The Terra Nova Project
Final Readiness Review
Addendum

NASA University Student Launch Flight Readiness Review
Addendum

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

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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 Addendum

1.1. Team Summary

Team Summary	
The Terra Nova Project	4750 Collegiate Dr. Panama City, FL 32405
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1.2. Purpose of Flights

The first flight conducted by the Terra Nova Team on February 22nd, 2026, was to fulfill the Vehicle Demonstration Flight (VDF) for the FRR. The second conducted March 29th, 2026, flight was to fulfill both the VDF and Payload Demonstration Flight (PDF).

1.2.1. Flight Summary Information (for each flight)

Team Summary		
	Flight #1 (pre-FRR)	Flight #2 (post-FRR)
Date of flight:	02/22/2026	03/29/2026
Location of flight:	Samson, AL	Samson, AL
Purpose of :	Vehicle Demonstration Flight	Payload Demonstration Flight & Vehicle Demonstration Re-Flight
Launch conditions:	7.5°; 22 ft/s wind velocity; 68.76°F; 102.3 kPa atmospheric pressure	7.5° launch angle; 10.3 ft/s wind velocity; 74.12°F; 102.4 kPa atmospheric pressure
Motor flown:	Cesaroni L1395	Cesaroni L1395
Ballast flown (lbs.):	4.86 lb	0 lb
Final payload flown (Y/N):	No- Mass component used in place	Yes – However due to burnt motor driver, the retention system was fastened closed using screws
Air brake system status during test flight:	N/A	N/A
Official target altitude (ft.):	4900 ft	4900 ft

Predicted altitude from simulations (ft.):	4469 ft	4387
Measured altitude (ft.):	4564	4753 ft
Identify any off-nominal events during mission execution:	Recovery: - At the deployment of the Drogue shoot the nosecone weight jerked the rocket body and pulled off the aft section due to weekend sheer pins, causing a main deployment near apogee, which resulted in an unacceptable recovery time. - Due to wires from the flight computer to the main, the reefing mechanism wires snapped, causing no unreefing of our main caused a faster decent and an unacceptable impact energy	Recovery: - Upon deployment of our main, as the nose cone was attached directly to the drogue, our nose cone collided with our main inciting a delayed full deployment. Moving forward we will be attaching our drogue along the shock cord to position the section below our main deployment, with an acceptable safety margin

1.3. Changes made since FRR

1.3.1. Changes made to Vehicle

1.3.1.1. Bulkheads

In the First VDF flight attempt the Inconel bulkheads to be supplied by Astro America were not yet received, so traditional plywood was used in their place along with ballast weight to account for the heavy metal. Astro America has since supplied these bulkheads to the Terra Nova team, and they were used in our recent VDF flight reported in this addendum.

Figure 1.1 – Inconel Bulkheads

These bulkheads combined weigh 77.72 oz or 4.86 lb, which can be compared to the ballast weight of 77.78 or 4.86 lb used in the first flight attempt to represent them with some additional ballast weight for paint. Some issues occurred in the manufacturing process, and the bulkheads were not in ideal usable shape when they were retrieved by the team. To account for this, a PETG mold was printed so that epoxy could be applied to the bulkheads in order to fix the somewhat distorted shape of some bulkheads. The result was a near perfect circular appearance that attached as intended to all components. However, due to both the material being denser than initially predicted and the added layers of epoxy, the bulkheads weight significantly more than originally expected. The forward and aft bulkheads were epoxied to their respective couplers, while the avionics bulkheads were held in place via the two AV bolts.

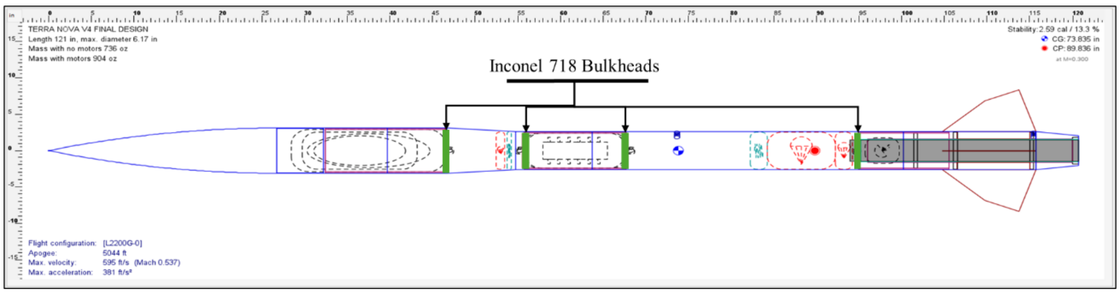

Figure 1.2 – Inconel Bulkhead Locations

1.3.1.2. Reefing Mechanism Removed

After completing the FRR presentation, the Terra Nova team discussed whether the reefing mechanism should be employed in the final flight. While the team had high confidence in the design, the decision was made not to risk our final qualification attempt for an unnecessary feature. The entire system was removed from the vehicle, greatly simplifying the recovery system.

The reefing system was implemented in response to extremely high recovery forces. This concern was disproven in the second launch attempt, as the recovery system recovered without any structural issue. Another justification for the reefing system was to decrease total descent time by keeping the main parachute small until fully opening it at a lower altitude. Opening the main at a high altitude would imply high wind drift and descent time, so the main recovery event was programmed to occur at 550 feet, rather than 1000ft or 650ft. This decision proved to be beneficial to our total descent time, as the rocket landed earlier than was predicted using the reefing system.

1.3.1.3. Shock Cords Bound

Taking the advice given by the NASA team during the FRR presentation, the Terra Nova's shock cords were bound periodically using painter's tape. This allowed the cord to lengthen more slowly while dissipating small amounts of load in the process.

1.3.1.4. Camera Added to Airframe

The first flight attempt did not see a camera attached to the airframe with the purpose of recording the launch. This was an oversight, and the team made sure to fix this before launching again. The camera was attached just forward of the AV bay and recorded the entire flight successfully. The video is available for viewing in the **Appendix**.

1.3.2. Changes made to Payload

In preparation and due to the attempted PDF flight, there have been a few changes to the payload design to optimize functionality and to ensure it meets the required parameters and safety standards as set by NASA and the Terra Nova Team. These changes include slight modifications to the linkage system design, modifications to the Rear Motor Mount, modifications to the Soil Container and lid, testing of a different soil quantity verification distance sensor, modification to the auger, modifications to the upper and lower drilling head couplers, motor change for the mechanical separation system, increasing strength of mechanical separation main plate, and implementation of custom PCB for the mechanical separation.

1.3.2.1. Linkage System

Upon further testing of the linkage system of the Terra Inquisitor, it was observed that one of cranks had stripped out where the driving D shaft connected. Due to this issue, the crank design was slightly modified to increase the material where the link joins to the 6mm D-shaft. Below in Figure 1.3 is a drawing of the design modification.

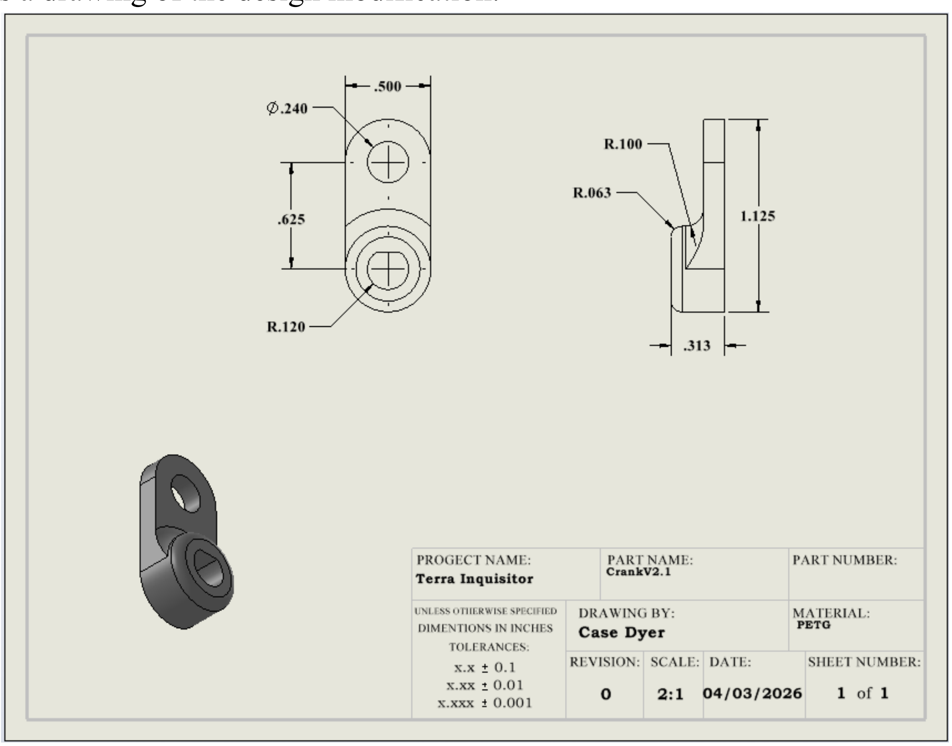

Figure 1.3 – Modified Crank Link Detailed Drawing

1.3.2.2. Rear Motor Mount

As the system has been tested more and more, it has been observed that the Idler gear attached to the rear motor mount (as can be seen in Figure 1.4) continuously pulls out it bearing from the seating location in the mount during operation of the servo motor. This causes the linkage system to function poorly and also cause significant wear damage to both the servo driving gear and the idler gear. The original design only included one bearing glued to the rear motor mount and through which the shaft of the idler gear was inserted. The new design incorporates second bearing on the other side of the motor mount so that a longer shaft can be inserted through both and cause the loading of the idler gear to be transferred to the motor mount instead of slowly wearing down and breaking the glue. In addition to this modification the motor mount strap over the servo motor has been modified to increase strength as this portion of the design had broken multiple times when assembling the system. Figure 1.5 details the drawing of the motor mount. The new design has proven to be substantially superior for operation as well as reduction in gear wear as the idler gears now remains in its correct position

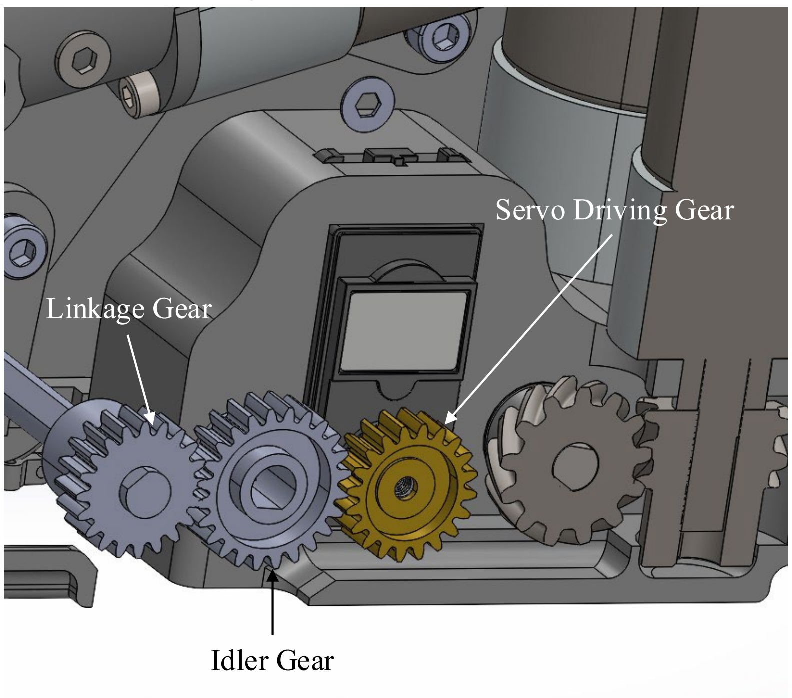

Figure 1.4 – Servo Motor Driving System Layout Schematic

1.3.2.3. Soil Container Modifications

In order for the temperature sensor to be held in its correct orientation some additional material needed to be added to retain the sensor. The modification can be observed in the detailed drawing below.

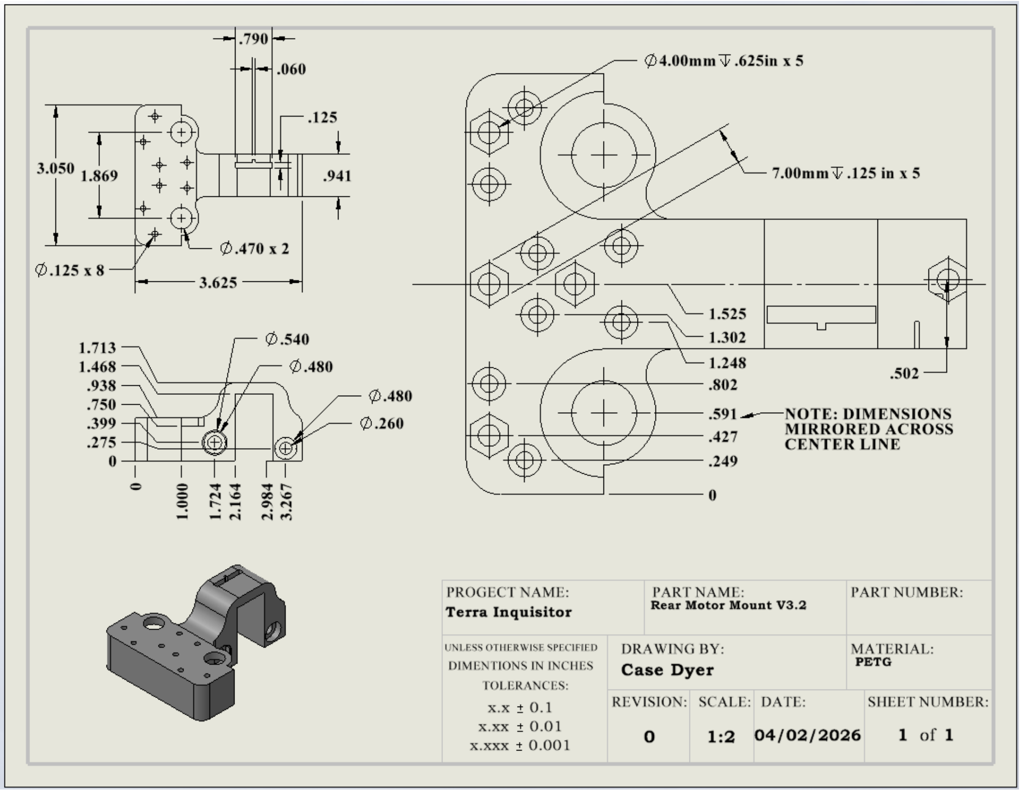

Figure 1.5 – Rear Motor Mount Detailed Drawing

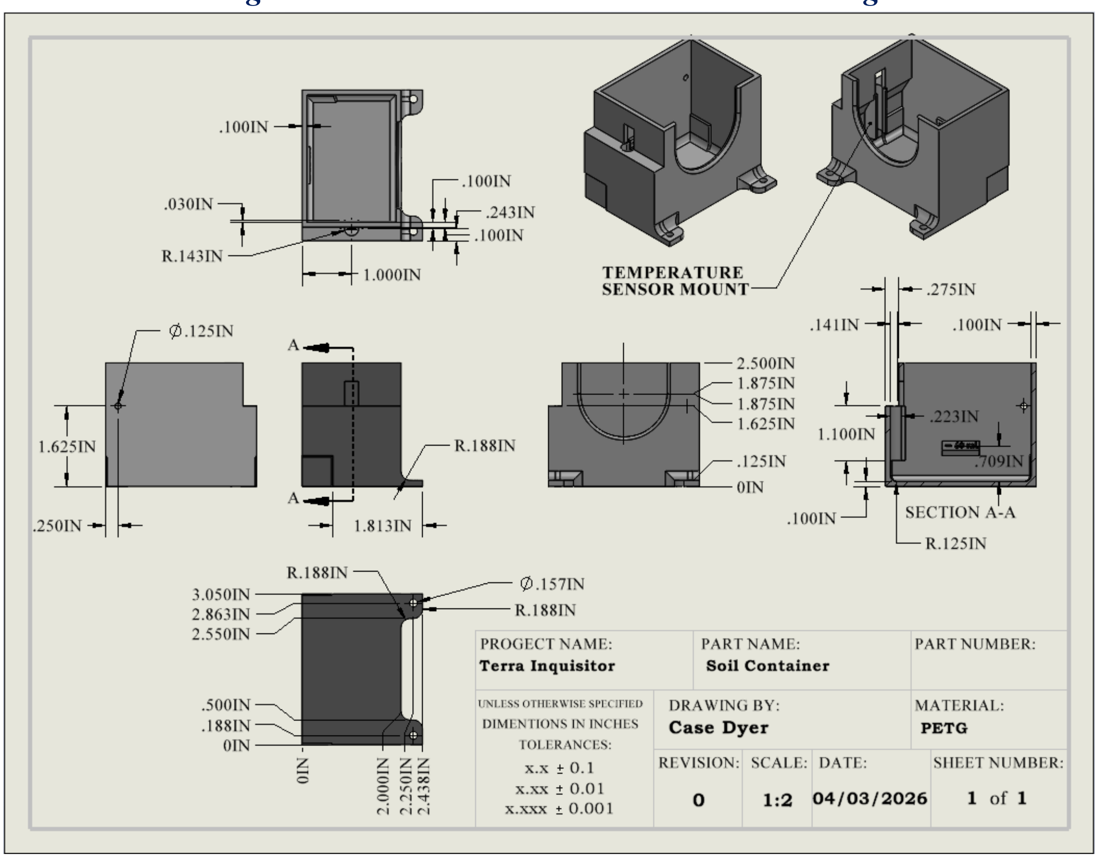

Figure 1.6 – Soil Container Detailed Drawing

1.3.2.4. Soil Quantity Verification Sensor

The distance sensor has been changed from a UT sensor to an Arduino Modulino Distance sensor due to the UT sensor possessed being unable to accurately measure within the range necessary. The sensor readings fluctuate such that the system may never realize it is filled or it will always think it is filled even if no soil has been collected. Due to this, the Arduino Modulino Distance sensor has been incorporated as it has a much shorter distance range and is comparatively accurate for the short distance to be measured. Due to the incorporation of this sensor, the soil container lid had to be modified as can be seen in Figure 2.7 below.

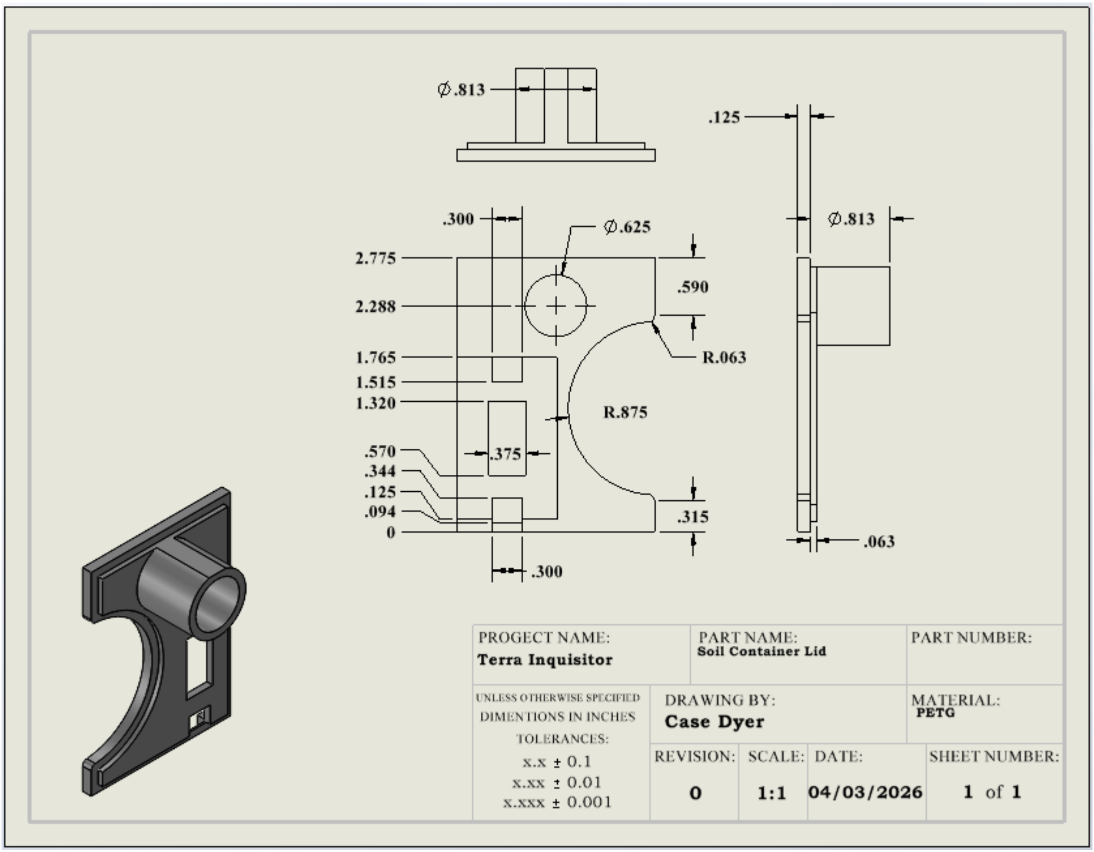

Figure 1.7 – Soil Container Lid Detailed Drawing

1.3.2.5. Auger

The auger design has been slightly modified to provide superior performance in soils with root systems. A small auger flightings have been added to the tip of the design. The design modification can be observed in the detailed drawing Figure 1.8.

1.3.2.6. Drilling Head Assembly

In addition to the auger being slightly modified, both the upper and lower coupler were modified to simplify the design and to reduce the friction withing the part. The original design featured rail grooves to guide the lower coupler in the upper coupler. However, these were deemed unnecessary for the design and from testing consistently cause the system to be jammed and the spring meant to ensure constant contact with the ground and then to extend the lower coupler for soil ejection was unable to do so. The detailed drawings of these designs can be observed in Figures 1.9 and 1.10.

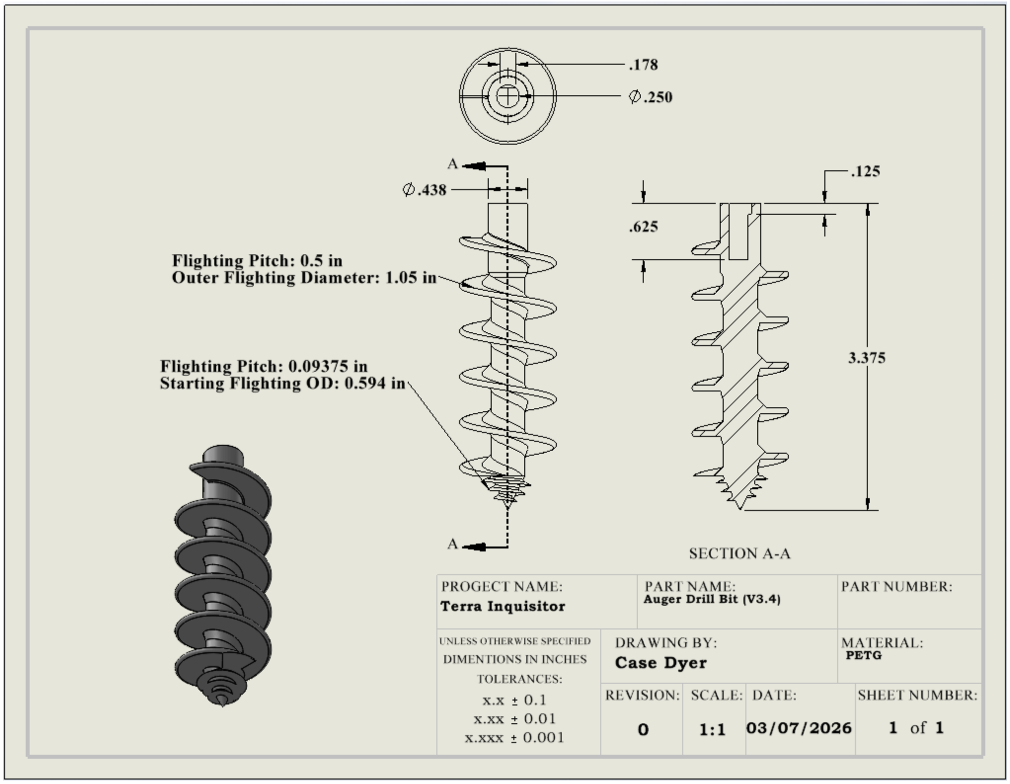

Figure 1.8 – Soil Container Lid Detailed Drawing

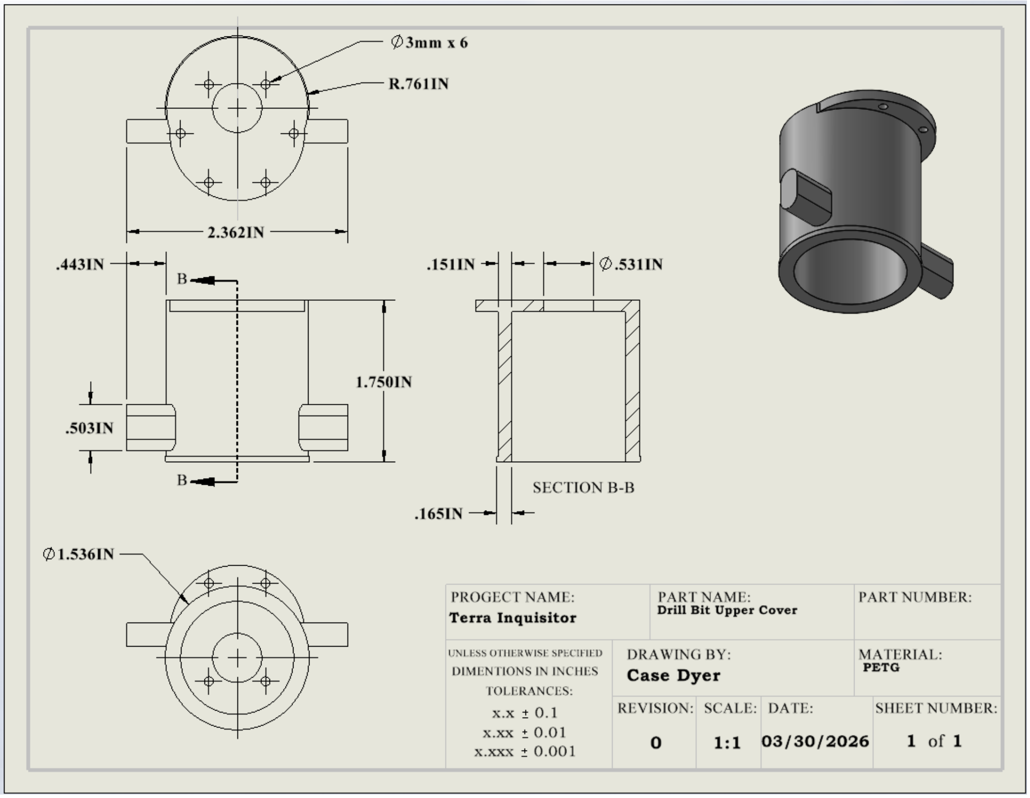

Figure 1.9 – Upper Coupler Detailed Drawing

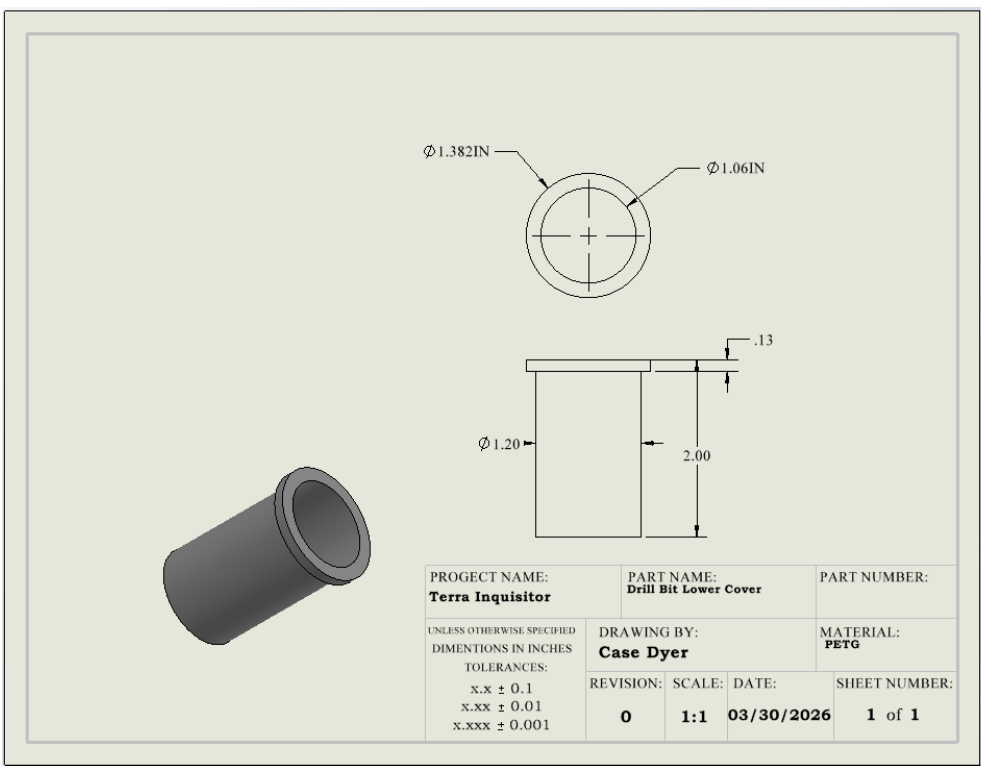

Figure 1.10 – Lower Coupler Detailed Drawing

1.3.2.7. Mechanical Separation Motor

The initial payload separation system utilized a NEMA 17 stepper motor; however, bench testing demonstrated that the stepper motor did not provide sufficient torque to reliably actuate the separation mechanism under load. To address this, the system was redesigned to use a 12V DC motor, which provides increased torque and higher rotational speed, enabling consistent and timely separation. The updated configuration was tested and successfully demonstrated the ability to actuate the mechanism under expected loading conditions. During launch-site assembly, a wiring error resulted in damage to the motor driver, preventing use of the separation mechanism. As a contingency, the payload was secured using screws to ensure safe flight.

As a result of this redesign:

- The CAD model was updated to accommodate the new motor geometry and mounting configuration
- The control system was modified from a stepper motor driver to a DC motor driver
- Electrical integration procedures were revised to reduce the risk of wiring errors

2. Payload Demonstration Flight Results

2.1. 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 geared DC motor to drive a worm gear system, 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. Afte the mechanical separation pushes the nosecone and payload out of the rocket it rotates the assembly into the correct orientation. The Terra Inquisitor then drives out of the nose cone turning from the rocket and immediately 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 18-22 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.

2.2. Payload Retention

The payload retention system is a mechanical deployment system designed to securely retain the payload during flight and reliably release it after landing. The system is triggered by a discontinuity switch tied to drogue deployment, which initiates a 180-second delay timer to ensure deployment occurs after landing and stabilization. Once the timer completes, a DC motor is activated, driving a gear train with an integrated worm gear. The worm gear provides a high mechanical advantage while preventing back-driving, ensuring that external forces (such as aerodynamic loads or nose cone movement) cannot unintentionally actuate the system. The gear train drives two lead screws positioned along the sides of the payload, which are mechanically connected to the nose cone assembly. As the lead screws rotate, corresponding nuts translate linearly, pushing against a pusher plate and forcing separation of the nose cone from the payload housing. Following separation, a passive tilt mechanism, consisting of springs and a lever arm, reorients the payload into its operational position.

2.3. Flight Data

As the VDF and PDF refights were conducted together, all telemetry data is included and analyzed in the next section **3. Vehicle Demonstration Re-flight** as the tests were conducted with the same launch.

2.4. System Operation Pre-launch

All systems for the Terra Inquisitor were individually operational prior to the launch. The propulsion system functioned as designed. All sensory systems functioned as designed except the UT sensor which was detailed in the prior section with its lack of ability to reliably measure the short distance for soil collection verification. The linkage system was operational. Prior to arrival at the launch site, the servo motor for the linkage system was damaged, due to this damage, the linkage system was powered by the only servo motor available. However, this motor's torque ratings were significantly below the needs of the system for effective operation and thus no soil sample was able to be collected as the servo could not drive the auger head into the ground. Complete system testing is yet to be fully verified as the full controlling code has not proven fully successful.

The mechanical separation system was initially operational, however, upon further verification ground testing the motor driver of the system failed. The exact cause of this failure is uncertain, however, due to this failure, the system could not be properly operated or trusted to either hold the payload securely or separate upon landing. Thus, in order to still achieve a successful VDF, the launch vehicle was fully constructed, the mechanical separation system was modified to allow all systems to be assembled manually, the payload was inserted and packed with "dog barf", and the nose cone was secured using two screws. Thus, all the systems were a part of the launch at Samson AL on the 29th of March. However, as the nose cone was fixed using screws and the mechanical separation system was inoperable, the payload could not exit from the launch vehicle upon its safe landing. “Dog barf” was included as padding for the payload as the since the modifications to the mechanical separation system would not properly retain the payload as originally design when properly operation.

2.5. Post-Launch Analysis

The image below (Figure 2.1) shows the payload in its state stored in the HAUS section upon the landing of the launch vehicle.

Figure 2.1 – Payload in HAUS Section as Landed

The payload chassis did withstand the forces of the launch with only a minor crack of the 3D print in the front that has no effect on the operation of the vehicle. This crack was only observed due to “dog barf” getting shoved into it during landing. This result can be observed in the image below (Figure 2.2)

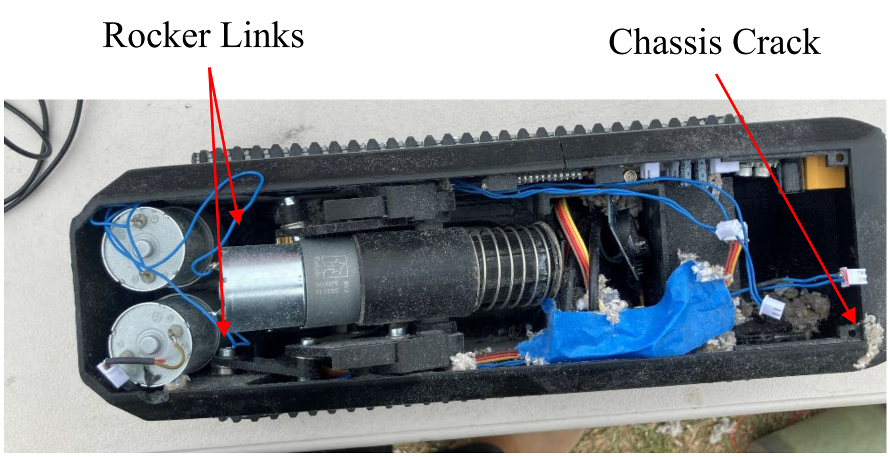

Figure 2.2 – Payload as Landed with Minor Track Repairs

In addition to the chassis crack, the rocker links were pulled out of their grounding locations and so the linkage was unable to operate upon landing. Both track systems had their front sprocket bearings pulled from the chassis and thus the tracks were not in operational condition. The above image does not show this as a picture of this was not taken. The above picture is after minor repairs to the track system. However, as can be observed in the above picture all these failures were easily reparable. Due to these system failures, improvements will be implemented to ensure the system is ready for the next launch. The front sprocket bearings will be more securely attached to the front chassis with superglue. They had originally been left only hand press-fit into the chassis due to the need to leave room for modifications and ease of taking apart the system. However, with the final designs of the Terra Inquisitor all such bearings will be permanently attached. As the servo motor was damaged prior to launch it has been replaced with a new one of the same model. Below is an image of the "dog barf" implemented to cushion the landing impact since the mechanical separation system was not fully operational. In the future, foam padding will be added to the nose cone plate to ensure the payload is securely set in the launch vehicle and to provide better and more reliable padding than the "dog barf." This will also be implemented due to the cracking that occurred at the front of the chassis and so by fixing the mechanical separation system and adding the foam padding, the likelihood of the chassis cracking will be greatly reduced. This will also ensure that "dog barf" will not be needed as it filled every part of the payload and would have further inhibited operation of the system, clogging the servo motor gearing, the soil container, and the cross helical gears for the propulsion system. Thus, risking the success of the mission of the Terra Inquisitor.

Figure 2.3 – Nose Cone Plate Dog Barf Padding

Finally, the mechanical separation system will receive the necessary modifications to its electronic system to ensure proper operation. However, it did not function as intended due to the usage of screws to hold the section together due to concerns prior to launch. Upon the approval of NASA, the nose cone will be secured with shear pins instead of screws so that it remains physically fastened to the launch vehicle, then upon landing, the mechanical separation system will activate, breaking the shear pins, and deploying the Terra Inqisitor.

Overall, there were no major repairs necessary due to the landing of the launch vehicle, but there were many lessons learned to ensure proper function at the competition launch. As mentioned, there are multiple steps to be taken to rectify the failures observed to the payload and mechanical separation systems due to this launch. These steps include fixing the mechanical separation electronics system for reliability, adding foam padding to the nosecone front plate to absorb and cushion the landing impact for the Terra Inquisitor, all bearings for the track system and linkage system are to be superglued in-place to ensure proper retention instead of just relying on press-fitting and the servo motor is to be replaced.

3. Vehicle Demonstration Re-flight

3.1. Functioning Systems Description

3.1.1. Airframe

The Terra Nova airframe functioned as intended, and no damage was sustained during flight or landing.

3.1.2. Attachment Hardware

Attachment hardware is defined in this case as any screws/epoxy holding airframe components together (static attachments), shear pins, and eyebolts used to attach recovery hardware. All static attachments functioned as intended and no components were damaged or separated from their intended fixed location. Shear pins were used to connect the three independent vehicle sections together prior to recovery events and successfully held these components together as intended. The shear pins failed as intended upon recovery event initiation. 4 eyebolts were used on each of the bulkheads, connecting the two shock cords to all three independent vehicle sections. Though the strength of the material used (stainless steel) was significantly above any predicted forces, it should still be noted that none of these components failed during flight or recovery.

3.1.3. Bulkheads

The Inconel bulkheads used in this flight were the least likely component to fail due to their significant documented/tested strength. The primary reason for concern was that epoxy was used to fix the distorted shape of the bulkheads created in the additive manufacturing process. While epoxies used in prior flights showed very little concern for failure, it was still a point to consider. Upon recovery, it was confirmed that all 4 bulkheads sustained no damage or detachment from the airframe.

3.1.4. Electronics

The electronics used in the Terra Nova rocket (not including payload systems) are limited to avionics components and the airframe camera. The avionics components include TeleMetrum and EZ Mini computers for primary and redundant events, respectively, a screw switch to arm the avionics bay, e-matches used to initiate events, and LiPo batteries used to power all computers. The Telemetrum was programmed to initiate the drogue event at apogee +1 second, and the main event at 550 ft. The EZ Mini had the same programming, though it followed the Telemetrum by 1 second (apogee +2s, 550ft +1s). Both programmed computers worked as intended. Both computers were armed by the screw switch and powered by the LiPo batteries, so working computers proves that these components worked as well.

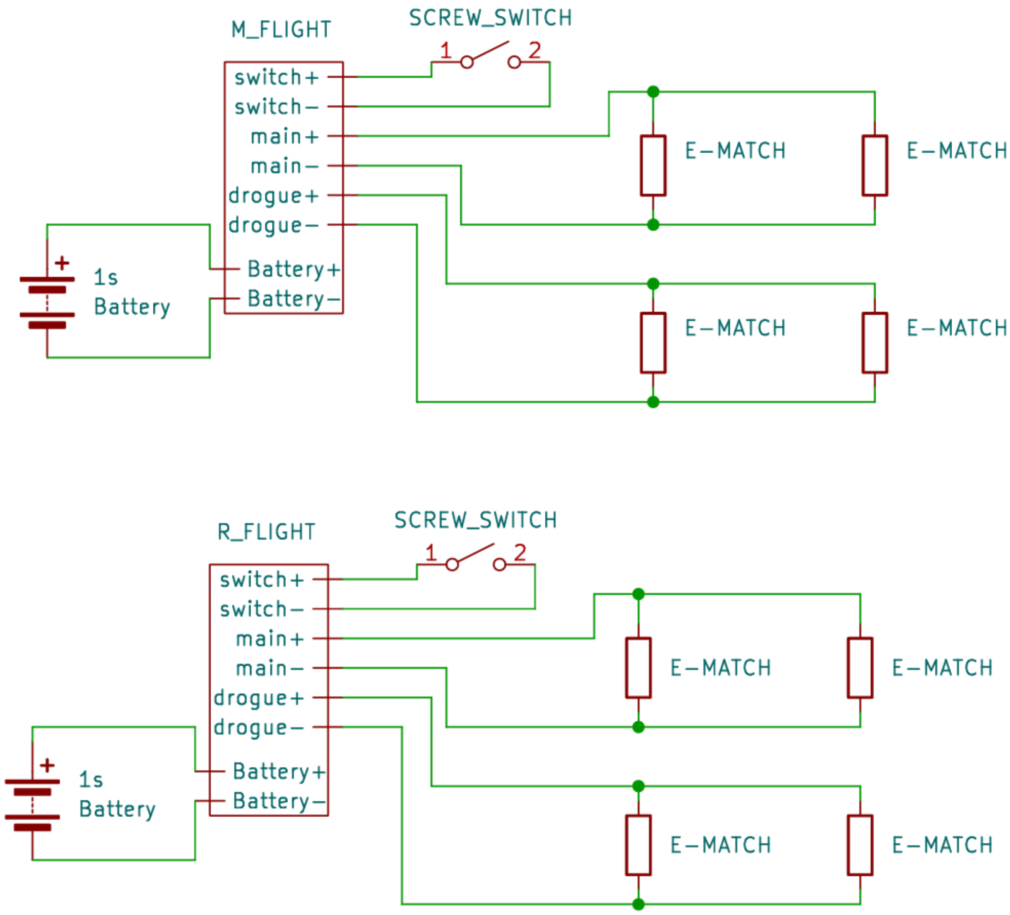

Figure 3.1 Main and Redundant Flight Computer Wiring Diagram

3.1.5. Recovery Hardware

Recovery hardware in this case includes both parachutes, shock cords, and the TR Eagle CO_2 ejection devices. Successful separation at intended altitudes proves that the TR Eagles were working as intended, and upon recovering the vehicle it was confirmed that all 4 devices fired. The shock cords successfully retained all three vehicle sections, and no damage was discovered. Both parachutes successfully deployed, though the main parachute had some complications (did not lead to a failed flight) that will be discussed in section 3.2.

3.1.6. Failures

The only failure to note was not a complete failure but it does require discussion in this addendum. During the deployment of the main parachute, it opened fully as intended but quickly made contact between the top of the canopy and the shock cord. This interaction forced the main parachute closed, but it made a full recovery prior to reaching the ground. Upon its reopening, the parachute reached below its projected terminal velocity of 15.5 ft/s, to a landing velocity of 13 ft/s. To mitigate the risks of this event reoccurring, we will attach our parachutes along the length of the shock cord rather than directly to the bulkheads. This should help to prevent any cord-parachute collisions in the future.

3.2. Pre-Flight Simulations

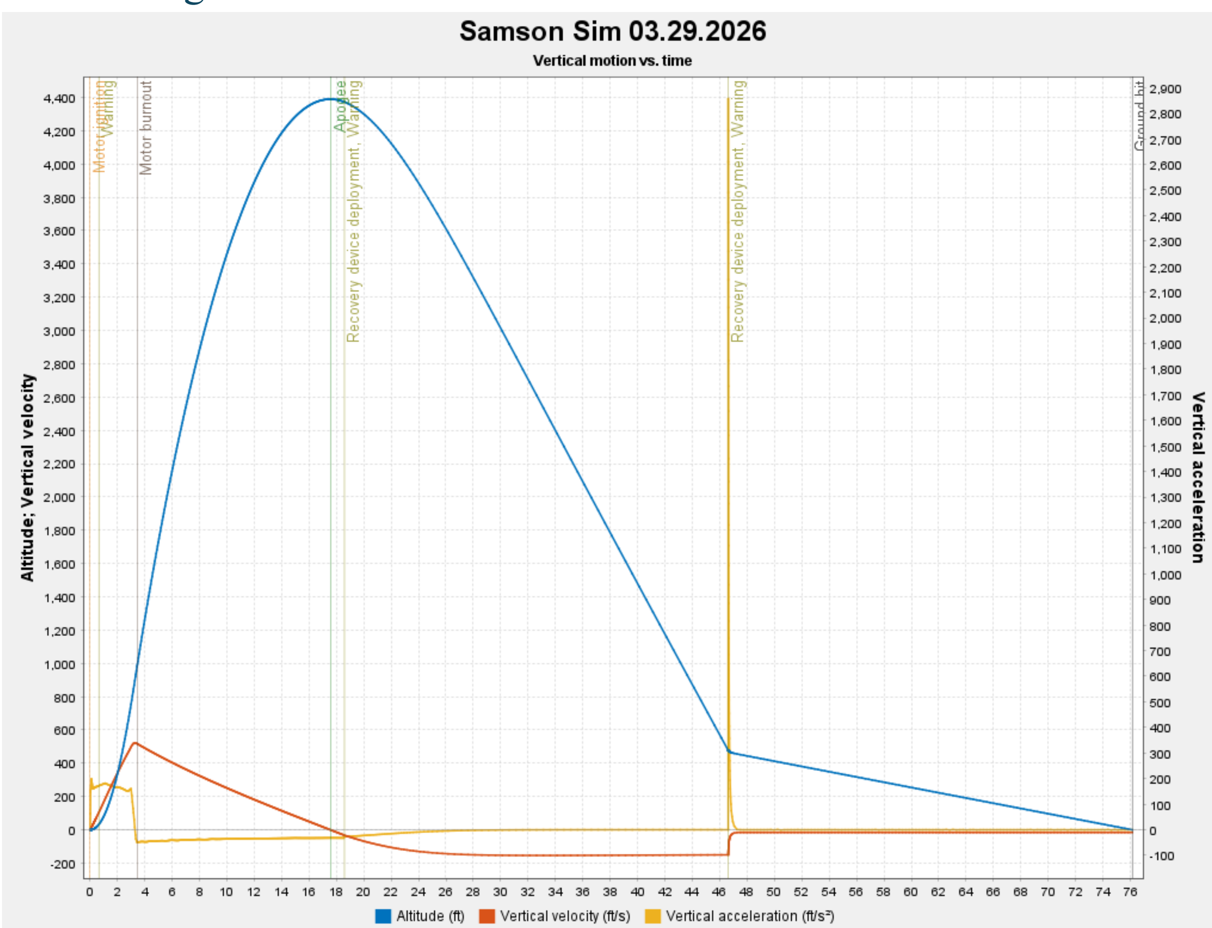

Figure 3.2 – VDF Attempt 2 Flight Simulations

VDF Attempt 2 Launch Predictions					
Apogee	Velocity off Rod	Landing Velocity	Descent Time	Heaviest Section	MAX Impact Energy
4387 ft	59.7 ft/s	15.8 ft/s	58.1 s	16.13 lbs	62.57 ft-lbs

3.3. Flight Results

3.3.1. Recorded Data

Shown below is the chart of recorded data from both the Telemetrum and EZ Mini flight computers. The Telemetrum uses a barometric altimeter alongside an accelerometer, while the EZ Mini uses only a barometric altimeter. Both plots show the entire flight from launch to landing, and provide altitude, velocity, acceleration, and time parameters.

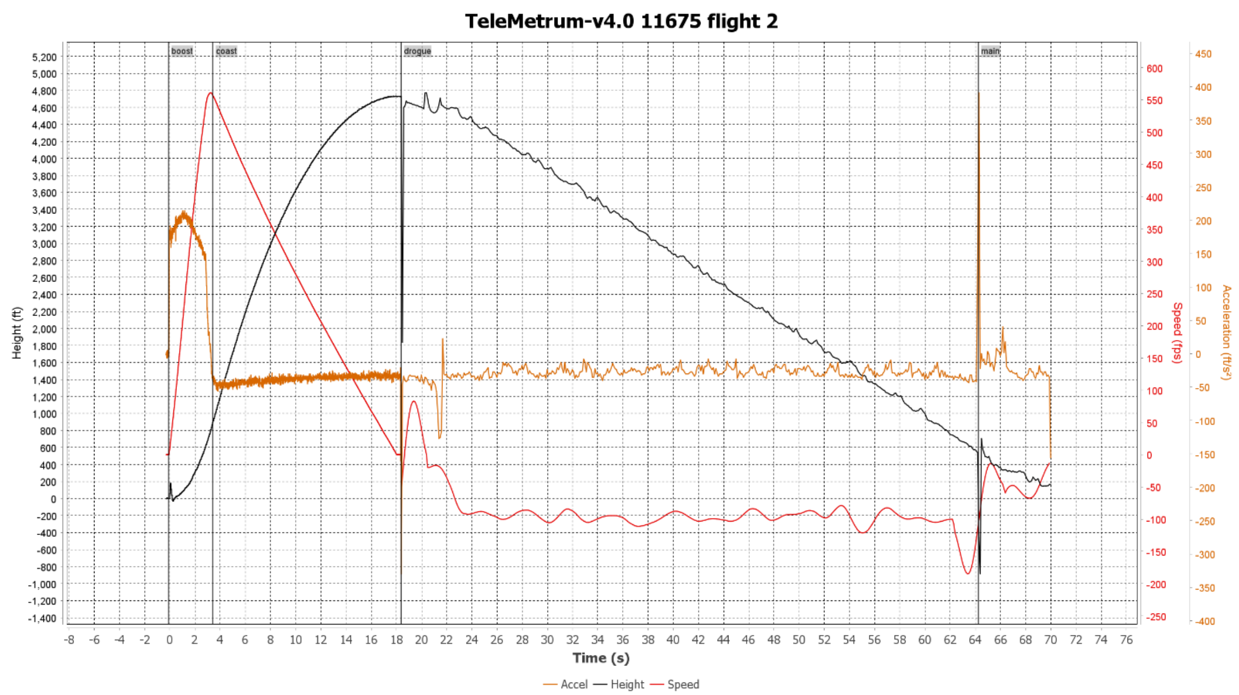

Figure 3.3 – VDF Attempt 2 Recorded Flight Data (Telemetrum)

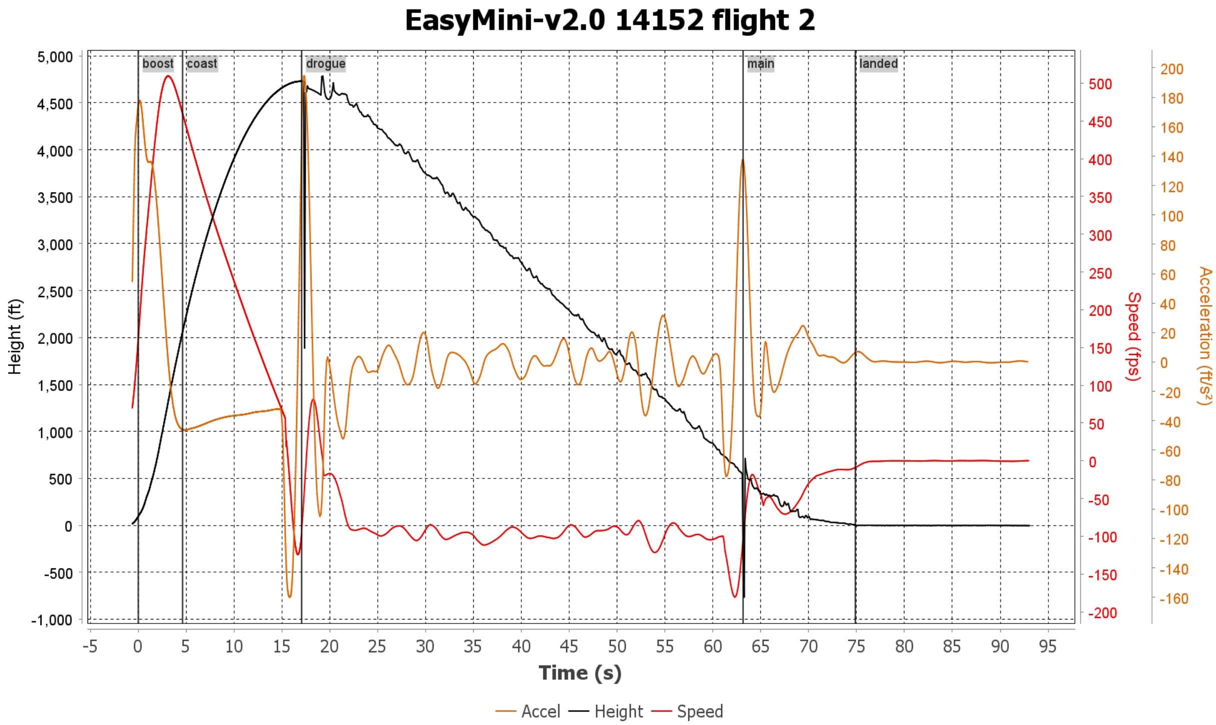

Figure 3.4 – VDF Attempt 2 Recorded Flight Data (EZ Mini)

In addition to the plots, a table of key values has also been provided. This can be seen below.

VDF Attempt 2 Launch Key Datapoints					
Average Apogee	Velocity off Rod	Landing Velocity	Descent Time	Heaviest Section	MAX Impact Energy
4753 ft	64.83 ft/s	13.3 ft/s	51.61 s	16.09 lbs	44.22 ft-lbs

3.4.2 Kinetic Energy & Descent

Kinetic Energy has been calculated for each independent section of the vehicle via the energy equation, using the mass of each section and its terminal velocity during each phase of descent. The equation used to model KE is shown below, as well as the results for each phase & section. NOTE: the velocity used under the drogue stage is taken as an average from the data, while the main/landing stage uses the terminal velocity of that phase.

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

Kinetic Energy Calculations					
Section	Stage	Velocity	Liftoff Mass	Landing Mass	KE Value
HAUS	Drogue	90 ft/s	257.5 oz / 0.500 slug	257.5 oz / 0.500 slug	2025.00 ft-lbs
Avionics	Drogue	90 ft/s	283.6 oz / 0.427 slug	214.8 oz / 0.417 slug	1688.85 ft-lbs
Propulsion	Drogue	90 ft/s	315.5 oz / 0.613 slug	228.7 oz / 0.444 slug	1798.20 ft-lbs
HAUS	Main/Landing	13.3 ft/s	257.5 oz / 0.500 slug	257.5 oz / 0.500 slug	44.22 ft-lbs
Avionics	Main/Landing	13.3 ft/s	283.6 oz / 0.427 slug	214.8 oz / 0.417 slug	36.88 ft-lbs
Propulsion	Main/Landing	13.3 ft/s	315.5 oz / 0.613 slug	228.7 oz / 0.444 slug	39.27 ft-lbs

The differences between takeoff and landing weights of each section involve spent CO_2 and recovery components like shock cords and parachutes. The masses of each item subtracted from takeoff weight can be seen in the table below.

Subtracted Masses		
Component	Section	Mass
CO_2 Canisters	Avionics	5.115 oz / 0.010 slug
Shock Cords 1 & 2	Avionics	32.6 oz / 0.063 slug
Main Parachute	Avionics	~1 oz / 0.002 slug
Drogue Parachute	Avionics	30 oz / 0.058 slug
Spent Propellant	Propulsion	86.8 oz / 0.169 slug

3.4.3 As Landed Configuration

Pictures of the as-landed configuration of the Terra Nova rocket were taken and documented in this addendum. They can be seen below.

Figure 3.5 – HAUS Section As-Landed

Figure 3.6 – Avionics Section As-Landed

Figure 3.7 – Propulsion Section As-Landed

3.4.4 Drag Coefficients

To calculate the drag coefficient of the vehicle during flight, we pulled the velocity and acceleration data from both avionics flight computers and solve for each recorded point's C_d value using Newton's second law.

$$\Sigma F = ma$$

After burnout, it was assumed that the only forces acting on the vehicle were drag and gravity, modeled by the following equation.

$$F_d - mg = ma$$

Given the drag force equation, the equation presented above can be rearranged into the working equation used to calculate the vehicle's drag coefficient.

$$\frac{1}{2} C_d \rho A v^2 - mg = ma$$

Using the acceleration and velocity datasets provided by both altimeters, this equation was solved for C_d and plotted for different velocities to represent the drag coefficient at different points. These plots, as well as key data points, can be seen below.

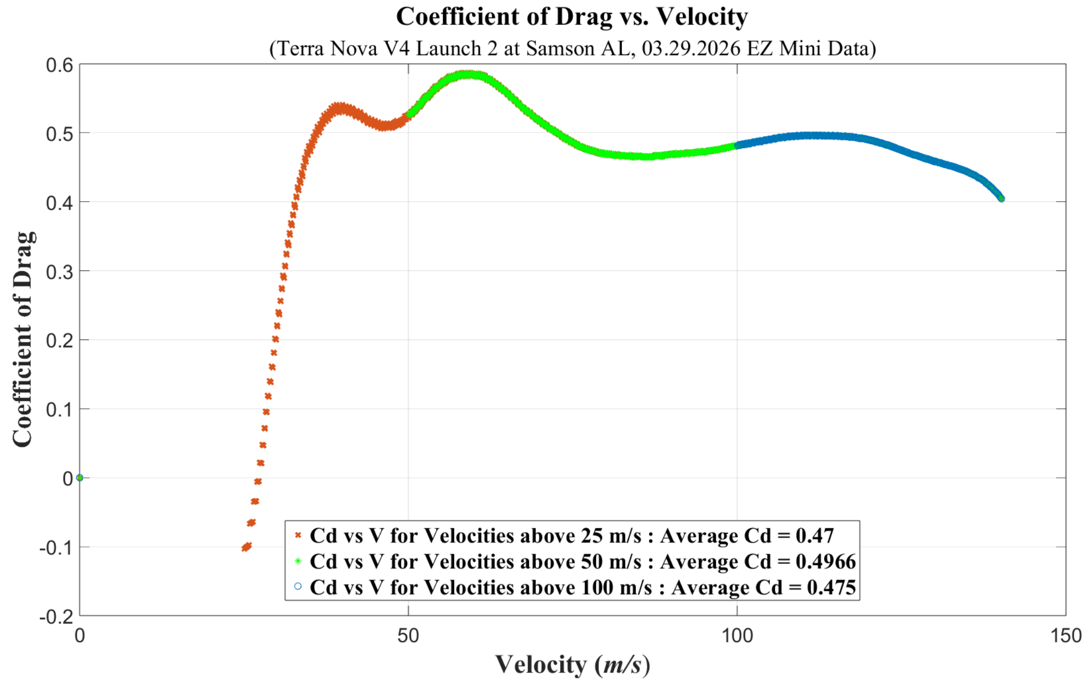

Figure 3.8 – EZ Mini C_d Calculations

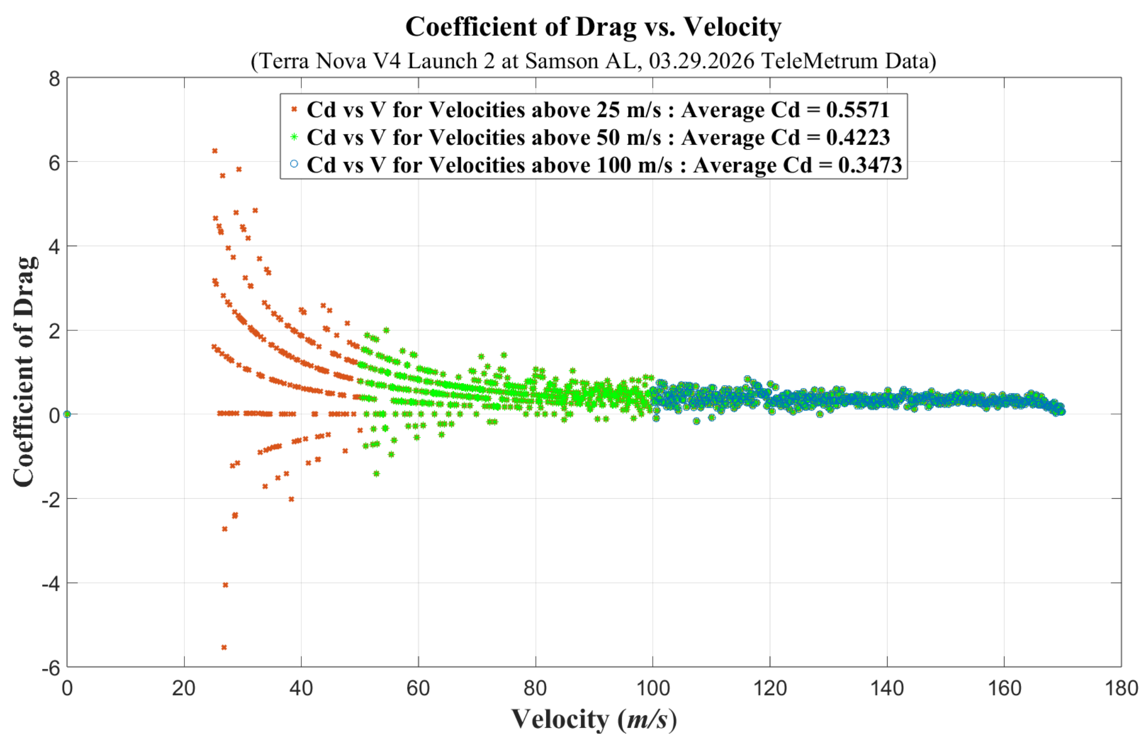

Figure 3.9 – TeleMetrum C_d Calculations

The differences between the two charts can be attributed to how the data was collected. The EZ Mini only uses a barometric altimeter, so velocity and acceleration are interpolated from the data it collects. In contrast, the Telemetrum has an accelerometer as well as a barometric altimeter, so the kinematic data is directly sensed and recorded. This describes the variance of data at lower velocities for the Telemetrum, which can be attributed to "jitters" in the sensor, though overall it is more accurate.

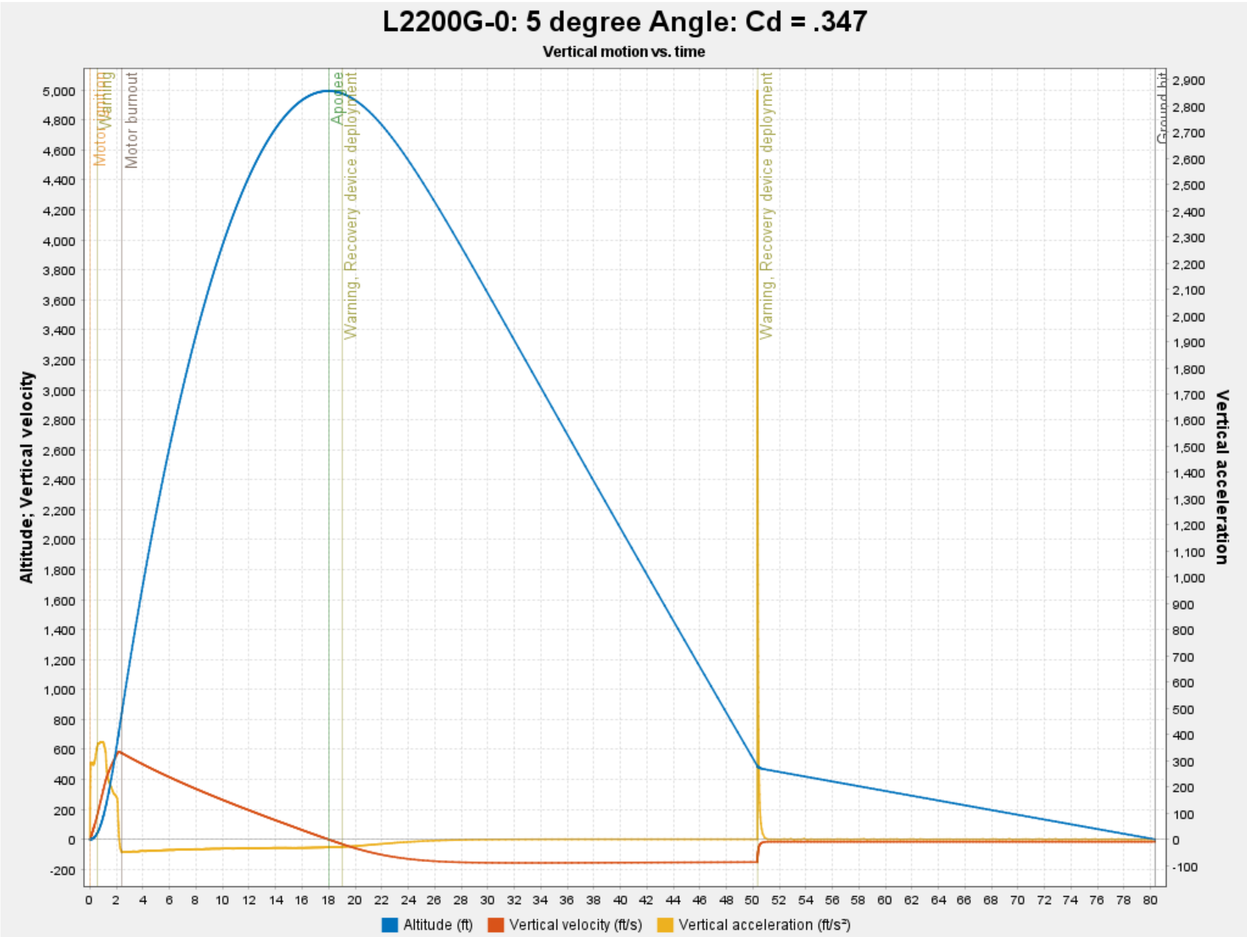

Figure 3.10 OpenRocket Prediction with $C_d = .347$

Since the data from the Telemetrum is more likely to be accurate, the simulation above uses the average $C_d = .347$. The original OpenRocket simulation predicted a $C_d = .367$. The predicted apogee changes from 4916 ft to 4994 ft. However, this does not account for the significant apogee difference that was initially predicted and what occurred. The predicted apogee was 366 ft lower than what actually occurred. Thus, another methodology was employed to estimate the C_d of the rocket. The method was to reduce the C_d until OpenRocket simulated within a foot or two of the same apogee. Using this methodology, the plot () below was created, with the estimated $C_d = .211$. Using this approach also for the first launch of the Terra Nova also yields a more consistent result than using the acceleration and velocity data from the TeleMetrum. For the first launch, the estimated OpenRocket $C_d = .357$ (smaller due to the newer simulation being modified to have an external camera mount), changing it so that the simulation results in the same apogee yields a $C_d = .318$. Using the velocity and acceleration data yielded a $C_d = .399$

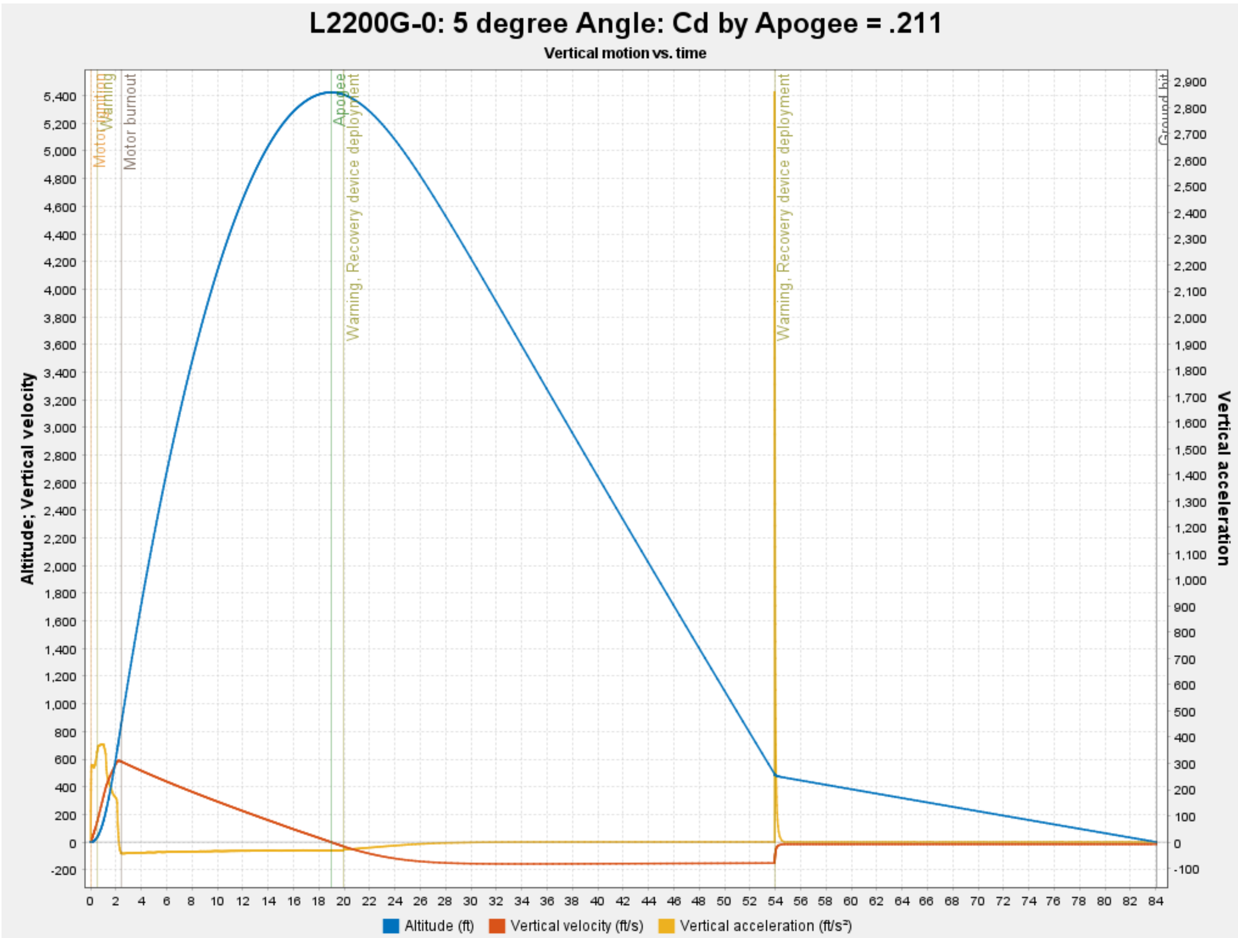

Figure 3.11 OpenRocket Prediction with $C_d = .211$

4. Appendix

VDF Flight 3.29.26.mp4