USLI

WORCESTER POLYTECHNIC INSTITUTE

G.O.A.T.S.

USLI PROJECT Flight Readiness Review Addendum 2018 - 2019

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Section 1. Summary of FRR Addendum

The purpose of this document is to be used in addition to the prior submitted Flight Readiness Review to evaluate WPI's second test flight and payload demonstration. In addition, this document details the repairs made after the first test flight and the team's proposed motor change and thus featuring the final iterations of design for flight in Huntsville.

Section 1.1. Team Summary

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Section 1.2. Purpose of Re-Flight

The purpose of the flight conducted was to fulfill both the Payload Demonstration Flight and the Vehicle Demonstration Re-flight.

Section 1.3. Flight Summary Information

Section 1.3.1 Full Scale Test for FRR

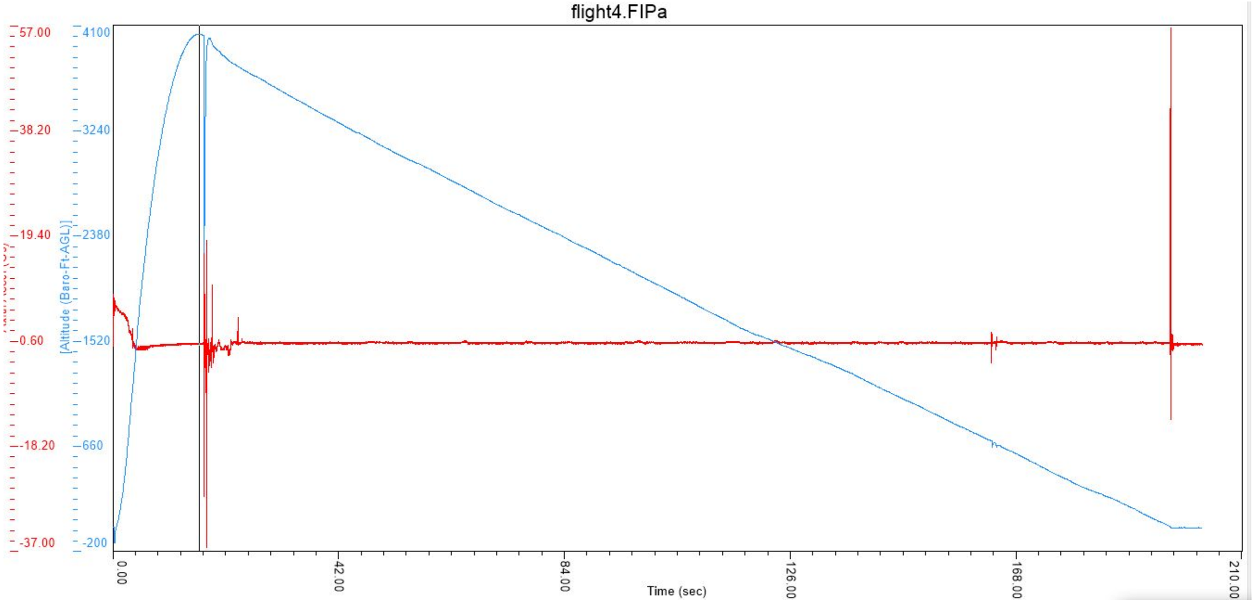

Figure 1.3.1.1. Test Launch 1: Altimeter Flight Data

The first full-scale launch vehicle was launched on Lake Winnipesaukee in Gilford New Hampshire on March 3rd, 2019. The lake was determined to be safe to launch on due to the thickness of the ice being measured to be around 26 inches. This minimum ice thickness able to support a car is 8 inches. With the ice being at 26in this gave us a safety factor of a little over three in terms of the ice being safe to drive on. A successful ejection test was performed before proceeding onto the lake for the full-scale launch. The launch vehicle was launched around 1:15 p.m., with a L730-0 Cesaroni Technology Incorporated motor, at which point the external temperature was about 30℉, with wind speeds of about 9 mph towards the south-east. On the test launch day, we started with an ejection test. We had 4.0 g apogee charge and 5.4 g main charge, which were successful in separating sections and deploying parachutes. We then proceeded to assemble the launch vehicle for a test launch. That process consisted of repacking the parachutes, making and attaching the primary and secondary charges, checking the altimeter, and connecting the sections with shear pins to fully assemble, all while going through our safety checklists. Then we set up the launch vehicle on the rail and launched. According to the data recovered from the primary altimeter both the apogee and main charges were successful in deploying. The graph in figure 1.3.1.1. details the altimeter data for the first test launch. However, due to the force on the top centering ring in the lower airframe when the drogue parachute deployed, the plywood centering ring cracked and in turn, was ripped and sheared from the airframe. Another issue was the weight of the final launch vehicle. Even with our simulated mass, the launch vehicle turned out to be heavier than expected. This explains the drop in apogee from our predicted value of 4500 ft and our simulated value of 4681 ft to 4031 ft. This is a value that falls just slightly above the 4000 ft height minimum.

Section 1.3.2. Full Scale Test for FRR Addendum

The second full-scale launch was launched on Lake Winnipesaukee in Gilford New Hampshire on March 24th, 2019. The lake was determined to be safe to launch on due to the thickness of the ice being measured to be around 20in. The ice around the edges of the lake, however, was too thin to use a car and the team instead hiked a little over two miles to the launch area. A successful ejection test was performed after proceeding onto the lake for the full-scale launch. The launch vehicle was launched around 4:30 p.m., with an L730-0 Cesaroni Technology Incorporated motor, at which point the external temperature was about 30°F, with wind speeds of about 10 mph towards the north-east. The assembly of the launch vehicle consisted of repacking the parachutes, making and attaching the primary and secondary charges, checking the altimeter, going through our safety checklists, and connecting the sections with shear pins to fully assemble. Then we moved the launch vehicle to the launch pad and set up for launch. The payload was also flown, housed inside of its retention system in the upper airframe. According to the data recovered from the primary altimeter both the apogee and main charges were successful in deploying. The measured height by our altimeter was 3182 ft. This is below our declared height of 4500ft and simulated height of 4062ft due to reasons explained in section 1.4.1. below. The only significant off-nominal event was the spike in our altimeter data, which we believe was due to warping of wood from being wet allowing for unexpected changes in pressure. This is discussed further in section 3.1. below. Featured below is a group photo of WPI’s team members that were able to attend the launch.

Figure 1.3.2.1. Group Photo at FRR Addendum Launch

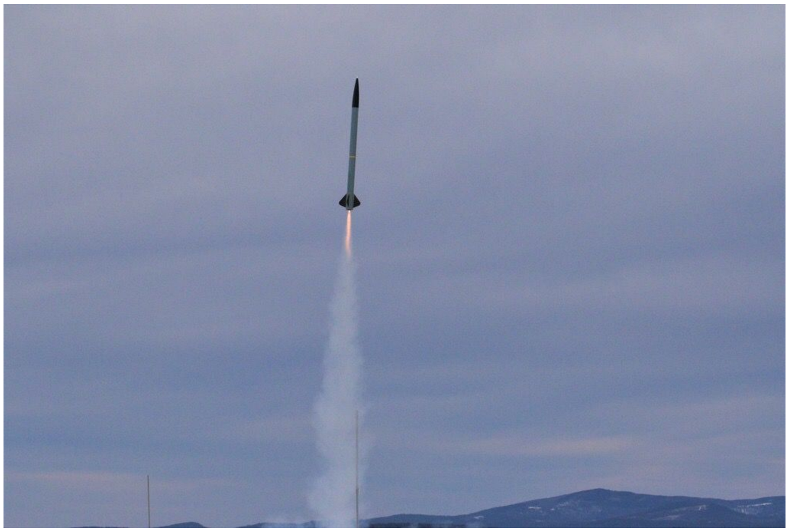

Figure 1.3.2.2. Launch Vehicle Take off at FRR Addendum Launch

Section 1.4. Changes made since FRR

Section 1.4.1. Changes in Launch Vehicle

Most of the changes in the launch vehicle were made to the lower airframe, which had to be rebuilt. Due to its failure in the previous flight, the body tube and top centering ring were broken. The motor tube and fins were able to be salvaged as they sustained no damage. In rebuilding, the main difference was the thickening of the nose cone bulkhead and centering rings from 0.25in to 0.5in. The lower airframe material was also changed from Blue Tube to fiberglass reinforced phenolic. This change was made due to availability of materials as ordering a new Blue Tube body tube may have taken too long. The reinforced phenolic was donated and thus readily available and cheaper. The team also changed the method of construction. The interior assembly of the motor tube, fins, and centering rings was built separately, cured in an oven, then fitted into the body tube. For adhesive, we used a composite of Kevlar pulp and epoxy. In addition, 2 wood screws were used per centering ring to further connect it to the body tube. Washers were added to all bolts. Additionally the drogue parachute size will be increased from 36in to 42in. This is because due to the added weight of repairs the ejection speed of the main parachute is too fast to be considered safe unless the drogue parachute is increased to slow the descent of the launch vehicle down further before deployment of the main parachute. All these changes were made to increase the strength of the lower airframe at the cost of weight and ensure the launch vehicle is safe.

The L935-IM will be the launch vehicle’s proposed new primary motor. It is 25.55in in length, 2.15in diameter and has a total impulse of 3076.45Ns. The following simulations for this motor were obtained using Open Rocket. The simulation resulted in an apogee of 4616ft AGL and descent time of 92.1 seconds. This puts us closer to our current goal apogee of 4500ft AGL.

Motor Specifications	
Average Thrust	932.26 N
Class	20% L
Delays	Plugged Seconds
Designation	L935
Diameter	54.0 mm
Igniter	E-Match
Length	649.0 mm
Letter	L
Manufacturer	CTI

Name	L935
Peak Thrust	1,582.74 N
Propellant	APCP
Propellant Weight	1,734.7 g
Thrust Duration	3.300 s
Total Impulse	3,076.45 Ns
Total Weight	2,542.0 g
Type	Reloadable

Table 1.4.1.1 Motor Specifications

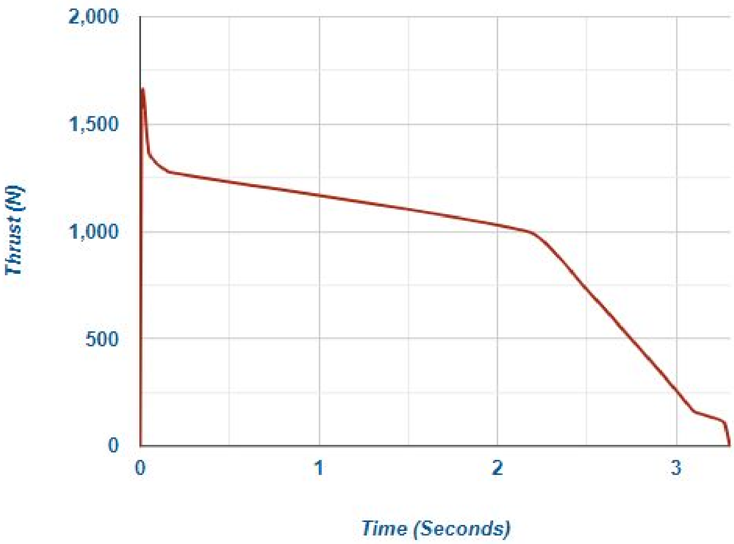

Figure 1.4.1.2. Thrust vs Time

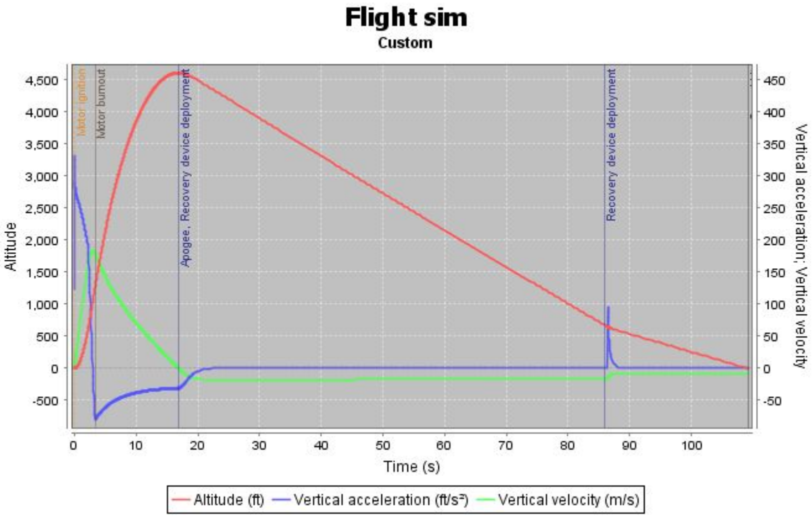

Figure 1.4.1.3 Flight Simulation

We are changing our motor because of the changes we needed to make to our launch vehicle. Through reinforcing our launch vehicle, weight was added to various components. The apogee we reached at our second launch, with all of our alterations to the launch vehicle, was 3182 ft AGL which is not enough to remain in the competition. With the new motor, we have a projected apogee of 4616ft AGL. Not only will this keep us in the competition, but we should be able to meet and potentially go over our goal apogee.

Section 1.4.2. Payload Changes

A change made to the retention system was the addition of small neodymium magnets to the top of the four quarter pipe pieces to provide additional strength in holding the retention system closed to ensure it will not significantly open during flight. These magnets are friction fit inside small 3D printed pieces which were epoxied in place to the wooden top sections of the retention system and can be seen as the small red triangular pieces in figure 1.4.2.1. below. When tested, the linear servos used to unfold the arms of the system had no issue pushing against the force of the magnets to provide the appropriate torque to open.

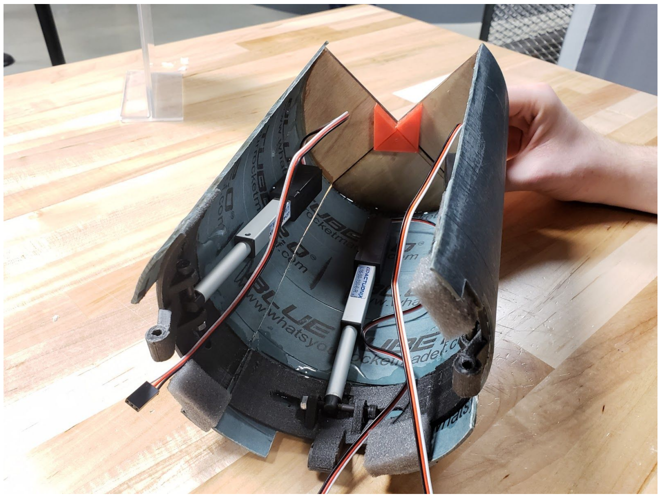

Figure 1.4.2.1. Retention System quarter pipe sections with magnets

Section 2. Payload Demonstration Flight Results

Figure 2.1. Retention System with UAV

Section 2.1. Payload Retention System Design Successes and Failures

The retention system is designed with four quarter-tube pieces that open such that no matter the landing orientation, the system will right itself in the process. This will happen by an activation signal sent to the system's transceiver after receiving permission from field officials. Once activated the UAV will be powered on and begin the mission of delivering the beacon.

For the second full-scale test flight, the retention system and UAV were both launched almost fully assembled. Electrical systems of both the retention system and the UAV were shown to be successful for the launch and no visible damage was sustained to either after inspection postflight. With the UAV housed within it, the retention system had no issue righting itself as intended and the UAV fit within it very well and was held within it.

Though the retention system was fully functional, the mounting of the electronics allowing it to function became very difficult as some dimensioning of certain electrical components in CAD were slightly incorrect, an issue discovered shortly before launch which caused a undesirable placement of some parts and the strength of their securing to the base. A simple yet effective solution is to file notches wherever necessary.

Section 2.2. Payload Mission Successes and Failures

The payload mission design is that upon initiation of deployment, the four quarter-tube pieces of the retention system open, righting the UAV in the process. Once upright, it will be powered on via a latching relay through contact pads allowing electrical connectivity between it and the retention system base. As the system unfolds, the arms of the UAV are driven down by torsion springs and held in place by locking radial buckles and neodymium magnets. The UAV will then fly up and out of the retention system, navigate to the FEA via autonomous GPS-based flight, and release the beacon from a pair servo driven holders.

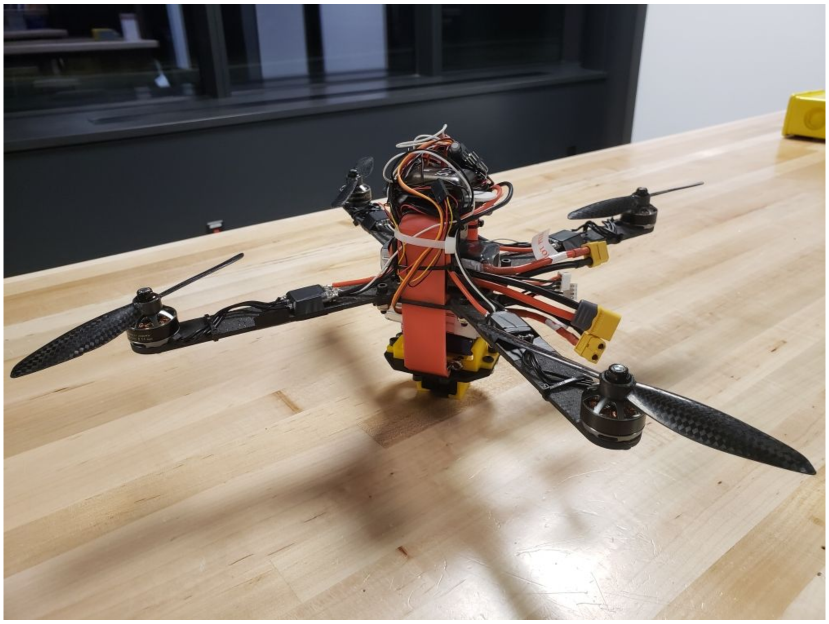

Figure 2.2.1. Assembled UAV

Physically, the UAV fit well within the retention system as intended and was not noticeably damaged in flight. Though the UAV was fully assembled and functional, the arm locking mechanisms proved troublesome to successfully manufacture and were unable to be completed beyond simple prototypes for the launch. This ultimately resulted in the UAV being unable to unfold and ascend from the retention system as designated in its mission criteria, with the arms being secured in their upright orientation with zip ties and tape which can be seen in figure 2.1.

A very important lesson learned from the inability to successfully 3D print the arm locking buckles is the importance of redundancy in manufacturability. Though the relatively complicated geometry of the parts made them a difficult print to perfect, this issue was vigorously troubleshooted. The NylonX 3D printer filament from Matterhackers, though very strong and reliable, proved difficult to print easily. The advanced 3D printer used to print the retention system bulkhead, also made of NylonX, became unavailable, forcing us to resort to using other 3D printers which resulted in lower quality prints. This issue is continuing to be looked into and we hope to soon have successful pieces which when implemented allow the UAV arms to fold and securely lock as intended.

Section 3. Vehicle Demonstration Re-flight

Section 3.1. Flight of Rocket Successes and Failures

Overall, the flight went according to plan. According to the altimeter data, provided in figure 3.1.1, all charges deployed as designed. The only anomaly within the data and the flight occurred with the detonation of the apogee charge. While the team sealed the electronics bay, it was noticed at the launch site that the electronics bay bulkhead had become slightly warped after an ejection test. This could be due to the icy, wet and snowy conditions of the lake. While it was not enough to be a structural concern, it prevented it from making a proper seal. Because of the long hike to the launch site, the team did not have all the proper materials on hand to seal it. This caused a fluctuation of the detected barometric altitude. While this did not affect the flight, the team will have materials on hand at the final launch to prevent this. All of the hardware worked as intended and was recovered with no damage. The payload was housed within the retention system for the launch. All parachutes correctly deployed at the correct time. There was no damage done to the hardware therefore no repairs or replacements need to be made.

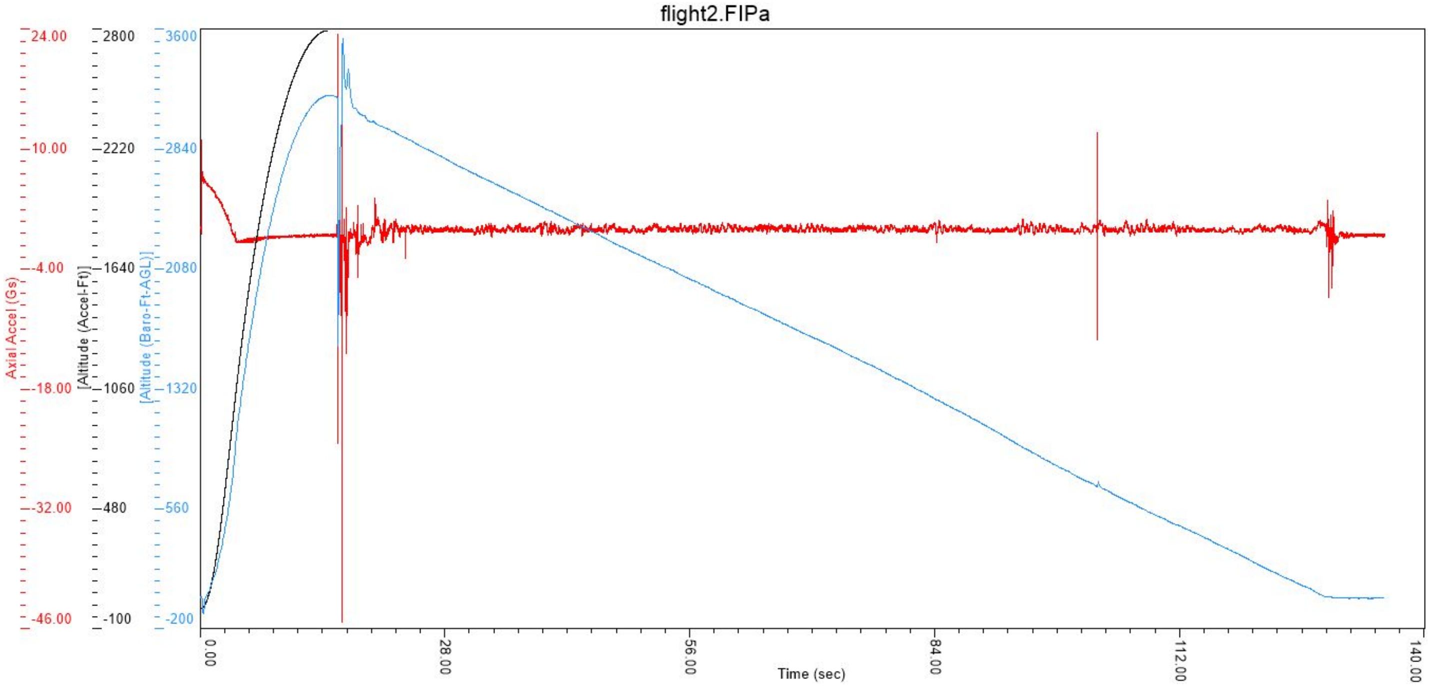

Figure 3.1.1. Altimeter Data

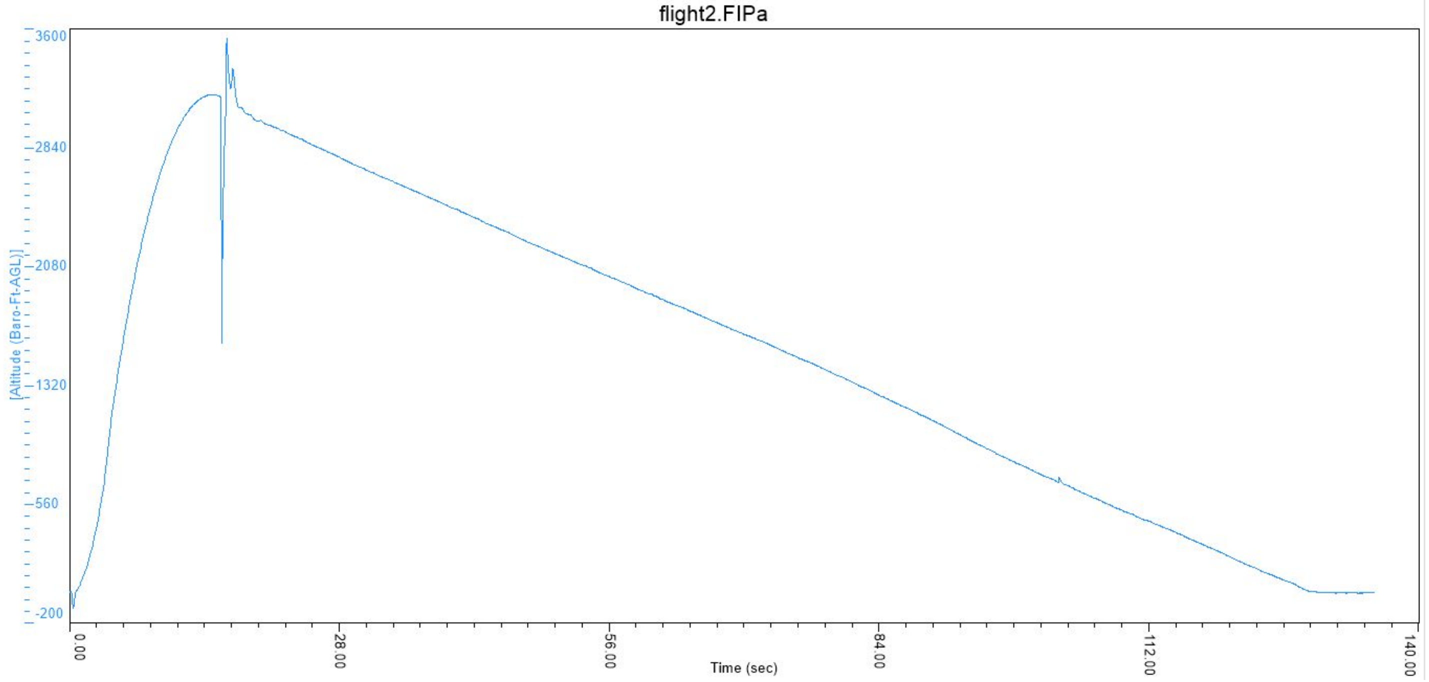

Figure 3.1.2. Altimeter Data (Only Barometric Altitude Data)

In terms of launch data the apogee charge was found to be at 3182 ft which is different from the predicted apogee of 4062 ft. This is due to the fact that the lower airframe was significantly heavier due to the reinforcements during reconstruction. Once entering the added weight into Open Rocket, the simulated apogee makes sense. This low altitude will be fixed via our proposed motor change. Looking at the altimeter data in figures 3.1.1 and 3.1.2 the charges all went off successfully during their designated configurations. The same issue however, that occured in our first test flight was the build up of pressure within the electronics bay. Cautionary measures were taken to seal the holes from the previous launch that may have caused the problem, however the warping of the electronics bay bulkhead created an opening that wasn't sealable with the materials we had on the ice. Due to this we believe there was a buildup of pressure in the electronics bay causing the altimeter to believe it was at a lower altitude as denoted by the downward spike in figure 3.1.2. This spike then shot upwards as the pressure within the electronics bay equalized and then the altimeter was able to detect accurate altitude values again. Even with the downward spike, however, it did not drop low enough to prematurely deploy the main charge. This charge instead deployed as configured at 700ft as denoted by the peak in axial acceleration at 700ft AGL in figure 3.1.1. In order to avoid this being a problem in Huntsville, bulkheads are being reprinted as well as reinforced to avoid warping and the charge holes will be sealed again as done for this launch.

In order to determine the theoretical drag coefficient for the full scale we used the Buckingham Pi Theorem and from this, Reynolds number. The formula for Reynolds number is $Re = \varrho vL/\mu$. Reynolds number is defined in fluid mechanics as the ratio between viscous and inertial force. Through this we found the drag coefficient with the formula, $D = mg = 1\ 2\ \varrho ACDv\ 2$. Theoretically, due to flow similarity within similar geometric shapes. The drag coefficient of the full scale can be seen below in figure 3.1.3.

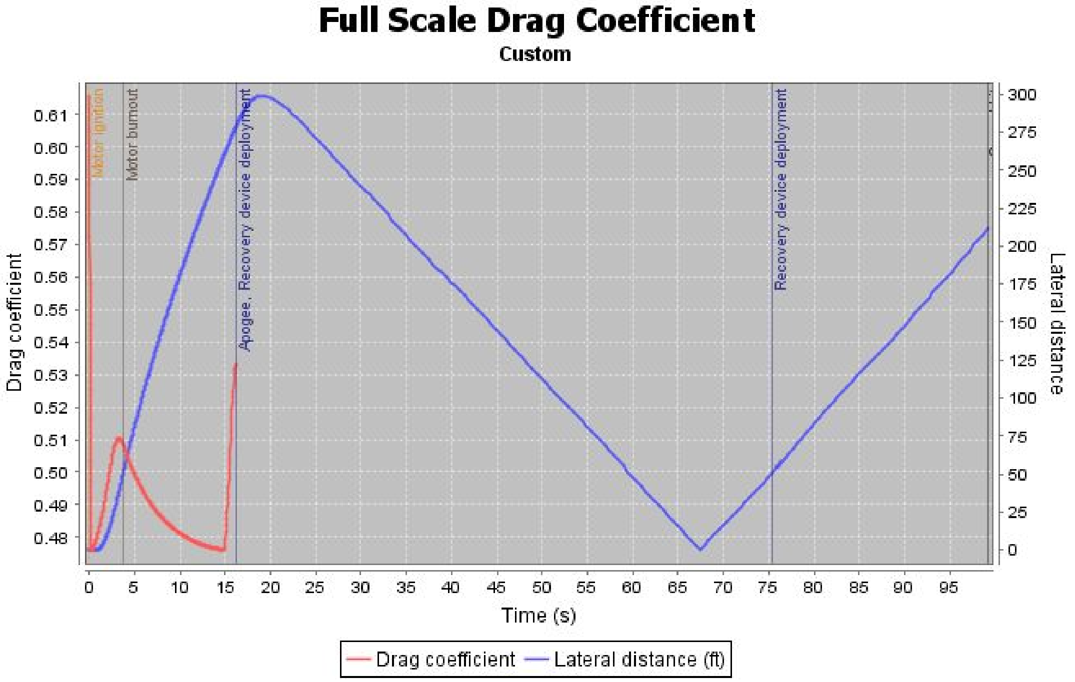

Figure 3.1.3. Drag Coefficient

From this launch, the team learned the importance of having materials for sealing vehicle compartments on hand and the limitations of launching on ice. While it is typically present in the team's launch day tool kit, it was not included in the limited supplies that the team carried on the 2.5 mi hike to the launch site.