Flight Readiness Review Addendum
2019 NASA University Student Launch Initiative
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1 Summary

1.1 Team Summary

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1.2 Purpose of Flight

At the Flight Readiness Review deadline, the CRW team had yet to fully implement and fly the finished payload to complete the Payload Demonstration Flight. Several delays were encountered during the development of the finalized payload; specifically, testing of the payload deployment mechanism led to the identification of several deficiencies which required significant redesign. After troubleshooting of and adjustments to the deployment system, it was re-tested and found to perform to the standards outlined in the FRR.

The purpose of the flight was to verify that the finalized, active payload would be properly retained throughout flight and could be successfully deployed after landing on the ground. Additionally, the flight would provide the team with additional flight data, determine the effect of the paint on the rocket coefficient of drag, and analyze the effects of additional ballast on flight apogee, velocity, and drift. The flight was carried out successfully, and the vehicle and payload are qualified for the competition launch on April 6th.

1.3 Flight Summary Information

The Payload Demonstration Flight was conducted on March 23rd, 2019 from the Bluegrass Rocketry Society field in Elizabethtown, Kentucky. The rocket was flown on an AeroTech L1420R motor with the finalized payload deployment system, the UAV, and 1 pound of ballast. The vehicle reached an apogee of 4570 feet.

Upon landing, the payload deployment system was still powered on and functioning after landing. At the request of the Range Safety Officer (RSO) at the field, the rocket was relocated between landing and payload deployment to avoid damage to the sod on the field. After being moved, the payload deployment black powder charges were successfully fired, separating the upper airframe from the payload and leaving the UAV in an upright, ready-for-flight position. The UAV did not power on after deployment; upon inspection, the flight computer power switch was found to be disconnected. This was determined to be due to incorrect assembly, and not the vehicle flight or landing. After re-connecting this switch, the UAV powered up as expected and was determined to be fully functional.

1.4 Changes made since FRR

The payload and payload deployment system have undergone significant changes to render them flight-ready. Since the additional flight was an opportunity to flight-qualify changes to the vehicle, minor changes were also made to enhance usability and ensure vehicle apogee was as close as possible to the target.

1.4.1 Changes to Vehicle

The vehicle has undergone minimal changes since FRR. Minor changes were made to the avionics assembly mount; standoffs were printed into the mount to reduce part count, engravings indicating where particular components are mounted were added to the part, and a pair of unused switch mounts were removed. This simplifies installation and provides guidance to future SLI teams that may use the part. A comparison of the two parts is shown in Figure 1; note that while the color is different, the parts were produced from the same filament type (PLA) on the same 3D printer.

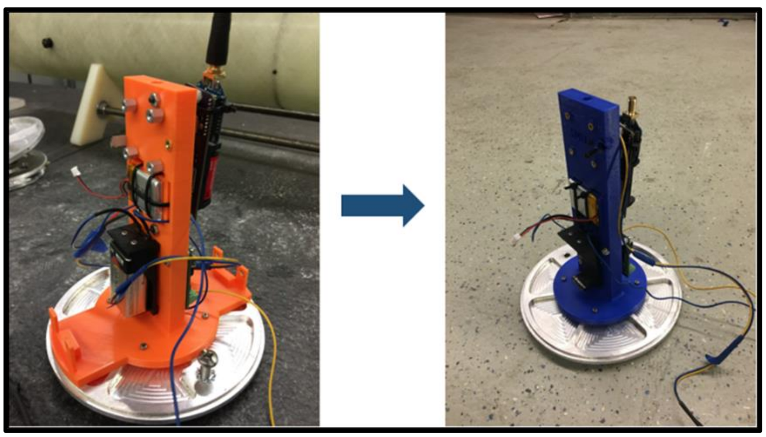


Figure 1: Changes to Vehicle Avionics Mount

A ballast mount was also added to the vehicle, as shown in Figure 2. The ballast mount was 3D printed in a half-toroidal shape with cutouts for ballast placement. Ballast was added by epoxying stainless steel BB pellets into pockets in the ring. This component was mounted via four #4-40 bolts to the top of the removable fin can system using brass heat-set inserts. This methodology is identical to how the motor retention ring is mounted to the bottom of the fin can. This mount will not be flown during the competition flight, as the payload demonstration flight showed that no ballast is required.

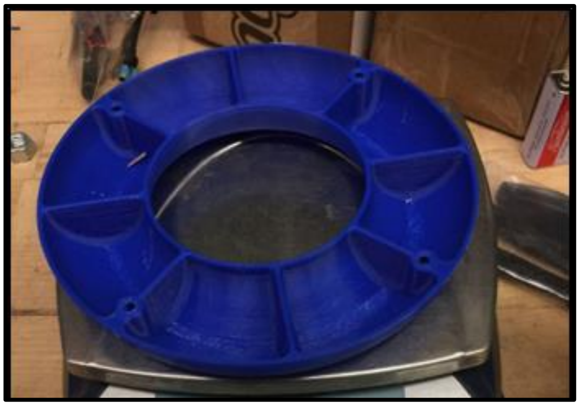


Figure 2: Vehicle Ballast Ring

1.4.2 Changes to UAV

Initial versions of the UAV arm retention pins often sheared when in use. This was corrected by reprinting the pins with the direction of loading normal to the build plane. This significantly increases the force required to shear the pins.

A sheet metal bracket for the beacon retention system was constructed and mounted to the UAV. Lastly, the holes on either end of the UAV that allowed it to be mounted onto the sheath were reinforced with large washers that were epoxied to the surface of the PLA. This provides support to the upper mounting plate of the UAV during the black powder ejection and is visible in Figure 3.

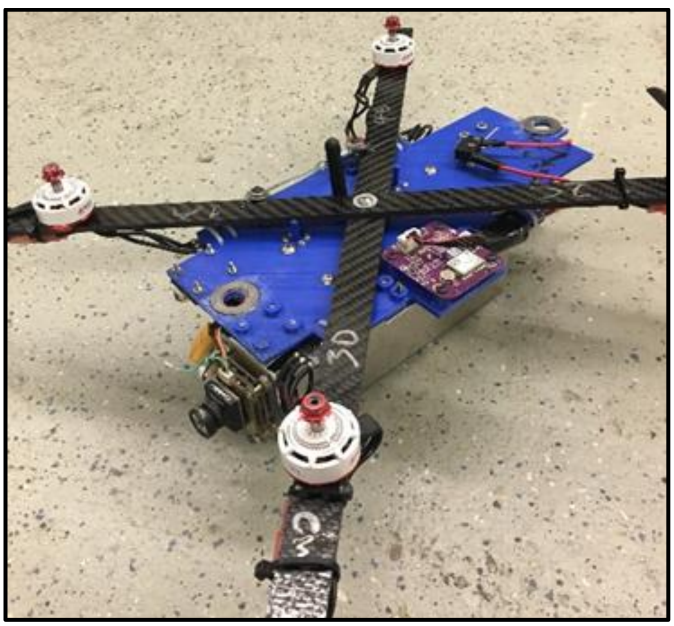


Figure 3: UAV with Changes Since FRR

1.4.3 Changes to Payload Deployment System

The deployment sheath was drastically strengthened after structural failure during black powder deployment testing. The overall design of an unfolding sheath wrapped around a carbon fiber beam with UAV retaining pins remained the same, but the system was significantly strengthened with brackets and bigger bolts, as shown in Figure 4. The 1/4 inch UAV retaining threaded bolts were replaced by 3/8 inch threaded bolts. The top 3 inches of the threads on each bolt were turned to create a smooth surface for the UAV to slide upwards on during takeoff. The rear bolt was further reinforced with two triangle brackets with gussets that held the bolt at the base and the middle of its height. This reduced the bending moment on the bolt caused by rapid acceleration of the system during deployment. Washers were placed between the brackets and the piston bulkhead to allow the piston to rotate independently of the UAV orientation sheath. This aided the payload integration process because it allowed the piston to more easily be rotated to the correct orientation once inside the rocket body tube. The connection between the front end of the sheath and the nosecone was strengthened by using a larger and more rigid L-bracket bolted to the nosecone at two points, eliminating rotation of the nosecone relative to the orientation sheath. Finally, the measuring tape springs added to the orientation sheath before FRR were attached to the deployment sheath with rivets, replacing the duct tape previously used.

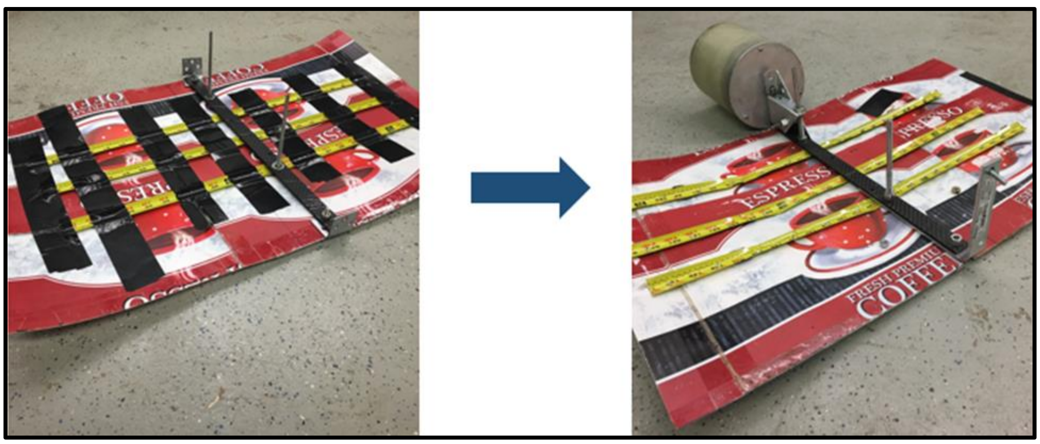


Figure 4: Reinforced Deployment Sheath

Testing showed that the solenoid used to provide fail-safe retention of the payload and nosecone often failed to retract, leaving the payload trapped in the upper airframe. Initial attempts to remediate this by detecting successful latch retraction in software were found to be unreliable, necessitating a mechanical solution. The root cause was determined to be friction on the solenoid due to contact between the solenoid arm and the piston retention beam. To fix this, the solenoid was moved 0.25 inches higher off of the upper airframe bulkhead, eliminating contact between the solenoid arm and the piston latch. However, this left the entire assembly free to slide axially in the body tube by up to 0.25 inches, potentially bringing the solenoid back into contact with the piston retention beam. To prevent this, the upper airframe and nosecone were connected with 8 #4-40 nylon shear pins at the end of payload integration. The shear pins are capable of safely retaining the deployment sheath and nosecone during flight, but the solenoid still serves as a fail system in case of shear pin failure during flight.

Ground black powder testing was conducted with the completed assembly, shear pins, and UAV. The system was qualified for flight after 2 successful, consecutive deployments with a UAV mass simulator, and an additional successful deployment with the UAV. Figure 5 shows the deployed payload after the final ejection test.

Figure 5: Deployed Payload After Black Powder Test

2 Payload Demonstration Flight

The launch occurred at 11:44 EDT in mostly sunny weather, with a temperature of 60 °F and windspeeds up to 5 MPH NNE. The rocket was launched at 11:44 a.m. EDT. The original vehicle drag was found to be an overestimation; during the previous flight, the full-scale rocket reached an apogee of 5017 feet, 217 feet above the target altitude of 4800 feet. Since then the rocket has been painted, which was expected to further reduce the drag coefficient and alter the flight altitude.

The vehicle was flown with ballast so that the team could remove ballast before competition and still meet the target altitude even if the reduced drag coefficient led to overshooting the target apogee of 4800 feet. The apogee was predicted to be 4515 feet in the measured launch conditions. However, the actual apogee was found to be 4570 feet based on the flown altimeters. All ballast will be removed for competition day to place the vehicle as close as possible to the target altitude.

2.1 Payload Retention and Deployment Systems

The payload was successfully retained and deployed during the Payload Demonstration Flight. All mechanical, electrical, and software systems functioned as expected. The payload and nosecone were held in place by shear pins throughout flight; the solenoid fail-safe retention system was in place but was not loaded.

At the request of the Range Safety Officer (RSO) at the field, the vehicle upper airframe was relocated after landing to avoid damage to the sod farm. To ensure the safety of personnel, the deployment controller was switched off after landing, and then switched on again at the selected deployment location. Controller power was switched on and off through the vehicle airframe, without any disassembly of any system.

After commanding deployment, the solenoid retracted and the primary black powder charge was ignited, pushing the payload out of the rocket body tube. The sheath reoriented the UAV to an upright position as intended, placing it in the position shown in Figure 6.

Figure 6: Payload After Deployment

2.2 Payload Mission

The UAV completed the vehicle flight and safely deployed without any hardware damage. The payload mission sequence was not performed during the payload demonstration flight because the UAV has not successfully completed hover testing, which is a prerequisite for attempting the mission flight sequence.

The orientation system functioned as expected. The deployment sheath unfurled so that the UAV was right side up. The UAV arms unfolded and released the flight computer power switch.

Inspection of the UAV after deployment showed that although the switch was released the UAV was still powered off. This was found to be due to a loose electrical connector on the flight computer power switch. Additionally, although the arms were unfolded, only one of the two arms was locked in position. This was because of inadequate tension on the arm extension spring. Finally, the solenoid mount, a U-shaped bracket made from aluminum, was slightly bent, allowing the solenoid to move away from the beacon. This is believed to be due to the acceleration during deployment black powder ejection.

When the electrical connector was correctly inserted, the UAV powered on and was fully functional. The ground station operator was able to establish communication with the UAV and retract the solenoid by sending the beacon release command through the controller. The FPV system began recording and transmitting video after power-up, as expected.

To avoid future failures due to loose electrical connections, the CRW payload team will inspect and gently tug the wires on all connectors of this type every time the UAV is assembled, verifying that all connections are secure. The 17.7 lb/inch spring used to extend the arms during the payload demonstration flight will be replaced with a similar 21.8 lb/inch spring to ensure the arms are fully extended and locked in place. Finally, the beacon mount will be stiffened by adding a 3D printed support to the existing aluminum bracket.

As the deployment system preparation was the most time intensive section of the launch day procedure, the CRW payload team will extensively rehearse the procedure to reduce the total preparation time. Finally, the CRW payload team plans to perform a tethered UAV hover test and extensively test the autonomous flight sequence before LRR to verify the team and UAV are ready to safely conduct the mission at the competition launch field.

2.3 Flight Results

The vehicle performed as intended, similarly to the performance Vehicle Demonstration Flight. However, since that flight, the system increased by three pounds with additional weight provided by the payload as well as one pound of added ballast. Using the same drag coefficient estimated from the first flight and flight configuration settings which closely mirrored those on the day of the flight, Rocksim predicted that the rocket would reach an apogee of 4507 feet. This suggested that ballast would not be required; nonetheless, the rocket was still flown with the full amount of ballast in the event that the drag coefficient was dramatically altered by the rocket's paint-job. **Error! Reference source not found.** shows the preflight predictions compared to the actual altitude recorded by the Stratologger altimeter. The rocket ascended to 4578 feet. This verified that the drag coefficient was reduced by the paint and that the rocket would ascend slightly higher than originally intended.

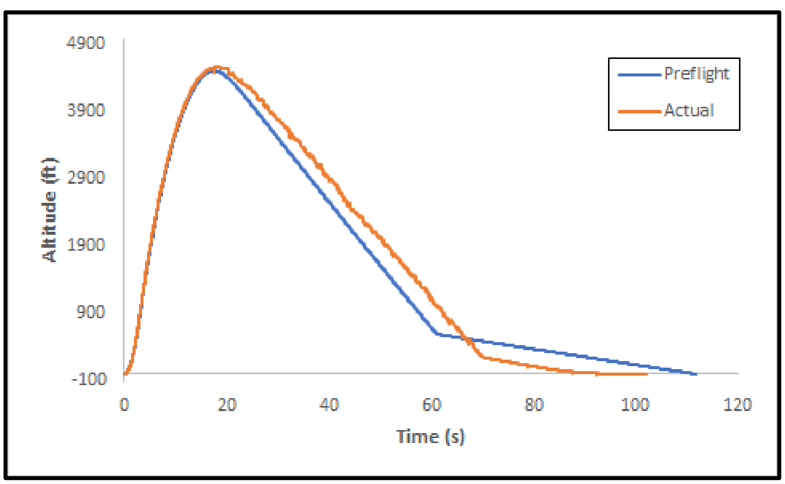


Figure 7: Flight Data Comparison

Based upon the new flight data for the given mass, the updated drag coefficient for the vehicle was estimated to be 0.355. This is smaller than the 0.375 calculated from the Vehicle

Demonstration Flight. Using this updated value, the performance of the rocket without ballast was assessed and found to reach an altitude of 4720 feet using the Rocksim software. This flight profile is shown in **Error! Reference source not found.**. Given that this places the rocket only 80 feet away from the target apogee, the vehicle will be flown in this configuration on the day of launch.

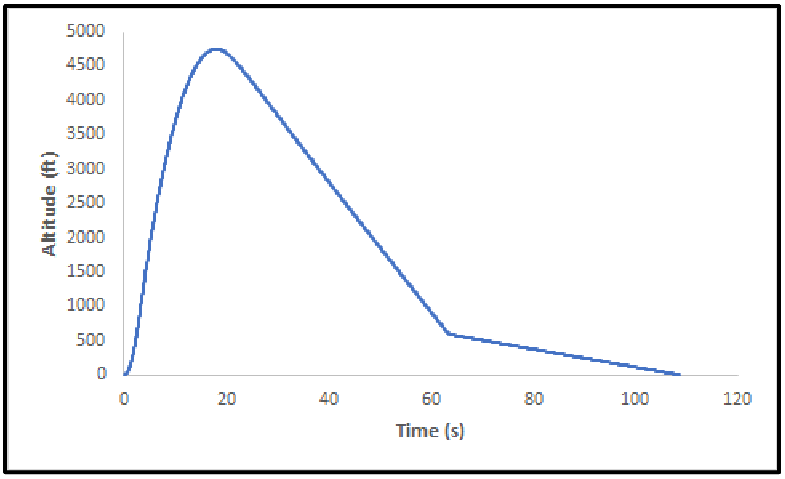
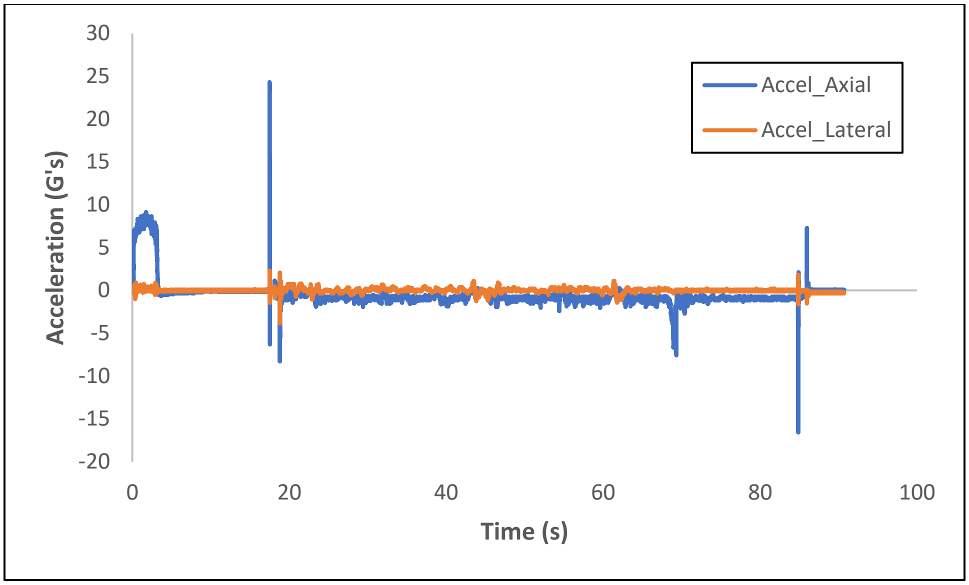


Figure 8: Future Flight Prediction Using Updated Values

There were no significant hardware issues encountered during flight. There was an issue with the Datalogger IMU placed on the nose cone avionics mount: the microSD card failed to properly record data during flight, so no high-resolution inertial data was recorded. This was most likely due to a faulty SD card. However, this component was not critical to flight performance and only served to collect additional flight data. This issue will be resolved by replacing the SD card prior to the day of competition. There were no major vehicle-related lessons learned during this flight. Additional flight data provided by the Raven3 altimeter is provided in Appendix A. From this data, it was found that the vehicle descended in 67.1 seconds, with a landing velocity of 13.2 ft/s. This equated to a landing kinetic energy of 53.19 lbf-ft. Additionally, GPS data found that the vehicle drifted a total of 1605 feet from the launch rail. This confirms that all recovery related requirements were once again met during flight.

3 Appendix A



Accel_Axial
Accel_Lateral
Acceleration (G's)
Time (s)
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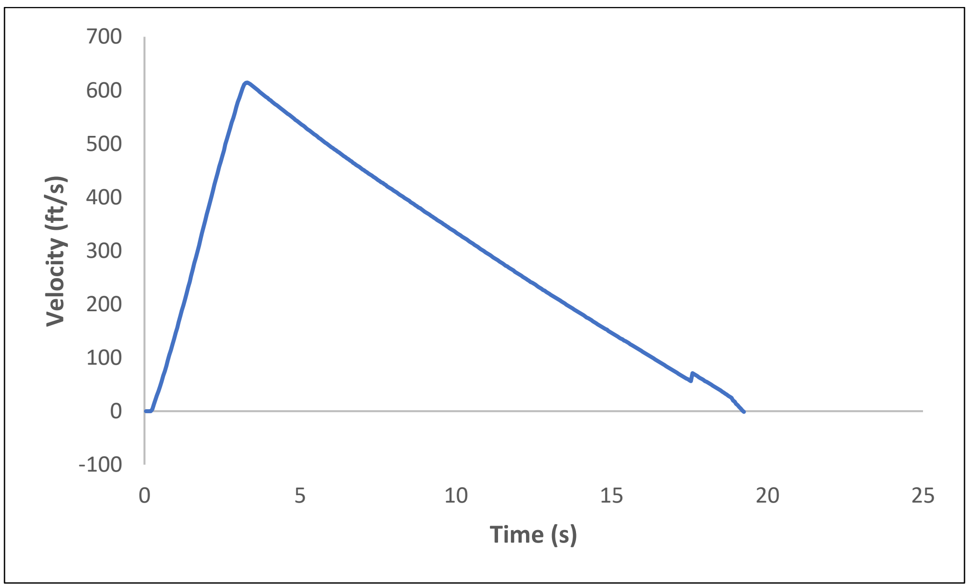
20
15
10
5
0
-5
-10
-15
-20
0
20
40
60
80
100



Velocity (ft/s)
Time (s)
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0
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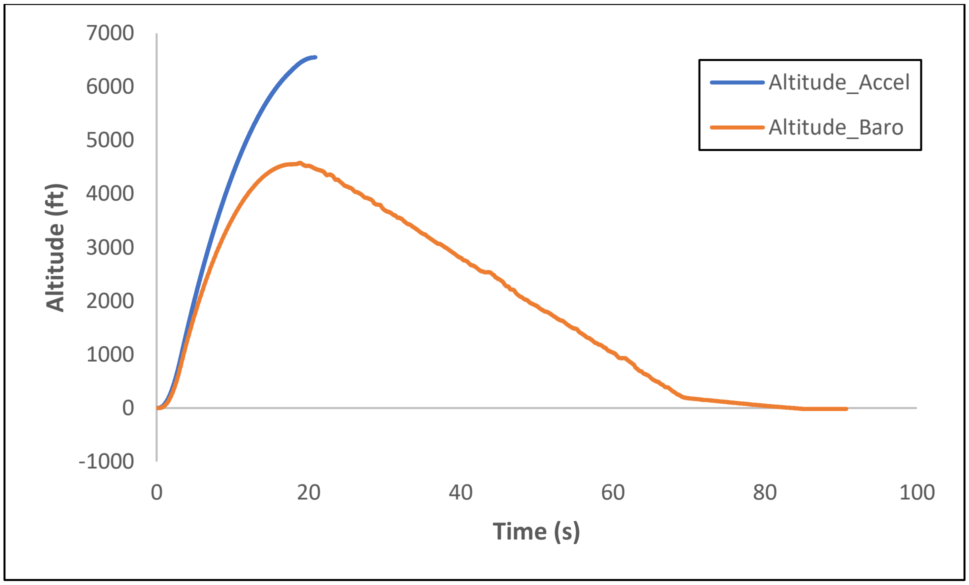
0
5
10
15
20
25



Altitude (ft)
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4000
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0
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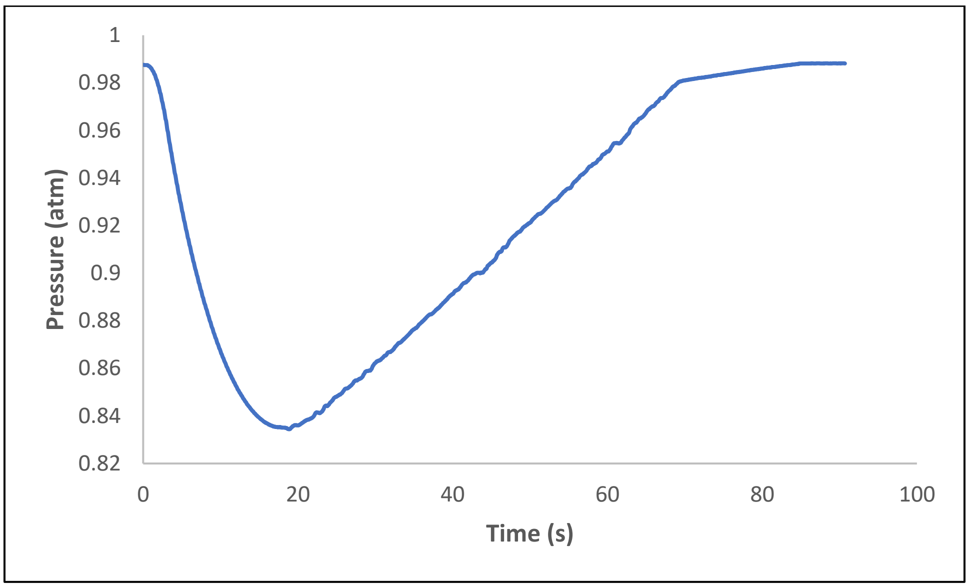
0
20
40
60
80
100
Time (s)
Altitude_Accel
Altitude_Baro



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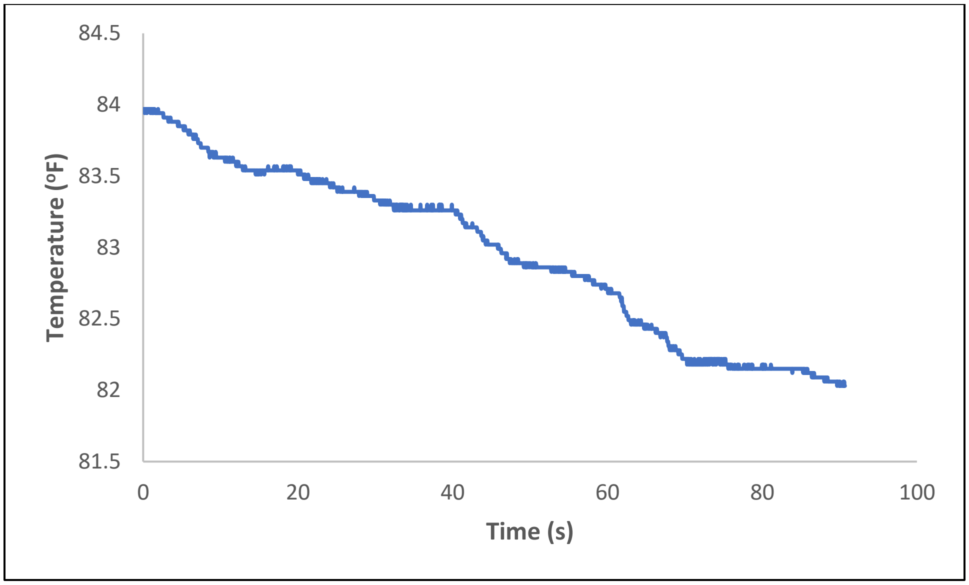
60
80
100
Time (s)


84.5
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83
82.5
82
81.5
Temperature (ºF)
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20
40
60
80
100
Time (s)