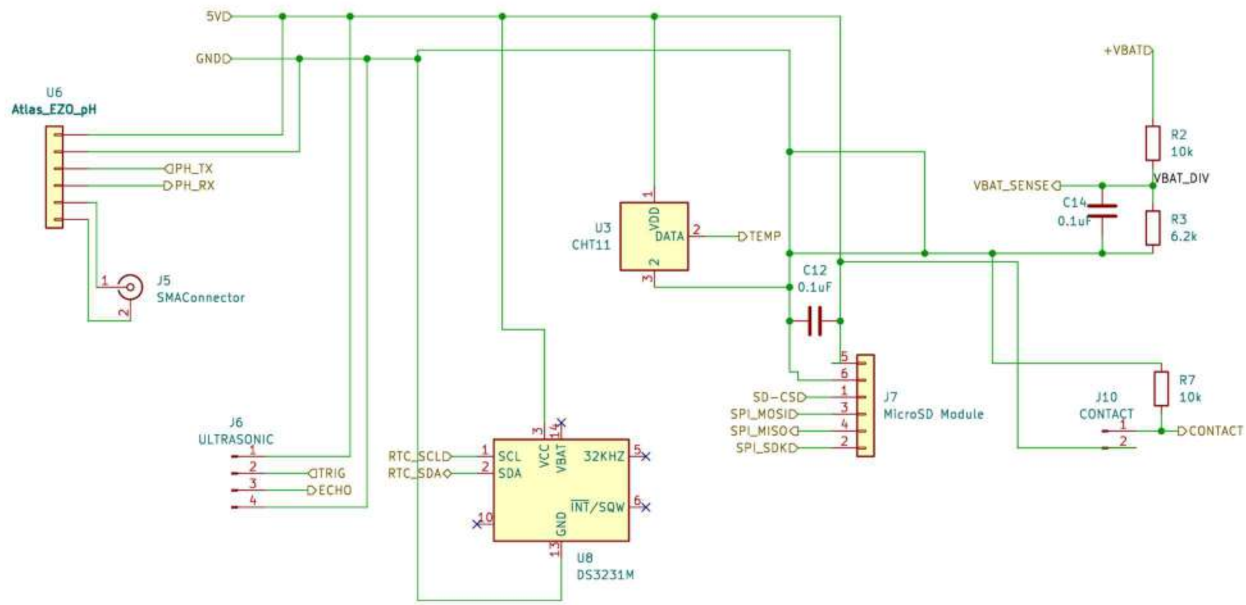



***Figure 4.38 Sensor System Schematic***

The ultrasonic sensor can be seen in the bottom left of Figure 4.20. This schematic includes the sensors utilized by the Terra Inquisitor. Visible is the EZO pH circuit and pH probe, the ultrasonic sensor, real time clock module, and the temperature sensor. Visible sensors not discussed yet are the voltage divider to detect battery levels, and the circuit for detecting contact to launch vehicle.

The "CONTACT" signal, visible in the bottom right corner of figure X, is responsible for relaying to the Arduino when the Terra Inquisitor has lost contact with the launch vehicle. One wire that is secured to the launch shorts the connector, holding the contact signal at a constant 5V or "high". Upon the forced separation of the nosecone and the rest of the launch vehicle, the connection is severed, allowing the 10k pull-down to force the contact signal to 0V or "low".

### 4.10.3. Motor Circuits

The movement of the payload tracks is defined by the control of two 12 V DC motors. The motor responsible for drill rotation is also a third 12 V DC motor. The model of the motors in question is the Pololu 19:1 Metal Gearmotor. These motors have stall currents of 5.5 A and stall torques of 8.5 cm*kg.

Incorporating these motors into the electrical system required the use of H-Bridge motors drivers that were economic in size, while being able to handle the current draw required by the DC motors. The motor drivers utilized by the Terra Inquisitor are TB6612FNG Dual DC Motor Drivers. Each of these ICs require only 7.6 x 8.3 mm on the PCB and can handle currents up to 3 A. While this is less than the extrapolated stall current of the DC motors, these motors will not be used at full power, and testing was done to ensure the motors will not require currents that would damage the device at the power levels of mission operation. This will be explained in further detail later in this report.

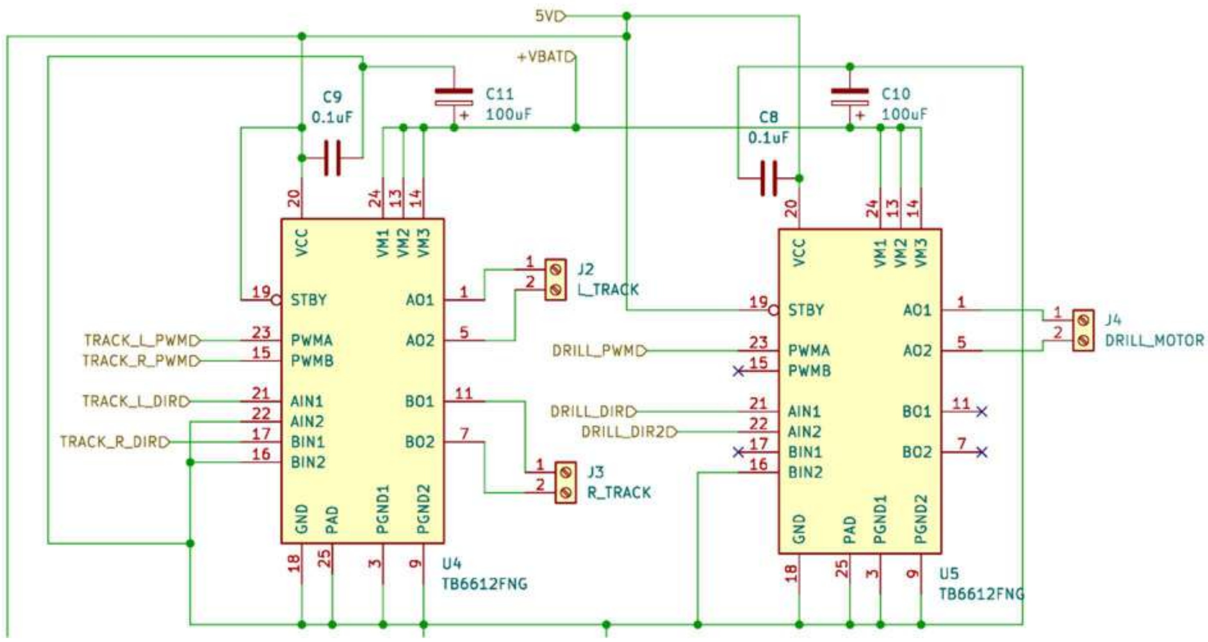



*Figure 4.39 Dual IC Motor Drivers Schematic*

Figure 4.21 displays the implementation of the motor drivers into the Terra Inquisitor electrical system. The unlabeled rail that spans the bottom of the figure is the GND rail. Visible is the motor driver responsible for controlling the left and right track motors (left), and the driver responsible for controlling the drill motor (right). Power directly from the lithium polymer battery is supplied, as well as power from the 5 V power rail for logic. The track motors driver requires two PWM signals and two enable signals (one of each for each motor). This configuration does not allow the tracks to be bidirectional, as this would require two more GPIO pins from the Arduino, and is not required by the mission. The drill motor driver requires one PWM signal and two enable signals (one for each direction).

The Terra Inquisitor uses a servo motor to adjust the location and angle of the drill. This servo motor is the 2000 Series Dual Mode Servo and has an input voltage range of 4.8-7.4 V. This motor does not require a driver, as it takes a control signal directly from the Arduino for operation.

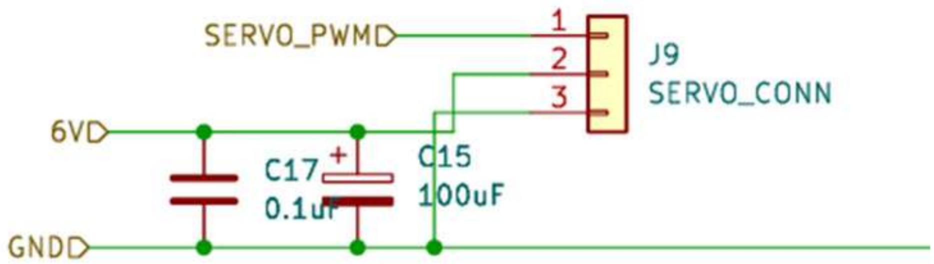



***Figure 4.40 Servo Motor Integration Schematic***

Figure 4.22 contains the incorrect 6V rail. This is replaced by a 7.5 V rail in the final design.

Powering and controlling the water pump used for saturating the soil sample is another task of the electrical system. This is accomplished using an NPN transistor, the 2N2222A. The water pump being used is the Adafruit Submersible 3V DC Water Pump. The final design powers this pump using the 5 V rail, which has worked without issue in testing.

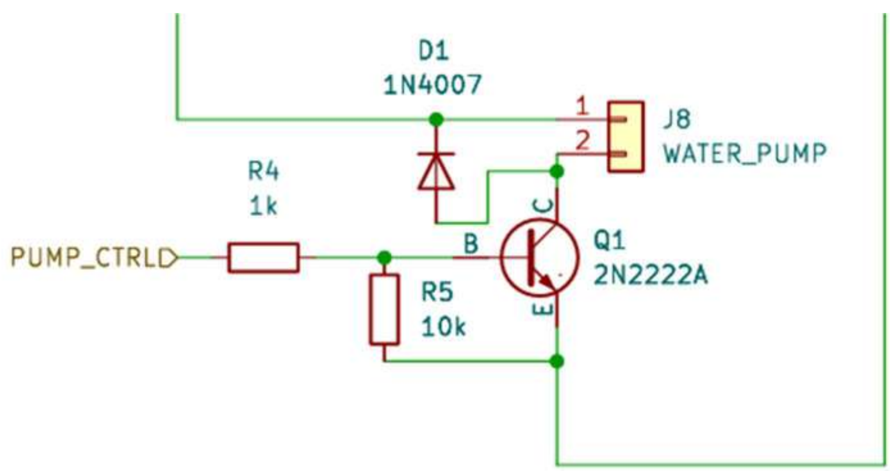



***Figure 4.41 Water Pump Circuit Schematic***

The figure above displays the circuit developed for driving the water pump. The unlabeled wire leading to pin 1 of the water pump is the 5 V rail, and the unlabeled wire connected to the emitter of the transistor is GND rail.

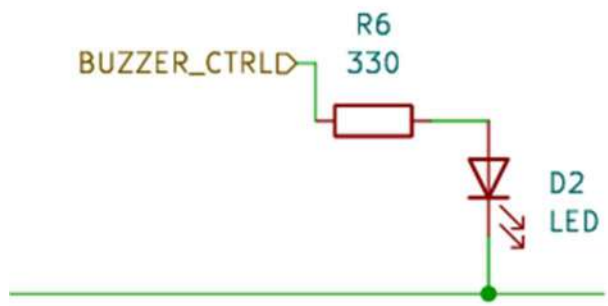



***Figure 4.42 LED Circuit Schematic***

Figure 4.24 displays the LED circuit implementation. This circuit was added to the Terra Inquisitor electrical system to aid in the testing process. The light flashes at different speeds to indicate visually which stage of the mission the Terra Inquisitor is in. It is also an easy and safe way to verify the ability to compile code to the control system.

### 4.10.4. PCB Implementation

The Terra Inquisitor electrical system utilizes a 4-layer PCB to meet the goals previously discussed. The purpose of these layers in their physical order from top to bottom are:

- Signal Layer
- GND Layer
- Power Layer
- Signal Layer

This configuration allowed for ease of signal routing and minimal resistance for the higher current draws. Physical PCB constraints include the dimensions of the inner wall of the Terra Inquisitor. This limited the size of the PCB to 27mm x 154mm. Mounting holes are placed for secure mounting to the inner wall of the rover. The resulting design based off these constraints can be seen in the following figures.

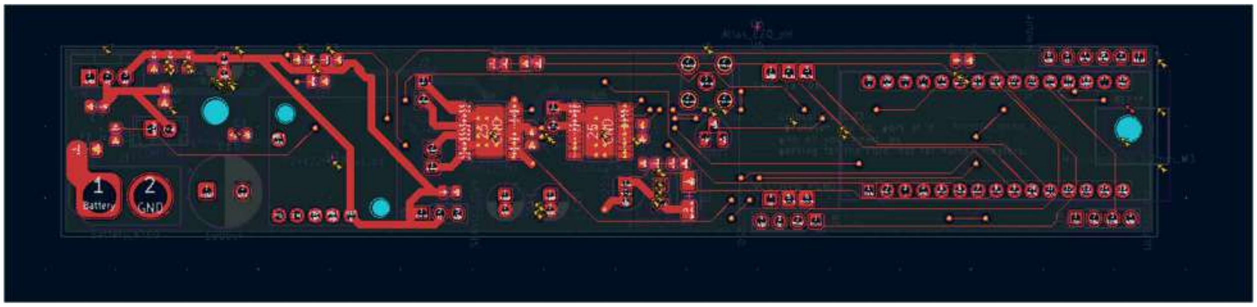


*Figure 4.40 PCB Signal Layer (Top)*

Due to the use of power and ground planes that span much of the board (Figure 4.25 and 4.26), large power buses were not required to reach across the board to power the many devices and sensors.

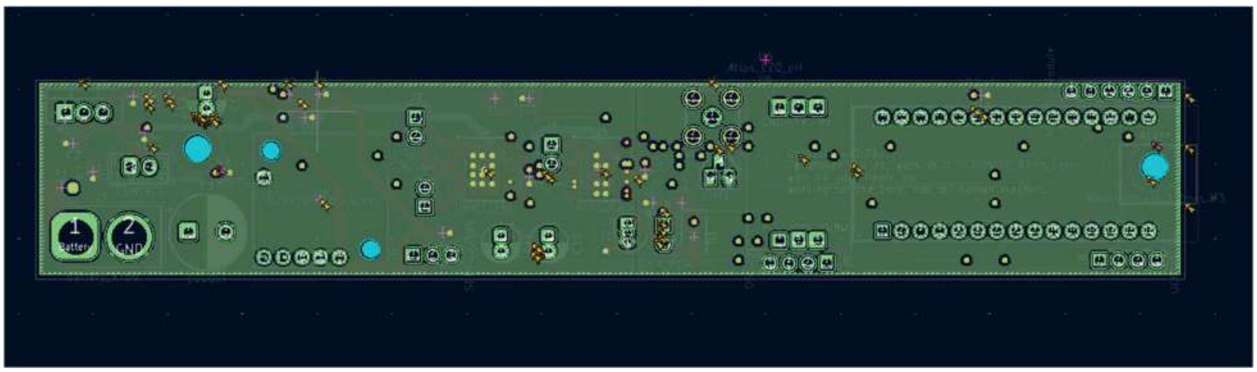


*Figure 4.41 PCB Ground Layer*

*Figure 4.42 PCB Power Layer*

Visible above are the two power plane sections responsible for spreading power across the board. A split can be seen near the middle of the board. This split separates the battery power section (12.6-11.1 V) from the 5 V section of the power plane.

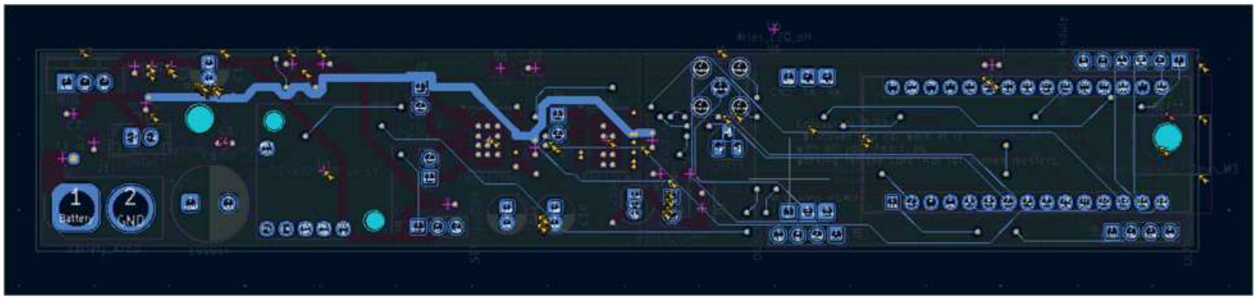


*Figure 4.43 PCB Signal Layer (Bottom)*

With tight size constraints and many control signals, the use of two signal layers was vital in the design of the Terra Inquisitor PCB. Figure 2.7 shows the bottom signal layer, utilizing many vias to transfer signal traces from one side of the board to another.

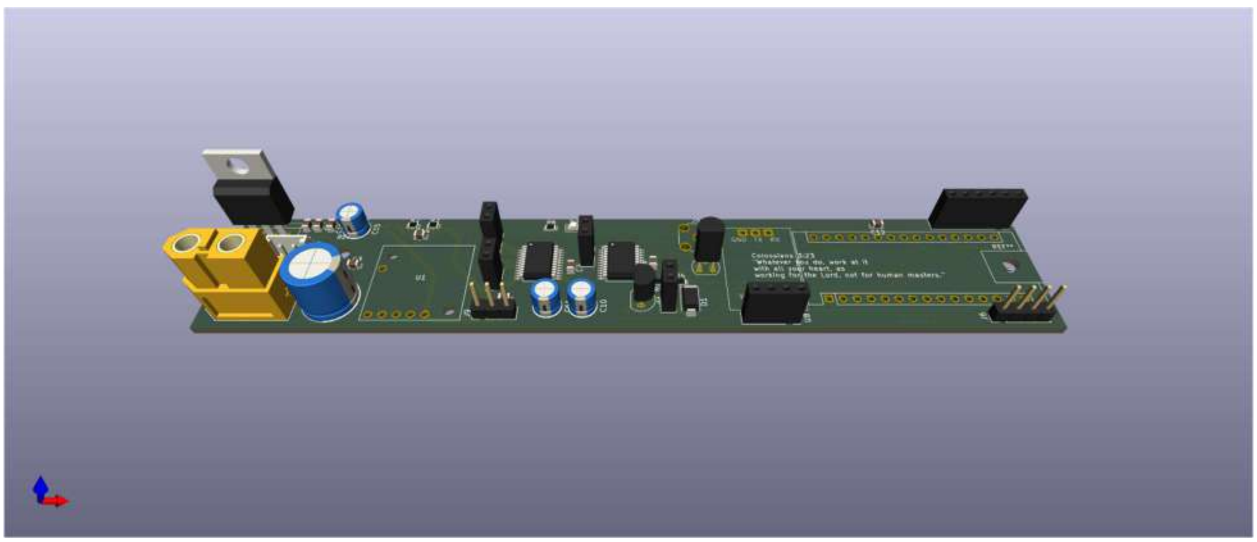


*Figure 4.44 PCB 3D Model*

## 4.11. Interface Locations

The payload system does not directly interface to the rocket. It is encased in the mechanical separation sleeve that is housed in the HAUS coupler. The mechanical separation system is mounted to the nose cone and to the Upper Transitional Airframe. This separation device safely retains the payload during flight and recovery.

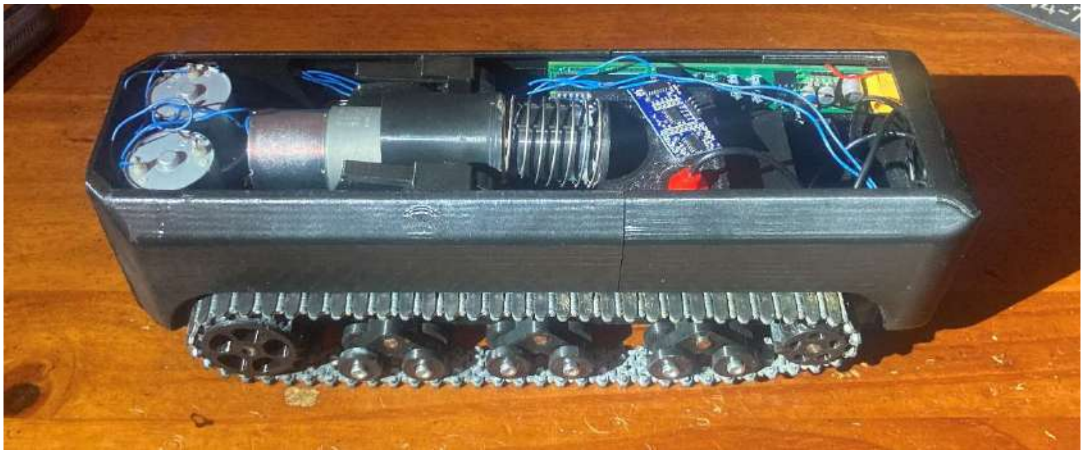
## 4.12. Payload Testing

### 4.12.1. Propulsion

The propulsion system has undergone many system tests. These tests involve the testing of the Pololu 4741 motors, the helical gear systems, the tracks, sprockets, chassis, and idler wheel assemblies. The propulsion motors are actuated using the custom PCB and required to perform various tasks. The tasks examined were speed, straight line driving, and navigation capabilities. These test were performed on various terrain, flat grass, contoured grass pasture, sand, and concreted. In all these test the design proved capable of achieving the desired goal.

### 4.12.2. Soil Collection and Containment

For the testing of soil collection, the linkage system and drilling head system were tested individually and in conjunction with each other. These test were to examen range of motion for the linkage as well as examine path of coupler point p to ensure drilling head was rotated to the correct orientations during storing and drilling stages. It as also done to examine possible interference locations of the linkage either with other parts of the linkage or other components within the assembly. One example of this test was examining the whether the coupler link would contact the idler gear powering the crank. Upon initial testing this was a significant issue an cause many linkage malfunctions. However, through testing and examination, the issue was resolved by adjusting the location of the idler and crank gears to eliminate the interference. The drilling head assembly was also tested for interference between its components. The motion of the spring and lower coupler were tested to ensure the lower coupler would continuously cover any soil being brought to the surface for collection by the drill as well as ensuring the spring would not require too much for to be compressed and thus limiting the capabilities of the drilling system. Finally, these systems were tested in conjunction to ensure all system functioning in tandem would not cause unforeseen interferences or errors. Based on these combined testing it was determined that it will require between 18-22 drill collection cycles to collect the appropriate volume of soil. Each drilling cycle takes less than 15 seconds, and thus for just soil collection the time required is 4 minutes of drilling and collecting. This is well within the required 15 minutes of full system function and soil collection upon landing. One major aspect of thus system that was tested was the ability of the auger assembly to eject the collected dirt into the board soil container. The design had absolutely no issue releasing the soil into its container and thus this method provided an excellent solution to transferring collected soil into the Terra Inquisitor. Soil containment was achieved through the soil container assembly. This system was initially designed to be too close to the end of the lower coupler and so during initial testing the drilling auger head assembly would make contact with the container and occasionally get stuck. However, the locations of mounting holes for the soil container were moved slightly back to remove this interference issue. The image below is the model of the Terra Inquisitor used for testing.



### 4.12.3. Electrical System

Testing the electrical system involved testing each subsystem individually prior to any assembly. This was to ensure the electrical subsystems worked as intended before attaching each device permanently.

The first test was carried out to verify a working control system. The Arduino was plugged into the PCB, while at the same time connected to a laptop capable of powering and programming the device via micro-USB cable. This allowed for the Arduino to power the 5 V plane via its 5 V output pin. The Arduino was then programmed to blink the Terra Inquisitor’s LED.

The next system tested was the power/voltage regulation system. The initial test was designed to ensure correct voltage outputs under no load. The buck converter and the linear regulator were plugged into the PCB, followed by plugging in the battery. A voltmeter was then used to verify the outputs of each component. Another test surrounding the power system included running the DC motors at an 80% duty cycle. This is the upper limit of the duty cycle range that will be used in the mission to ensure the motor drivers are not overloaded. The goal of this test was to measure the current draw from the battery as the motors operated without any physical load, then simulating physical load by pushing against the rotation of the motors. With the motors completely unplugged, the electrical system drew 25 mA of current from the battery. As system operated the motors at the 80% duty cycle with no external resistance, the electrical system drew near 800mA from the battery. Simulating resistance on both track motors at the same time drew up to 1.3 A of current from the battery. This is an acceptable amount considering the parameters of the movement system and the voltage regulation system and allows for a decent safety margin.

Prior to the secondary power system test listed above, the motor driver ICs were tested individually under no load and with load to inspect for any distortion.

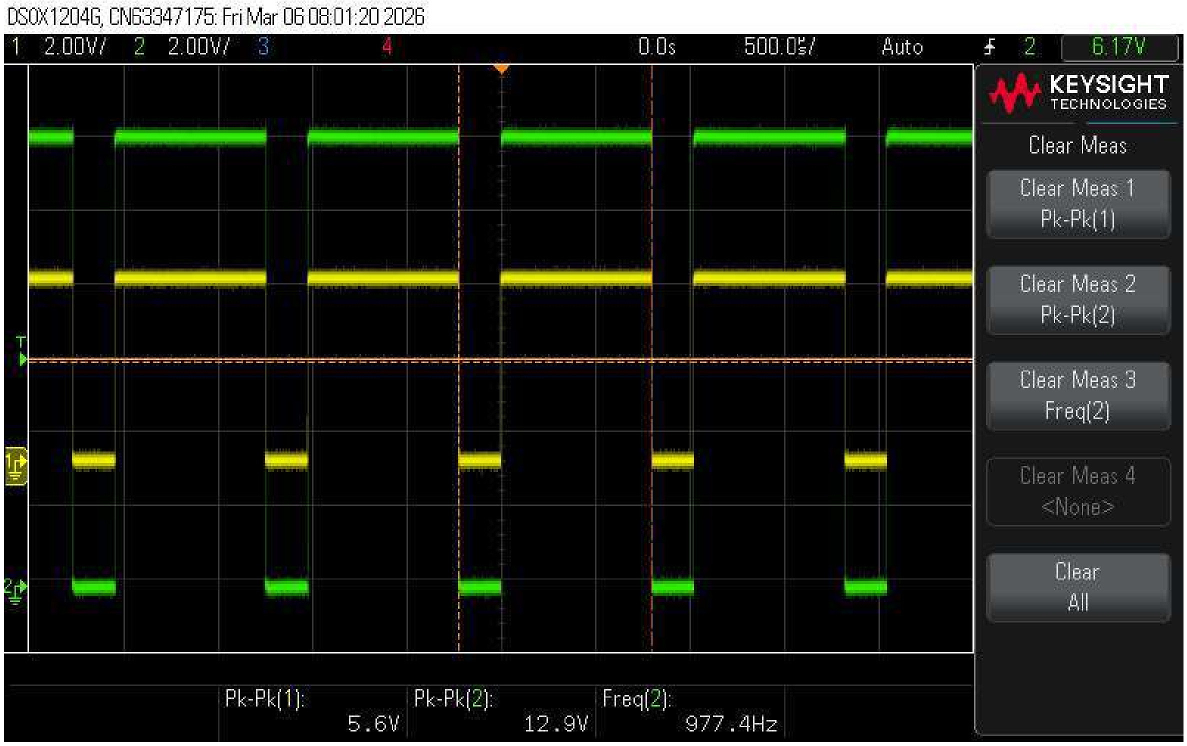



***Figure 4.45 Unloaded Motor Driver Input vs. Output***

The scope output shown above displays the output of the motor driver circuit (green) compared to the PWM signal coming from the Arduino. As expected, the PWM signal is the 0 – 5 V square wave with a 80% duty cycle and the output is a similar square wave stretched to near 12 V. This verified the circuit functionality, including control signal production and motor driver operation.

The next step of the movement system test was to compare the unloaded output of the motor driving circuit with a loaded output voltage. Below is a more precise view of the unloaded output voltage.

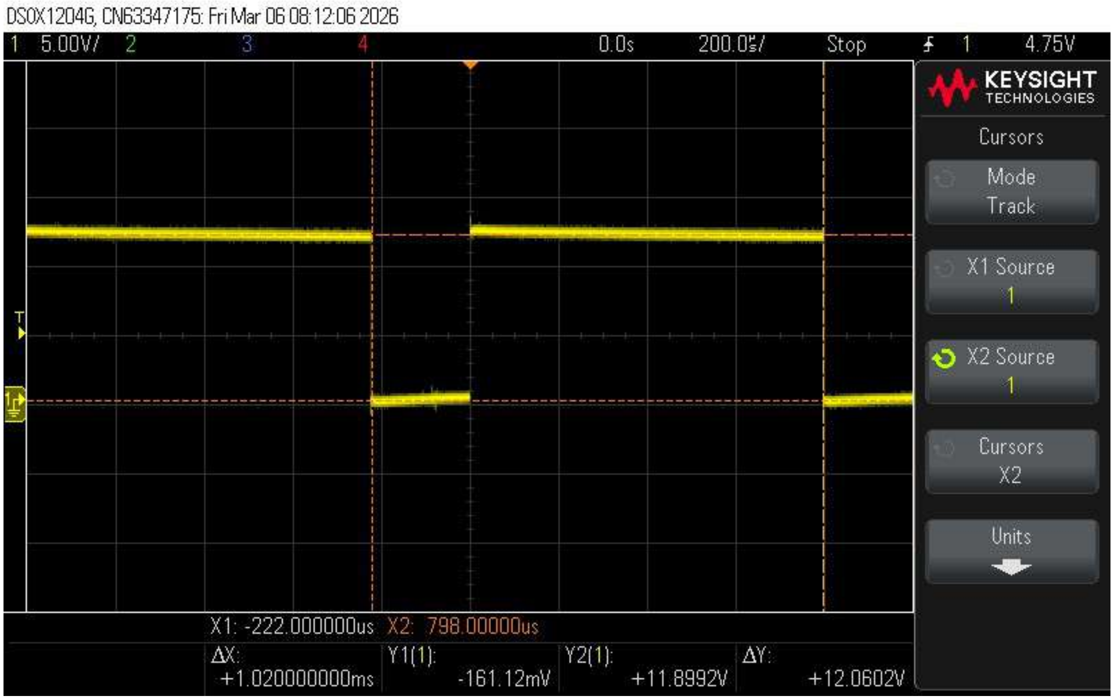



*Figure 4.46 Unloaded Motor Driver Output*

Using the cursors feature on the oscilloscope, a more accurate value of the output voltage was observed. This waveform was then compared with the waveform below, where no differences are observed. This was a good indication of the power system and the motor drivers responding well to larger amounts of current.

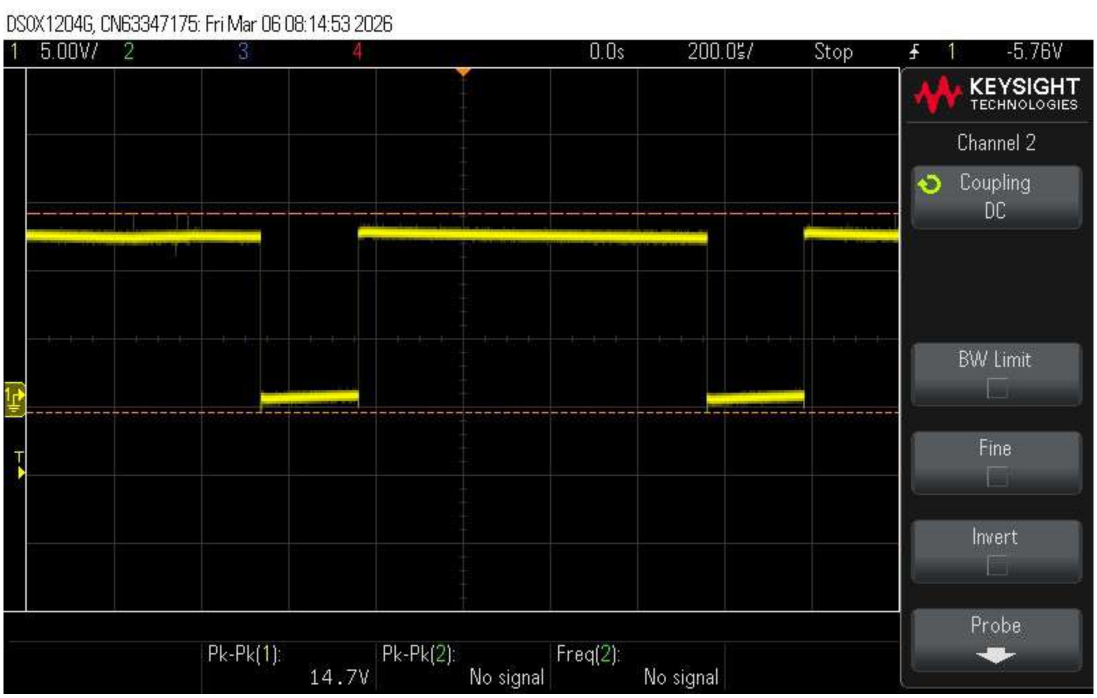



*Figure 4.50 Loaded Motor Driver Output*

The final and most relevant testing of the Terra Inquisitor electrical system surrounded the pH probe and supporting circuit. The material required for this included 3 different pH buffer solutions used to calibrate and then test the pH probe accuracy. The EZO pH circuit contains its own calibration procedure that ensures accuracy. After following the calibration procedure, the pH probe was dropped into all 3 pH buffer solutions. The buffer solutions had pH levels of 4, 7, and 10. The pH probes were rinsed in distilled water between measurements. All three measurements were within an error range of 1% in a 25° C environment. This proved the system integration valid and ensured a level of accuracy acceptable for use by the Terra Inquisitor.

### 4.12.4. Mechanical Separation

Initial testing of the payload separation mechanism revealed several design issues that were identified and subsequently corrected. The original system was fabricated using the lead screw actuation system driven through a worm gear and miter gear transmission. Control logic was implemented using a microcontroller-based system designed to manage payload retention and deployment.

The control system utilized a discontinuity switch to detect when the payload system had separated from the vehicle structure. Once this separation signal was detected, the system initiated a programmed delay before activating the deployment mechanism. A secondary limit switch was incorporated into the retention system to detect when the payload was fully retracted and secured. While continuity was present through the discontinuity connector, the motor system commanded the lead screw to retract until the retention limit switch was triggered, ensuring the payload remained securely held during flight.

Bench testing of the control logic and mechanical actuation system demonstrated successful operation of both the retention and deployment logic. However, during integration testing with the payload installed inside the nose cone assembly, it was discovered that the available internal volume was insufficient for the mechanism and payload to fit together as originally designed. This interference prevented proper seating of the payload and restricted the intended separation motion.

As a result of this finding, the separation mechanism and surrounding structure underwent a redesign to increase internal clearance within the nose cone assembly. The revised design allows adequate space for the payload to be fully retained during flight and to separate freely during deployment without obstruction.

# 5. Demonstration Flights

## 5.1. Vehicle Demonstration Flight

The only full-scale launch of the Terra Nova Rocket to date took place on February 21, 2026. The event occurred at a launch site in Samson AL. During the launch, measured wind gusts of up to 25 mph were recorded, while sustained winds of 13 mph were measured on the ground.

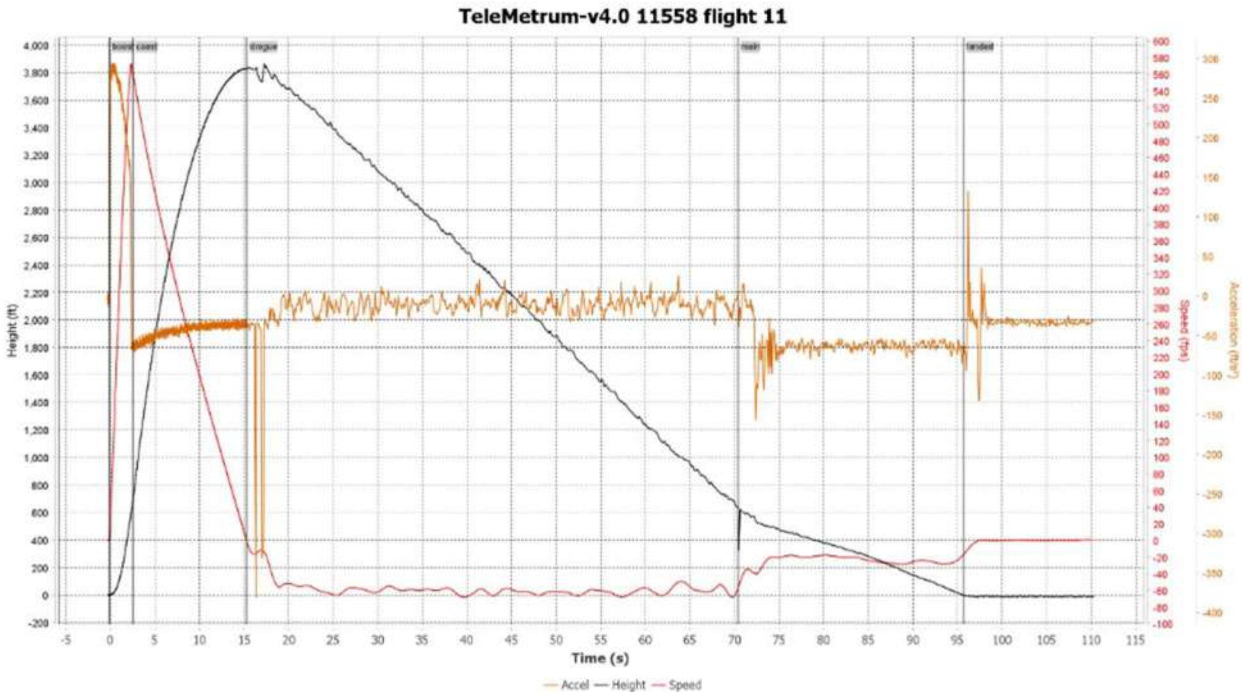
The motor flown was a Cesaroni Technology Incorporated L1395-CTI Blue Streak Rocket Motor. This was not the specified motor for the competition day, which is the L2200G-0. This was due to the fact that all L2200G-0 motors were not in stock, so NASA was contacted and the L1395-CTI was used instead.

A total of 26 oz of ballast was flown; however, in the absence of Inconel bulkheads the weight of the bulkheads was also added to the weight canister. The final payload was not flown. The payload was not present for the flight, but a weighted mass of 6 lbs was installed in the transition body tube to simulate the weight of the payload and the effect it would have on the flight of the rocket. This mass was created through the use of filling a 3D printed container with metal fasteners, nuts, and washers, accompanied by sand to prevent the metal components from moving during flight.

The official target altitude for the flight was 4900 ft. The launch vehicle reached a measured altitude of approximately 4600 ft. According to the flight telemetry, the avionics bay functioned as intended and fired both $CO_2$ charges at their specified altitudes. The dedicated flight computer for the reefing system also successfully deployed the reefing system at the target altitude. However, the reefing system failed to operate due to a severed connection between the reefing system flight computer and the mako line cutter. This was discovered upon retrieval of the launch vehicle. It is suspected that the connection was severed during the main deployment recovery event.

Unfortunately, we did not have an on-site barometer measuring the wind speed conditions throughout the day; however, we did get a reading from one of the range officers earlier that day. We also did not have a tool capable of measuring the actual angle of launch at the launch pad. The rocket was also not painted, so the roughness of the surface of the rocket is probably a little higher according to the simulation in OpenRocket.

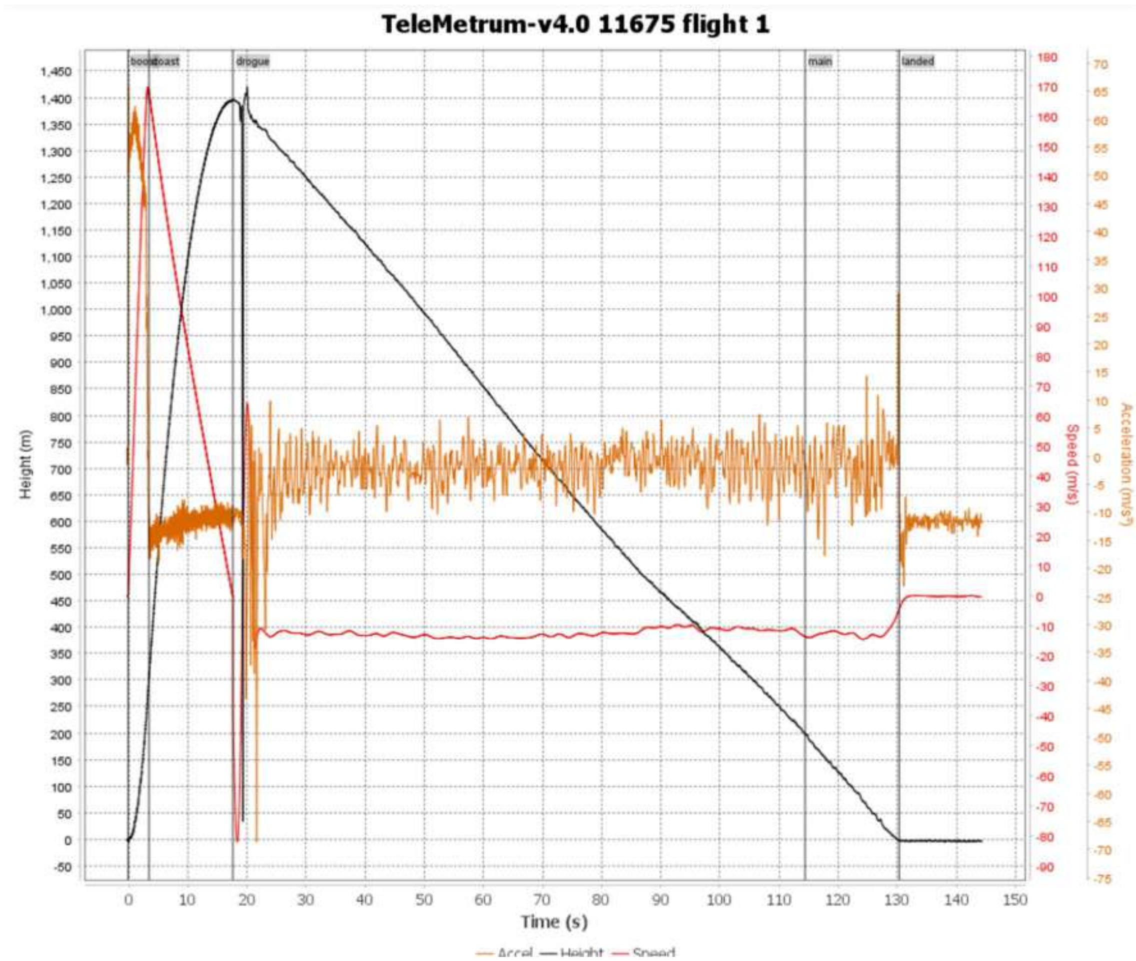
## 5.2. Subscale and Full-Scale Flight Comparison




**Flight Telemetry of non-reefed flight of sub-scale**

| V2 Launch 1 Predictions | | | | | |
|---|---|---|---|---|---|
| Apogee | Velocity off Rod | Landing Velocity | Descent Time | Heaviest Section | MAX Impact Energy |
| 3749 ft | 80.3 ft/s | 18.8 ft/s | 64.9 s | 5.82 lbs | 31.97 ft-lbs |
| | | | | | |

| V2 Recorded Launch Data | | | | | |
|---|---|---|---|---|---|
| Apogee | Velocity off Rod | Landing Velocity | Descent Time | Heaviest Section | MAX Impact Energy |
| 3510 ft | ~80 ft/s | 25 ft/s | 74.7 s | 5.82 lbs | 56.54 ft-lbs |
| | | | | | |




**Flight Telemetry of non-reefed flight of full-scale**

| Full-Scale Launch Predictions | | | | | |
|---|---|---|---|---|---|
| Apogee | Velocity off Rod | Landing Velocity | Descent Time | Heaviest Section | MAX Impact Energy |
| 4555 ft | 58.9 ft/s | 20.1 ft/s | 81.3 s | 19.5 lbs | 122.33 ft-lbs |
| | | | | | |

| Full-Scale Recorded Launch Data | | | | | |
|---|---|---|---|---|---|
| Apogee | Velocity off Rod | Landing Velocity | Descent Time | Heaviest Section | MAX Impact Energy |
| 4600ft | 49.2 ft/s | 45.9 ft/s | 111.7 s | 19.5 lbs | 638.76 ft-lbs |
| | | | | | |

To discuss the full-scale flight data with the flight data from our subscale, we found it most effective to compare the full-scale findings with the unreefed flight data. We chose this due to the fact that our reef failed to deploy, so comparing it to a subscale flight without reefing was the most comparable. The Terra Parvis V2 (unreefed flight) was launched on 01/11/2026 in Samson, AL, where the flight computer recorded an average temperature of 76.1°F and an average pressure of 14.8 psi. Along with the length and angle of the launch rod, these metrics were input to our pre-launch simulations to determine important metrics to compare results to. This simulation provided key predicted metrics which were then compared with the recorded flight data.

The Terra Parvis V2 was first launched without the reefing system installed in order to ensure a successful flight, and that was exactly what was achieved. The boost phase went without issue, and recovery events occurred exactly as intended. The vehicle reached an actual apogee of 3863 ft, just 114 ft above the projected altitude of 3749 ft, showing strong agreement between simulation predictions and the actual flight. Similarly, the first launch of the full-scale Terra Nova rocket demonstrated comparable ascent performance. The launch vehicle met an apogee of approximately 4600 ft, which was close to the predicted apogee of 4555 ft. This similarity between the subscale and full-scale launches indicates that Open Rocket provided accurate predictions of the boost phase for both vehicles. Despite these similarities during ascent, significant differences were observed during the recovery phase. In the subscale launch, recovery events occurred exactly as intended, with the drogue phase and main parachute phase following the predicted recovery sequence. However, there was a noticeable discrepancy between predicted and actual descent performance. During the drogue phase the rocket was projected to fall at roughly 95 ft/s, but only reached slightly above 80 ft/s during flight. This data, along with several helpful comments from the NASA team, led to the conclusion that drag forces unaccounted for in simulation will decrease the actual descent velocity under the drogue phase. This is not nearly as pertinent during the main parachute stage since drag forces are largely influenced by flow velocity. In simpler terms, a higher ideal descent speed would lead to a greater error in predictions that do not account for real-world interference. In this case, the predictions in the drogue phase presented an 18.75% error.

While the drogue phase fell slower than expected, the main phase of the subscale rocket fell at a higher speed than predicted. The leading conclusion is that OpenRocket incorrectly calculated the drag force by neglecting the spill hole in the center of the parachute. Including this spill hole would decrease the effective area of the parachute and increase the descent velocity, though simulations accounting for this area difference only increase the landing velocity to approximately 19.3 ft/s. Despite these differences, the rocket landed with a velocity of approximately 25 ft/s and produced a maximum impact energy of 56.54 ft-lbs, remaining within the 65 ft-lb goal and sustaining no structural damage. The full-scale Terra Nova flight experienced a significantly different recovery outcome. The launch was deemed unsuccessful due to a recovery event sequence that did not align with design expectations. Upon meeting apogee, the rocket deployed the drogue as expected. Only moments after the drogue was deployed, the main was observed deploying at an altitude near apogee. These observations were confirmed in the telemetry data recorded by the flight computer, as the slope of the descent is constant from apogee to the ground. The reason behind this early main deployment is still largely unknown; however, after extensive post-launch testing the launch vehicle has not responded in a similar manner. This leads to the belief that a redundant e-match in the avionics bay was routed to the incorrect terminal. This would allow for the main flight computer to initiate the accurate deployment of the drogue, while the redundant flight computer might have initiated the early release of the main parachute. As a result of this recovery sequence anomaly, the landing velocity increased to approximately 45.9 ft/s compared to the predicted 20.1 ft/s, producing a maximum impact energy of 638.76 ft-lbs for the heaviest section.

Overall, the subscale launch successfully validated the boost phase predictions and demonstrated proper recovery system functionality, while also highlighting differences between simulated and real-world drag effects during descent.

## 5.3. Hardware Damage and Lessons Learned

The severed wire between the reefing flight computer and the line cutting mechanism was identified to be the failure resulting in a non-successful flight. The wire connecting these devices spans the length of the parachute cords. When the main deployment event is initiated, the wire is at risk of being severed or dislodged from one of the connected devices by the main parachute. This risk can be mitigated through the use of secure wire connection points and inspecting the location of the wire within the launch vehicle. Preparing the wire in a proper storage configuration can decrease the risk of tangling with the main parachute.

The bulkhead for Body Tube 1 failed after experiencing an impact energy of 638.93 ft-lbs. The design of the payload was never meant to support an impact energy of that magnitude. In the future, steps will be taken to add ballast weight to other areas of the rocket, decreasing the magnitude of impact energy that can be imparted into the HAUS section. We will also allow for more time for epoxy to fully cure before flighting. As a team, we were trying to finish too many objectives on the launch site that should have been done well in advance. This is an issue as it rushes the team to get a variety of tasks done within the window of opportunity that we have to fly. This can lead to more human error and negligence when integrating subsystems into the full assembly and makes it much harder for the procedural checklists to be implemented to their fullness.

# 6. Safety and Procedures

To ensure the safety of team members and all involved during the full progression of this project, a safety plan must be developed and implemented. The Safety plan will show a team-wide comprehension of the guidelines and expectations that must be upheld. As specified by the 2026 Student Launch Handbook, section 5.2, each team is required to have a safety officer. The responsibilities of the safety officers are also described in section 5.2 and give an essential understanding of expectations and requirements. The team safety officer will support the team leader in completing all tasks safely and incident-free. This will be done with adherence to all governing authorities included in 5.2 Compliance with Laws, Codes, and Regulations. During all launch procedures, NAR launch procedures and safety regulations will be used for flight design and operations. NAR/TRA team mentor and the Range Safety Officer (RSO) will oversee the launch operation and motor handling and have ultimate authority over launch readiness and viability. While facilitating and implementing the safety plan is the main responsibility of Jonathan Serbest, our safety officer, all team members acknowledge the individual requirements of understanding and compliance of the plan outlined below. This has been done through a safety briefing and confirms safety plan competency and pledge to plan adherence.

## 6.1. Hazard Analysis Methodology

**Probability Levels**

Table 6-1

| Definition | Value | Probability of Occurrence |
|---|---|---|
| Unlikely | 1 | <1% |
| Uncommon | 2 | 1% to 15% |
| Occasional | 3 | 15% to 50% |
| Probable | 4 | 50% to 80% |
| Likely | 5 | Above 80% |

Now that the metrics for our probabilities are defined, the criteria for assessing risks and hazards will be handled through both the severity of the hazard and its likelihood. **Table 6-4** below illustrates this.

**Hazard Severity Criteria**

Table 6-2

| Description | Value | Personnel Health | Equipment Health | Launch Vehicle | Mission Health |
|---|---|---|---|---|---|
| Negligible | 1 | No injury | Insignificant damage | Insignificant damage/ minor reconstruction | Mission success not impacted |

| | | | | | |
|---|---|---|---|---|---|
| Moderate | 2 | Minor injury | Moderate damage | Moderate reconstruction | Possible mission success |
| Critical | 3 | Severe injury | Major damage | Major reconstruction required | Partial mission success |
| Disastrous | 4 | Life-threatening injuries | Complete destruction | Complete loss | Mission failure |

With the hazard severity visually defined, the point hierarchy from both graphs combine to give us a comprehensive understanding of the risk analysis. Defined in color and number notation is the risk level. The risk level is found by multiplying the corresponding number rating of the x-plane identifier by the intersecting y-plane identifier. This gives us the ability to score risks across our two identifiers. Note that the ranking of these hazards will be made under the assumption that none of the mitigations have been instituted yet.

**Risk and Hazard Assessment Matrix**

Table 6-3

| | | Severity | | | |
|---|---|---|---|---|---|
| | | Negligible (1) | Moderate (2) | Critical (3) | Disastrous (4) |
| Probability | Unlikely (1) | 1 | 2 | 3 | 4 |
| | Uncommon (2) | 2 | 4 | 6 | 8 |
| | Occasional (3) | 3 | 6 | 9 | 12 |
| | Probable (4) | 4 | 8 | 12 | 16 |
| | Likely (5) | 5 | 10 | 15 | 20 |

The Consolidated Hazard Assessment Matrix simplifies the numerical results of the hazard analysis by grouping the full range of values into four categories. Each category provides clear guidance on risk level, assists the team in making informed decisions per the severity of hazards, the intensity of required mitigations, and overall safety measures necessary for project activities.

| Consolidated Hazard Assessment<br>Table 6-4 | |
|---|---|
| Definition | Value |
| Minimal | 1-5 |
| Tolerable | 6-10 |
| Immediate Attention | 11-15 |
| Failure | 16-20 |

<u>List and meaning of hazard groups:</u>

**Minimal (1–6):**
Hazards of this caliber are small and can be easily avoided by using standard safety procedures.
**Tolerable (6–10):**
Hazards of this caliber require the implementation of mitigation measures as the average severity for these cases is moderate. Mitigations like training, proper PPE, spatial awareness, etc. must be constantly enforced.

**Immediate Attention (11–15):**
Hazards of this caliber must be dealt with swift and rigorous mitigation. Before proceeding, the Safety Officer must be notified and holds the authority to stop activities if deemed necessary.

**Failure (16–20):**
Hazards of this caliber are unacceptable and will not be attempted. The Safety Officer must be notified, and a new technique, design, safety mitigation, etc., must be implemented to lower the risk level before proceeding.

## 6.2. Personal Hazard Analysis (PHA)

### 6.2.1. Chemical Hazards

| Chemical Hazards Table<br>Table 6-5 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Chemical | P' | S' | Value | Use | Cause | Effects | Mitigations and Verifications |

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| Acetone | 3 | 2 | 6 | Used for cleaning off surfaces of debris that could interfere with paint and coating bonding. | Inhalation of off-gases. | Trouble breathing, respiratory irritation, dizziness, lightheadedness, fainting | Wearing proper PPE, operating in well-ventilated areas, only required personnel are allowed to be in the area while operating, closing the can when finished, and storing it away properly.<br><br>Verifications:<br>▪ PPE shall always be in an easily accessible area and always stocked.<br>▪ Check the room for non-required personnel before beginning<br>▪ Discard reusable mask after use<br><br>Required PPE: Gloves, safety goggles, and a face mask capable of filtering chemical and partial inhalants shall be used. |
| Degreasers | 2 | 2 | 4 | . Cleaning components on rocket-like parts for the Avionics Bay. | Inhalation of off-gases | ▪ Trouble breathing,<br>▪ respiratory irritation,<br>▪ dizziness<br>▪ lightheadedness<br>▪ fainting | Verifications:<br>▪ PPE shall always be in an easily accessible area and always stocked.<br>▪ Check the room for non-required personnel before beginning<br>▪ If PPE stock is low or empty, notify the safety officer before proceeding.<br>▪ Discard reusable mask after use<br><br>Required PPE: Gloves, safety goggles (If using aerosols), and a face mask capable of filtering chemical and partial inhalants shall be used. |
| Epoxy | 4 | 2 | 8 | Responsible for securing the fins rigidly to the air frame through the use of internal and external fillets. | Most epoxy has a two-step reaction that causes volatile gas to fill the area. | ▪ Skin irritation<br>▪ Trouble breathing,<br>▪ respiratory irritation,<br>▪ dizziness<br>▪ lightheadedness<br>▪ fainting | Proper PPE shall be worn at all times. The area must be properly ventilated, and all non-essential personnel must not be in the area of effect. Leftover epoxy must be disposed of properly in accordance to the disposal ordinance on the back of the package.<br><br>Verifications:<br>▪ PPE shall always be in an easily accessible area and always stocked.<br>▪ Check the room for non-required personnel before beginning. |

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| | | | | | | | ▪ If PPE stock is low or empty, notify the safety officer before proceeding.<br>▪ Discard reusable mask after use<br><br>Required PPE: Gloves, safety goggles, and a face mask capable of filtering chemical and partial inhalants shall be used. |
| Pyrodex | 1 | 4 | 4 | Used in the Avionics Bay and reefing system for controlled detonations. | Premature ignition while handling due to the ignition fee zone requirement not being met. | ▪ 1st, 2nd, and 3rd degree burns<br>▪ Smoke inhalation | Pydrodex will only be used in ignition-free zones. Non-essential personnel must not be in the area of effect, and all must have proper PPE.<br><br>▪ Verifications: PPE shall always be in an easily accessible area and always stocked.<br>▪ Check the room for non-required personnel before beginning.<br>▪ If PPE stock is low or empty, notify the safety officer before proceeding.<br>▪ DO NOT THROW PYRODEX IN CONVENTINAL TRASH CAN. Not of the safety officer of it's need for removal.<br><br>Required PPE: Gloves, safety glasses |
| Spray paint | 1 | 4 | 4 | Rocket will be painted to lower the skin friction during flight | Paint cans explode in hot areas | ▪ Flying debris or shrapnel<br>▪ Cuts<br>▪ Lacerations<br>▪ Bleeding<br>▪ Paint inhalation | DON'T NOT PAINT INDOORS Painting indoors is prohibited by the university, so painting must happen outside in an unoccupied area with proper PPE. If occupants are near the area of effect while painting, stop and wait for a clear area before continuing.<br><br>Verifications:<br>▪ PPE shall always be in an easily accessible area and always stocked.<br>▪ Check the room for non-required personnel before beginning.<br>▪ If PPE stock is low or empty, notify the safety officer before proceeding<br>▪ Discard reusable mask after use<br><br>Required PPE: Gloves, safety goggles (If using aerosols), and a face mask capable of |

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| | | | | | | | filtering chemical and partial inhalants shall be used. |
| WD-40 or greases | 2 | 2 | 4 | Utilized when fitting low-tolerance or high-friction components together | Most greases or aerosol lubricants have VOC's (typically around 24% to 50%) | ▪ VOC inhalation<br>▪ Skin irritation<br>▪ Respiratory irritation | Proper PPE must be in use at any time grease is being utilized. For cases involving aerosol, ensure that the area is properly ventilated and non-essential occupants are out of the area of effect.<br><br>Verifications:<br>▪ PPE shall always be in an easily accessible area and always stocked.<br>▪ Check the room for non-required personnel before beginning.<br>▪ If PPE stock is low or empty, notify the safety officer before proceeding<br>▪ Discard reusable mask after use<br><br>Required PPE: Gloves, safety goggles (If using aerosols), and a face mask capable of filtering chemical and partial inhalants shall be used. |

### 6.2.2. Construction Hazards

**Construction Hazard Table**

Table 6-6

| Hazard | P' | S' | Value | Cause | Effects | Mitigation and Verifications |
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| Chop Saw contact or Amputation Injury | 1 | 4 | 4 | Chop saw blade jumps and jitters when cutting with a dull blade.<br><br>Improper maintenance or cleaning | Cuts, lacerations, or even lib amputation. | Make sure that the blade shield is in place.<br><br>All wires shall be inspected before use.<br><br>Storage of tools safely away from heavily occupied zones and safe to hold in their stored state.<br><br>Work shall not be done with a dull blade.<br><br>Verification:<br><br>▪ PPE shall always be in an easily accessible area and always stocked.<br>▪ Ensure that a first aid kit is easily accessible<br>▪<br>▪ Check the room for non-required personnel before beginning.<br>▪ If PPE stock is low or empty, notify the safety officer before proceeding.<br>▪ Discard reusable mask and earbuds after use<br>▪ Notify another team member before using the chop saw.<br>▪ Check the quality of the blade with the tool disconnected before cutting with the saw.<br>▪ Inspect the blade shield to ensure its condition is up to standard.<br>Ex. If any hardware, including but not limited to screw, bolts, nuts, or fasteners are loose or missing, notify the safety officer. <u>AWAIT FURTHER INSTRUCTION BEFORE PROCEEDING.</u><br><br>PPE: Heavy-duty gloves, Safety glasses, earplugs or earmuffs, and a face mask capable of filtering chemical and partial inhalants shall be used. |
| Drilling Tool Injury | 1 | 4 | 4 | Unclean or oily hands while working<br><br>Negligent handling<br><br>Leaving energized tools unattended<br><br>Open wires | Cuts and lacerations | Use proper technique for drilling. This includes that the drill head is orthogonal to the drilling surface, the object being drilled is supported, and limbs or other body parts are not at risk of being punctured when the drill bit fully penetrates the object. This shall be done while using proper PPE, and a clear area of occupants must be established before using the tool. <u>DO NOT USE THE DRILL FOR ANYTHING OTHER THAN ITS INTENDED USE.</u><br><br>Verification:<br><br>▪ PPE shall always be in an easily accessible area and always stocked.<br>▪ Ensure that a first aid kit is easily accessible<br>▪ Check the room for non-required personnel before beginning. |

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| | | | | | | ▪ If PPE stock is low or empty, notify the safety officer before proceeding.<br>▪ Use a proper drill bit for the specified material<br>▪ Discard reusable mask after use<br><br>PPE: Heavy-duty gloves, Safety glasses, face mask capable of filtering chemicals and partial inhalants shall be used. |
| Epoxy inhalation | 3 | 2 | 6 | While applying and sanding epoxy, VOCs are emitted that are toxic to breathe. | Perspiratory irritation or difficulty breathing. | Operate tools capable of sanding epoxy in a well-ventilated area. This must be done with proper PPE and ensure that others are wearing proper PPE or are not in the area of effect.<br><br>Verification:<br><br>▪ PPE shall always be in an easily accessible area and always stocked.<br>▪ Check the room for non-required personnel before beginning.<br>▪ If PPE stock is low or empty, notify the safety officer before proceeding.<br>▪ Discard reusable mask after use<br><br>PPE: Gloves, Safety glasses, and a face mask capable of filtering chemical and partial inhalants shall be used. |
| Excessive Noise E xposure | 3 | 2 | 6 | Environments with power tools are used for extended periods of time. | Hearing loss | Use earmuffs or plugs when using tools that are capable of 85 decibels or more.<br><br>Verification:<br><br>▪ PPE shall always be in an easily accessible area and always stocked.<br>▪ Check the room for non-required personnel before beginning.<br>▪ If PPE stock is low or empty, notify the safety officer before proceeding.<br>▪ Discard earbuds after use<br><br>PPE: Earplugs or earmuffs |

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| Fiberglass Dust In halation | 3 | 3 | 9 | The fiberglass airframe of the rocket will be subject to cutting and sanding, causing airborne debris. | Perspiratory irritation or difficulty breathing. | Operate tools capable of sanding and cutting fiberglass in a well-ventilated area.<br><br>Ensure that others are wearing proper PPE or are not in the area of effect.<br><br>Verification:<br>▪ PPE shall always be in an easily accessible area and always stocked.<br>▪ Check the room for non-required personnel before beginning.<br>▪ If PPE stock is low or empty, notify the safety officer before proceeding.<br>▪ Discard reusable mask after use<br><br>PPE: Gloves, Safety glasses, and a face mask capable of filtering chemical and partial inhalants shall be used. |
| Hand Saw contact | 1 | 3 | 3 | Cutting with excessive force can cause the slipping or jumping of the blade.<br><br>Unclean or oily hands while working | Cuts and lacerations. | Proper PPE shall be used when conducting any attempt to use a hand saw. This will be done with proper PPE and verify that gloves are clean when working. Use proper cutting technique when cutting. Cutting shall be done with a sharp blade.<br><br>Verification:<br><br>▪ PPE shall always be in an easily accessible area and always stocked.<br>▪ Ensure that a first aid kit is easily accessible<br>▪ Check the room for non-required personnel before beginning.<br>▪ If PPE stock is low or empty, notify the safety officer before proceeding.<br>▪ Discard reusable mask after use<br><br>PPE: Heavy-duty gloves. Safety glasses, a face mask capable of filtering chemical and partial inhalants, shall be used. |
| Hot Solder Contac t Injury | 2 | 2 | 4 | The soldering iron head is extremely hot.<br><br>Leaving the iron energized and unatte nded | Burns vary in degree depending on severity. | The soldering iron mount should be utilized when not in use. Do not leave the iron powered on when not in use.The area must be well ventilated and always done with proper PPE.<br><br>Verification:<br>• PPE shall always be in an easily accessible area and always stocked. |

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| Hot Solder Gas In halation | 3 | 2 | 6 | Gases are created when soldering metal flux. | Perspiratory irritation or difficulty breathing. | • Check the room for non-required personnel before beginning.<br>• If PPE stock is low or empty, notify the safety officer before proceeding.<br>• Discard reusable mask after use.<br>• Discard used latex gloves<br><br>PPE: Safety glasses, latex gloves, face mask capable of filtering chemicals and partial inhalants shall be used. |
| Rotary Sander Inj ury | 3 | 3 | 9 | High RPM rotary head can be unstable and hard to control when improp erly sanding a surface.<br><br>Leaving energized tools unattended.<br><br>Negligent handling<br><br>Rough, tool head.<br><br>Exposed wires | Skin abrasion and lib entanglement, and inhaling debris. | Operate the sander head parallel to the surface of interest. Use new sandpaper when needed. Ensure that others are wearing proper PPE or are not in the area of effect. This should all be done while the operator is using proper PPE and in a well-ventilated room.<br><br>Verification:<br><br>• PPE shall always be in an easily accessible area and always stocked.<br>• Check the room for non-required personnel before beginning.<br>• If PPE stock is low or empty, notify the safety officer before proceeding.<br>• Discard reusable mask after use<br><br>PPE: Heavy-duty gloves, Safety glasses, earplugs, muffs, and a face mask capable of filtering chemical and partial inhalants shall be used. |

### 6.2.3. Pre-Launch Hazards

| Pre-Launch Hazards<br>Table 6-7 | | | | | | |
|---|---|---|---|---|---|---|
| Hazard | P' | S' | Value | Cause | Effects | Mitigation and Verification |
| Battery runaway | 1 | 3 | 3 | Negligence in charging before preparing for launch.<br><br>Cell Defects/Degradation | Electric shock<br><br>1st, 2nd, and 3rd Burns<br><br>Puncture of the battery | • Disconnect from the charger before leaving and store it in a secure place.<br>• Disconnect battery from charger when fully charged. This is to prevent the battery from overcharging and risking the chance of it becoming unstable.<br>• Do not use sharp objects when the battery is in the immediate area.<br><br>Verification:<br><br>• The battery pack must be inspected for bulging or any discontinuity. If the battery is not in pristine condition, deem it unsafe to use.<br>• If deemed unsafe for use, deposit the battery in the battery discard box for further disposal.<br><br>PPE: Gloves |
| Electrical Short | 1 | 2 | 2 | Damaged or Worn Wiring<br><br>Loose connections<br><br>Moisture from the environment<br><br>Water reservoir leaks water onto the microcontroller<br><br>Excessive current | Electric shock<br><br>Minor burns | • Inspect all wires before events like storage, testing, and launch.<br>• Inspect all terminal connections for loose wires or broken connections.<br><br>Verification:<br><br>Verify the continuity of all systems before subsystem integration<br><br>PPE: Latex Gloves |

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| Injury using power tools | 3 | 3 | 3 | Unclean or oily hands while working<br><br>Negligent handling<br><br>Leaving energized tools unattended<br><br>Open wires | Cuts<br><br>Lacerations<br><br>Punctures | Utilize the power tools for their intended use.<br><br>Verification:<br><br>• PPE shall always be in an easily accessible area and always stocked.<br>• Check the room for non-required personnel before beginning.<br>• If PPE stock is low or empty, notify the safety officer before proceeding.<br>• Discard reusable mask after use<br><br>PPE: Heavy-duty gloves and Safety glasses |
| Trip or falling hazards | 3 | 1 | 3 | Unclean workstation | Bruises<br><br>Cuts<br><br>Broken bones | Wear proper footwear that provides ankle support. Keep the workstation clean and tidy. Ensure that there is a wide path of obstruction-free space for foot traffic.<br><br>Verification:<br>Safety Officer ensures that all required personnel are adhering to the footwear code<br><br>PPE: Closed-toed shoes with |
| Unintentional ignition of black powder or energetic devices | 1 | 4 | 4 | Electrical current is run through the system prematurely | 1st, 2nd, and 3rd Burns<br><br>Bleeding<br><br>Cuts | Black powder must be stored in dry, ignition-free areas.<br><br>Possession and loading of the motor shall be done by the team mentor.<br><br>Avionics bay, including CO2 canisters, black powder, and E-matches, shall be handled while deactivated and unarmed.<br><br>Stored in accordance with NFPA standard.<br><br>Transported in accordance with ATF<br><br>Verification:<br><br>PPE: Gloves, safety glasses |

### 6.2.4. Launch Hazards

| Launch Hazards<br>Table 6-8 | | | | | | |
|---|---|---|---|---|---|---|
| Hazard | P’ | S’ | Value | Cause | Effects | Mitigation and Verification |
| Debris Impact | 1 | 4 | 4 | Rocket fails to deploy in a controlled manner and breaks apart in flight<br><br>Rocket safely deploys and is falling back down to the ground | Injuries like blunt force trauma, bleeding, puncture wounds, or even death | • When the rocket is launched, point to the rocket until safely on the ground. This is to continually make the rocket’s location known to the surrounding personnel<br><br>Verification:<br><br>• Verify that the simulation data shows a controlled descent after all components are weighted at the launch site. |
| Motor misfire due to igniter misfire | 1 | 4 | 4 | Electrical current is present while or after connecting the motor igniter | Severe injuries, including burns, hearing loss, and blindness, may occur if personnel are in the immediate area of the rocket when the igniter fires. | • Ensure that the electrical circuit is closed before connecting the ignitor<br>• Only required personnel should be near the rocket when the ignitor is installed<br><br>Verification:<br><br>All field installations of motor igniters shall be done in accordance with the Igniter Installation procedure included in section 6.5 Launch Operations Procedures<br><br>PPE: Latex gloves, Safety glasses<br><br>(Heavy-duty gloves will not be used to prevent cumbersomeness) |
| Late Main deployment | 3 | 2 | 6 | Improper folding<br><br>Loss of connection between the airframe | Rocket does not slow to a manageable velocity before hitting the ground, and contact with someone could be fatal | • Extensive testing of the reefing system before launch.<br>• Inspect the parachute to look for preexisting weakness before launch.<br><br>Verification: |

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| | | | | and the parachutes during deployment<br><br>Forgetting to attach the parachute system to the eye bolt of the bulkhead<br><br>Reef does not fully open at its expected altitude.<br><br>Reef lines are tangled. | | • Ensure that all components are assembled correctly before launching.<br>• Verify that the simulation data shows a controlled descent after all components are weighted at the launch site. |
| Premature separation | 2 | 3 | 6 | Higher than expected jerk during chute deployment or improper shear pin sizing for the size of the rocket.<br><br>Premature detonation<br><br>Electrical current is run through the e-match prematurely | The motor impulse remains in effect while the airframe separates, potentially causing a catastrophic failure and resulting in the loss of the rocket. This could result in falling debris of varying velocities. | • Extensive testing of the recovery system before launch.<br>• Inspect the microcontroller and ensure that e-matches are utilizing the proper output ports.<br><br>Verification:<br><br>• Ensure that the flight computer is disabled to prevent premature puncture while assembling and to prevent possible injury to the team and surrounding persons<br>• Verify that the simulation data shows a controlled descent after all components are weighted at the launch site. |
| Vehicle instability | 3 | 3 | 9 | Wind or rail departure anomaly<br><br>Inaccurate measurement of weights<br><br>Recovery structures or airframe geometry are compromised | The motor impulse remains in effect while the airframe separates, potentially causing a catastrophic failure and resulting in the loss of the rocket. This could result in falling debris of varying velocities. | • Ballast weight shall be incorporated as needed<br><br>Verification:<br><br>• Verify that the simulation data shows a controlled descent after all components are weighted at the launch site.<br>• Weight the rocket's dry and wet mass<br>• Ensure that the wind on site is below 20 mph. |

### 6.2.5. Post-Launch Hazards

| Post-Launch Hazards<br>Table 6-9 | | | | | | |
|---|---|---|---|---|---|---|
| Hazard | P’ | S’ | Value | Cause | Effects | Mitigation and Verifications |
| Burns from handling hot RMS | 3 | 4 | 12 | Premature direct handling of the RMS without allowing time for cooling. | 1st , 2nd , and 3rd degree burns | Wait an ample amount of time before attempting to unload the RMS from the aft of the rocket<br>Verification:<br>Wait for the safety officer to confirm to unload the motor before continuing<br>PPE: Heat-resistant gloves |
| Injury during disassembly | 3 | 2 | 6 | Negligence with tools or unaware of surroundings while disassembling. | Cuts<br>Bruises<br>Lacerations<br>Bleeding | Make sure that there is a clear area to disassemble the rocket for transport off of the site.<br>Keep tools in their respective containers when not using them.<br>Verification:<br>PPE: cut-resistant gloves |
| Slip or fall hazards for non-nominal recovery terrain | 2 | 3 | 6 | Unaware of surroundings while disassembling.<br>Improper footwear | Cuts<br>Bruises<br>Lacerations<br>Bleeding | Wear proper footwear that provides ankle support<br>Verification:<br>The Safety Officer ensures that all required personnel are adhering to the footwear code<br><br>PPE: Closed-toed shoes with ankle support |

## 6.3. Failure Mode and Effects Analysis (FMEA)

The Failure Mode and Effects Analysis provides a detailed list of possible failures and mitigation strategies. Potential failure modes for payload, recovery, and all of its supporting systems are described along with their causes, resulting effects, and mitigation and verification responses. For the following tables, the FMEA is performed by finding a complete list of all causes to the failure defined and its respective effects at three levels: component, sub-scale, and system levels. A failure that appears minor at a component level can become a larger hazard as the effects continue to propagate to higher levels of the system. Each component onboard the rocket serves a specific and critical role, and failure at any of these levels has the potential to influence the overall mission success. By examining failures across the board of level hierarchy, the FMEA ensures that both localized and system-wide consequences are properly identified and mitigated. The FMEA ensures the safety of personnel, mission success, and a launch compliant with the NASA USLI expectations. FMEA risk and hazard rankings are determined using probability and severity criteria, with consideration given to impacts on personnel safety, hardware integrity, and mission success.

### 6.3.1. Recovery Structure and Components (FMEA)

**Recovery Structures and Components**

Table 6-10

| Item | P | S | T | Use | Failure Mode | Failure Cause | Effects | | | Mitigations and Verifications |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Component-Level | Subsystem-Level | System-Level | |
| **Mechanical** | | | | | | | | | | |
| Airframe body tubes | 1 | 3 | 3 | Provides the geometry of the structure and the majority of rigidity. Contains payload, avionics system, motor, and respective hardware. | Cracking or bent (Depending on material composition) | Damage while transporting or in-transit while in a package. | Cracks, breaks, and fiberglass fraying during construction or assembly. | Incapable of containing all components and sub-systems or unstable. | Does not meet safety protocol and standard, disqualifying it from launch. | Sand down the surface of the airframe after cutting to length. Inspect all body tubes before construction and assembly. |
| | 1 | 3 | 3 | | Cracking or bent (Depending on material composition) | Damage during the deployment of parachutes. | Cracks or breaks during construction or assembly. | Incapable of containing all components and sub-systems or unstable. | Does not meet safety protocol and standard; disqualifying it from launch | Verify that the simulation data shows a controlled descent after all components are weighted at the launch site. |
| Bulkheads | 3 | 4 | 12 | Use primary to subdivide portions of the rocket into smaller compartments, which provides structural rigidity and, in some cases, allows tie-off areas for parachutes. | Use primary to subdivide portions of the rocket into smaller compartment s, which provides structural rigidity and, in some cases, allows tie-off areas | Epoxy fails | Failure due to high instant acceleration from payload and ballast weight during chute deployment | Epoxy fails, and bulkheads fall out of place. . | The bulkhead is unable to contain the contents within the sub-section, or possible loss of the parachute and /or payload. | Properly mix the epoxy and apply it generously to the edges of the bulkhead Allow ample time for curing epoxy before launch. |

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| | | | | | for parachutes. | | | | | |
| | 2 | 4 | 8 | | Use primary to subdivide portions of the rocket into smaller compartments, which provides structural rigidity and, in some cases, allows tie-off areas for parachutes. | Epoxy fails | Lack of adhesion between the airframe and the centering rings. | | | |
| | 2 | 4 | 8 | | Use primary to subdivide portions of the rocket into smaller compartments, which provides structural rigidity and, in some cases, allows tie-off areas for parachutes. | Eye bolt fails | Eye bolt shears out of the bulkhead | Loss of parachute from bulkhead | Rocket is incapable of falling in a controlled and safe manner. | Ensure that the eye bolt is firmly secured to the bulkhead Verify that the simulation data shows a controlled descent after all components are weighted at the launch site. |
| Centering rings | 1 | 3 | 3 | Located in the lower unit of the rocket. Centering rings provide stability and proper fitment of the motor throughout the flight of the vehicle. | Geometry fails | Cracking or splitting due to high jerk during chute deployment. Typically, at the location of the chute eye bolt, due to local stress | Rings fail and fall out of place. | Failure to provide motor support causes the motor shifts inside the body tube of the rocket. | Flight is unstable, erratic, or catastrophically fails. | Inspect the centering rings before installing them into the aft of the rocket |

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| | | | | | | concentration. | | | | |
| | 1 | 3 | 3 | | Epoxy fails | Failure due to high jerk during chute deployment or lack of adhesion between airframe and centering rings. | Epoxy fails and ring fall out of place. | Failure to provide motor support causes the motor shifts inside the body tube of the rocket. | Flight is unstable, erratic, or catastrophically fails. | Properly mix the epoxy and apply it generously to the edges of the bulkhead Allow ample time for curing of the epoxy before launch. |
| | 1 | 3 | 3 | | Epoxy fails | Improper application, due to a lack of adhesion. Improper mix of two-step solution, or insufficient amount used. | Epoxy fails and ring fall out of place. | Failure to provide motor support causes the motor shifts inside the body tube of the rocket. | Flight is unstable, erratic, or catastrophically fails. | Properly mix the epoxy and apply it generously to the edges of the bulkhead Allow ample time for curing epoxy before launch |
| Couplers | 1 | 3 | 3 | Positioned between two body tubes and provides support between sections. | Geometry fails | Cracking or splitting due to high jerk during chute deployment. These sites of failure would typically be located at the screws that fix the coupler and the airframe. | Coupler cracks or breaks during flight. | Coupler isn't fixed to the body tube | Stability of the rocket or its geometry is compromised. | Inspect the couplers for preexisting weaknesses before installing them throughout the rocket during the construction and assembly. |
| | 1 | 3 | 3 | | Epoxy fails | Improper application, mostly likely due to a lack of adhesion , improper mix of two step solution, or insufficient amount used. | Coupler epoxy fails during flight. | Coupler isn't fixed to the body tube | Stability of the rocket or its geometry is compromised. | Properly mix the epoxy and apply generously to the edges of the bulkhead Allow ample time for curing of epoxy before launch. |
| CO2 Canisters | 1 | 3 | 3 | Utilized as an energetic source for airframe separation after | Premature puncture of the CO2 canister | E-match is set off prematurely | CO2 canister is punctured and gas is expelled into the airframe | Airframe separates | The motor impulse remains in effect while the airframe separates, | Inspect the microcontroller and ensure that e-matches are utilizing the proper output ports. |

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| | 1 | 4 | 4 | apogee is reached. | | | | | potentially causing a catastrophic failure and resulting in the loss of the rocket. | Ensure that the flight computer is disabled to prevent premature puncture while assembling and to prevent possible injury to the team and surrounding persons. |
| E-match | 1 | 4 | 4 | Used to send an electrical charge from the microcontroller to a black powder charge. This charge is what sets the firing pin into motion, and ultimately, the CO2 canister puncturing. | Electrical current is run through the e-match prematurely | E-match is set off prematurely | The CO2 canister is punctured, and gas is expelled into the airframe | Airframe separates | The motor impulse remains in effect while the airframe separates, potentially causing a catastrophic failure and resulting in the loss of the rocket. | |
| | 2 | 2 | 4 | | E-match disconnects during launch | E-match has a loss of power transfer capabilities | The flight computer is incapable of reefing chute at the prescribed altitude | Rocket falls faster than expected | Rocket lands with a larger impact force than the prescribed 65 ft/Ibs and is deemed an unsuccessful flight. | Inspect e-match and verify that ample slack is given for change in length of the paracord during main deployment. |
| Eye-Bolt | 1 | 4 | 4 | Used as a rigid component to fasten the drogue and main parachutes. | Eye-Bolt shears | Eye-bolt shears when trying to install motor into the RMS | Eye-bolt shears from the upper enclosure of the RMS | Rocket is unable to launch | Rocket is incapable of launching without a main eyebolt tie down and cannot be until replaced | Do not use the eyebolt as a means of tightening the forward closer of the RMS by inserting an object through it, and subjecting it to torsion. |
| Fins | 1 | 4 | 4 | Primary provides stability to the rocket and proper trajectory. These are located at the base of the rocket. | Geometry fails | Cracking or splitting when the rocket hits the ground after flight. | Fins crack or break when the rocket hits the ground at the end of flight. | Fin separates from the airframe. | Does not meet the NASA USLI protocol for reusability and is deemed an unsuccessful flight. | Inspect the surface of fins to ensure that there are no preexisting weaknesses before launch. |
| | 1 | 3 | 3 | | Epoxy fails | Improper application, mostly likely due to a lack of adhesion , improper mix of two step solution, or insufficient | Epoxy cracks or breaks when the rocket hits the ground at the end of flight. | Fin separates from the airframe. | Does not meet the NASA USLI protocol for reusability and deemed as an unsuccessful flight. | Properly mix the epoxy and apply generously to the edges of the bulkhead Allow ample time for curing of epoxy before launch. |

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| | | | | | | amount used. | | | | |
| Firing Pins | 1 | 1 | 4 | A small metal pin that punctures CO2 canisters when a controlled explosion like black powder or Pyrodex occurs. | Premature detonation | E-match is set off prematurely | CO2 canister is punctured and gas is expelled into the airframe | Airframe separates | The motor impulse remains in effect while the airframe separates, potentially causing a catastrophic failure and resulting in the loss of the rocket. | Inspect the microcontroller and ensure that e-matches are utilizing the proper output ports. Ensure that the flight computer is disabled to prevent premature puncture while assembling and to prevent possible injury to the team and surrounding persons |
| Motor | 1 | 2 | 2 | Delivers trust to the rocket. . | Motor doesn't ignite. | Damage while transporting or in-transit while in package or manufacture defect. | Failure to ignite from the launch pad. | Lack of trust provided to the rocket | The launch is scrapped, and the motor must be inspected to determine the issue before continuing. | Inspect the motor for any defects to the motor. Team Mentor shall be present and in charge or motor inspection and loading. |
| | 2 | 1 | 2 | | Motor doesn't ignite. | Improper or faulty motor igniter installation. | Failure to ignite from the launch pad. | Lack of trust provided to the rocket | The launch is scrapped, and the motor must be inspected to determine the issue before continuing. | Ensure that the igniter wire legs are not touching or crossing. Ensure that the igniter has hit the top of the motor before completing the circuit. |
| | 3 | 1 | 3 | | Premature burnout | Increased wind resistance or unaccounted additional weight. | Motor burns out before the expected apogee simulated. | Rocket begins to fall prematurely. | Premature initiation of the recovery process with the onset of drogue deployment. | Verify that the simulation data shows a controlled descent after all components are weighted at the launch site. |
| Paracord | 1 | 4 | 4 | Connects the parachute to the bulkhead | Severing | Higher than expected jerk during chute deployment | Paracord fails | Chute connection to airframe is severed. | The rocket begins to speed up, and a catastrophic impact is imminent. | Testing of paracord strength is employed to ensure strength in the worst situations |
| Parachute | 3 | 4 | 12 | Ensures the safe descent of the rocket after apogee is reached. This is done by slowing the | The Drogue parachute does not open | Improper folding Loss of connection between the airframe and the parachutes | Failure to deploy parachute | Rocket does not slow to a manageable velocity before the main parachute is deployed | Upon main deployment, Main parachute is destroyed, and a catastrophic impact is imminent. | Inspect the parachute to look for preexisting weakness before lauch. Ensure that all components are assembled correctly before launching. |

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| | | | 12 | rocket down to a manageable ground hit velocity Ensures the safe descent of the rocket after apogee is reached. This is done by slowing the rocket down to a manageable ground hit velocity | | during deployment Forgetting to attach the parachute system to the eye bolt of the bulkhead | | Rocket does not slow to a manageable velocity before hitting the ground Rocket does not slow to a manageable velocity before hitting the ground | | Verify that the simulation data shows a controlled descent after all components are weighted at the launch site. |
| | 3 | 4 | 12 | | Main Parachute does not open | Improper folding Loss of connection between the airframe and the parachutes during deployment Forgetting to attach the parachute system to the eye bolt of the bulkhead Reef does not fully open at its expected altitude. Reef lines are tangled | Failure to deploy parachute | | . The rocket is likely to incur irreversible damage and flight is deemed unsuccessful due to an inability to relaunch in its final state. | Extensive testing of the reefing system before launch. Inspect the parachute to look for preexisting weakness before launch. Ensure that all components are assembled correctly before launching. Verify that the simulation data shows a controlled descent after all components are weighted at the launch site. |
| | 2 | 4 | 8 | | Parachute integrity fails | Shroud lines sever Reefing patches tear from the canopy skirt Canopy tears Higher than expected jerk during chute deployment | Parachute geometry fails | | | |
| | 3 | 4 | 12 | | Chutes do not open | Failure to attach chutes to eye bolts during the pre-launch procedure | Failure to deploy the parachute | | | Ensure that the pre-launch procedure “Rocket Assembly Preparation and Verification Procedure.” |
| Screw Switch | 1 | 1 | 1 | Used to arm the rocket once secured to the launch pad and ready for flight. | Screw switch fails to arm the avionics bay and reefing electronics | Loss of connectivity between the switch and the electrical components The electrical | Screw switch fails | Lack of power in the avionics bay | Unable to launch | Bring multiple switches to the launch site Test the system with the key switch before launch day |

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| | | | | | | circuit is stuck closed. Frayed or severed wires | | | | |
| Shear pins | 1 | 3 | 3 | Allow for selective separation of rocket airframe. | Premature separations | Higher than expected jerk during chute deployment or improper shear pin sizing for the size of the rocket. | Premature shearing | Premature separation between coupler and airframe components, which could lead to an unauthorized dual deployment at apogee. | The rocket falls at a much slower rate of decent and fails to hit the apogee-to-ground time that was anticipated. | Verify that the simulation data shows a controlled descent after all components are weighted at the launch site. |
| | 2 | 3 | 6 | | Premature separations | Shear pins fail due to improper mating between body tubes. This creates a small gap that can shear the pin due to the force of motor ignition. | | | | |
| | 1 | 3 | 3 | | Premature separations | Shear Pins are weakened when super glue is applied. | | | | Verify the condition of all shear pins before inserting them into the airframe. <u>DO NOT USE SUPER GLUE TO HOLD SHEAR PINS INSIDE THE ROCKET.</u> |
| **Electrical** | | | | | | | | | | |
| Antenna (TeleTB) | 2 | 2 | 6 | Provides wireless connection to the rocket avionics bay | Failure to configure | Lack of connection between Avionics Bay. | Data transfer between the electronics on board and the antenna is nonexistent | Real time data is not recorded during flight | Lack of data required for comparing with the projected flight data from Openrocket simulation | Test system before launch<br>Ensure connectivity before launch |
| Battery | 3 | 4 | 12 | Provides necessary power to effectively operate all electronic components in | Battery insufficient charge | Negligence in charging before preparing for launch. Cell Defects/Degradation | Battery doesn't have the potential expected | Lack of power needed to effectively use the electronic onboard the payload | Payload is unable to complete its mission. | Charge batteries after reach round of usage.<br>Carry battery charger and portable battery pack to launch site<br>Bring extra batteries to launch site |

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| | 1 | 4 | 4 | the payload vehicle. | Battery thermal runaway | Over charging<br><br>Over-discharging<br><br>Cell Defects/Degradation<br><br>External Short Circuit Overheating | Battery explodes | Fire<br><br>Lack of power needed to effectively use electronic onboard the payload | Payload is unable to complete its mission<br>VOCs are released in the immediate area<br>Potential to cause chemical burns from battery acid | Disconnect from the charger before leaving and store in a secure place.<br>Disconnect battery from charger when full charged<br>Bring extra batteries to launch site |
| Electrical Circuit | 3 | 3 | 9 | Delivers power through the recovery system | Electrical short | Damaged or Worn Wiring<br>Loose connections<br>Moisture from the environment<br>Water reservoir leaks water onto microcontroller<br>Excessive current | Loss of power | Microcontroller is incapable of communicating with internal electrical components within the payload.<br>Lack of power or communication between components to effectively use the electronic onboard the payload. | Payload is unable to complete its mission | Inspect all wires before an events like storage, testing, and launch.<br>Inspect all terminal connections for loose wires or broken connections<br>Test water pump and reservoir for leaks or areas of concern |
| Flight computer (Telemetrum ) | 2 | 3 | 6 | Responsible for deployment events of drogue and main parachutes by means of airframe separation | The flight computer fails to separate airframe and deploy parachutes | Lack of power<br><br>Loose connection<br>Frayed or broke wires | Chutes do not deploy | Rocket does not slow to a manageable velocity before hitting the ground | The rocket is likely to incur irreversible damage, and flight is deemed unsuccessful due to an inability to relaunch in its final state. | Inspect the flight computer for chips, missing components, and other preexisting weakness before launch.<br>Ensure that all components are assembled correctly before launching.<br>Ensure that battery is charged and connected to the flight computer<br>Ensure that the screw switch allows power to flow to flight computer once engaged. |
| Reefing system | 3 | 3 | 9 | Allows for the main Parachute to have a small surface area for a faster ground descent time and open to the full capacity of the parachute | Reefing electronic system fails to open the main parachute when specified | Lack of power<br><br>Loose connection<br>Frayed or broke wires | The reefing system is not open main fully | Rocket is falling at a fast velocity than expected. | The rocket is likely to incur irreversible damage, and flight is deemed unsuccessful due to an inability to relaunch in its final state. | Inspect all electrical components for chips, missing components, and other preexisting weaknesses before launch.<br>Ensure that all components are |

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| | | | | at a specified altitude. | | | | | assembled correctly before launching. Ensure that the battery is charged and connected to the flight computer Ensure that the screw switch allows power to flow to the flight computer once engaged. |
| **Software** | | | | | | | | | |
| AltOS | 1 | 2 | 2 | Open-source software and compatible with firmware for hardware products from Altus Metrum, the AltOS source tree also includes AltosUI, which provides for flight monitoring, post-flight analysis, device configuration and firmware updating | Failure to configure | Lack of connection between Avionics Bay. | Data transfer between the electronics on board and the antenna is nonexistent | Real time data is not recorded during flight | Lack of data required for comparing with the projected flight data from Openrocket simulation | Test system before launch Ensure connectivity before launch |
| Arduino IDE | 3 | 3 | 9 | IDE used to code the reefing flight computer. | Failure to configure Unexpected deployment of the full main parachute | Bugs | Premature or late deployment of main parachute and reefing | Unexpected descent velocity and time-to-ground. | The rocket is likely to incur irreversible damage if the velocity is too high, and flight is deemed unsuccessful due to an inability to relaunch in its final state. Has the possibility of missing the 80 sec window for time to ground that is projected | Extensive tests to ensure the reefing system is bug-free |
| Open rocket | 3 | 2 | 6 | Software that provides Simulation data capable of giving us proper altitude | Inaccurate simulation | Inaccurate weight of the rocket at the launch site Unexpected wind speeds that are | Premature or late deployment of main parachute and reefing | Unexpected descent velocity and time-to-ground | The rocket is likely to incur irreversible damage if the velocity is too high, and flight is deemed | Compare data from launch with simulation to find error |

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| | | | | deployment based off many parameters like weight, wind velocity, site altitude, and more. This is used when confirming altitude for main and reefing deployments. | | unaccounted for in the program | | | unsuccessful due to an inability to relaunch in its final state. Has the possibility of missing the 80 sec window for time to ground that is projected | |

## 6.3.2. Payload Separation Mechanism (FMEA)

| Payload Separation Mechanism<br>Table 6-11 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Item | P | S | T | Use | Failure Mode | Failure Cause | Effects | | | Mitigations and Verification |
| | | | | | | | Component-Level | Subsystem-Level | System-Level | |
| Mechanical | | | | | | | | | | |
| Discontinuity Switch | 1 | 4 | 4 | Detects the separation of the transition and the forward body tube after the drogue chute is deployed | Switch decouples prematurely | Due to high acceleration forces experienced during recovery, the switch fails | The switch disconnects, and power is no longer flowing through it. | The countdown time starts prematurely for the payload to separate from the rocket transition tube | Separation of the payload could happen during recovery, and loss of the payload would be imminent | Design ensures that the connectors used are capable of sustaining all recovery forces.<br><br>Ensure that the discontinuity switch passes voltage before the subsystem integration into the rocket. |
| Stepper Motor | 1 | 4 | 4 | The stepper motor is responsible for providing the movement necessary to drive the separation plate. | Motor reaches stall torque | Due to friction and improper fitting of separation systems, the force required to overcome the constriction is too great. | Stepper motor reaches stall torque | Motor is unable to separate the nose cone from the transition body tube | Payload cannot be successfully deployed and cannot complete its mission | The separation mechanism shall be thoroughly tested with the specified motor before launch day.<br><br>Ensure that the nose cone and transition are easily separable by hand before launching. |

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| Tilt Mechanism | 3 | 4 | 12 | Responsible for positioning the rocket in a particular axial orientation to create an unrestricted ejection of the payload | Spring is not strong enough to orient the rocket into its required position due to the final launching site of the rocket. | Environment prohibits the rocket from moving due to geographic constriction | Tilt mechanism extends level arms from the rocket | Level arms can not provide ample torque against their environment to rotate the rocket properly | | Springs are rated for the force required to move the rocket in a variety of environments. Ensure that springs are in ample tension before sub-system integration |
| **Electrical** | | | | | | | | | | |
| Electrical System | 2 | 4 | 8 | Delivers power and control signals through the separation system. | Short circuit | Hot wire shorts to ground | Circuit shorts and losses power transfer capabilities | The circuit is unable to communicate with the surrounding sensors and motors | Payload is unable to complete the mission | Ensure that all wires and hardware are safely secure and rigidly fixed in place for system integration. |
| Motor Driver | 1 | 4 | 4 | Power and control stepper motors | Overloading | Short in the circuit near the motors | Drivers ICs are ruined | Motors are unusable | | Visually ensure no bare metal exists near motor wires |
| Soldered components | 2 | 4 | 8 | Solder is used to connect metal surfaces through a similar metal | Solder cracks or breaks | Not enough solder used<br>High acceleration during recovery | Solder is broken from the metal surface | The electrical circuit is closed | | Ensure that all wires and hardware are safely secure and rigidly fixed in place for system integration. |

## 6.3.3. Payload System and Components (FMEA)

**FMEA** Payload System and Components
Table 6-12

| Item | P | S | T | Use | Failure Mode | Failure Cause | Effects | | | Mitigations and Verifications |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Component-Level | Subsystem-Level | System-Level | |
| **Mechanical** | | | | | | | | | | |
| Auger Head | 4 | 2 | 8 | Utilize for soil collection by drilling into the ground and rotating counterclockwise to deposit the soil into the | Dirt is trapped in the auger cover | Dirt gets packed into the upper cover and can't be evacuated since the auger head does not travel through the entirety of the cylinder | Dirt is packed inside the auger | Dirt may cause excessive power requirements to turn the auger head | The motor may reach stall torque and be unable to drill for additional dirt effectively | Extensive testing will be done with different auger designs before launching |

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| | 2 | 3 | 6 | containment bin | Trapped Dirt and Debris | Dirt and debris gets wedged between the augar and cover wall. | Rocks and debris are trapped inside the Auger teeth | Rocks and debris may cause excessive power requirements to turn the auger head | | |
| Bearings | 2 | 4 | 8 | Allow for all components to smoothly move, dependent from each other | Bearings pop out | High acceleration during recovery causes bearings to loosen from the components. | Bearings have fallen out of the component | Smooth movement between components is not possible | Mission success may be in jeopardy depending on the severity of the movement | Ensure that all bearings are rigidly attached to all relevant components before launch |
| Body | 1 | 2 | 2 | The shell of the payload houses all of the major payload components. | The body of the payload cracks | High acceleration during recovery causes cracks to propagate | PETG body is cracked | The rigidity of the payload is weakened | Payload could perform subpart due to structural degradation | Ensure that the body is properly attached to the payload before subsystem assembly |
| Linkage assembly | 3 | 3 | 9 | Used in delivering the auger head between multiple orientations during the sampling process. | Drill head jams before full deployment | Drill head clearance between its motion travel from its vertical to horizontal orientation and the ground is restricted due to geometric constraints within the airframe. | The drill head is unable to reach a perpendicular orientation to the ground | Drill cannot gather the ideal volume of soil in the correct orientation | Sample collection will take longer than projected to harvest an adequate amount of soil | Test payload on multiple types of terrain to determine if clearance is an issue |
| | 3 | 3 | 9 | | Mechanical linkage binds during deployment | Tight tolerances while manufacturing assembly components Lack of cleaning or dirt and grime buildup while completing the soil extraction, sampling, and testing. | Hindered movement between links and joints | The assembly is unable to move under its own power | Incapable of completing the task and failure of the mission. | Test linkage assembly underload to ensure that all components work smoothly |
| | 2 | 3 | 6 | | Linkage structural failure under load | The torque of the servo motor exceeds the strength of the linkage assembly. | Cracking, splintering, or snapping links Linkage joints sheer | The assembly is unable to move | Incapable of completing the task and failure of the mission. | Test motor mounts under the highest simulated forces to verify structural integrity under load. |
| Motor mount | 2 | 3 | 6 | Mounts provide stability and rigid support of the motor while under load. | Motor mount failure (torque or flight loads | The torque of the servo motor exceeds the strength of the motor mount. | Motor mount breaks or cracks | The motor mount is unable to support the weight of the motor. | Erratic movement or large amounts of jerk between the assembly and motor. | Test motor mounts under the highest simulated forces to verify structural integrity under load. |

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| | | | | | | Damages due to excessive vibration or turbulence during flight or at landing | | Incapable of providing support to the motor under load.<br><br>Incapable of providing support to the motor under load. | Possible incapacitation of assembly and motor cooperation | |
| Shafts | 2 | 4 | 8 | Allows for smooth movement between moving components and fixes components rigidly in place. | Shafts decouple from bearings | High acceleration during recovery causes shafts to decouple from fixed bearings. | Shafts are no longer concentric with the bearing | Sub-system movements, like linkage rotation, could be affected catastrophicall y | Payload is unable to complete the mission and fails | Ensure that the shafts are properly attached to the payload before subsystem assembly |
| Tracks | 1 | 4 | 4 | Tracks provide a large surface area with the ground and deliver the power from DC motors to the ground, allowing propulsion | Tracks fall off | Tracks slip off the tensioner or idler pulleys. | Tracks are disabled | The motor is unable to deliver power to the ground in the form of payload movement | The payload is unable to complete the mission and fails. | Ensure that the tracks are properly attached to the payload before subsystem assembly |
| Water container | 2 | 4 | 8 | Used to store water during flight and available to add to the collected soil when testing PH | Water container fails | Due to high accelerations imparted on the payload during flight, the water containment seal fails and the water content splatters along the payload components | The water container fails and spills water content | Water content soaks the internal payload components | The payload is unable to complete the mission and fails. | Ensure that the water container is properly sealed and shake to test for leaks under external forces |
| **Electrical** | | | | | | | | | | |
| Battery | 2 | 3 | 6 | Provides necessary power to effectively operate all electronic components in the payload vehicle.<br>. | Battery insufficient charge | Negligence while preparing for launch. | Battery doesn't have the potential expected. | Lack of power needed to effectively use the electronic onboard the payload | Payload is unable to complete its mission. | Charge batteries after each round of usage.<br><br>Carry a battery charger and a portable battery pack to the launch site |
| | 1 | 3 | 3 | | Battery thermal runaway | Over charging<br><br>Over-discharging<br><br>Cell Defects/Degradatio n | Battery explodes | Fire<br><br>Lack of power needed to effectively use electronic | Payload is unable to complete its mission<br><br>VOCs are released in the | Disconnect from the charger before leaving and store in a secure place. |

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| | | | | | | External Short Circuit<br>Overheating | | onboard the payload | immediate area<br><br>Potential to cause chemical burns from battery acid | Disconnect battery from charger when full charged |
| Electrical circuit | 3 | 4 | 12 | Provides power distribution and communication between all electrical components | Electrical short | Damaged or Worn Wiring<br><br>Loose connections<br><br>Moisture from the environment<br><br>Water reservoir leaks water onto microcontroller<br>Excessive current | Loss of power | Microcontroller is incapable of communicating with the internal electrical components within the payload.<br>Lack of power or communication between components to effectively use the electronic onboard the payload. | Payload is unable to complete its mission | Inspect all wires before an events like storage, testing, and launch.<br><br>Inspect all terminal connections for loose wires or broken connections<br><br>Test water pump and reservoir for leaks or areas of concern |
| DC motor | 1 | 3 | 3 | Utilized in the operation of vehicle movement by driving tracks and operates the auger head during soil collection. | DC motor failure | Mechanical wear<br><br>Loose connections<br><br>Poor ventilation<br><br>Overloading<br><br>Environmental factors such as dirt, moisture<br>Vibration experienced during flight | Overheating<br><br>Lack of movement | Payload track is unable to operate<br>Drill head is unable to operate | Lack of movement needed to effectively use the electronic onboard the payload | Inspect component for dirt and grime or everyday use wear.<br><br>Inspect all wires before an events like storage, testing, and launch.<br><br>Inspect all terminal connections for loose wires or broken connections |
| Servo Motor | 1 | 3 | 3 | Utilized in the movement of the linkage assembly | Servo motor failure | Mechanical wear<br><br>Poor ventilation<br><br>Overloading<br><br>Environmental factors such as dirt, moisture<br>Vibration experienced during flight | Overheating<br><br>Lack of movement | Linkage assembly is unable to operate | Lack of movement needed to effectively use the electronic onboard the payload | |
| Soldered components | 2 | 4 | 8 | Solder is used to connect metal surfaces through a similar metal | Solder cracks or breaks | Not enough solder used<br><br>High acceleration during recovery | Solder is broken from the metal surface | The electrical circuit is closed | Payload is unable to complete its mission | |

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|---|---|---|---|---|---|---|---|---|---|---|
| Motor drivers | 1 | 3 | 3 | Electrical interface between the motor and the microcontroller and controls the speed, direction, and torque of motors. | Motor driver failure | Mechanical wear<br><br>Poor ventilation<br><br>Overloading<br><br>Environmental factors such as dirt, moisture<br>Vibration experienced during flight | Overheating<br><br>Lack of movement | Payload track is unable to operate<br><br>Drill head is unable to operate<br><br>Linkage assembly is unable to operate | Lack of movement needed to effectively use the electronic onboard the payload | |
| Software | | | | | | | | | | |
| Multi-Motor Communication | 3 | 3 | 9 | The variety of motors all have specific roles but work together to produce successful payload operation. | Motor synchronization failure | Code discrepancy<br><br>Issues with communications between microcontrollers and motors<br><br>Inadequate current to operate all motors for the duration of the mission | Unwanted independence between each motor. | Communication between multiple servo and DC motors do not work in harmony. | Erradic movement of the payload vehicle<br><br>Possible failure of the mission. | Ensure proper sizing of the battery.<br><br>Ensure that the battery is fully charged<br>De-bug and troubleshoot code with payload testing |
| Data Interpretation | 4 | 3 | 12 | Data interpretation is needed to effectively utilize sensor data for procedure implementation which in code. | Incorrect sensor data interpretation | Human error when interpreting data received from sensors. | Inaccurate data constants or data analysis. | Hinders benchmark and sub-system testing | Inadequate amounts of sample material tested | De-bug and troubleshoot code with payload testing |
| Servo motor movement | 3 | 3 | 9 | Utilized in the movement of the linkage assembly | Servo motor range insufficient or excessive | Code discrepancy in rotation range.<br><br>Inadequate torque for assembly movement. . | The servo motor doesn't turn the full range expected<br><br>The servo has a larger range than expected | Too little range in servo motor rotation prevents linkage from reaching its vertical orientation<br><br>Too much range in servo motor rotation causes linkage to go into a toggle position | Sample collection will take longer than project to harvest the adequate amount of soil<br><br>Binding of assembly causing incapacitation and mission failure | De-bug and troubleshoot code and verify motor sizing with payload testing |

### 6.3.4. Environmental Hazard Analysis (EHA)

## Environmental Hazards

Table 6-13

| Hazards | P' | S' | Value | Causes | Effects | Mitigations and Verification |
|---|---|---|---|---|---|---|
| **Potential Effects and Hazards to Environment** | | | | | | |
| Material Waste | 5 | 1 | 5 | PLA filament waste due to supports and shaping.<br><br>Packaging (cardboard, Styrofoam, bubble wrap)<br><br>Excess epoxy. | Recycle as much material as possible.<br><br>Use as much as needed | Recycle as much material as possible.<br><br>Use as much as needed<br><br>Verification: A designated recycling bin will be located in the major area of waste production such as the Senior Design Lab. |
| Chemical Aerosol | 3 | 2 | 6 | Chemical reaction producing a aer osol by-product. | Were proper PPE when using any chemical<br><br>Ventilated room or open air is required. | Were proper PPE when using any chemical<br><br>Ventilated room or open air is required.<br><br>Verification: Proper PPE for according to manufacturer specification |
| Energetic by-product (post launch) | 5 | 1 | 5 | Ash, smoke, dust, and soot. | Do not approach rocket launch pad or rocket until by-products have clearly dissipated. | Do not approach rocket launch pad or rocket until by-products have clearly dissipated.<br><br>Verification: Post-Launch check log shall be implemented to verify completion of debris removal. |
| Field Debris | 5 | 1 | 5 | Broken fins, launch preparation disp osables, snack trash and water bottles. | Continue to clean throughout the day.<br><br>Bring plenty of trash bags and dispose of the trash properly with any recyclable trash be handled accordingly. | Continue to clean throughout the day.<br><br>Bring plenty of trash bags and dispose of the trash properly with any recyclable trash be handled accordingly.<br><br>Verification: Post-Launch check log shall be implemented to verify completion of debris removal. |
| Batteries | 5 | 2 | 10 | Improper disposal of batteries or any device using lead-acid or AGM technology. | Dispose of batteries per the manufacture specification. | Dispose of batteries per the manufacture specification.<br><br>Verification: Log of all batteries being disposed of and when. |
| **Potential Environmental Effects and Hazards on the Rocket** | | | | | | |
| Dense pockets of air and cross wind | 3 | 3 | 9 | Early deployment due to avionics bay air density verification. | The avionics bay will be equipped with multiple pitot tubes for ample air circulation and barometric pressure accuracy | The avionics bay will be equipped with multiple pitot tubes for ample air circulation and barometric pressure accuracy<br><br>Verification: Pre-flight check for any pitot tubes obstructions. |

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| | | | | | | Flight computer and avionics will be calibrated to launch site elevation.<br><br>Pre-Launch check log shall be implemented to verify completion of calibration and obstruction check. |
| Typical Barometric Pressure Change | 5 | 1 | 5 | Impacts accuracy of data collection. | The avionics bay will be equipped with multiple pitot tubes for ample air circulation and barometric pressure accuracy | The avionics bay will be equipped with multiple pitot tubes for ample air circulation and barometric pressure accuracy<br><br>Verification: Pre-flight check for any pitot tubes obstructions.<br><br>Flight computer and avionics will be calibrated to launch site elevation.<br><br>Pre-Launch check log shall be implemented to verify completion of calibration and obstruction check. |
| Terrain and Vegetation (including water landing) | 3 | 1 | 3 | Harsh landing to rocket body.<br><br>Incapable of rocket recovery.<br><br>Risks to payload deployment | Air frame shall be made with a safety factor ≥ 2 of forces expected at ground hit velocity.<br><br>Avionics bay will house a remote GPS<br><br>Payload shall be designed to traverse a multitude of terrains. | Air frame shall be made with a safety factor ≥ 2 of forces expected at ground hit velocity.<br><br>Avionics bay will house a remote GPS<br><br>Payload shall be designed to traverse a multitude of terrains.<br><br>Verification: Testing of material strength prior to launch.<br><br>Testing of Avionics Bay GPS will occur prior to launch.<br><br>Payload will be tested for its ability to operate in extreme terrains during its design and building processes.<br><br>Pre-Launch check log shall be implemented to verify completion of GPS calibration check. |
| Temperature and Humidity Extremes | 4 | 1 | 4 | Affect to burn time, apogee, ground hit velocity, and time to ground. | Rocket preparation shall be done in shade for as long as possible.<br><br>Survey weather patterns thought the day. | Rocket preparation shall be done in shade for as long as possible.<br><br>Survey weather patterns thought the day.<br><br>Verification: Ensure there are sufficient tent coverings to work under. |

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| Solar Exposure and Thermal Gradients | 4 | 1 | 4 | Weakness adhesives | Rocket preparation shall be done in the shade for as long as possible.<br><br>Survey weather patterns throughout the day.<br><br>Check epoxy fillets for structural rigidity. | Rocket preparation shall be done in shade for as long as possible.<br><br>Survey weather patterns thought the day.<br><br>Check epoxy fillets for structural rigidity.<br><br>Verification: Check material rigidity<br><br>Pre-Launch check log shall be implemented to document confirmation of material rigidity verification. |
| Lightning or Severe Weather | 3 | 2 | 6 | Safety of the mission is jeopardized as it causes severe concerns for equipment and personnel's well-being. | Do not fly until instructed further by the RSO | Do not flight until instructed at further notice by the RSO<br><br>Verification: Verbal confirmation my mentor and RSO before resuming launch.<br><br>Pre-Launch check log shall be implemented to document confirmation of both parties. |

## 6.4. Launch Operations Procedures

Procedural checklists are implemented to verify that all phases of the team's actions and decisions are in accordance with all acting authorities and NASA guidelines. Checklists help the team to systematically verify all sub-system competition while also mitigating safety hazards the team could be exposed to during the process. All team members are required to follow the procedures listed below, and the Verification Authority in charge must certify that the procedures are followed.

In the case that a lead is absent on launch day, a capable substitute lead will be implemented. The Safety Officer must be notified of the change and documented. If the safety officer is absent, the responsibility will fall onto the Project Lead (Krieg Conrad). If the Project Lead is absent, the responsibilities will fall to the Safety Officer (Jonathan Serbest). These events will be documented.

## 6.5. Pre- Launch Procedures

### 6.5.1. Recovery and Respective Electronics Preparation with Reefing System and Verification Procedure

Verification Authority: Jonathan Serbest (Safety Officer)
Lead: Austin Zaal (Recovery Officer)

**GENERAL PPE REQUIRED:**

- Closed-toe shoes
- Safety glasses
- Gloves

The recovery system is extremely important in ensuring the safe launch and landing of the rocket. All high-powered rockets require a recovery system capable of returning the rocket and all components safely to the ground. This will be done while preserving the rocket's original condition and at a non-hazardous ground high velocity. Since the motor selected has an impulse over 2560 N-sec, this requires the implementation and use of an electronic actuated recovery system. Our rocket will satisfy both of these requirements in accordance with NFPA 1127 (4.10.1 & 4.10.2).

1. **Disarmed Electronics Verification** – Ensure no voltages or currents are present in avionics bay when systems are unarmed. *This must be done to prevent the possibility of premature detonation and possible injury.* This includes:
    a. Verifying there is no power to either flight computer.
    b. Verifying energetic circuits are open in two places (open switch and unarmed flight computer).
    c. Ensure solid soldered connections among energic circuits.
    d. Verify two fully charged power sources are present.
2. **Ensure Energetics are Disabled** – Ensure black powder/CO2 cartridges are unarmed and placed in avionics bay housing. *This must be done to prevent the possibility of premature detonation and possible injury.*
3. **Reefing System Connection** – Ensure reefing system is disconnected from power by opening the box and checking for red or green lights. If no lights are visible, connect e-match to reefing system by inserting wire through small hole in box, insert individual e-match leads into screw terminals, and secure using screwdriver.
4. **Verify Arming Screw Switch is Properly Installed** – Ensure arming system is working correctly. *Screw switch must be used to activate electronics on-board only after the rocket is on the pad to prevent premature separation while handling.* This is done by:
    a. Remove both power sources from the avionics bay.

b. Connect the multimeter to the terminals of the arming switch.
c. Turn the screw switch to the "armed" position.
d. With the multimeter in the "Continuity" mode, verify the terminals are properly connected.
e. Turn the screw switch to the unarmed mode.
f. Using the multimeter, verify the connection is open.
g. Replace the power sources back into the avionics bay.

5. **Verify Means to Fire Energetics are Present –** Visually verify electronics matches have been secured in proper position and have secure connections to logic electrics and power.
6. **Check Reefing System Electronics –** Visually inspect the electronics within the reefing system electrical box. Ensure all components are seated securely within the box. Using multimeter, ensure lithium battery is charged to at least 4.0V.
7. **Reefing System Power Verification -** Connect battery to JST connector and tighten screw switch. Verify one green light for each of the devices (2 lights total) and listen for audible beeps from each device. Close and secure reefing electrical box.
8. **Check Bulkhead Rigidity** – Ensure all bulkhead connection points are secure.
9. **Prep Chutes and Components** – Properly fold & bag drogue, pilot, and main parachutes respectively.
10. **Prep Shock Cords** – Properly bundle shock cords and connect shock cord to bulkheads via quick links.
11. **Insert Chutes and Components** – Carefully pack reefing electronics, cords and parachute bags into their respective housings. Parachute bags will be flame-resistant bags since black powder is being utilized for separation. *Ensuring the reefing parachute is not tanked and properly folded limits the chances of reefing malfunction. These malfunctions can lead to a fast ground-hit-velocity and possess a greater hazard to the personnel present on site*. NFPA 1127 (4.10.3)

I certify that all steps in this procedure have been completed in accordance with the documented instructions. I acknowledge that the procedure has been reviewed in full and that all required safety and operational checks have been performed to the best of my knowledge.

Verification Authority Only

**Name:** ___________________________
**Position/Role:** ___________________
**Signature:** ______________________
**Date:** ____________________________

### 6.5.2. Payload Preparation, Mechanical Separation, and Verification Procedure

Verification Authority: Jonathan Serbest (Safety Officer)
Lead: Case Dyer (Payload Officer)

**GENERAL PPE REQUIRED:**

- Closed-toe shoes
- Safety glasses
- Gloves

- ☐ Verify the mechanical separation assembly is correctly assembled, with all fasteners properly installed, torqued, and secured.
- ☐ Verify all gear system shafts are in proper alignment and all gears are properly fastened to the shafts.
- ☐ Ensure payload sleeve is properly threaded onto separation power screws and in the proper orientation based on the orientation control system
- ☐ Ensure payload sleeve can be inserted easily into Body 1 and Upper Transition Coupler.

- ☐ Verify all payload fasteners are tight and safety checked.

1. **Confirm the retention system is engaged** – Ensure that the retention system and microcontroller are connected and power is present.

- ☐ Verify the water applicator system is secured and leak-free.
- ☐ Verify the payload is installed into the forward body tube and oriented correctly.
- ☐ Verify payload wiring is secured, strain-relieved, and free of pinch points.
- ☐ Verify the forward body tube is properly sealed.
- ☐ Verify payload batteries are charged to greater than 90%.
- ☐ Verify all electronic connections and solder joints are intact.

2. **Power on the payload and verify successful boot of the payload computer** – Communication between the mechanical and electrical are paramount in ensuring satisfaction.

    -  Verify voltage levels are within nominal operating limits.
    -  Verify means to log data is present.
    -  Verify tracking system functionality.
    -  Verify the mechanical linkage actuates correctly.
    -  Ensure red LED stays on for 3 seconds when initially turning on device. This indicates the device is in stand by and setting all necessary conditions
    -  Ensure red LED blinks every 20 seconds indicating the system sense proper contact and thus is in waiting mode for the separation of the drogue.
    -  Simulate the breaking of contact and the systems response of 2 blinks every 5 seconds.
    -  Verify system initiates payload deployment after proper time delay of drogue separation by red LED blinking four times slowly. This indicates system has begun the deployment sequence for the payload and moving to drilling and testing phase
    -  Ensure indication LED displays all are occurring properly and in proper timing during drilling procedure indicating both drilling cycles and also breaks of the cycles for soil testing.

3. **Cycle the drill mechanism through its full range of motion** – This is to make sure that drill is capable of expected movement to critical positions. This can be done by physically operating the linkage through its entire expected path of movement.

    -  Verify drill motor direction and operation.
    -  Ensure indicator red LED blinks for each cycle of drilling

4. **Perform full payload test -** This is to make sure all system work together properly an the payload can successfully collect and test the required soil quantity within the allotted time.

- Initiate system operation
- Observe all red LED indication blinks and time periods
- Verify break contact system functions and initiates payload deployment procedures
- Verify payload turns away from rocket deployment
- Verify payload initiates drilling by turning on the drill motor
- Verify payload linkage system actuates and presses the auger sufficiently into the soil
- Ensure linkage reverses and ejects collected soil into container
- Ensure drilling cycle occurs four times before payload moves to testing and verification phase
- Verify payload saturates soil container with proper quantities of water
- Verify payload displays pH testing LED sequences
- Allow payload to continue to operate till operation termination has been initiated by the payload due to detection of sufficient soil
- Allow system to collect longer streams of pH data
- Test completed
- Check SD card for stored pH and temperature data, examine corrected pH.

5. **Perform a no-load test of separation motors –** To verify that separation system is in working order before launch, engage motor drivers to spin all motors.

6. **Initiate mechanical separation test –**

    a. Verify nose cone cannot be removed due to the worm gear retention

    b. Verify orientation stepper motor rotates the assembly to the correct deployment position.

    c. Verify separation stepper motors extend to the designed deployment length.

- Verify the mechanical separation system pushes out, pushes off nose cone, pushed out payload retention sleeve, and rotates assembly into proper payload release position.

7. **Inspect all components** - Looking for signs of overheating, abnormal wear, or damage.

- Re-verify battery state of charge, voltage, and current draw.
- Verify no abnormal power consumption is present.
- Verify mechanical separation assembly is securely mounted to the rocket airframe.

- ☐ Ensure payload is snug within separation retention sleeve and Body tube 1 and Upper transition coupler. If necessary, insert "dog barf" into assembly to ensure payload has minimal side to side motion.

8. **Re-initiate mechanical separation test with payload or proper simulation mass** – to confirm system readiness for flight.

I certify that all steps in this procedure have been completed in accordance with the documented instructions. I acknowledge that the procedure has been reviewed in full and that all required safety and operational checks have been performed to the best of my knowledge.

Verification Authority Only

**Name:** ___________________________
**Position/Role:** __________________
**Signature:** ______________________
**Date:** ____________________________

### 6.5.3. Rocket Assembly Preparation and Verification Procedure

Authority Responsible: Jonathan Serbest (Safety Officer)
Lead: Krieg Conrad (Project Lead) and Austin Zaal (Recovery Officer)

**GENERAL PPE REQUIRED:**

- Closed-toe shoes
- Safety glasses
- Gloves

☐ Identify all Airframe Components
- ☐ Body Tube 1 (With Nosecone & Sep Mechanism)
- ☐ Transition
- ☐ AV Coupler
- ☐ Body Tube 2
- ☐ Body Tube 2-3 Coupler
- ☐ Body Tube 3 (w/motor tube & fins)
- ☐ RMS

☐ Identify all Avionics Components

☐ Avionics Bay Plate (w/retaining bolts & nuts)
☐ Avionics Bay Computers (Telemetrum & EZ Mini)
☐ Avionics Bay Batteries (2x 9V LiPo)
☐ 15” Drogue Parachute
☐ 120” Main Parachute
☐ Shock Cords 1&2 (40’ long)
☐ Reefing Cord (117” long)
☐ 38g $CO_2$ Canister (2x)
☐ 25g $CO_2$ Canister
☐ 48g $CO_2$ Canister
☐ TR Eagle Kit
☐ 8x E-Matches

☐ Identify All Reefing Components
☐ Reef Plate
☐ Telemetrum & EZ Mini
☐ 9V LiPo (2x)
☐ TR Mako Kit

☐ Ensure all Recovery Software is functioning and prepared for launch.
☐ Program the Telemetrum Flight Computer (AV Bay) to initiate drogue event at Apogee +1 seconds, and the main event at 1000 ft
☐ Program the EZ Mini Flight Computer (AV Bay) to initiate drogue event at Apogee +2 seconds, and the main event at 950 ft
☐ Program the Telemetrum Flight Computer (Reef Bay) to initiate “main” event at 650 ft
☐ Program the EZ Mini Flight Computer (Reef Bay) to initiate “main” event at 600 ft

☐ Ensure all recovery-dependent components and hardware are functioning and prepared for launch.
☐ Attach all computers/batteries to their respective AV & Reef plates
☐ Ensure AV Screw Switch is turned OFF
☐ Prepare all 4 TR Eagle Devices for AV Bay assembly
☐ Assemble AV Bay, ensuring the Screw Switch is aligned with its access port
☐ Thread 2-4 E-Matches through the aft bulkhead and attach them to the respective computers
☐ Insert the AV Plate over the motor tube on Body Tube 3
☐ Insert the Aft Coupler onto Body Tube 3
☐ Thread the Reef Line through the Main Parachute, attach the Mako, and tie off the line
☐ Attach a Shock Cord to the RMS Eyebolt, and thread it through Body Tube 2

☐ Fold the Main Parachute and attach it to the RMS Eyebolt
☐ Insert the Main Parachute into Body Tube 2
☐ Attach the other end of the previously mentioned Shock Cord to the AFT end of the AV Coupler
☐ Carefully coil the previously mentioned Shock Cord into Body Tube 2, and insert the AV Bay
☐ Screw in the AV Bay to Body Tube 2, ensuring all screw holes/ports are aligned
☐ Attach the second Shock Cord to the forward AV Eyebolt and thread it through the Transition
☐ Screw the Transition to the AV Bay, ensuring all screw holes/ports are aligned
☐ Ensure the Separation Mechanism is properly in place and operational inside the nosecone
☐ Insert the payload into the Separation Mechanism after verification of operation
☐ Attach the other end of the second Shock Cord to the Eyebolt on Body Tube 1
☐ Fold and Attach the Drogue Parachute to the Eyebolt on Body Tube 1
☐ Carefully wind the second Shock Cord into Body Tube 2
☐ Attach and Screw Body Tube 1 onto Body Tube 2
☐ Ensure all components of the rocket are in order before launch
☐ Install Shear Pins
☐ Install First Set of Shear Pins
☐ Install shear pins at all designated joints
☐ Verify pins are fully seated and secure
☐ Install Second Set of Shear Pins
☐ Install shear pins at all remaining designated joints
☐ Verify proper shear pin count and placement
☐ Inspect Vent Ports
☐ Verify all vent holes are clear and unobstructed
☐ Ensure vent holes align with avionics bay requirements

☐ Verify and simulate final properties of rocket assembly
- ☐ Weigh the dry mass of the final rocket assembly
- ☐ Weigh the final rocket assembly
- ☐ Simulate final flight patterns with the final rocket weight using OpenRocket
  - ☐ Perform Stability Measurements
  - ☐ Add ballast weight if necessary

☐ Measure and mark Center of Pressure (CP)

☐ Measure and mark Center of Gravity (CG)

I certify that all steps in this procedure have been completed in accordance with the documented instructions. I acknowledge that the procedure has been reviewed in full and that all required safety and operational checks have been performed to the best of my knowledge.

Verification Authority Only

**Name:** ___________________________
**Position/Role:** __________________
**Signature:** ______________________
**Date:** ____________________________

### 6.5.4. Motor Preparation

Verification Authority: Jonathan Serbest (Safety Officer)
Lead: Elizabeth Gildersleeve (Team Mentor)

**Note**: Reloadable motor kit shall not be removed from manufacturer packaging until team is ready to install the motor into the reloadable motor system (RMS) and ready to proceed with launch upon competition. During the process of motor preparation and loading, the motor shall be handled by the NAR/TRA team mentor, Elizebeth Gildersleeve and accompanied by the team Safety Officer, Jonathan Serbest.

**GENERAL PPE REQUIRED:**

- Safety glasses
- Nitrile or latex gloves
- Closed-toe shoes

**PRELIMENARY PROCEDURE:**

**Ensure Locational Safety** – Before continuing further, the nature of the following steps includes highly explosive material. In accordance with NAR/TRA, NFPA 1127, and ATF 27 CFR, motor preparation shall not be within "50 feet of any smoking, matches, open flames, and spark producing devices" (27 CFR 555.212).

**RMS Inspection** – RMS must be fully capable of housing the specified motor. This means that the RMS must be clean and without any internal impedance, blocking the motor from being installed. If inspection reveals a defect, the motor shall not be installed until the issue is resolved.

**Motor Kit Inspection –** Remove motor from manufacturer sealed packaging and begin inspecting all components of the kit. The kit must pass a detailed inspection before use. Possible defects include but are not limited to indentions, incisions, tears, missing components, and leaking solid propellant.

**Failure to complete the preliminary procedure will result in the stoppage from advancing to the procedure until satisfied.**

**PROCEDURE:**

1. **Load Motor into RMS –** Using the instructions included in the Kit, install the motor into the RMS. During this time, the team safety officer must survey the area, continuing to make sure that the area utilized is an ignition-free zone.
2. **Load RMS into Rocket** – Once the team mentor has successfully installed the motor and additional components into the RMS, insert the RMS into the bottom of the rocket and push until the top of the RMS is pressed firm against the bottom of the lower bulkhead.
3. **Secure the RMS into Rocket** – Once the RMS is pressed firmly into place, screw the boattail onto the threaded end of the aft. When fully screwed on, the boat tail presses against the bottom of the RMS and secures it in place.

   **RMS and Boat-tail Inspection** – Make sure that both RMS and Boattail are ridged and mated together

**Do not insert igniter. This will be done once the rocket is attached to the launch rod and resting in its vertical position on the launch pad.**

I certify that all steps in this procedure have been completed in accordance with the documented instructions. I acknowledge that the procedure has been reviewed in full and that all required safety and operational checks have been performed to the best of my knowledge.

Verification Authority Only

**Name:** ___________________________

**Position/Role:** ___________________

**Signature: ______________________**
**Date: ___________________________**

### 6.5.5. Setup on the launch pad

Verification Authority: Krieg Conrad (Project Lead)
Lead: Jonathan Serbest (Safety Officer)

**GENERAL PPE REQUIRED:**

- Safety glasses
- Nitrile or latex gloves
- Closed-toe shoes

1. **Disarmed Electronics Verification** – Look to step one of the *Recovery and Respective Electronics Preparation* for procedure information.
2. **Ensure Electronic are disabled** - Ensure that any onboard energetics and firing circuits of any kind are to be disabled until the rocket is firmly fixed to the launch rod and in its vertical orientation on the launch pad. NFPA 1127 (4.13.7)
   This applies to:
   a. Avionics Bay
   b. Reefing system (if applicable)
   c. Payload Vehicle
   d. Payload Mechanical Separation
3. **Rocket Transport** – Once the rocket is prepared for launch, 3 team members, similar in shoulder height, will begin to carry the rocket to the designated launch rod.
4. **Securing the Rocket to Launch Rod –** The rail buttons are located on the outside of the rocket air frame and will slide into the launch rod grove. This groove runs up the entirety of the rod. Once inserted, secure the rocket at rest, to the bottom of the pad.
5. **Initiate Payload and Separation Power Systems** – Power to payload rover and mechanical separation systems must be initiated using mechanical switches. These systems then wait for activation protocol within the software to be carried out.
6. **Arm Energetics and Firing Systems** – Using key cylinder switch, all electronic within the avionics bay must be armed. During the arming of all onboard energetics and firing circuits, there shall be no participants or spectators of any kind near the launch pad other than authorized personnel tending to the arming and disarming operations.
7. **Installing the Electrical Motor Igniters** – Once the rocket is in the correct orientation, install the motor igniters into the motor. Please see the "*Igniter installation*" section for information on proper installation procedure. A safety interlock is required to be wired in series, and the launch switch shall not be installed until the rocket is ready for launch.

I certify that all steps in this procedure have been completed in accordance with the documented instructions. I acknowledge that the procedure has been reviewed in full and that all required safety and operational checks have been performed to the best of my knowledge.

Verification Authority Only

**Name:** ___________________________
**Position/Role:** __________________
**Signature:** ______________________
**Date:** ___________________________

## 6.5.6. Igniter Installation

Authority Responsible: Jonathan Serbest (Safety Officer)
Lead: Elizabeth Gildersleeve (Team Mentor)

**GENERAL PPE REQUIRED:**

- Closed-toe shoes
- Safety Glasses

**1. Rocket Transport** – The safety officer will carry the motor igniter as the rocket is being transported to the launch pad. Once the rocket is attached to the launch rod and in place, igniter installation can begin. Diagram below is provided by ESTES.

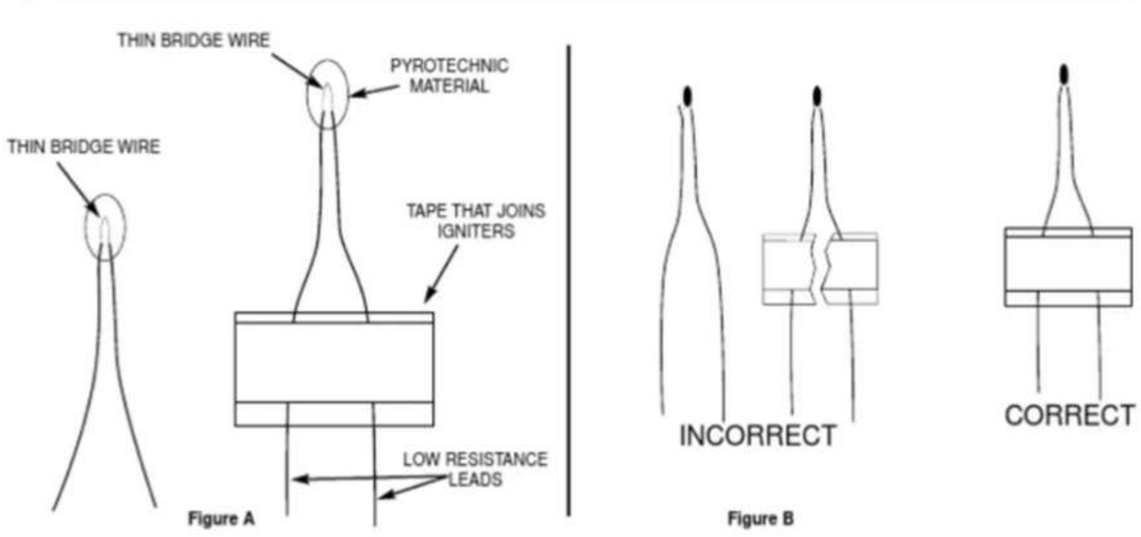


*Figure 6-13 Igniter Installation Guide*

1. **Igniter Installation** – Insert the igniter end into the base of the rocket motor. This should be inserted until the igniter reaches the top of the motor opening.
2. **Tape Leads** – Leads must be separated from each other and taped to prevent contact. This is to prevent pre-detonation.
3. **Tape Leads to Rocket Base** – To keep the igniter pressed to the top of the motor, bend the ends of the exposed wire over the base of the rocket and tape to the air frame.
4. **Lead Connection** – Connect each lead to separate alligator clips and the alligator clip wires to the ignition system.

I certify that all steps in this procedure have been completed in accordance with the documented instructions. I acknowledge that the procedure has been reviewed in full and that all required safety and operational checks have been performed to the best of my knowledge.

Verification Authority Only

**Name:** ___________________________
**Position/Role:** ___________________
**Signature:** ______________________
**Date:** ____________________________

### 6.5.7. Launch

Verification Authority: Krieg Conrad (Project Lead)
Lead: Jonathan Serbest (Safety Officer)

At launch, rocket is in place and inspection has deemed the rocket adequate for flight through the use of the defined procedure/checklists and verified through respective documentation and AHJ confirmation including the team mentor, Elizebeth Gildersleeve and RSO.

Note: All sanctioned launch areas by NAR / TRA are to have proper safety accommodation based on all AHJ.

- ☐ **Confirmation of area safety and shutdown to launch** – Area is deemed safe when location of all participants and spectators meet the minimum distance table, provided by NAR High Power Rocket Safety Code highlighted below.

MINIMUM DISTANCE TABLE

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

Note: A Complex rocket is one that is multi-staged or that is propelled by two or more rocket motors
Revision of August 2012

After the area is deemed to be safe for launch, a five second countdown will be used before launch initiation.

- **Verify Rocket Stability** –Verify rocket stability on the launch pad and firmly coupled to the launch rod. If stability is inadequate, launch of the rocket must not proceed and must be cancelled until future notice.

1. **Watch Rocket** – It is crucial that the team and nearby spectators are always informed of the rocket's location throughout the length of its flight. Pointing to its location will be employed to inform the location of the rocket.
2. **Stay clear of rocket until it has hit the ground** – There shall not be an attempt to catch the rocket while descending or retrieving the rocket in areas of hazard like powerlines or on top of trees. If the rocket lands on a powerline, local AHJ shall be called. NFPA 1127 (4.10.4-6).

I certify that all steps in this procedure have been completed in accordance with the documented instructions. I acknowledge that the procedure has been reviewed in full and that all required safety and operational checks have been performed to the best of my knowledge.

Verification Authority Only

**Name:** ____________________________
**Position/Role:** ___________________
**Signature:** _______________________
**Date:** _____________________________

## 6.6. Troubleshooting

### 6.6.1. No continuity detected during testing:

**GENERAL PPE REQUIRED:**
- Safety glasses
- Nitrile or latex gloves
- Closed-toe shoes

1. Take apart avionics bay where electronics are visible.
2. Visibly inspect e-matches and connections.
   a. Verify match wire are completely intact.
   b. Verify match wires are secure within screw terminals.
   c. Verify match wires are in correct screw terminals.

I certify that all steps in this procedure have been completed in accordance with the documented instructions. I acknowledge that the procedure has been reviewed in full and that all required safety and operational checks have been performed to the best of my knowledge.

Verification Authority Only

**Name:** ____________________________
**Position/Role:** ___________________
**Signature:** _______________________
**Date:** _____________________________

### 6.6.2. No connection between TeleBT and TeleMetrum for Testing

1. Unplug TeleBT from computer and close AltOS.
   a. Plug TeleBT back into computer.
   b. Verify battery is plugged into TeleBT
   c. Try connection again using the “Monitor Idle” menu option.
   d. Wait 60 seconds for connection.

2. Remove electronics from avionics bay
   a. Verify power is delivered to flight computer by ensuring light is on.
   b. Visually inspect antenna solder joint.
   c. Place electronics back in avionics bay.

I certify that all steps in this procedure have been completed in accordance with the documented instructions. I acknowledge that the procedure has been reviewed in full and that all required safety and operational checks have been performed to the best of my knowledge.

Verification Authority Only

**Name:** ____________________________
**Position/Role:** ___________________
**Signature:** _______________________
**Date:** _____________________________

## 6.7. Post-Launch

Verification Authority: Krieg Conrad (Project Lead)
Lead: Jonathan Serbest (Safety Officer)

**GENERAL PPE REQUIRED:**

- Safety glasses
- Nitrile or latex gloves
- Closed-toe shoes

3. **Confirm recovery location –**
   • Establish visual contact with the vehicle
   • Acquire and verify GPS signal

4. **Recover vehicle –**
   • Approach vehicle cautiously from upwind
   • Verify no visible hazards (smoke, heat, damaged components)
   • Secure the vehicle

5. **Safe all systems –**
   • Power down all avionics and payload electronics
   • Verify no energetic devices are armed

**6. Inspect energetics and hardware –**
- Inspect for residual black powder or ejection charge debris
- Verify no unintended ignition or damage occurred

**7. Retrieve flight data –**
- Remove data storage devices
- Verify successful data retrieval

I certify that all steps in this procedure have been completed in accordance with the documented instructions. I acknowledge that the procedure has been reviewed in full and that all required safety and operational checks have been performed to the best of my knowledge.

<u>Verification Authority Only</u>

**Name:** ___________________________
**Position/Role:** ___________________
**Signature:** _______________________
**Date:** ____________________________

# 7. Project Plan

## 7.1. Testing

### 7.1.1. Launch Vehicle Testing

### 7.1.2. Launch Vehicle – Required Testing Plan

| Test ID | Test Name | Objective | Variable(s) | Method | Status |
|---|---|---|---|---|---|
| LV-MAT-01 | Inconel 718 Material Testing | Verify Material Properties are sufficient | Post-Processing, Load | Tension and Torsion Tests | Partially Complete |
| LV-MAT-02 | Cord Material Test | Verify shock cord withstands deployment loads | Cord type, Load | Tension tests | Complete |
| LV-DEP-01 | Full-Scale Drogue Deployment Verification | Verify reliable drogue deployment | CO2 Canister sizing | Ground deployment Test | Complete |
| LV-DEP-02 | Full-Scale Main Deployment Verification | Verify main parachute deployment | CO2 Canister sizing | Ground deployment Test | Complete |
| LV-DEP-03 | Reefing Line Cutter Actuation Test | Verify cutter reliability under load | Cutter charge mass | Bench / ground test | Complete |
| LV-DEP-04 | Sub-Scale Drogue Deployment Verification | Verify reliable drogue deployment | CO2 Canister sizing | Ground deployment test | Complete |
| LV-DEP-05 | Sub-Scale Main Deployment Verification | Verify main parachute deployment | CO2 Canister sizing | Ground deployment test | Complete |
| LV-AV-01 | Avionics Arming & Continuity Test | Verify arming logic and wiring continuity | Arming state | Bench test & inspection | Complete |
| LV-AV-02 | Deployment Channel Output Verification | Verify altimeter firing channels | Channel configuration | Bench test | Complete |
| LV-AV-03 | Battery Endurance Verification | Verify power margin for mission duration | Load profile | Bench test | Complete |
| LV-SFT-01 | Flight Test #1 – Baseline Configuration | Identify integration & recovery failure modes | Baseline | Flight test | Complete |
| LV-SFT-02 | Flight Test #2 – No Reefing Configuration | Validate recovery without reefing | No Reefing | Flight test | Complete |
| LV-SFT-03 | Flight Test #3 – Reefed Configuration | Validate full recovery system | Reefed | Flight test | Complete |
| LV-FFT-01 | Flight Test #1 – Baseline Configuration | Identify integration & recovery failure modes | Baseline | Flight test | Complete |

| | | | | | |
|---|---|---|---|---|---|
| LV-FFT-02 | Flight Test #2 – Final Configuration | Validate recovery and flight | Payload Onboard | Flight test | Planned |

## 7.1.3. Launch Vehicle Testing – Success Criteria and Justifications

| Test Number | Test Name | Success Criteria | Justification |
|---|---|---|---|
| LV-MAT-01 | Inconel 718 Material Testing | Data provides sufficient information to confirm that Inconel bulkhead material properties meet structural design requirements. | Bulkheads serve as critical load-bearing components during parachute deployment. Material testing verifies that the printed Inconel 718 bulkheads possess sufficient strength and stiffness to withstand predicted recovery loads with acceptable safety margin. |
| LV-MAT-02 | Cord Material Test | Test data provides sufficient information to determine a shock cord material capable of withstanding predicted deployment loads without rupture or excessive elongation. | The shock cord connects rocket sections during recovery and experiences high dynamic loads during parachute deployment. Failure of this component would result in vehicle separation and mission failure. |
| LV-DEP-01 | Full-Scale Drogue Deployment Verification | Drogue parachute deploys cleanly and consistently without entanglement or incomplete separation. | Reliable drogue deployment is necessary to stabilize the vehicle during the initial recovery phase and reduce descent velocity prior to main parachute deployment. |
| LV-DEP-02 | Full-Scale Main Deployment Verification | Main parachute deploys fully with clean separation and no structural damage. | The main parachute provides the final descent control and ensures the launch vehicle lands safely within allowable landing energy limits. |
| LV-DEP-03 | Reefing Line Cutter Actuation Test | Cutter successfully severs reefing line under representative tension loads. | The reefing system controls parachute opening rate and reduces peak loads on the vehicle. Reliable cutter actuation is required to transition from reefed to full parachute deployment. |
| LV-DEP-04 | Subscale Drogue Deployment Verification | Drogue parachute deploys cleanly during ground testing. | Ground validation of the drogue system reduces risk prior to flight testing and confirms packing configuration and deployment energy requirements. |
| LV-DEP-05 | Subscale Main Deployment Verification | Main parachute deploys consistently during ground testing without tangling or incomplete inflation. | Ground deployment testing confirms that parachute packing and deployment configuration function reliably before subscale flight testing. |
| LV-AV-01 | Avionics Arming & Continuity Test | Correct arming indication and full electrical continuity across deployment circuits. | Proper avionics operation is required to trigger recovery events. This test verifies that electrical connections and arming logic function correctly prior to flight. |

| | | | |
|---|---|---|---|
| LV-AV-02 | Deployment Channel Output Verification | Deployment channels produce correct firing output at programmed events. | Verifying altimeter output ensures deployment charges will activate at the correct flight conditions, preventing recovery system failure. |
| LV-AV-03 | Battery Endurance Verification | Battery supports at least 150% of the expected mission duration under representative loads. | Adequate power margin ensures avionics remain operational throughout the entire flight and recovery sequence. |
| LV-SFT-01 | Subscale Flight Test #1 – Baseline Configuration | Flight provides sufficient data to identify integration and recovery failure modes. | Initial flight testing is intended to evaluate the integrated launch vehicle system and identify unexpected interactions between subsystems. |
| LV-SFT-02 | Subscale Flight Test #2 – No Reefing Configuration | Rocket exhibits stable flight and nominal recovery system performance. | This test isolates recovery system performance without reefing in order to evaluate baseline recovery behavior. |
| LV-SFT-03 | Subscale Flight Test #3 – Reefed Configuration | Rocket demonstrates stable flight and successful staged recovery sequence. | This flight validates the full recovery system configuration prior to implementation in the full-scale vehicle. |
| LV-FFT-01 | Full-Scale Flight Test #1 – Baseline Configuration | Flight produces stable ascent and provides data to identify integration issues. | The first full-scale flight validates the integrated vehicle and identifies final system integration issues prior to final configuration flight. |

### 7.1.4. Launch Vehicle Testing – Resultant Effects

Results from the launch vehicle testing program directly informed several design decisions and refinements to the Terra Nova launch vehicle. The following sections summarize the design impacts associated with each completed test.

**LV-MAT-01 – Inconel 718 Material Testing**

**Methodology:**

Additively manufactured Inconel 718 specimens were subjected to torsion testing using laboratory test equipment. Samples were loaded incrementally while recording applied force and resulting deformation in order to characterize elastic behavior and verify that the material properties were consistent with the assumptions used in the launch vehicle structural analysis.

**Predicted Result:**

The material was expected to exhibit mechanical behavior consistent with published Inconel 718 material properties and demonstrate sufficient stiffness and strength to support the predicted recovery system loads with an adequate safety factor.

**Actual Result:**

Testing demonstrated behavior exceeding expected Inconel 718 performance. The fracture point far exceeded the expected fracture point in torsion (still waiting on stronger equipment to test in tension).

**Success Determination:**
Partial Success.

**Discussion and Lessons Learned:**
The test confirmed that the printed Inconel material can behave as the structural components used in the recovery system. The results were sufficient to support design decisions, although future testing with higher-capacity equipment will be conducted to fully characterize the ultimate strength of the material.

**LV-MAT-02 – Cord Material Test**

**Methodology:**
Multiple candidate recovery harness materials were subjected to controlled tensile loading using a laboratory test frame. Each cord sample was incrementally loaded until either failure occurred. The test measured tensile strength, elongation under load, and overall failure behavior in order to evaluate suitability for use in the rocket recovery harness.

**Predicted Result:**
At least one candidate cord material would demonstrate sufficient tensile strength and acceptable elongation characteristics to safely withstand the loads experienced during parachute deployment.

**Actual Result:**
Paramax and Kevlar cord materials demonstrated sufficient tensile strength and acceptable elongation characteristics. The 550 paracord exhibited significantly greater elongation under load than the other materials tested and was determined to be unsuitable for recovery harness use.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
Testing demonstrated that elongation behavior is a critical factor in recovery harness design in addition to ultimate tensile strength. Excessive elongation can lead to undesirable recovery dynamics and increased structural loads during parachute deployment. Based on the results of this testing, Paramax was selected as the primary recovery harness material due to its favorable strength and elongation characteristics.

**LV-DEP-01 – Full-Scale Drogue Deployment Verification**

**Methodology:**
The full-scale drogue recovery system was assembled in a flight-representative configuration including parachute packing, harness routing, and recovery bay hardware. Ground deployment

tests were performed using the $CO_2$ deployment system while observing separation behavior, parachute extraction, and inflation characteristics. Multiple trials were conducted to verify consistent deployment performance.

**Predicted Result:**
The drogue parachute was expected to deploy cleanly and consistently without entanglement, incomplete extraction, or interference with surrounding recovery hardware.

**Actual Result:**
During ground deployment testing, the drogue parachute consistently extracted from the recovery bay and deployed without entanglement or incomplete inflation. Separation between vehicle sections occurred as expected.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
The testing confirmed that the selected drogue parachute packing procedure and $CO_2$ deployment configuration provide sufficient deployment energy for reliable operation. The test also reinforced the importance of maintaining consistent packing procedures to ensure repeatable deployment performance.

**V-DEP-02 – Full-Scale Main Deployment Verification**

**Methodology:**
The full-scale main recovery system was assembled in a flight-representative configuration including the parachute, shock cord routing, deployment hardware, and recovery bay components. The parachute was packed using the intended flight packing procedure and deployed using the $CO_2$ deployment system during ground testing. Multiple deployment trials were conducted to observe extraction behavior, line extension, canopy inflation, and section separation.

**Predicted Result:**
The main parachute was expected to deploy cleanly from the recovery bay, extend all suspension lines without tangling, and inflate without obstruction or structural interference.

**Actual Result:**
Ground deployment tests showed that the main parachute consistently extracted from the recovery bay and fully extended its suspension lines. No tangling or interference with recovery hardware was observed. There were some failed deployments but were attributed to user error.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
The testing confirmed that the selected parachute packing procedure and deployment configuration provide reliable main parachute deployment. The test also allowed the team to refine packing techniques and verify that the $CO_2$ canister size provides sufficient deployment energy for consistent parachute extraction.

**LV-DEP-03 – Reefing Line Cutter Actuation Test**

**Methodology:**
The reefing line cutter was installed in a representative recovery configuration with the reefing line placed under tension similar to expected parachute loading conditions. Bench tests were conducted by activating the cutter using the intended electrical firing circuit. Multiple trials were performed while varying the cutter charge mass to determine the minimum charge required for reliable severance of the reefing line.

**Predicted Result:**
The cutter was expected to reliably sever the reefing line when activated, allowing the parachute to transition from a reefed configuration to full inflation.

**Actual Result:**
During testing, the cutter successfully severed the reefing line in each trial using the selected charge mass configuration. The cut occurred rapidly and cleanly with no partial severance or delayed actuation observed.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
Testing demonstrated that proper charge sizing and installation orientation are critical factors in achieving reliable cutter performance. The results allowed the team to finalize the cutter charge mass used in the recovery system and confirmed that the reefing mechanism will reliably transition the parachute to full deployment during flight.

**LV-DEP-04 – Sub-Scale Drogue Deployment Verification**

**Methodology:**
The subscale drogue recovery system was assembled in a flight-representative configuration and packed using the same packing procedure intended for flight. Ground deployment testing was conducted to observe parachute extraction behavior and section separation. Multiple deployment trials were performed to ensure repeatable results.

**Predicted Result:**
The drogue parachute was expected to extract cleanly from the recovery bay and deploy without tangling or incomplete inflation.

**Actual Result:**
The drogue parachute consistently deployed during ground testing and achieved full canopy extension without entanglement. Separation between rocket sections occurred as expected.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
The results confirmed that the subscale recovery configuration performs as expected and provided confidence in the drogue packing procedure used for flight testing. These ground tests helped validate the recovery configuration prior to conducting subscale flight tests.

**LV-DEP-05 – Sub-Scale Main Deployment Verification**

**Methodology:**
The subscale main parachute recovery system was assembled in a flight-representative configuration including the parachute, harness routing, and deployment hardware. The parachute was packed using the same packing method intended for subscale flight testing. Ground deployment tests were conducted using the recovery system deployment hardware to observe parachute extraction, line extension, canopy inflation, and vehicle section separation. Multiple trials were performed to verify repeatability of the deployment behavior.

**Predicted Result:**
The parachute was expected to deploy cleanly from the recovery bay with full suspension line extension and canopy inflation without tangling or interference with the vehicle structure.

**Actual Result:**
During ground testing the parachute consistently extracted from the recovery bay and deployed without tangling. Suspension lines extended fully and the canopy inflated as expected during each trial.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
The ground tests confirmed that the parachute packing configuration and recovery hardware produce reliable deployment behavior for the subscale vehicle. These tests helped validate the recovery system configuration prior to flight testing and provided confidence that the system would perform as intended during subscale flights.

**LV-AV-01 – Avionics Arming & Continuity Test**

**Methodology:**
The launch vehicle avionics system was assembled in a flight-representative configuration including the altimeters, power system, wiring harnesses, and deployment circuits. The system

was repeatedly cycled between safe and armed states while performing electrical continuity checks across the recovery system firing circuits. The arming indicators and electrical connections were monitored to verify correct behavior.

**Predicted Result:**
The avionics system was expected to correctly indicate safe and armed states while maintaining electrical continuity across all deployment circuits without intermittent connections.

**Actual Result:**
The avionics system correctly detected arming states and maintained electrical continuity across all deployment circuits during testing. No intermittent connections or wiring faults were observed.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
The test verified that the avionics wiring and arming logic function correctly and that all deployment circuits are electrically continuous. During testing, minor improvements were made to wiring strain relief and connector retention to further improve reliability during flight operations.

**LV-AV-02 – Deployment Channel Output Verification**

**Methodology:**
Each deployment channel of the altimeter was tested individually using representative electrical loads to simulate deployment charges. The altimeter was configured with the intended deployment parameters and triggered under controlled conditions while monitoring the output signal to confirm proper firing behavior.

**Predicted Result:**
Each deployment channel was expected to produce the correct firing signal at the programmed event condition, delivering sufficient current to activate the deployment device.

**Actual Result:**
During bench testing the altimeter channels produced the correct firing outputs when the programmed conditions were met. The output signals were sufficient to activate the simulated deployment loads.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
This test confirmed that the altimeter deployment channels function correctly and that the configuration parameters used for recovery events are properly programmed. Verifying

deployment channel output prior to flight helps reduce the risk of recovery system failure due to electrical misconfiguration.

**LV-AV-03 – Battery Endurance Verification**

**Methodology:**
The avionics battery system was connected to the full flight avionics stack, including altimeters, sensors, and any associated electronics, to simulate the electrical load experienced during a typical mission. The battery was operated continuously and system functionality over a duration exceeding the expected mission timeline. The test included simulated pre-launch idle time, ascent, descent, and post-landing data logging periods.

**Predicted Result:**
The battery system was expected to support continuous avionics operation for at least 150% of the expected mission duration while maintaining voltage levels within the operating range of the avionics hardware.

**Actual Result:**
During testing, the battery successfully powered the avionics system for longer than 24 hours.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
The battery endurance test confirmed that the selected battery configuration provides sufficient power margin to support the full mission timeline, including pre-launch delays and post-landing operations. The test also reinforced the importance of monitoring voltage levels during extended operation to ensure that avionics components remain within their required operating voltage range.

**LV-SFT-01 – Flight Test #1 – Baseline Configuration**

**Methodology:**
The baseline subscale launch vehicle configuration was flown in order to evaluate integrated vehicle performance and validate aerodynamic and recovery system behavior. The rocket was equipped with onboard avionics to record altitude, acceleration, and deployment events. Flight performance was also observed visually and documented through ground-based video. Following recovery, the vehicle was inspected for structural damage and recovery system performance.

**Predicted Result:**
The vehicle was expected to demonstrate stable ascent, achieve an apogee altitude consistent with simulation predictions, and perform a nominal dual-deployment recovery sequence consisting of drogue deployment at apogee followed by main parachute deployment at the programmed altitude.

**Actual Result:**
The rocket achieved stable ascent and reached an altitude close to the predicted apogee. However, a drogue deployment non-fire event occurred, resulting in an failed recovery sequence and higher-than-expected descent velocity. The vehicle sustained structural damage due to the abnormal recovery conditions.

**Success Determination:**
Failure.

**Discussion and Lessons Learned:**
Although the flight validated aerodynamic stability and confirmed the accuracy of the simulation models, the drogue deployment failure revealed a critical issue in the recovery system configuration. Post-flight inspection identified weaknesses in certain structural components and highlighted the need for improved avionics verification procedures prior to launch. As a result of this flight, several structural components were redesigned and additional pre-flight avionics checks were implemented to improve system reliability.

**LV-SFT-02 – Flight Test #2 – No Reefing Configuration**

**Methodology:**
The second subscale flight was conducted with the reefing system removed in order to isolate baseline recovery system performance. The rocket was launched in a configuration similar to the first flight but without the reefing mechanism installed. Onboard avionics recorded flight telemetry while visual observations and video documentation were used to monitor recovery behavior. The vehicle was inspected following recovery.

**Predicted Result:**
The rocket was expected to demonstrate stable flight and perform a nominal recovery sequence using the drogue and main parachutes without the influence of the reefing system.

**Actual Result:**
The rocket demonstrated stable ascent and both recovery events occurred as expected. The parachutes deployed successfully and the vehicle descended under control without structural damage.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
This flight confirmed that the recovery system functions reliably in the baseline configuration without reefing. The results provided a useful comparison point for evaluating the effects of the reefing system during later tests. The successful recovery also demonstrated that the improvements implemented following the first subscale flight effectively addressed the previously observed issues.

**LV-SFT-03 – Flight Test #3 – Reefed Configuration**

**Methodology:**
The third subscale flight was conducted with the full recovery system configuration installed, including the reefing mechanism. The vehicle was assembled in the intended flight configuration and launched while onboard avionics recorded altitude, acceleration, and recovery event timing. Visual observations and ground video were used to document parachute deployment behavior. After recovery, the vehicle was inspected to evaluate structural integrity and recovery system performance.

**Predicted Result:**
The rocket was expected to demonstrate stable ascent and a staged recovery sequence in which the drogue parachute deploys at apogee and the main parachute deploys in a reefed configuration before transitioning to full inflation.

**Actual Result:**
The rocket achieved stable ascent and the recovery sequence occurred as intended. The drogue parachute deployed at apogee and the main parachute deployed in a reefed configuration before fully inflating. The vehicle descended under controlled conditions and was recovered without structural damage.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
The successful operation of the reefing system confirmed that the recovery system configuration performs as intended when fully integrated. The staged parachute deployment reduced peak opening loads and resulted in a stable descent profile. The flight provided confidence that the recovery system configuration is suitable for use in the full-scale launch vehicle.

**LV-FFT-01 – Flight Test #1 – Baseline Configuration**

**Methodology:**
The first full-scale flight test was conducted to evaluate the integrated performance of the full-scale launch vehicle. The rocket was assembled in its baseline configuration and launched using the L1395. Onboard avionics recorded flight telemetry including altitude, acceleration, and deployment events. Ground-based observations and video were used to monitor flight behavior. After recovery, the vehicle was inspected to evaluate structural integrity and recovery system performance.

**Predicted Result:**
The rocket was expected to achieve stable ascent, reach an altitude consistent with simulation predictions, and perform a nominal dual-deployment + reefed recovery sequence.

**Actual Result:**
The rocket demonstrated stable ascent and produced flight behavior consistent with aerodynamic stability predictions. Flight telemetry provided valuable data regarding vehicle performance and recovery system operation; however, both the main and drogue deployed at apogee, and the reef line was never cut.

**Success Determination:**
Failed.

**Discussion and Lessons Learned:**
The first full-scale flight successfully validated the integrated launch vehicle configuration. The flight provided valuable flight data that will be used to further refine simulation models and confirm system performance. Failure mode was attributed to an excessive deployment force of the main pulled the tail section off as well as a tangle in the reef line cutter caused the e-match to disconnect.

**LV-FFT-02 – Flight Test #2 – Final Configuration**

**Methodology:**
The second full-scale flight will be conducted using the final launch vehicle configuration including the integrated payload system. The rocket will be launched using the competition motor configuration while onboard avionics record flight telemetry. Recovery system performance will be evaluated using both onboard data and visual observation. Following recovery, the vehicle and payload systems will be inspected to verify structural integrity and system functionality.

**Predicted Result:**
The rocket is expected to demonstrate stable aerodynamic performance and execute a nominal recovery sequence while carrying the payload system. The payload is expected to remain intact and functional following recovery.

**Actual Result:**
Testing pending.

**Success Determination:**
Pending completion of the full-scale final configuration flight test.

**Discussion and Lessons Learned:**
This test will serve as the final validation of the launch vehicle configuration prior to the competition launch. Data collected during this flight will confirm aerodynamic stability, recovery system reliability, and payload integration performance. Any lessons learned from this flight will be incorporated into final launch procedures and vehicle preparation.

### 7.1.5. Payload Testing

### 7.1.6. Payload – Required Testing Plan

| Test ID | Test Name | Objective | Variable(s) | Method | Status |
|---|---|---|---|---|---|
| PL-INT-01 | Separation Mechanism Functional Test | Verify payload releases reliably | Alignment, surface condition | Bench demo | Planned |
| PL-INT-02 | Separation Cycle Test | Verify reliability over repeated use | Cycle count | Bench demo | Planned |
| PL-INT-03 | Post-Landing Deployment Test | Verify deployment after landing-like conditions | Orientation/tilt, surface condition | Flight Test | Planned |
| PL-ELEC-01 | Power-On / Boot Verification | Verify payload reliably powers on and initializes | Battery voltage | Bench test | Complete |
| PL-ELEC-02 | Battery Endurance Test | Verify power margin for mission | Load profile | Bench test | Complete |
| PL-ELEC-03 | Connector / Continuity Verification | Verify wiring integrity | Handling state | Inspection/bench | Complete |
| PL-SW-01 | Data Logging & Timestamp Verification | Verify data retention and timestamp accuracy | Sample rate | Bench test | Planned |
| PL-SW-02 | Full Autonomous Sequence Dry Run | Verify complete mission sequence without errors | Config state | Bench demo | Planned |
| PL-MECH-01 | Soil Acquisition Mechanism Functional Test | Verify collection mechanism operates reliably | Soil type | Bench demo | Complete |
| PL-MECH-02 | Mobility / Actuation Test | Verify actuation/mobility performance | Surface condition | Ground demo | Complete |
| PL-MECH-03 | Containment Integrity Test | Verify sample retained | Orientation/tilt | Inspection/demo | Planned |
| PL-EXP-01 | Soil Volume Collection Verification | Verify minimum sample volume collected | Soil moisture/type | Bench measurement | Complete |
| PL-EXP-02 | pH Calibration Verification | Verify pH accuracy | Buffer solutions | Bench test | Complete |
| PL-EXP-03 | pH Repeatability Test | Verify repeatability of readings | Repeated trials | Bench test | Complete |
| PL-EXP-04 | Full Mission Timeline Test | Verify experiment completion within time limit | Terrain/soil | Ground demo | Planned |
| PL-EXP-05 | End-to-End Integrated Mission Demo | Verify full payload mission flow post-deploy | Configuration | Ground demo | Planned |

| | | | | | |
|---|---|---|---|---|---|
| PL-SURV-01 | Mechanical Survivability Verification | Verify payload mechanisms survive launch & landing | Flight configuration | Flight-derived + inspection | Planned |
| PL-SURV-02 | Electrical/Software Survivability Verification | Verify payload electronics survive launch & landing | Flight configuration | Flight-derived + inspection | Planned |

### 7.1.7. Payload Testing – Success Criteria and Justifications

| Test Number | Test Name | Success Criteria | Justification |
|---|---|---|---|
| PL-INT-01 | Separation Mechanism Functional Test | Payload release mechanism successfully actuates in at least 3 out of 3 trials. | Reliable separation is required for the payload to begin the post-landing mission sequence. Failure to release would prevent the experiment from occurring. |
| PL-INT-02 | Separation Cycle Test | Separation mechanism successfully operates for at least three consecutive cycles without degradation. | Cycle testing verifies the mechanism remains reliable through repeated testing and handling prior to launch. |
| PL-INT-03 | Post-Landing Deployment Test | Payload begins deployment within 45 seconds and experiences no binding failures. | The payload must autonomously deploy after landing regardless of vehicle orientation or terrain conditions. |
| PL-ELEC-01 | Power-On / Boot Verification | Payload boots successfully in at least three consecutive startup attempts. | Reliable startup ensures that the payload electronics begin executing the experiment sequence after landing. |
| PL-ELEC-02 | Battery Endurance Test | Battery capacity supports at least 150% of the expected mission duration. | Adequate battery margin ensures the payload remains operational throughout the entire mission timeline. |
| PL-ELEC-03 | Connector / Continuity Verification | Electrical connections maintain continuity with no intermittent failures. | Electrical integrity is necessary to ensure sensors, actuators, and data logging components operate correctly. |
| PL-SW-01 | Data Logging & Timestamp Verification | All data logs are retained with valid timestamps. | Accurate data logging is required to verify experiment results and demonstrate mission success. |
| PL-SW-02 | Full Autonomous Sequence Dry Run | Payload completes full mission sequence without errors. | End-to-end mission testing confirms that all subsystems function correctly when integrated together. |
| PL-MECH-01 | Soil Acquisition Mechanism Functional Test | Soil collection mechanism successfully collects soil without jamming. | Reliable soil collection is required to obtain a sample for the pH measurement experiment. |
| PL-MECH-02 | Mobility / Actuation Test | Payload actuators operate reliably across representative surface conditions. | Mobility or actuator performance is necessary for proper positioning during soil collection and measurement. |

| | | | |
|---|---|---|---|
| PL-MECH-03 | Containment Integrity Test | Collected soil remains contained with no leakage or spillage. | Sample containment ensures that the collected soil remains available for pH measurement. |
| PL-EXP-01 | Soil Volume Collection Verification | Payload collects at least 50 mL of soil. | Minimum sample volume is required to perform a valid pH measurement. |
| PL-EXP-02 | pH Calibration Verification | pH measurement error is less than or equal to 0.1 pH units. | Calibration verification ensures the scientific accuracy of the experiment results. |
| PL-EXP-03 | pH Repeatability Test | Standard deviation of repeated pH measurements is less than or equal to 0.5. | Repeatability ensures that measurements reflect actual soil properties rather than sensor noise. |
| PL-EXP-04 | Full Mission Timeline Test | Entire experiment completes within 15 minutes. | NASA competition rules require payload experiments to complete within the specified mission time window. |
| PL-EXP-05 | End-to-End Integrated Mission Demo | Payload successfully completes the full experiment sequence after deployment. | Integrated testing confirms that all payload subsystems operate together as intended. |
| PL-SURV-01 | Mechanical Survivability Verification | Payload mechanisms remain functional after flight loads. | Launch and landing loads can damage mechanisms, so survivability must be verified. |
| PL-SURV-02 | Electrical/Software Survivability Verification | Payload powers on and records data successfully after flight. | Electronics must remain operational after flight to ensure mission success. |

### 7.1.8. Payload Testing – Resultant Effects

Results from payload testing have informed several refinements to the payload mechanical systems, electrical architecture, and experiment procedures.

**PL-INT-01 – Separation Mechanism Functional Test**

**Methodology:**
The payload separation mechanism was assembled in a flight-representative configuration and mounted to the payload interface structure. The mechanism was actuated using the intended electrical trigger system while varying alignment conditions and surface contact states to simulate realistic integration tolerances. Multiple trials were conducted to observe the reliability of the separation action and confirm that the payload could disengage cleanly from the launch vehicle interface.

**Predicted Result:**
The separation mechanism was expected to actuate reliably and release the payload cleanly from the launch vehicle interface during each trial without binding or incomplete separation.

**Actual Result:**
Testing is scheduled to be performed using the final payload interface configuration prior to integrated system testing.

**Success Determination:**
Pending.

**Discussion and Lessons Learned:**
The separation mechanism functional test is intended to verify that the mechanical release system operates reliably under realistic alignment conditions. Ensuring consistent separation is critical because failure of the release system would prevent the payload from initiating its post-landing experiment sequence. Results from this test will inform any necessary adjustments to alignment tolerances or mechanical clearances in the payload interface design.

**PL-INT-02 – Separation Cycle Test**

**Methodology:**
The payload separation mechanism was repeatedly actuated in a bench test configuration to simulate repeated use during testing and integration activities. The mechanism was cycled multiple times while monitoring mechanical wear, actuation consistency, and overall reliability. Each actuation cycle was inspected to confirm that the mechanism continued to operate smoothly without degradation.

**Predicted Result:**
The separation mechanism was expected to operate reliably across multiple actuation cycles without mechanical wear or performance degradation that could affect release reliability.

**Actual Result:**
Testing is planned to be conducted during final payload integration testing to verify cycle reliability of the mechanism.

**Success Determination:**
Pending.

**Discussion and Lessons Learned:**
Cycle testing is important to confirm that the separation mechanism remains reliable after repeated use during integration and pre-flight testing. This test ensures that the mechanical components maintain consistent performance and do not experience excessive wear that could compromise payload deployment reliability during flight operations.

**PL-INT-03 – Post-Landing Deployment Test**

**Methodology:**
The payload was placed in multiple simulated landing orientations including upright, angled, and partially inverted configurations. The payload deployment system was then activated to observe

whether the mechanism could begin its deployment sequence under varying surface conditions and orientations representative of possible landing scenarios.

**Predicted Result:**
The payload was expected to begin deployment within the required time window after activation and complete the initial deployment motion without mechanical interference or binding.

**Actual Result:**
Testing will be conducted once the payload integration and deployment mechanism assembly are finalized.

**Success Determination:**
Pending.

**Discussion and Lessons Learned:**
This test ensures that the payload can successfully begin its experiment sequence even if the vehicle lands in an unfavorable orientation. Evaluating deployment behavior under realistic landing conditions helps reduce the risk that terrain or vehicle orientation could prevent the payload from operating as intended during the mission.

**PL-ELEC-01 – Power-On / Boot Verification**

**Methodology:**
The payload electronics system was assembled in a representative operational configuration including the onboard controller, sensors, data logging hardware, and battery system. The payload was repeatedly powered on using the intended battery configuration to evaluate system initialization behavior. During each startup attempt, the controller initialization sequence, sensor activation, and software startup routines were monitored to verify that the system booted correctly and entered its operational state.

**Predicted Result:**
The payload electronics were expected to reliably power on and initialize all hardware components during each startup attempt. The system was expected to complete the boot sequence without errors and begin executing the payload control software.

**Actual Result:**
The payload electronics successfully powered on and completed the initialization sequence during repeated startup trials. The controller booted correctly and all connected sensors and data logging components initialized as expected.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
The testing confirmed that the electrical system architecture and power distribution design

provide reliable startup performance for the payload electronics. The repeated startup tests helped verify that the system can reliably initialize after being powered on, which is critical to ensure that the payload begins executing its experiment sequence following landing.

**PL-ELEC-02 – Battery Endurance Test**

**Methodology:**
The payload battery was connected to the complete payload electronics system and operated under a simulated mission load profile. The test simulated the expected mission timeline including system startup, experiment operation, sensor measurements, and data logging activities. Battery voltage and system functionality were monitored throughout the test to evaluate power capacity and electrical stability.

**Predicted Result:**
The battery was expected to support continuous payload operation for at least 150% of the expected mission duration while maintaining voltage levels within the operating range of the electronics.

**Actual Result:**
During testing, the battery supported continuous operation of the payload electronics for a duration exceeding the expected mission timeline. Voltage levels remained stable and all electronic subsystems remained operational throughout the test.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
The battery endurance test confirmed that the selected battery configuration provides sufficient power margin to support the entire payload mission sequence. The test also demonstrated that the payload electronics operate reliably over extended periods, ensuring that the system can remain operational even if delays occur before or after the primary experiment timeline.

**PL-ELEC-03 – Connector / Continuity Verification**

**Methodology:**
All electrical connectors and wiring harnesses within the payload were inspected and tested for electrical continuity using standard continuity testing equipment. Connections were checked under normal handling conditions and after minor mechanical movement to ensure that wiring integrity remained intact. The tests verified proper electrical connections between the controller, sensors, actuators, and data logging components.

**Predicted Result:**
All electrical connections were expected to maintain continuous electrical contact without intermittent failures or signal loss during handling.

**Actual Result:**
All tested electrical connections maintained proper continuity and no intermittent connections were detected during testing.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
The connector verification testing confirmed that the payload wiring architecture provides reliable electrical connections between system components. During testing, minor improvements were made to connector strain relief and cable routing to further reduce the risk of disconnection during handling or flight operations.

**PL-SW-01 – Data Logging & Timestamp Verification**

**Methodology:**
The payload control software was operated in a bench-test configuration while connected to all relevant sensors and the onboard data storage system. During testing, the software was commanded to record sensor measurements at the intended sampling rate while simultaneously generating timestamps for each recorded data point. After each test run, the resulting log files were retrieved and inspected to verify that all expected data fields were recorded and that timestamp values corresponded correctly with the system clock.

**Predicted Result:**
The payload software was expected to successfully record all sensor data during operation while assigning accurate timestamps to each data entry. Log files were expected to contain complete datasets with no missing or corrupted entries.

**Actual Result:**
Testing of the data logging system is scheduled to be conducted during final payload software integration. Log file verification will be performed following execution of the data recording routines.

**Success Determination:**
Pending.

**Discussion and Lessons Learned:**
Reliable data logging is essential to demonstrate the success of the payload experiment and provide verifiable experiment results. This test ensures that the payload software correctly records and timestamps all experiment data. Verifying data integrity prior to flight reduces the risk of data loss during the mission.

**PL-SW-02 – Full Autonomous Sequence Dry Run**

**Methodology:**
The payload system was operated through a simulated mission sequence in a ground-test configuration. The test included activation of the payload, execution of the deployment sequence, operation of the soil acquisition mechanism, pH measurement, and data logging. The software was allowed to run autonomously without operator intervention in order to replicate the intended mission operation.

**Predicted Result:**
The payload software was expected to successfully execute the complete mission sequence without errors or interruptions. Each subsystem was expected to activate in the correct order according to the programmed sequence.

**Actual Result:**
Testing will be conducted after final integration of the payload hardware and software systems to verify full autonomous operation.

**Success Determination:**
Pending.

**Discussion and Lessons Learned:**
This test verifies that the payload control software correctly coordinates the operation of all payload subsystems during the mission. Running the system autonomously helps identify potential sequencing issues or timing conflicts between mechanical and electronic components.

**PL-MECH-01 – Soil Acquisition Mechanism Functional Test**

**Methodology:**
The soil acquisition mechanism was tested using representative soil samples to evaluate its ability to collect and retain soil material. The mechanism was operated repeatedly while observing collection performance, mechanical movement, and resistance to jamming. Multiple soil conditions were used in order to simulate potential landing environments.

**Predicted Result:**
The soil acquisition mechanism was expected to collect soil samples without mechanical jamming while successfully transferring collected material into the containment area for measurement.

**Actual Result:**
Testing demonstrated that the mechanism was able to collect soil samples during repeated trials without mechanical jamming. Soil was successfully transferred into the containment area during testing.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
The testing confirmed that the soil acquisition mechanism operates reliably under representative soil conditions. Minor adjustments were made to the collection geometry to improve soil capture efficiency and ensure consistent sample collection during operation.

**PL-MECH-02 – Mobility / Actuation Test**

**Methodology:**
The payload actuation system responsible for positioning and operating the soil acquisition mechanism was tested on representative ground surfaces. The actuators were commanded to perform their intended motion sequences while monitoring actuator response, movement range, and resistance to stalling. Tests were conducted on multiple surface conditions to simulate potential terrain encountered after landing.

**Predicted Result:**
The actuator system was expected to provide sufficient torque and motion control to perform the required mechanical operations without stalling or mechanical binding across representative surface conditions.

**Actual Result:**
Testing demonstrated that the actuators were capable of completing the required motion sequences without stalling. The system maintained reliable movement across the tested surfaces and completed the commanded operations successfully.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
The test confirmed that the actuator selection and mechanical design provide sufficient torque margin for payload operations. The results also helped validate that the payload can perform its required motions under realistic terrain conditions, improving confidence that the mechanism will function reliably after landing.

**PL-MECH-03 – Containment Integrity Test**

**Methodology:**
The soil containment system was tested by placing collected soil samples into the containment area and subjecting the payload to various orientations and movements that simulate potential landing and deployment conditions. The payload was rotated and tilted while observing whether soil material remained contained within the designated storage area.

**Predicted Result:**
The containment system was expected to retain the collected soil sample without leakage or spillage during movement or orientation changes.

**Actual Result:**
Testing of the containment system is scheduled to be conducted after final integration of the payload sample storage assembly.

**Success Determination:**
Pending.

**Discussion and Lessons Learned:**
Maintaining containment of the collected soil sample is necessary to ensure that the pH measurement experiment can be performed successfully. This test will confirm that the containment design prevents loss of collected material during payload operation and movement.

**PL-EXP-01 – Soil Volume Collection Verification**

**Methodology:**
Following operation of the soil acquisition mechanism, the collected soil sample was measured using a graduated container to determine the volume of material obtained during collection. Multiple trials were conducted to evaluate whether the mechanism consistently collects sufficient soil volume for the experiment.

**Predicted Result:**
The soil acquisition mechanism was expected to collect at least the minimum required soil volume necessary to perform the pH measurement experiment.

**Actual Result:**
Testing confirmed that the mechanism consistently collected soil volumes exceeding the minimum required threshold for the experiment.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
The results verified that the soil acquisition mechanism is capable of collecting sufficient material to support the payload experiment. This testing provided confidence that the payload will be able to obtain a usable soil sample during mission operations.

**PL-EXP-02 – pH Calibration Verification**

**Methodology:**
The pH sensor used for the payload experiment was calibrated using standard buffer solutions with known pH values. The sensor probe was placed in each buffer solution and allowed to stabilize before recording the measured value. Multiple calibration points were tested to verify sensor accuracy across the expected operating range. The recorded sensor outputs were compared to the known buffer solution values.

**Predicted Result:**
The pH sensor was expected to produce measurements within ±0.1 pH units of the known calibration solution values after calibration.

**Actual Result:**
During testing the pH sensor readings remained within the acceptable error range when compared to the reference buffer solutions.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
The calibration test confirmed that the pH sensor provides sufficiently accurate measurements for the payload experiment. Performing calibration prior to flight operations ensures that the experiment results represent actual soil properties rather than sensor measurement error.

**PL-EXP-03 – pH Repeatability Test**

**Methodology:**
The pH measurement system was tested by repeatedly measuring the pH of the same solution under identical conditions. Multiple measurements were recorded and analyzed to evaluate the consistency and repeatability of the sensor readings. The variation between readings was calculated to determine measurement stability.

**Predicted Result:**
Repeated measurements of the same sample were expected to produce consistent readings with minimal variation between trials.

**Actual Result:**
Testing showed that the pH measurement system produced consistent readings across repeated measurements, with variation remaining within the acceptable range for the experiment.

**Success Determination:**
Success.

**Discussion and Lessons Learned:**
The repeatability testing confirmed that the sensor provides stable and reliable measurements. This result indicates that the payload experiment can produce consistent data and that variations in measured pH values will reflect actual soil properties rather than measurement noise.

**PL-EXP-04 – Full Mission Timeline Test**

**Methodology:**
The payload was operated through a simulated mission sequence that included deployment, soil acquisition, pH measurement, and data logging. The duration of each step was recorded to determine the total time required for the experiment to complete. The test was conducted under

controlled conditions to verify that the entire sequence can be completed within the allowed mission timeframe.

**Predicted Result:**
The complete experiment sequence was expected to be completed within the 15-minute mission window specified by the competition requirements.

**Actual Result:**
Testing is scheduled to be conducted after final integration of the payload hardware and software systems to verify the full mission timeline.

**Success Determination:**
Pending.

**Discussion and Lessons Learned:**
This test ensures that the payload experiment can be completed within the time constraints required by the competition rules. Verifying the timeline prior to flight helps identify any steps in the experiment sequence that may require optimization or adjustment.

**PL-EXP-05 – End-to-End Integrated Mission Demonstration**

**Methodology:**
An integrated mission simulation was conducted in which the payload was operated through the complete experiment sequence under controlled ground conditions. The test included simulated payload deployment, activation of the soil acquisition mechanism, pH measurement of the collected soil sample, and storage of experiment data to onboard memory. The payload was allowed to operate autonomously during the test to replicate the expected flight mission workflow.

**Predicted Result:**
The payload system was expected to successfully execute the full experiment sequence without operator intervention, completing soil collection, pH measurement, and data logging within the allowed mission timeline.

**Actual Result:**
Testing will be conducted following final integration of all payload hardware and software subsystems. The end-to-end mission demonstration will verify complete system functionality prior to flight.

**Success Determination:**
Pending.

**Discussion and Lessons Learned:**
The end-to-end mission test is critical for verifying that all payload subsystems operate correctly when integrated together. This test helps identify timing conflicts, subsystem interactions, or

software sequencing issues that may not be visible when subsystems are tested independently. Results from this test will be used to refine the payload mission sequence if necessary.

**PL-SURV-01 – Mechanical Survivability Verification**

**Methodology:**
The payload mechanical structure and moving mechanisms were inspected following exposure to simulated or flight-derived mechanical loads representative of launch acceleration, descent forces, and landing impact. The payload was examined for structural deformation, component loosening, or damage to mechanical subsystems. Functional checks of key mechanisms were also performed to verify continued operability.

**Predicted Result:**
All payload mechanical components were expected to remain structurally intact and functional following exposure to representative launch and landing loads.

**Actual Result:**
Mechanical survivability verification will be performed following flight testing and post-flight inspection of the recovered payload.

**Success Determination:**
Pending.

**Discussion and Lessons Learned:**
Mechanical survivability testing ensures that the payload structure and mechanisms can withstand the dynamic loads encountered during launch, descent, and landing. Post-flight inspection will confirm that the payload hardware remains operational and capable of performing its intended functions following flight conditions.

**PL-SURV-02 – Electrical / Software Survivability Verification**

**Methodology:**
Following exposure to simulated or flight-derived mechanical loads, the payload electronics were powered on using the intended battery configuration. The system boot sequence, sensor initialization, and software operation were monitored to verify that the electronics and control software remained functional. Data logging functionality was also tested to confirm that the payload could continue recording experiment data after experiencing flight conditions.

**Predicted Result:**
The payload electronics and software systems were expected to remain operational following launch and landing loads. Upon power-up, the system was expected to successfully boot, initialize all sensors, and resume normal operation without hardware or software faults.

**Actual Result:**
Electrical survivability verification will be conducted following flight testing when the payload is recovered and powered on for post-flight inspection.

**Success Determination:**
Pending.

**Discussion and Lessons Learned:**
Electrical survivability testing verifies that the payload electronics are capable of withstanding the mechanical stresses experienced during flight. Successful verification will confirm that the payload remains capable of collecting and storing experiment data following launch and landing conditions.

## 7.2. Requirements Compliance

### 7.2.1. Handbook Requirements Verification Plan (Sections 1–5)

#### Launch Vehicle Requirements

| Requirement | Implementation Plan | Method of Verification | Status |
|---|---|---|---|
| **2.1 The vehicle shall deliver the payload to an apogee altitude between 4,000 and 6,000 feet AGL.** | The vehicle was designed and simulated to achieve the declared target altitude within the required altitude band using the selected competition motor. | **Analysis + Test:** OpenRocket simulations and full-scale demonstration flight altimeter data. | Verified |
| **2.2 The launch vehicle and payload shall remain launch-ready on the pad for a minimum of 3 hours without losing critical functionality.** | The avionics and payload power systems were sized with margin and tested for extended duration operation. | **Test:** Battery endurance testing and operational readiness duration testing. | Verified |
| **2.3 Teams shall declare their target altitude goal at CDR.** | The team declared its target altitude in the CDR documentation and uses that value for subsequent performance evaluation. | **Inspection:** Review of CDR documentation. | Verified |
| **2.4 The launch vehicle shall be designed to be recoverable and reusable.** | The airframe, recovery system, and structural components were designed to survive flight and recovery without requiring repair before a same-day reflight. | **Analysis + Inspection + Test:** Structural design review, post-flight inspection, and demonstration flight results. | In Progress |
| **2.5 The launch vehicle shall have a maximum of four independent sections.** | The Terra Nova launch vehicle separates into no more than four | **Inspection:** Review of vehicle configuration drawings and assembly. | Verified |

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| | independent sections in flight. | | |
| **2.5.1 Coupler/airframe shoulders at in-flight separation points shall be at least two airframe diameters in length.** | All in-flight separation couplers were designed to meet or exceed the required engagement length. | **Inspection:** Measurement of coupler geometry from CAD and as-built hardware. | Verified |
| **2.5.2 Coupler/airframe shoulders at non-in-flight separation points shall be at least 1.5 airframe diameters in length.** | All non-flight separation interfaces were designed to meet or exceed the required engagement length. | **Inspection:** CAD review and as-built dimensional verification. | Verified |
| **2.5.3 Nosecone shoulders shall be at least ½ body diameter in length.** | The nosecone shoulder geometry was selected to exceed the required minimum insertion length. | **Inspection:** Nosecone drawing review and physical measurement. | Verified |
| **2.6 The launch vehicle shall be capable of being launched by a standard 12-volt DC firing system.** | The vehicle uses a standard commercially available igniter and motor ignition setup compatible with the launch provider system. | **Inspection + Test:** Launch configuration review and successful flight demonstration. | Verified |
| **2.6.1 Each team shall use commercially available ematches or igniters.** | The team uses commercially available igniters/ematches for deployment and ignition systems. | **Inspection:** Component purchase and hardware inspection. | Verified |
| **2.7 The launch vehicle shall use a commercially available solid APCP motor certified by NAR/TRA/CAR.** | The team uses a certified commercially available APCP motor from an approved manufacturer. | **Inspection:** Motor certification and manufacturer documentation review. | Verified |
| **2.8 The launch vehicle shall be limited to a single motor propulsion system.** | The vehicle uses one certified motor only. | **Inspection:** Propulsion configuration review. | Verified |
| **2.9 Total impulse shall not exceed 5,120 N-s (L-class).** | The selected competition motor remains within the allowed total impulse limit. | **Inspection:** Motor data sheet and certification review. | Verified |
| **2.10 Pressure vessels on the vehicle must be approved by the RSO and meet the stated criteria.** | Pressure vessel hardware used in the recovery system was selected and documented to meet design and safety requirements. | **Inspection + Analysis:** Pressure vessel review, relief valve verification, and supporting documentation. | In Progress |

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| **2.10.1 Pressure vessels shall have a minimum factor of safety of 4:1.** | Pressure vessels were selected with documented ratings exceeding the maximum expected operating pressure by at least 4:1. | **Analysis + Inspection:** Manufacturer ratings and operating pressure comparison. | In Progress |
| **2.10.2 Each pressure vessel shall include a pressure relief valve.** | The pressure vessel configuration includes a relief mechanism capable of seeing full tank pressure. | **Inspection:** Hardware inspection and design documentation review. | In Progress |
| **2.10.3 The full pedigree of the tank shall be described.** | Pressure vessel usage history and supporting documentation are maintained and included in project records. | **Inspection:** Pressure vessel pedigree documentation review. | In Progress |
| **2.11 The launch vehicle shall have a minimum static stability margin of 2.0 while sitting on the pad.** | The vehicle was designed such that the measured/simulated CG and CP yield a static stability margin greater than 2.0 calibers in pad configuration. | **Analysis + Test:** OpenRocket as-built simulation and verification with subscale/full-scale flight performance. | Verified |
| **2.12 The launch vehicle shall have a minimum thrust-to-weight ratio of 5.0:1.0.** | Vehicle mass and selected motor thrust were chosen to exceed the required minimum ratio. | **Analysis:** Thrust-to-weight calculation using motor thrust curve and as-built launch mass. | Verified |
| **2.13 Any structural protuberance shall be located aft of the burnout center of gravity.** | Vehicle external components were positioned so that protuberances remain aft of the burnout CG, except where permitted. | **Analysis + Inspection:** Burnout CG analysis and external configuration inspection. | Verified |
| **2.14 The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.** | Rail exit velocity was evaluated in simulation and confirmed through flight analysis. | **Analysis + Test:** OpenRocket simulations and flight telemetry comparison. | Verified |
| **2.15 Subscale rockets are required to use a minimum motor impulse class of E.** | The subscale vehicle was flown using a motor that meets or exceeds the minimum impulse requirement. | **Inspection:** Subscale motor selection review. | Verified |
| **2.16 The subscale rocket shall not exceed 75% of the dimensions of the full-scale rocket.** | The subscale vehicle dimensions were chosen to remain within the allowed scale factor relative to the full-scale design. | **Inspection:** Dimensional comparison of subscale and full-scale CAD models. | Verified |

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| **2.17 All teams shall complete demonstration flights as outlined below.** | The team completed the required subscale and vehicle demonstration flight sequence within the required timeline. | **Inspection + Test:** Review of flight records and milestone evidence. | Verified |
| **2.18 Vehicle Demonstration Flight—purpose is to validate stability, structural integrity, recovery systems, and flight preparation capability.** | The full-scale demonstration flight was conducted using the final vehicle configuration to validate these characteristics. | **Test:** Full-scale demonstration flight, telemetry review, and post-flight inspection. | Verified |
| **2.19 All Lithium Polymer batteries shall be protected from impact, brightly colored, clearly marked as a fire hazard, and distinguishable.** | All LiPo batteries in the vehicle and payload are enclosed, protected, and clearly labeled. | **Inspection:** Hardware inspection of installed batteries and labels. | Verified |
| **2.20.1 The launch vehicle shall not utilize forward firing motors.** | The propulsion system contains no forward firing motor elements. | **Inspection:** Propulsion configuration review. | Verified |
| **2.20.2 The launch vehicle shall not utilize motors that expel titanium sponges.** | The selected motor is not a sparky/skidmark-type motor. | **Inspection:** Motor specification review. | Verified |
| **2.20.3 The launch vehicle shall not utilize hybrid motors.** | The vehicle uses a certified APCP solid motor only. | **Inspection:** Motor specification review. | Verified |
| **2.20.4 The launch vehicle shall not utilize a cluster of motors.** | The vehicle uses one motor only. | **Inspection:** Propulsion configuration review. | Verified |
| **2.20.5 The launch vehicle shall not utilize friction fitting for motors.** | The motor retention system uses positive retention hardware. | **Inspection:** Motor retention hardware inspection. | Verified |
| **2.20.6 The launch vehicle shall not exceed Mach 1 during flight.** | The vehicle was simulated below Mach 1 for all approved flight configurations. | **Analysis + Test:** OpenRocket performance simulation and flight telemetry review. | Verified |
| **2.20.7 Vehicle ballast shall not exceed 10% of total un-ballasted launch weight.** | Ballast mass was limited below the handbook maximum and incorporated into simulation and mass property reviews. | **Inspection + Analysis:** Ballast mass measurement and launch mass calculation. | Verified |

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| **2.20.7.2 Ballast must be mechanically retained.** | All ballast is fixed using mechanical retention methods. | **Inspection:** Ballast installation inspection. | Verified |
| **2.20.7.3 Ballast shall be removable.** | Ballast installation was designed to be removable for verification and configuration control. | **Inspection:** Physical inspection of ballast retention design. | Verified |
| **2.20.7.4 All requirements in sections 1–5 shall be met in both minimum and maximum ballast configurations.** | Simulations and performance calculations were reviewed for all relevant ballast conditions. | **Analysis:** Configuration-dependent simulation and performance verification. | Verified |
| **2.20.8 On-board transmissions active prior to landing shall not exceed 250 mW.** | Tracking system power output was selected to remain below the allowable transmission limit. | **Inspection:** Manufacturer device specification review. | Verified |
| **Requirement** | **Implementation Plan** | **Method of Verification** | **Status** |
| **2.1 The vehicle shall deliver the payload to an apogee altitude between 4,000 and 6,000 feet AGL.** | The vehicle was designed and simulated to achieve the declared target altitude within the required altitude band using the selected competition motor. | **Analysis + Test:** OpenRocket simulations and full-scale demonstration flight altimeter data. | Verified |
| **2.2 The launch vehicle and payload shall remain launch-ready on the pad for a minimum of 3 hours without losing critical functionality.** | The avionics and payload power systems were sized with margin and tested for extended duration operation. | **Test:** Battery endurance testing and operational readiness duration testing. | Verified |
| **2.3 Teams shall declare their target altitude goal at CDR.** | The team declared its target altitude in the CDR documentation and uses that value for subsequent performance evaluation. | **Inspection:** Review of CDR documentation. | Verified |
| **2.4 The launch vehicle shall be designed to be recoverable and reusable.** | The airframe, recovery system, and structural components were designed to survive flight and recovery without requiring repair before a same-day reflight. | **Analysis + Inspection + Test:** Structural design review, post-flight inspection, and demonstration flight results. | In Progress |
| **2.5 The launch vehicle shall have a maximum of four independent sections.** | The Terra Nova launch vehicle separates into no more than four | **Inspection:** Review of vehicle configuration drawings and assembly. | Verified |

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| | independent sections in flight. | | |
| **2.5.1 Coupler/airframe shoulders at in-flight separation points shall be at least two airframe diameters in length.** | All in-flight separation couplers were designed to meet or exceed the required engagement length. | **Inspection:** Measurement of coupler geometry from CAD and as-built hardware. | Verified |
| **2.5.2 Coupler/airframe shoulders at non-in-flight separation points shall be at least 1.5 airframe diameters in length.** | All non-flight separation interfaces were designed to meet or exceed the required engagement length. | **Inspection:** CAD review and as-built dimensional verification. | Verified |
| **2.5.3 Nosecone shoulders shall be at least ½ body diameter in length.** | The nosecone shoulder geometry was selected to exceed the required minimum insertion length. | **Inspection:** Nosecone drawing review and physical measurement. | Verified |
| **2.6 The launch vehicle shall be capable of being launched by a standard 12-volt DC firing system.** | The vehicle uses a standard commercially available igniter and motor ignition setup compatible with the launch provider system. | **Inspection + Test:** Launch configuration review and successful flight demonstration. | Verified |
| **2.6.1 Each team shall use commercially available ematches or igniters.** | The team uses commercially available igniters/ematches for deployment and ignition systems. | **Inspection:** Component purchase and hardware inspection. | Verified |
| **2.7 The launch vehicle shall use a commercially available solid APCP motor certified by NAR/TRA/CAR.** | The team uses a certified commercially available APCP motor from an approved manufacturer. | **Inspection:** Motor certification and manufacturer documentation review. | Verified |
| **2.8 The launch vehicle shall be limited to a single motor propulsion system.** | The vehicle uses one certified motor only. | **Inspection:** Propulsion configuration review. | Verified |
| **2.9 Total impulse shall not exceed 5,120 N-s (L-class).** | The selected competition motor remains within the allowed total impulse limit. | **Inspection:** Motor data sheet and certification review. | Verified |
| **2.10 Pressure vessels on the vehicle must be approved by the RSO and meet the stated criteria.** | Pressure vessel hardware used in the recovery system was selected and documented to meet design and safety requirements. | **Inspection + Analysis:** Pressure vessel review, relief valve verification, and supporting documentation. | In Progress |

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| **2.10.1 Pressure vessels shall have a minimum factor of safety of 4:1.** | Pressure vessels were selected with documented ratings exceeding the maximum expected operating pressure by at least 4:1. | **Analysis + Inspection:** Manufacturer ratings and operating pressure comparison. | In Progress |
| **2.10.2 Each pressure vessel shall include a pressure relief valve.** | The pressure vessel configuration includes a relief mechanism capable of seeing full tank pressure. | **Inspection:** Hardware inspection and design documentation review. | In Progress |
| **2.10.3 The full pedigree of the tank shall be described.** | Pressure vessel usage history and supporting documentation are maintained and included in project records. | **Inspection:** Pressure vessel pedigree documentation review. | In Progress |
| **2.11 The launch vehicle shall have a minimum static stability margin of 2.0 while sitting on the pad.** | The vehicle was designed such that the measured/simulated CG and CP yield a static stability margin greater than 2.0 calibers in pad configuration. | **Analysis + Test:** OpenRocket as-built simulation and verification with subscale/full-scale flight performance. | Verified |
| **2.12 The launch vehicle shall have a minimum thrust-to-weight ratio of 5.0:1.0.** | Vehicle mass and selected motor thrust were chosen to exceed the required minimum ratio. | **Analysis:** Thrust-to-weight calculation using motor thrust curve and as-built launch mass. | Verified |
| **2.13 Any structural protuberance shall be located aft of the burnout center of gravity.** | Vehicle external components were positioned so that protuberances remain aft of the burnout CG, except where permitted. | **Analysis + Inspection:** Burnout CG analysis and external configuration inspection. | Verified |
| **2.14 The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit.** | Rail exit velocity was evaluated in simulation and confirmed through flight analysis. | **Analysis + Test:** OpenRocket simulations and flight telemetry comparison. | Verified |
| **2.15 Subscale rockets are required to use a minimum motor impulse class of E.** | The subscale vehicle was flown using a motor that meets or exceeds the minimum impulse requirement. | **Inspection:** Subscale motor selection review. | Verified |
| **2.16 The subscale rocket shall not exceed 75% of the dimensions of the full-scale rocket.** | The subscale vehicle dimensions were chosen to remain within the allowed scale factor relative to the full-scale design. | **Inspection:** Dimensional comparison of subscale and full-scale CAD models. | Verified |

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| **2.17 All teams shall complete demonstration flights as outlined below.** | The team completed the required subscale and vehicle demonstration flight sequence within the required timeline. | **Inspection + Test:** Review of flight records and milestone evidence. | Verified |
| **2.18 Vehicle Demonstration Flight—purpose is to validate stability, structural integrity, recovery systems, and flight preparation capability.** | The full-scale demonstration flight was conducted using the final vehicle configuration to validate these characteristics. | **Test:** Full-scale demonstration flight, telemetry review, and post-flight inspection. | Verified |
| **2.19 All Lithium Polymer batteries shall be protected from impact, brightly colored, clearly marked as a fire hazard, and distinguishable.** | All LiPo batteries in the vehicle and payload are enclosed, protected, and clearly labeled. | **Inspection:** Hardware inspection of installed batteries and labels. | Verified |
| **2.20.1 The launch vehicle shall not utilize forward firing motors.** | The propulsion system contains no forward firing motor elements. | **Inspection:** Propulsion configuration review. | Verified |
| **2.20.2 The launch vehicle shall not utilize motors that expel titanium sponges.** | The selected motor is not a sparky/skidmark-type motor. | **Inspection:** Motor specification review. | Verified |
| **2.20.3 The launch vehicle shall not utilize hybrid motors.** | The vehicle uses a certified APCP solid motor only. | **Inspection:** Motor specification review. | Verified |
| **2.20.4 The launch vehicle shall not utilize a cluster of motors.** | The vehicle uses one motor only. | **Inspection:** Propulsion configuration review. | Verified |
| **2.20.5 The launch vehicle shall not utilize friction fitting for motors.** | The motor retention system uses positive retention hardware. | **Inspection:** Motor retention hardware inspection. | Verified |
| **2.20.6 The launch vehicle shall not exceed Mach 1 during flight.** | The vehicle was simulated below Mach 1 for all approved flight configurations. | **Analysis + Test:** OpenRocket performance simulation and flight telemetry review. | Verified |
| **2.20.7 Vehicle ballast shall not exceed 10% of total un-ballasted launch weight.** | Ballast mass was limited below the handbook maximum and incorporated into simulation and mass property reviews. | **Inspection + Analysis:** Ballast mass measurement and launch mass calculation. | Verified |

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| **2.20.7.2 Ballast must be mechanically retained.** | All ballast is fixed using mechanical retention methods. | **Inspection:** Ballast installation inspection. | Verified |
| **2.20.7.3 Ballast shall be removable.** | Ballast installation was designed to be removable for verification and configuration control. | **Inspection:** Physical inspection of ballast retention design. | Verified |
| **2.20.7.4 All requirements in sections 1–5 shall be met in both minimum and maximum ballast configurations.** | Simulations and performance calculations were reviewed for all relevant ballast conditions. | **Analysis:** Configuration-dependent simulation and performance verification. | Verified |
| **2.20.8 On-board transmissions active prior to landing shall not exceed 250 mW.** | Tracking system power output was selected to remain below the allowable transmission limit. | **Inspection:** Manufacturer device specification review. | Verified |

## Recovery System Requirements

| Requirement | Implementation Plan | Method of Verification | Status |
|---|---|---|---|
| **3.1 The full-scale launch vehicle shall stage deployment of its recovery devices.** | The recovery architecture uses drogue deployment at apogee followed by main deployment at lower altitude. | **Test:** Ground deployment testing and full-scale demonstration flight. | Verified |
| **3.1.1 The main parachute shall be deployed no lower than 500 feet.** | Altimeter deployment logic was configured to deploy the main above the minimum allowable altitude. | **Test + Analysis:** Altimeter programming review and flight telemetry confirmation. | Verified |
| **3.1.2 The apogee event shall contain a delay of no more than 2 seconds.** | Recovery electronics were programmed for near-immediate apogee event initiation. | **Test + Analysis:** Altimeter settings and flight profile review. | Verified |
| **3.1.3 Motor ejection is not a permissible form of primary or secondary deployment.** | Recovery deployment is fully electronics-initiated and independent of motor ejection. | **Inspection:** Recovery architecture review. | Verified |
| **3.2 Each independent section shall have a maximum kinetic energy of 75 ft-lbf at landing.** | Section masses and descent velocities were selected and analyzed to maintain landing energy below the allowable limit. | **Analysis + Test:** Descent calculations and demonstration flight telemetry. | Verified |
| **3.3 The recovery system shall contain redundant** | The recovery system uses two commercially | **Inspection:** Avionics hardware inspection. | Verified |

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| **commercially available barometric altimeters.** | available recovery altimeters. | | |
| **3.4 Each altimeter shall have a dedicated power supply.** | Each altimeter is powered by an independent battery. | **Inspection:** Avionics wiring and power system inspection. | Verified |
| **3.5 Each altimeter shall be armed by a dedicated mechanical arming switch accessible from the exterior.** | The avionics bay uses dedicated external arming switches for each altimeter. | **Inspection + Test:** Avionics bay inspection and arming tests. | Verified |
| **3.6 Each arming switch shall be capable of being locked in the ON position.** | Locking arming switch hardware was selected and verified in the avionics system. | **Inspection:** Arming switch hardware inspection. | Verified |
| **3.7 Recovery system electronics shall be independent of payload electrical circuits.** | Recovery electronics and payload electronics are powered and wired independently. | **Inspection:** Wiring architecture review. | Verified |
| **3.8 Removable shear pins shall be used for both the main and drogue parachute compartments.** | Shear pins are used at both recovery event compartments as part of the final vehicle design. | **Inspection:** Recovery system hardware inspection. | Verified |
| **3.9 Bent eyebolts shall not be permitted in the recovery subsystem.** | Straight, rated hardware was used throughout the recovery subsystem. | **Inspection:** Hardware inspection. | Verified |
| **3.10 The recovery area shall be limited to a 2,500 ft radius from the launch pads.** | The recovery design targets descent performance that keeps landing points within the acceptable radius. | **Analysis + Test:** Descent analysis and demonstration flight landing location review. | Verified |
| **3.11 Descent time shall be limited to 90 seconds (apogee to touch down).** | The recovery system was designed to meet the required descent time while maintaining safe landing energy. | **Analysis + Test:** Simulations and demonstration flight telemetry. | Verified |
| **3.12 GPS tracking devices shall be installed and transmit the position of the tethered vehicle and any independent sections.** | The vehicle includes GPS tracking hardware for the launch vehicle and applicable recoverable sections. | **Inspection + Test:** Hardware inspection and functional tracking verification. | Verified |
| **3.13.1 Recovery altimeters shall be physically located in a separate compartment from RF transmitters** | The avionics bay was designed to isolate recovery altimeters from transmitting devices and other interference sources. | **Inspection:** Avionics bay configuration inspection. | Verified |

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| **and magnetic-wave-producing devices.** | | | |
| **3.13.2 Recovery electronics shall be shielded from on-board transmitting devices.** | Recovery electronics were isolated and routed to minimize RF interference risk. | **Inspection:** Avionics design review. | Verified |
| **3.13.3 Recovery electronics shall be shielded from devices generating magnetic waves.** | The vehicle design avoids magnetic interference sources near recovery electronics and separates relevant systems. | **Inspection:** Avionics and subsystem layout inspection. | Verified |
| **3.13.4 Recovery electronics shall be shielded from any other devices that may adversely affect them.** | The avionics architecture isolates the recovery system from other payload and vehicle electronics. | **Inspection:** System integration review. | Verified |

## 7.2.2. Payload Mission Requirements

| Requirement | Implementation Plan | Method of Verification | Status |
|---|---|---|---|
| **4.1 After landing, teams shall autonomously collect and retain a soil sample of at least 50 mL.** | The payload includes an autonomous soil acquisition and containment mechanism sized to collect at least 50 mL of soil. | **Test + Demonstration:** Soil collection testing and integrated payload demonstrations. | In Progress |
| **4.1.1 All soil collection and analysis must be completed within 15 minutes of landing.** | The payload sequence is designed to complete deployment, collection, analysis, and logging within the mission time window. | **Demonstration + Test:** Mission timeline testing and integrated end-to-end demonstration. | In Progress |
| **4.2 Teams shall autonomously test the collected sample for at least one required parameter.** | The payload was designed to autonomously measure soil pH after collection. | **Test:** pH calibration, repeatability, and integrated payload testing. | In Progress |
| **4.2.1 Analysis results shall include time stamps for verification.** | The data logging system stores experiment data with timestamps. | **Test:** Data logging and timestamp verification. | In Progress |
| **4.2.2 Results shall be included in the PLAR and preliminary results made available at competition launch.** | The payload data handling plan includes storage and retrieval of experiment results for inclusion in the PLAR and on-site verification. | **Inspection + Test:** Data log review and post-flight data retrieval. | Planned |
| **4.3 The autonomous functions may be initiated by remote command.** | The payload control architecture allows the experiment sequence to | **Demonstration:** Payload control demonstration and integrated testing. | In Progress |

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|---|---|---|---|
| | be initiated remotely if required. | | |
| **4.4 The HAUS structure shall include an atmosphere-isolated compartment for 4 STEMnauts.** | The payload structure includes an enclosed compartment representing the STEMnaut habitat. | **Inspection:** Payload design inspection and CAD review. | Verified |
| **4.4.1 The HAUS enclosure shall not incorporate or rely on the structural airframe of the launch vehicle.** | The payload housing is structurally self-contained and does not rely on the launch vehicle airframe to satisfy the requirement. | **Inspection:** Payload structural design review. | Verified |
| **4.5 The STEMnauts shall be safely retained within the HAUS during flight.** | The STEMnaut representations are retained inside the payload structure for the duration of flight. | **Inspection + Test:** Retention mechanism inspection and payload retention verification. | In Progress |
| **4.6 The payload shall not have protrusions prior to apogee extending beyond ¼ inch external to the airframe.** | Payload hardware is fully enclosed within the launch vehicle until the appropriate deployment phase. | **Inspection:** External configuration inspection. | Verified |
| **4.7.1 Energetics are only permitted for in-flight recovery systems; none are permitted for surface operations.** | The payload surface operations use non-energetic mechanisms only. | **Inspection:** Payload mechanism design review. | Verified |

### 7.2.3. Safety Requirements

| Requirement | Implementation Plan | Method of Verification | Status |
|---|---|---|---|
| **5.1 The final checklists shall be included in the FRR report and used during LRR and Launch Day operations.** | The team developed final launch and safety checklists and includes them in the FRR package. | **Inspection:** Checklist documentation review. | Verified |
| **5.2 Each team shall identify a student safety officer.** | The team has designated a student safety officer responsible for safety oversight across project activities. | **Inspection:** Team organization and safety documentation review. | Verified |

### 7.2.4. Team-Derived Requirements Verification Plan

#### Launch Vehicle – Team-Derived Requirements

| Requirement | Justification | Method of Verification | Status |
|---|---|---|---|

| | | | |
|---|---|---|---|
| The Inconel 718 recovery bulkheads shall maintain a **minimum factor of safety ≥ 5 against the predicted parachute deployment load of 1200 N**. | The recovery bulkheads transfer parachute deployment loads to the airframe. Maintaining a sufficient safety factor ensures the structure can withstand recovery loads without failure. | **Analysis + Test:** Structural analysis combined with **Inconel material testing (LV-MAT-01)**. | In Progress |
| The launch vehicle center of gravity shall remain **within ±5% of the simulation center of gravity used in OpenRocket analysis**. | Accurate mass properties ensure that the stability margin predicted in simulation remains valid during flight. | **Inspection + Analysis:** Physical CG measurement and simulation verification. | Planned |
| The launch vehicle shall maintain a **minimum static stability margin ≥ 2.0 calibers at liftoff with the selected motor and payload mass**. | Adequate stability margin ensures stable aerodynamic flight and prevents excessive oscillation during ascent. | **Analysis + Flight Test:** OpenRocket simulations verified through **subscale flight testing (LV-SFT-01, LV-SFT-02, LV-SFT-03)**. | Verified |
| The launch vehicle structural components shall **withstand predicted flight and recovery loads without permanent deformation**. | Structural survivability is necessary to prevent vehicle failure during ascent, recovery deployment, and landing. | **Inspection + Flight Test:** Post-flight inspection of vehicle structure following subscale flight testing. | In Progress |

## Recovery System – Team-Derived Requirements

| Requirement | Justification | Method of Verification | Status |
|---|---|---|---|
| The reefing line cutter shall **fully sever the reefing line within 1 second of activation under representative tension loads**. | Reliable cutter actuation is required for the parachute to transition from reefed deployment to full inflation. | **Test:** Bench testing of the cutter under load (**LV-DEP-03**). | Verified |
| The drogue parachute shall **deploy cleanly in ≥3 consecutive ground tests without entanglement or incomplete extraction**. | Reliable drogue deployment is required to stabilize the vehicle immediately after apogee. | **Demonstration + Test:** Ground deployment tests (**LV-DEP-01, LV-DEP-04**). | Verified |
| The main parachute shall **deploy and fully inflate without line** | Proper main parachute deployment ensures a controlled descent rate | **Demonstration + Test:** Ground deployment tests | Verified |

| | | | |
|---|---|---|---|
| **tangling during ground deployment tests**. | and safe landing velocity. | (**LV-DEP-02, LV-DEP-05**). | |
| The recovery harness configuration shall **prevent entanglement between vehicle sections during descent**. | Entanglement between vehicle sections could damage the airframe or recovery system during descent. | **Flight Test:** Verified during **subscale flight tests (LV-SFT-02 and LV-SFT-03)**. | In Progress |
| The recovery system shall **limit the launch vehicle descent velocity to ≤7 m/s under main parachute**. | Limiting descent velocity reduces landing impact forces and prevents structural damage. | **Analysis + Flight Data:** Descent rate analysis using flight telemetry and parachute performance calculations. | Planned |

## Payload Mission – Team-Derived Requirements

| Requirement | Justification | Method of Verification | Status |
|---|---|---|---|
| The payload shall **successfully power on and initialize in ≥3 consecutive startup attempts in the flight configuration**. | Reliable payload startup ensures that the experiment sequence begins correctly after landing. | **Test:** Electrical startup testing (**PL-ELEC-01**). | Planned |
| The soil acquisition mechanism shall **collect at least 50 mL of soil during operation**. | The experiment requires a minimum soil volume in order to perform pH measurement. | **Test:** Soil collection verification (**PL-EXP-01**). | Planned |
| The soil containment system shall **retain collected soil without leakage when the payload is tilted up to 45°**. | Soil containment is necessary to ensure the collected sample remains available for measurement. | **Demonstration:** Containment integrity testing (**PL-MECH-03**). | Planned |
| The pH measurement system shall **measure soil pH with an accuracy ≤ ±0.1 pH units following calibration**. | Accurate pH measurement is required for meaningful experiment results. | **Test:** Sensor calibration testing (**PL-EXP-02**). | Planned |
| The payload shall **generate a complete and readable data** | Data logging is required to verify experiment | **Test:** Data logging verification (**PL-SW-01**). | Planned |

| | | | |
|---|---|---|---|
| **file containing pH measurements and timestamps**. | completion and analyze results. | | |
| Payload electronics and mechanisms shall **remain functional following launch and landing loads**. | The payload must survive flight conditions to successfully perform the experiment. | **Inspection + Test:** Post-flight survivability verification (**PL-SURV-01, PL-SURV-02**). | Planned |

### 7.2.5. Requirements Verification Status Summary

At the time of the Critical Design Review, launch vehicle structural, stability, and subscale recovery requirements have been partially or fully verified through analysis, ground testing, and subscale flight testing. Payload verification activities are planned and scheduled prior to FRR.

## 7.3. Budgeting and Funding Summary

### 7.3.1. Budget

The budget shown below provides a comprehensive, line-item breakdown of all components required for the project. Items not listed are materials, tools, or components already available to the team through existing university or lab resources. Some costs are estimated or flexible due to available inventory and shared resources, but all major procurements and critical hardware are fully accounted for.

Terra Nova Project Budget

| Item | Description | Quantity | Estimate Shipping & Handling | Price ea. | Total | Link | Vendor | Status |
|---|---|---|---|---|---|---|---|---|
| **Full Scale Airframe and Motors** | | | | | | | | |
| Motor Tubing/ MMTHD-300x34 | 75mm Motor tube, Redundancy | 1 | $10.00 | $23.18 | $33.18 | (Click Here) | locprecision | Purchased |
| L1395 CTI Blue | Motor Propellant | 1 | $70.00 | $428.65 | $498.65 | (Click Here) | wildmanrocketry | Purchased |
| 75MM Forwarded Closure | 75MM FORWARD CLOSURE Aerotech 75 mm forward closure | 1 | $0.00 | $98.99 | $98.99 | (Click Here) | wildmanrocketry | Purchased |
| Fiberglass Nose Cone | 6 inch, 4:1 Ogive | 1 | $0.00 | $190.98 | $190.98 | (Click Here) | locprecision | Purchased |
| Motor Tubing/ MMTHD-300x34 | 75mm Motor Tube, Length 34" | 1 | $0.00 | $23.18 | $23.18 | (Click Here) | locprecision | Purchased |
| 5 inch fiberglass airframe | Length: 60" | 1 | $0.00 | $259.35 | $259.35 | (Click Here) | wildmanrocketry | Purchased |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5 inch fiberglass couplers | Length: 12" | 2 | $0.00 | $62.57 | $125.14 | (Click Here) | wildmanrocketry | Purchased |
| Fiberglass Sheet | 1/4" thick, 1ft x 1ft, | 2 | $0.00 | $46.00 | $92.00 | (Click Here) | wildmanrocketry | Purchased |
| L1395 CTI Blue | Motor Propellant | 2 | $0.00 | $428.65 | $857.30 | (Click Here) | wildmanrocketry | Purchased |
| L2200G Mojive Green | Motor Propellant | 1 | $0.00 | $376.99 | $376.99 | (Click Here) | wildmanrocketry | Purchased |
| Motor Retainer | 75mm motor RMS motor retainer | 1 | $5.00 | $55.00 | $60.00 | (Click Here) | Chris' Rocketry | Purchased |
| 54mm X 17in Motor Mount | | 1 | | $9.14 | $9.14 | (Click Here) | Chris' Rocketry | Purchased |
| 54mm X 14in Motor Mount | | 1 | | $6.18 | $6.18 | (Click Here) | locprecision | Purchased |
| Fiberglass Cloth | #120-38-E-Glass (Quantity in yards) | 20 | $28.00 | $10.50 | $238.00 | (Click Here) | aircraftspruce | Purchased |
| | | | | | | | Total: | $2,869.08 |
| **Sub-Scale Airframe and Motors** | | | | | | | | |
| Rail Button | 1515 rail | 1 | | $2.50 | $2.50 | (Click Here) | Chris' Rocketry | Purchased |
| Aerotech J540R-14A Redline Rocket Motor | Purchased for first launch | 1 | $70.00 | $135.99 | $205.99 | (Click Here) | Chris' Rocketry | Purchased |
| Aerotech J540R-14A Redline Rocket Motor | Purchase for 2nd and 3rd launch | 2 | $70.00 | $135.99 | $341.98 | (Click Here) | Chris' Rocketry | Purchased |
| RMS | AeroTech RMS-54/1280 Complete Motor | 1 | | $232.99 | $232.99 | (click here) | Aerotech | Purchased |
| Possible Forward Bulkhead | | 1 | $0.00 | $4.44 | $4.44 | (click here) | locprecision | Purchased |
| Possible Aft Bulkhead | | 3 | $0.00 | $5.06 | $15.18 | (click here) | locprecision | Purchased |
| Lower Couplers | | 2 | $0.00 | $5.31 | $10.62 | (click here) | locprecision | Purchased |
| Nose Cone (3.9" - $30) | | 1 | $0.00 | $29.16 | $29.16 | (click here) | locprecision | Purchased |
| Upper Body Tube | | 1 | $0.00 | $17.77 | $17.77 | (click here) | wildmanrocketry | Purchased |
| Aft Body Tube | | 2 | $0.00 | $14.16 | $28.32 | (click here) | wildmanrocketry | Purchased |
| Upper Coupler | | 1 | $0.00 | $7.14 | $7.14 | (click here) | wildmanrocketry | Purchased |
| Tail cone Assembly ($53) | | 1 | $0.00 | $53.00 | $53.00 | (click here) | wildmanrocketry | Purchased |
| G12CT-3 | 12 in | 1 | $0.00 | $33.48 | $33.48 | (click here) | wildmanrocketry | Purchased |
| G12CT-4 | 8 in | 1 | $0.00 | $25.12 | $25.12 | (click here) | wildmanrocketry | Purchased |
| G12-4.0 - 30" | | 1 | $0.00 | $71.39 | $71.39 | (click here) | wildmanrocketry | Purchased |
| G12-3.0 - 30" | | 2 | $0.00 | $62.92 | $125.84 | (click here) | wildmanrocketry | Purchased |
| | | | | | | | Total: | $1,204.92 |

| Recovery Systems | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| MAKO Line Cutters (1 Pair - $180) | Pair | 1 | $0.00 | $180.00 | $180.00 | (Click Here) | Tinder Rocketry | Purchased |
| Super Epoxy Pack | For both subscale and full scale | 1 | $0.00 | $196.98 | $196.98 | (click here) | Amazon | Purchased |
| PARAMAX Shock Cord (100 ft - $35) | We need 2, 100 foot sections | 2 | $0.00 | $34.75 | $69.50 | (click here) | theparacordstore | Purchased |
| Paracord Reef (100ft - $11) | We need 2, 100 foot sections | 2 | $0.00 | $10.75 | $21.50 | (click here) | theparacordstore | Purchased |
| 12" Fruity Chutes | | 1 | $0.00 | $87.51 | $87.51 | (click here) | Fruity Chutes | Purchased |
| 72" Parachute CD:2.2 | | 1 | $0.00 | $175.00 | $175.00 | (Click Here) | RocketMan | Purchased |
| 12in Topflight Chute | | 1 | $0.00 | $6.50 | $6.50 | (Click Here) | Chris' Rocketry | Purchased |
| 24in Parachute | | 1 | $0.00 | $50.00 | $50.00 | (Click Here) | RocketMan | Purchased |
| 48in Parachute | | 1 | $0.00 | $120.00 | $120.00 | (Click Here) | RocketMan | Purchased |
| 45 gm CO2 ctg | Recovery Testing | 2 | $0.00 | $23.00 | $46.00 | (Click Here) | Tinder Rocketry | Purchased |
| E-match O-rings | Recovery Testing/Launch | 2 | $8.50 | $3.00 | $14.50 | (Click Here) | Tinder Rocketry | Purchased |
| Eye bolts | 3/8-16 in. Forged Steel Machinery Eye Bolt in Shoulder Pattern (1-Pack) | 4 | $0.00 | $11.24 | $44.96 | (Click Here) | Home Depot | Purchased |
| 25gm CO2 Cartridge | | 6 | $0.00 | $14.00 | $84.00 | (Click Here) | Tinder Rocketry | Purchased |
| Eagle Replacement O-rings | | 2 | $0.00 | $3.00 | $6.00 | (Click Here) | Tinder Rocketry | Purchased |
| 45gm CO2 Cartridge | | 2 | $0.00 | $23.00 | $46.00 | (Click Here) | Tinder Rocketry | Purchased |
| PDW CO2 38g Threaded Cartridges | | 4 | $0.00 | $15.00 | $60.00 | (Click Here) | Planet Cyclery | Purchased |
| CO2 38 Gram | Only 4 available, purchase as many as possible | 4 | $0.00 | $8.25 | $33.00 | (Click Here) | Chris' Rocketry | Purchased |
| Firewire Electric Match Bundle of 20 | | 3 | $0.00 | $16.00 | $48.00 | (Click Here) | Chris' Rocketry | Purchased |
| 15" Parachute | Drogue Parachute | 1 | $0.00 | $88.20 | $88.20 | (Click Here) | Fruity Chutes | Purchased |
| Paracord 550 | Reefing Supplies (Quantity in 100 ft) | 1 | $0.00 | $10.75 | $10.75 | (Click Here) | theparacordstore | Purchased |
| 120" Parachute | Main Parachute | 1 | $0.00 | $325.00 | $325.00 | (Click Here) | RocketMan | Purchased |
| 1/2" Brass Grommets 24 pack | Reefing Supplies | 0 | $0.00 | $0.00 | $8.99 | (Click Here) | ACE | Purchased |
| 25g CO2 Cartridge | Supplier: Evo | 4 | $0.00 | $5.00 | $20.00 | (Click Here) | EVO | Purchased |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 38G CO2 Cartridge | Separation CO2 Cartridge | 4 | $0.00 | $15.00 | $60.00 | (Click Here) | ridepdw | Purchased |
| 48g CO2 Cartridge | Redundancy Separation CO2 Cartridge | 3 | $0.00 | $13.39 | $40.17 | (Click Here) | bulkreefsupply | Purchased |
| E-Match O-Rings | | 3 | $0.00 | $3.00 | $9.00 | (Click Here) | bellhelmets | Purchased |
| TR Lube | | 3 | $0.00 | $3.00 | $9.00 | (Click Here) | Tinder Rocketry | Purchased |
| Eagle Return Spring | | 4 | $0.00 | $3.00 | $12.00 | (Click Here) | Tinder Rocketry | Purchased |
| Eagle O-Rings | | 3 | $0.00 | $3.00 | $9.00 | (Click Here) | Tinder Rocketry | Purchased |
| | | | | | | | Total: | $1,881.56 |
| **Payload System** | | | | | | | | |
| 4mm Non-Flanged Ball Bearings | SKU: 1600-0410-0004 | 6 | $0.00 | $3.39 | $20.34 | (Click Here) | GoBilda | Purchased |
| 6mm Flanged Ball Bearings | SKU: 1601-0412-0006 | 4 | $0.00 | $2.88 | $11.52 | (Click Here) | GoBilda | Purchased |
| Submersible Water Pump | Soil Testing | 1 | $0.00 | $2.95 | $2.95 | (Click Here) | DigiKey | Purchased |
| TB6612FNG | Motor Controllers | 6 | $0.00 | $1.82 | $10.92 | (Click Here) | DigiKey | Purchased |
| HX711 | Amplifier | 2 | $0.00 | $11.50 | $23.00 | (Click Here) | DigiKey | Purchased |
| LM1117T-5.0/NOPB | Voltage Regulator | 2 | $0.00 | $1.37 | $2.74 | (Click Here) | DigiKey | Purchased |
| Micro_SD | SD Card | 1 | $0.00 | $15.39 | $15.39 | (Click Here) | DigiKey | Purchased |
| Female SMA Connector | Soil Testing | 1 | $0.00 | $2.80 | $2.80 | (Click Here) | DigiKey | Purchased |
| Pololu 37D 4741 | DC Motors | 3 | $15.00 | $44.95 | $149.85 | (Click Here) | Pololu | Purchased |
| Pololu 6V D24V22F6 | Buck Converter | 1 | $5.00 | $19.95 | $24.95 | (Click Here) | Pololu | Purchased |
| Mini Lab Grade pH Probe | | 1 | $0.00 | $89.99 | $89.99 | (Click Here) | atlas-scientific | Purchased |
| EZO pH Circuit | | 1 | $20.00 | $45.99 | $65.99 | (Click Here) | atlas-scientific | Purchased |
| Crossed Helical Gears | Part #: 3598N291 | 4 | $0.00 | $17.99 | $71.96 | (Click Here) | McMaster-CARR | Purchased |
| Carbon Steel Acme Lead Screw | Right Hand, 1/4"-16 Thread Size, 6 Feet Long | 1 | $0.00 | $29.28 | $29.28 | (Click Here) | McMaster-CARR | Purchased |
| Carbon Steel Acme Hex Nut | Right Hand, 1/4"-16 Thread Size | 6 | $0.00 | $3.51 | $21.06 | (Click Here) | McMaster-CARR | Purchased |
| Metal Worm Gear | Bronze, 1 Module, 10:1 Speed Ratio | 2 | $0.00 | $29.06 | $58.12 | (Click Here) | McMaster-CARR | Purchased |
| Steel Worm | 1 Module, 6 mm Shaft Diameter, 2 Starts | 2 | $0.00 | $15.63 | $31.26 | (Click Here) | McMaster-CARR | Purchased |
| Button Loadcell | FS1901-0000-0500-G | 1 | $15.00 | $40.06 | $55.06 | (Click Here) | DigiKey | Purchased |
| M3 Screws, 6mm Length | SKU: 2800-0003-0006 | 2 | $0.00 | $2.99 | $5.98 | (Click Here) | GoBilda | Purchased |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| M3 Screws, 6mm Length | SKU: 2800-0003-0012 | 3 | $0.00 | $3.29 | $9.87 | (Click Here) | GoBilda | Purchased |
| 4002 Series Flexible Clamping Shaft Coupler | 6mm Round Bore to 0.250" Round Bore | 2 | $15.00 | $6.99 | $28.98 | (Click Here) | GoBilda | Purchased |
| Steel Miter Gear (6mm round Bore, 24 Tooth) | SKU: 2317-0006-0024 | 2 | $0.00 | $10.19 | $20.38 | (Click Here) | GoBilda | Purchased |
| PTFE Cable-Guide Tubing | SKU: 2926-0204-1000 | 1 | $0.00 | $5.99 | $5.99 | (Click Here) | GoBilda | Purchased |
| Springs | Extension Spring, Spring Steel Const, Nickel-Plated Finish, .047 GA x 7/16 in. x 1-7/8 in., Closed Single Loop, (2-Pack) | 2 | $0.00 | $2.65 | $5.30 | (Click Here) | Home Depot | Purchased |
| Battery | Common Sense RC Lectron Pro 1350mAh 80C LiPo Battery with XT60 Connector for FPV Racers (3-Cell, 11.1V) | 1 | $0.00 | $25.74 | $25.74 | (Click Here) | bhphotovideo | Purchased |
| Lower cover spring #1 | 11908CS | 1 | $15.00 | $10.43 | $25.43 | (Click Here) | centuryspring | Purchased |
| Lower cover spring #2 | S-151CS | 1 | $0.00 | $12.08 | $12.08 | (Click Here) | centuryspring | Purchased |
| 6mm Flanged Bearings | | 6 | $0.00 | $3.39 | $20.34 | (Click Here) | GoBilda | Purchased |
| Carbon Steel Acme Lead Screw | Left Hand, 1/4"-16 Thread Size, 3 Feet Long | 1 | $0.00 | $36.62 | $36.62 | (Click Here) | McMaster-CARR | Purchased |
| Carbon Steel Acme Hex Nut | Left Hand, 1/4"-16 Thread Size, 15/64" | 1 | $0.00 | $3.64 | $3.64 | (Click Here) | McMaster-CARR | Purchased |
| | | | | | | Total: | | $887.53 |
| **Saftey** | | | | | | | | |
| Eye Protection | 3M SecureFit 200 Safety Eyewear SF200P1-DC: Premium eyewear with anti-fog lens and flexible fit; also, from Home Depot. | 4 | $0.00 | $6.98 | $27.92 | (Click Here) | Home Depot | Purchased |
| Eye Protection (Over-the-glasses) | 3M Over-the-Glass Safety Eyewear (47110-WV24) | 2 | $0.00 | $1.22 | $2.44 | (Click Here) | Home Depot | Purchased |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Lung Protection | 3M Disposable Particulate Respirator, N95, 20/Pack (8200) | 1 | $15.00 | $28.19 | $43.19 | (Click Here) | Staples | Purchased |
| Gloves | Gloveworks GWON Nitrile Gloves, Large, Orange, 100/Box | 1 | $0.00 | $24.69 | $24.69 | (Click Here) | Staples | Purchased |
| Ear Protection | 3M E-A-Rsoft Uncorded Earplugs, 33 dB, Neon Yellow, 200/Pack | 1 | $0.00 | $45.49 | $45.49 | (Click Here) | Staples | Purchased |
| Heavy Duty Gloves | ProFlex 812 Standard Utility Glove | 3 | $0.00 | $21.99 | $65.97 | (Click Here) | Staples | Purchased |
| | | | | | | Total: | | $209.70 |
| **Transportation, Lodging, Community Outreach, & Misc.** | | | | | | | | |
| Campus Vehicle | Provided by Florida State University - Panama City | 1 | Not Applicable | $0.00 | $0.00 | Not Applicable | | ----- |
| Gas | Estimate For all Travel both community events and launches | 1 | Not Applicable | $400.00 | $400.00 | (Estimate) | | ----- |
| Air B&B | Housing for the 22nd to the 26th of April | 1 | Not Applicable | $1,946.16 | $1,946.16 | (Click Here) | Air B&B | Purchased |
| Shirts | Custom designs incorporating University branding, team logo, and team sponsors | | Not Applicable | | In-Kind Donation | Not Applicable | | Purchased |
| Food | Food for students for occasions like launch days and the Huntsville Trip | 1 | Not applicable | $600.00 | $600.00 | (Estimates) | | ----- |
| PETG Creality Printing Filament | 1 kg rolls | 4 | $0.00 | $29.76 | $119.04 | (Click Here) | Grainger | Purchased |
| PETG Sunlu Printing Filament | 4kg, 1kg per spool | 2 | $0.00 | $39.99 | $79.98 | (Click Here) | Sunlu | Purchased |
| | | | | | | Total: | | $3,199.02 |

**Fundraised**

| **Company** | **Description** | **Given Funds** | **Contact** |
|---|---|---|---|
| Florida State University Panama City | Funding through the Deans Office to participate in the NASA USLI Competition | $10,000.00 | |

| | | | |
|---|---|---|---|
| Jim & Sandy Defoe | | $500.00 | |
| | | $0.00 | |
| | | $0.00 | |
| | | $0.00 | |
| | | $0.00 | |
| **NOTE:** The variance is set to add 10% to help mitigate any unexpected price changes throughout the year. | | **Total:** | $10,251.81 |
| | | **Fundraised:** | $10,500.00 |
| | | **Remaining Funds:** | $248.19 |

***Figure 7.1 Line-Item Budget***

## 7.3.2. Fundraising

### Funding Plan

The Terra Nova Team has a comprehensive finance plan to support participation in the 2026 NASA University Student Launch Initiative.

The strategy utilized institutional support, industry partnerships, and community engagement to secure funding for all project phases: design, fabrication, testing, competition participation, and STEM outreach.

The projected total budget is $*10,251.81*, as outlined in Table 5-1.

#### *Funding Sources*

#### University Support

- Florida State University – Panama City (FSU-PC):
  The Dean's Office has committed $10,000 in funding to ensure project completion.

- INSPIRE Program and their Industrial Partners:
  The FSU Inspire Program, in collaboration with Astro America and Maritech Machining Inc., has offered in-kind manufacturing support including 3D-printed metal parts and heat treating at no cost to the team.

#### In-Kind Contributions

The team receives substantial non-monetary support through:

- Astro America – 3D metal printing and prototype support.
- Maritech Machining – Fabrication and heat-treating services.
- Coastal Machine – CNC Machining

These contributions significantly reduce the team's direct expenditure and fabrication lead times.

*Financial Oversight and Accountability*

- Project Lead (Krieg Conrad) maintains primary financial oversight.
- Weekly budget reviews occur at team meetings, with monthly financial summaries documented in team minutes.
- Procurement Process:
    - All purchases follow FSU-PC purchasing policies.
    - Each expenditure requires approval by Project Lead and relevant subsystem lead.
    - Receipts and transaction records are maintained in the team's shared financial log.

Summary

The Terra Nova Team has developed a sustainable financial strategy that combines university support, industry partnerships, and community support.
With in-kind contributions, and a preliminary 10% contingency reserve that was estimated at an earlier deliverable, the team is financially positioned for full mission execution — from subscale testing to launch week in Huntsville.

The Terra Nova Team is confident that this plan will meet the $10,251.81 project requirement and ensure successful participation in the NASA USLI 2026 competition.

### 7.3.3. Timeline

Our timeline is shown here, along with a Gantt chart that breaks it down into weekly objectives. In addition to working on the documentation deliverables, several system officers and their teams will focus on certain tasks. Depending on the availability of the local schools, we will continue our community participation on Fridays and weekends with the goal of visiting K–12 institutions at least once a month. We'll also go to university events like Tech Days and Discovery Days. To guarantee timeline compliance, the leadership team will convene once a week. We are currently meeting every Wednesday at 1pm. The Terra Nova Project's timetable and Gantt chart are shown below, starting after the submission of the PDR. By using both, we are able to get a visual depiction of our project status as well as a work list.

| Week | Dates | Documentation & Analysis | Build, Fabrication & Testing | Outreach & Administrative |
|---|---|---|---|---|
| | | | | |
| **Week** | **Dates** | **Documentation & Analysis** | **Build, Fabrication & Testing** | **Outreach & Administrative** |
| **Week 1** | Sep 22 – 28 2025 | Draft PDR outline and deliverables (Report, Slides, Flysheet). Transfer Proposal content (facilities, team org, safety, engagement). Initialize payload design via Pugh chart. | Receive Inconel 718 tensile specimens; define labeling & test process. | Schedule preliminary STEM visits; confirm mentor meetings. |
| **Week 2** | Sep 29 – Oct 5 | Add morphological charts & design iterations; enter payload design; begin hazard & FMEA drafts; document recovery subsystem calculations & wiring. | — | Continue outreach scheduling; update safety roster. |
| **Week 3** | Oct 6 – 12 | Draft "Changes Since Proposal"; complete mission performance predictions. | — | NASA Kickoff & PDR Q&A (Oct 9); funding outreach begins. |
| **Week 4** | Oct 13 – 19 | Transfer draft report into slides; peer-review formatting; integrate subsystems. | — | Coordinate community availability; mentor check-in. |
| **Week 5** | Oct 20 – 26 | Finalize PDR outline; integrate subsystem sections; peer review hazard/FMEA; Decision **Gate #1 – confirm content owners.** | Verify inventory; draft test templates; prep SharePoint test log. | Schedule ≥1 STEM outreach; confirm PDR rehearsal mentor; update file system. |
| **Decision Gate #1** | **Confirm all subsystem sections, FMEA, and safety documentation are peer-reviewed and compliant before PDR submission.** | | | |
| **Week 6** | Oct 27 – Nov 2 | Final review of PDR Report/Slides/Flysheet; integrate final CAD & simulations; mentor mock presentation. | Manufacturability review; confirm materials & labeling process. | Verify budget; test NASA upload; update outreach tracking. |

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| **Week 7 — PDR Due** | Nov 3 – 9 | **Submit PDR (Nov 3)**; record lessons learned; outline CDR structure; documentation carry-forward. | Begin payload/avionics mock-ups; create build logs; verify recovery fit. | Publish outreach summary; update travel roster. |
| **Week 8** | Nov 10 – 16 | Expand CDR skeleton; draft "Changes Since PDR"; electronics layout narrative; risk matrix update. | Bench prototyping (payload & avionics); drogue deployment mock-up. | Conduct first school event; plan spring outreach. |
| **Week 9** | Nov 17 – 23 | Insert CADs into CDR draft; add recovery diagrams & narrative. | Continue payload prototyping; iterate avionics bench tests. | Log outreach data; mentor updates. |
| **Week 10 Gateway Due** | Nov 24 – 30 | Proofread CDR draft; refine subsystem text; compliance check for Gateway. | Inventory received parts; continue prototyping. | **Submit Gateway Registration (Nov 28)**; light outreach. |
| **Week 11 CDR Q&A** | Dec 1 – 7 | Light workload (finals); attend **CDR Q&A (Dec 3)**; integrate NASA feedback. | — | Maintain outreach log; record Q&A minutes. |
| **Week 12 Subscale Launch** | Dec 8 – 14 | Add placeholders for Subscale Results in CDR; prep data templates. | Finalize subscale build; integrate avionics; **Subscale Launch Dec 13**; log & backup data. | Document launch outreach; capture media. |
| **Week 13** | Dec 15 – 21 | Draft Subscale Results, payload lessons, recovery updates; compile near-final CDR. Compare subscale flight vs. simulation. **Decision Gate #2 – Post Subscale** | Begin full-scale prep; redesign payload via subscale data; update PCB. | File outreach photos; coordinate travel funding. |
| **Decision Gate #2** | **Evaluate subscale flight data vs. simulation (±10 % apogee tolerance) to authorize full-scale fabrication.** | | | |
| **Week 14 (Holiday)** | Dec 22 – 28 | Add "Changes Since PDR"; polish subsystem sections. | Finalize payload technical design. | Maintain sponsor contact; light outreach. |
| **Week 15** | Dec 29 – Jan 4 2026 | Integrate subsystem text; proofread & format. | Send bulkhead & boat-tail designs; confirm heat-treat & finishing specs. | Year-end budget & outreach update. |
| **Week 16 CDR Due**<br><br>**Re-Flights** | Jan 5 – 11 | **Submit CDR (Jan 7)**; prepare subscale data templates. | Subscale relaunch preparation; avionics integration. | Sponsor updates. |

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| | | | **Subscale Flight Tests (2 flights)** – Samson, AL. | Media capture and Outreach for launch. |
| **Week 17** | Jan 12 – 18 | Analyze subscale data; document anomalies; update recovery configuration. | Begin **payload fabrication**; minor vehicle rework if required. **Ground testing.** | Logistics prep for test launches. |
| **Decision Gate #1** | **Evaluate subscale performance and recovery behavior to authorize full-scale build.** | | | |
| **Week 18** | Jan 19 – 25 | Update FRR skeleton; update CAD to as-built. | Continue payload build; 3D printing and assembly of parts | Confirm spring outreach calendar. |
| **Week 19** | Jan 26 – Feb 1 | Hazard analysis update; test procedure documentation**.** | Full-scale vehicle integration (create attachment points and secure fasteners). | Sponsor engagement; finalize Huntsville travel. |
| **Week 20** | Feb 2 – 8 | Draft **FRR verification sections**; launch procedures. | Final integration; parachute packing; continuity checks | Mentor review. |
| **Decision Gate #2** | **Verify integration, dual ejection tests, and safety sign-offs before proceeding to full-scale launch and FRR submission.** | | | |
| **Week 21 FRR Q&A** | Feb 9 – 15 | Team photos (Feb 9); attend **FRR Q&A (Feb 11)**; integrate feedback. | Final readiness checks; buffer. | Plan community flight-test event. |
| **Week 22 Full-Scale Flight Test** | Feb 16 – 22 | Draft Full-Scale Results templates ahead of test. | **Full-Scale Flight Attempt #1 (SEARS or Propel Science Foundation)** flight execution & inspection. | Host outreach at launch; capture media. |
| **Week 23** | Feb 23 – Mar 1 | Insert Full-Scale Results finalize FRR draft. | Disassembly & Inspection. | Outreach/media for backup launch. |
| **Week 24** | Mar 2 – 8 | Proofread FRR; mentor safety review; compliance check. | NONE | Prepare FRR outreach materials. |
| **Week 25 FRR Due** | Mar 9 – 15 | **Submit FRR (Mar 9)**; debrief; prep Addendum. | Rebuild/reintegrate per NASA feedback; continue payload testing.<br>Paint Rocket | |
| **Week 26 Spring Break** | Mar 16 – 22 | Prepare FRR Addendum templates; update STEM documentation. | Touch-ups, paint, pack spares.<br>**Full-Scale Flight Attempt #2 (SEARS or Propel Science** | Light outreach; travel logistics. |

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| | | | **Foundation)** flight execution & inspection. | |
| **Week 27** | Mar 23 – 29 | Draft Launch-Week logistics & outreach report updates. | Final rocket prep; test ejection/payload. **Full-Scale Flight Attempt #3 (SEARS or Propel Science Foundation)** If Needed | Confirm travel roles; safety docs. |
| **Week 28** | Mar 30 – Apr 5 | Finalize Launch-Week docs; print checklists; plan PLAR structure. Finalize FRR Addendum. | Final bench & power-cycle tests. **Full-Scale Flight Attempt #4 (SEARS or Propel Science Foundation)** If Needed | Pre-travel outreach posts; community reminders. |
| **Week 29 Addendum (if req.)** | Apr 6 – 12 | Submit FRR Addendum; final proofing. | Final maintenance & packing for transport. | Confirm lodging & transport. |
| **Week 30 Launch Week Q&A** | Apr 13 – 19 | Attend **Launch Week Q&A (Apr 15)**; finalize checklists; compliance verification. | Final readiness & continuity tests; crate packing. | Final travel docs; emergency contacts. |
| **Week 31 Competition Launch Week (Huntsville)** | Apr 20 – 26 | **Apr 20–26 Detailed Ops:**<br>**Mon:** Checklist print & travel prep.<br>Tue: Transport arrival & inventory.<br>**Wed:** RSO inspection & manifest upload.<br>**Thu:** Full assembly & RSO approval.<br>**Fri:** Internal rehearsal & final checks.<br>**Sat Apr 25: Competition Launch Day** (Flight & retrieval).<br>Sun: Post-flight data backup & teardown. | Field operations, launch execution, and post-flight inspection. | On-site outreach & sponsor engagement; attend closing ceremonies. |
| **Week 32** | Apr 27 – May 3 | Draft PLAR; insert flight & payload analysis; lessons learned. | Post-flight teardown; anomaly analysis. | Publish outreach report; send sponsor thanks. |

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| **Week 33 — PLAR Due** | May 4 – 10 | **Submit PLAR (May 10)**; archive documentation & raw data. | — | Final outreach report; budget closeout; mentor debrief. |

***Table 7.2 Project Timeline***

Full-scale flight attempts are planned in coordination with either the Southeast Association of Rocketry (SEARS) under the SEARS Treasurer John Hansel or the Propel Science Foundation, both of which have confirmed launch availability within the project timeline.

The FRR schedule is structured to allow incorporation of subscale relaunch data and at least one full-scale flight prior to FRR submission, with a second full-scale opportunity available for final configuration validation.

## The Terra Nova Project - Gantt Chart

Week Highligh 16

| Category | ACTIVITY | PLAN START | PLAN DURATION | ACTUAL START | ACTUAL DURATION | PERCENT COMPLETE |
|---|---|---|---|---|---|---|
| PDR Development | | | | | | |
| | Draft PDR Outline & Assign Content | 1 | 1 | 1 | 1 | 100% |
| | Write Subsystem Sections: | 2 | 2 | 2 | 2 | 100% |
| | Draft Hazard Analysis & FMEA: | 2 | 2 | 2 | 2 | 100% |
| | Mission Performance Sims | 3 | 1 | 3 | 1 | 100% |
| | Format & Peer Review PDR: | 4 | 2 | 4 | 2 | 100% |
| | PDR Mock Presentation | 6 | 1 | 6 | 1 | 100% |
| | Submit PDR Deliverables: | 7 | 1 | 7 | 1 | 100% |
| Material Testing | | | | | | |
| | Prepare Inconel Specimens: | 9 | 1 | 9 | 1 | 50% |
| | Conduct Material Tests: | 10 | 4 | 10 | 4 | 50% |
| Subscale Build & Test | | | | | | |
| | Subscale Design Finalization: | 1 | 2 | 1 | 2 | 100% |
| | Subscale Fabrication: | 8 | 5 | 8 | 6 | 100% |
| | Subscale Launch: | 12 | 0 | 12 | 5 | 33% |
| | Analyze Subscale Flight Data: | 13 | 1 | 13 | 4 | 33% |
| CDR Development | | | | | | |
| | CDR Draft: | 8 | 2 | 8 | 2 | 100% |
| | Integrate Subscale Lessons: | 13 | 2 | 13 | 2 | 100% |
| | Finalize CDR Report & Slides: | 15 | 2 | 15 | 2 | 100% |
| | Submit CDR Deliverables: | 16 | 1 | 16 | 1 | 100% |
| Full-Scale Build & Test | | | | | | |
| | Begin Full-Scale Fabrication: | 16 | 3 | 16 | 3 | 0% |
| | Ground Ejection Tests: | 18 | 2 | 18 | 2 | 0% |
| | Payload Vibration Tests: | 19 | 2 | 19 | 2 | 0% |
| | Final Integration & Assembly: | 20 | 2 | 20 | 2 | 0% |
| | Full-Scale Launch (VDF): | 22 | 3 | 22 | 3 | 0% |
| FRR Development | | | | | | |
| | Draft FRR Report & Slides: | 22 | 3 | 18 | 7 | 0% |
| | Submit FRR Deliverables: | 25 | 0 | 25 | 0 | 0% |
| Launch Week | | | | | | |
| | Prepare Logistics & Travel: | 26 | 2 | 26 | 2 | 0% |
| | Competition Launch: | 31 | 0 | 31 | 0 | 0% |
| Post Launch | | | | | | |
| | Draft PLAR & Lessons Learned: | 32 | 2 | 32 | 2 | 0% |
| | Submit PLAR: | 33 | 0 | 33 | 0 | 0% |
| Ongoing Activities | | | | | | |
| | STEM Outreach Visits: | 1 | 30 | 1 | 30 | 55% |
| | Sponsor & Budget Mgmt: | 1 | 33 | 1 | 33 | 50% |
| | Safety & Risk Updates: | 2 | 30 | 2 | 30 | 50% |

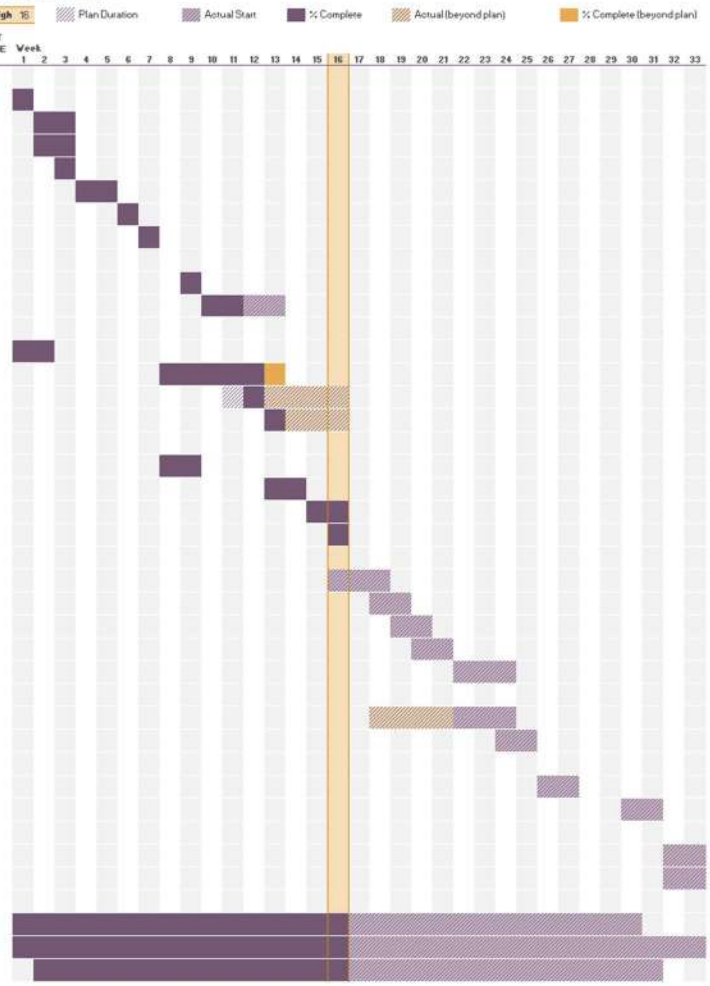


***Table 7.3 Gantt Chart***