5-5-2024

Integrating Senior Design Skills to Test New Technology and Achieve L1 & L2 Rocketry Licenses

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Integrating Senior Design Skills to Test New Technology and Achieve L1 & L2 Rocketry Licenses

by

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An Honors Capstone

submitted in partial fulfillment of the requirements

for the Honors Diploma

to

The Honors College

of

The University of Alabama in Huntsville

May 5, 2024

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1. Abstract

The honors capstone project documented herein represents a culmination of academic endeavors, practical applications, and personal growth within the realm of high-power rocketry. One of UAH's senior design courses is rocket design in which a class of students compete in the NASA USLI competition. Each year the mission is different which requires new technologies to be explored in order to be prepared for future competitions. The focus of this capstone project is evaluation of a commercial-off-the-shelf camera system on a small single or dual deploy rocket. An inflight camera can provide a visual record of inflight events and aid in understanding of the rocket flight. To evaluate the camera, a Wildman Rocketry 2.6 in diameter Intimidator rocket kit was assembled. A RunCam 6 camera with an Additive Aerospace shroud was installed on the exterior of the forward airframe. Methodologies and simulated flight results are discussed for two commercial high power rocket motors: an I-218 and a J-420. Results from ground tests for the RunCam 6 are discussed. The rocket and camera have been fully prepared for flight testing, however because of schedule constraint test flights were not conducted. Project outcomes, lessons learned, future plans post-submission, and suggestions for future work are presented. Overall, this capstone project, even though it didn't go according to plan, acts as a well-rounded conclusion to the senior design course that makes room for future extension and benefits other students in the long run.

2. Purpose

The purpose of this capstone is to meet Honors diploma requirements while also helping expand the CRW USLI knowledge pool for future teams. The NASA USLI competition is fast-paced so there isn't a lot of time to spend trying out new technologies or systems. For this project, multiple new technologies were considered for evaluation. These included new altimeters, cameras and a 3D printed shroud, fly-away rail buttons, or a version of a load cell/peak load indicator for shock cords. I decided to test out the RunCam 6 camera and its 3D-printed shroud from Additive Aerospace. My decision stemmed from wanting to find a way to have a close-up view of the recovery system as it exits the recovery bay. Much insight can be gained from an inflight camera. My project allows future teams to get a head start on using cameras on either their subscale and/or full scale rockets. The camera can be tested from the ground, but a more insightful test would be to attach it to a rocket and fly it. Building the technology demonstrator rocket and testing the camera in flight also allows me the opportunity to obtain my L1 and L2 rocketry licenses. Overall, the project is a great final wrap up to my senior design course as it requires me to use all the knowledge that I have gained throughout the past two semesters.

3. Materials

The materials in this project are commercial off-the-shelf items. Most of the materials used in this project are materials that were readily available from the senior design course. The materials in Figure 1 and Figure 15 were specifically bought for this project. The Intimidator-2.6 38 MMT Rocket Kit from Wildman Rocketry was purchased as the technology demonstrator rocket for this project. After talking with an employee from Additive Aerospace it was suggested that the RunCam 6 be the camera tested instead of the Mobius Maxi camera. As a result, the RunCam 6 and its shroud were purchased from Additive Aerospace and are the technology being tested in this project. Aerotech 38/360 and a 38/720 motor cases were available from the MAE 490 inventory and are seen in Figure 4. An I-218 motor for the L1 flight was also available from MAE 490 surplus inventory. The J-420 motor for the L2 flight will be purchased for this project. An Egg Timer Quantum altimeter is being provided and will be used for flight data and for the separation event at apogee. The Quantum can be seen in Figure 4. Lord 310A/B epoxy was purchased for this project. A Jolly Logic chute release was provided and will be used to keep the provided 3 ft Fruity Chutes Iris Ultra Compact parachute bundled until 700 ft. The Jolly Logic is pictured in Figure 4. The parachute is seen in Figure 2. 0.25 inch thick quick links and ¼ -20 with 1 inch inner diameter U-bolts were purchased from McMaster for this build and are seen in Figure 3. 10-24 all thread was also purchased from McMaster to construct the avionics bay. It is seen in Figure 3. The motor retainer in Figure 3 was also purchased for this project. Filament for creating the avionics bay sled was also available from surplus USLI inventory. The assembled technology demonstrator rocket with the camera and shroud attached can be seen in Figure 10.

Figure 1 Purchased Materials

Figure 2 Purchased and Supplied Materials

Figure 3 Bulkheads, U-Bolts, All Threads, and Motor Retainer

Figure 4 Reloadable Motor Tubes, Altimeters, Quick Links, and Nomex Blankets

Construction of the rocket followed the steps given by the senior design course workshop rocket project. It was an almost three-day building process. Most of the lead time in building came from letting the epoxy harden. The body tubes needed to be washed, sanded, holes drilled in the proper places as well. The Intimidator-2.6 38 MMT kit can be used as a single or dual deploy rocket. For this project it will be used as a single deploy. The kit consists of fiberglass components. The body tubes are 2.6 inches in diameter. Lengths of each section are summarized in Table 1. Portions of the construction process can be seen in Figure 5 through Figure 10.

Table 1 Structural Project Components

Component	Length (inches)
Nose Cone Coupler	5.875
Nose Cone	15.25
Lower Airframe	32
Avionics Bay	6
Upper Airframe	15.375
Motor Tube	7.4375

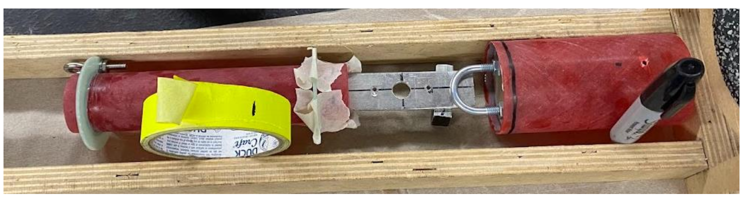


Figure 5 Curing Orientation for Motor Mount Tube and Nose Cone Coupler

Figure 6 Epoxied Nose Cone Coupler Bulkhead with U-Bolt Installed

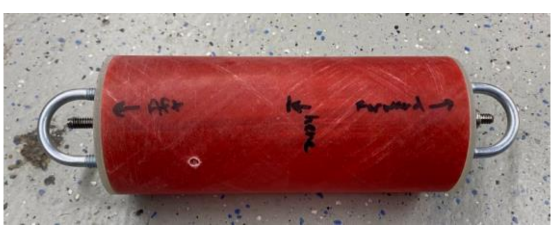


Figure 7 Manufactured Avionics Bay

Figure 8 Curing Set Up for Lower Airframe Assembly

Figure 9 Manufactured Recovery Harness

Figure 10 Fully Assembled Rocket with Camera and Shroud

The RunCam 6 is a small portable camera that can be used for RC products, high power rocketry, dashcams, outdoor activities like fishing, and much more. It weighs 49 g with the battery or 35 g without the battery. It is 2.64 inches long, 0.98 inches wide, and 0.79 inches tall. There are eight resolution options to choose from. The highest being 4K at 30 FPS with a battery life of 1 hour and the lowest being 1080P at 30 FPS with a battery life of 135 minutes. The camera lens has an adjustable frame of view. It has a built-in gyroscope that supports electronic image stabilization (EIS) and GyroFlow which makes videos look very clean, stable, and smooth. It is also made for tough conditions as it has replaceable lens protectors as well as replaceable lens filters for varying light conditions. On top of the camera are the WiFi/Menu button, the Power/Shutter button, and the OLED display which readily gives information about video resolution, battery life, SD card status, and camera mode. The camera is compatible with up to a 512 GB MicroSD. Photos and videos can also be transferred by inserting the MicroSD card into the computer or through the provided Type-C cable. The camera also comes with the Type-C control cable that allows for it to be used with a remote control such as a UART Flight Controller. It also comes with instructions for connecting the camera to a PWM remote control. RunCam 6 is also compatible with the RunCam app via a WiFi connection on an Android or IOS device. All of these capabilities combined allow for first-person view and recording at the same time. Figure 11 through Figure 16 provide a look at the RunCam 6 and its shroud.

Figure 11 RunCam 6 Camera

Figure 12 Top of RunCam 6 Camera

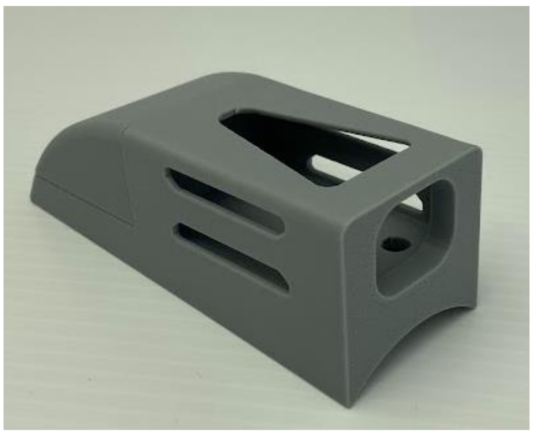


Figure 13 RunCam 6 3D Printed Shroud

Figure 14 Backside of Shroud

Figure 15 RunCam 6 Installed in Shroud

Figure 16 Side View of RunCam 6 Installed in Shroud

4. Planning

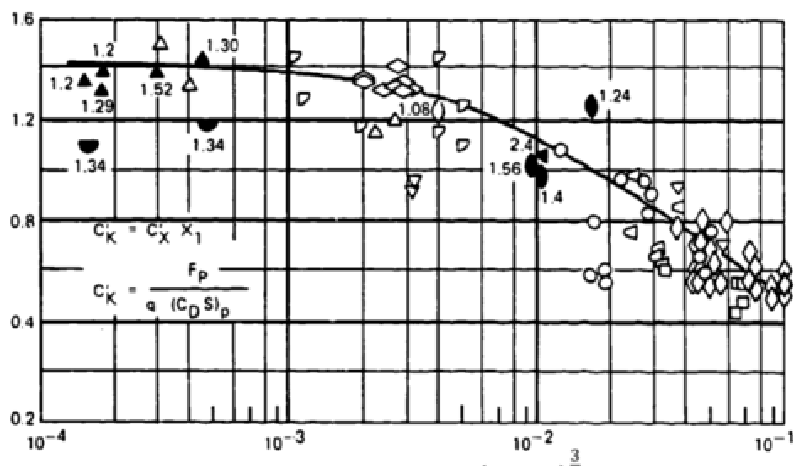
Planning for capstone started in early January. The proposal was completed and approved by January 22, 2024. Between January and April some thoughts were put into what rocket kit I wanted to use along with what new technology I wanted to test. My course load coupled with work and writing an article with another faculty member resulted in my capstone being pushed off until after the NASA USLI competition was over in April. The technologies that I looked into trying were altimeters such as MicroSplash and MicroPeak, a camera and a 3D printed shroud, fly away rail buttons, or a version of a load cell/peak load indicator for shock cords. I decided to test out the camera and its 3D-printed shroud. The camera being tested is a RunCam 6 and the 3D-printed shroud for it came from Additive Aerospace. I had to balance budget with available resources. This resulted in using a lot of materials that were already at the PRC. Design and ordering of materials occurred during April 2024 and manufacturing occurred between May 1 and May 4, 2024. Writing and compiling of the manuscript occurred between April 28 and May 5, 2024. I was unable to make it to the April 21 MC^2 launch in Olmstead, KY. As a result, the next available launch date is May 18th at Olmstead, KY again. This results in the two flight test data not being included in this manuscript.

5. Methodologies & Simulation Results

After finding a kit rocket and all other needed materials that fit within the desired budget, initial OpenRocket simulations were run in order to pick two viable motors, one for an L1 rocketry license and one for an L2 rocketry license. Surplus reloadable rocket motors from the USLI inventory were evaluated through simulations to see if those could be used. Initial simulations showed that the I-218 could, so only a J motor would need to be purchased for the L2 launch. Criteria for picking an L1 motor consisted of an H or I class motor that had a rail exit velocity greater than 60 ft/s and resulted in an apogee less than 2,500 ft. The criteria for an L2 motor consisted of a J, K, or L motor that had a rail exit velocity greater than 60 ft/s and resulted in an apogee less than 5,500 ft. Motors that also used Warp 9 propellant were also avoided due to the high total impulse and extremely short burn time. All OpenRocket simulation conditions were kept consistent. The average windspeed was 4.47 ft/s with a 90-degree wind direction with a 12 ft launch rail at a 5-degree launch angle. The launch site was also kept the same.

The Wildman Rocketry website didn't show exact dimensions or instructions for the rocket, so the final length and weight of the kit rocket was unknown. An OpenRocket simulation was found on the website for a larger diameter version of this kit rocket. This model was scaled down to the appropriate diameter size. This set the predicted length of the rocket to 72.64 ft. The predicted dry weight with all components was 4.57 lbm and the wet mass was predicted to be 5.38 lbm. The I-218 motor pushed the rocket up to an apogee of 2044 ft in 11.4 seconds. The simulated drag coefficient for ascent was 0.56. When the Egg Timer Quantum detects apogee a black powder charge will go off and the rocket will separate. Upon separation a bundle main parachute will be pushed out of the rocket. Once 700 ft is reached the Jolly Logic that is bundling the main parachute will release and allow the main parachute to unfurl and fully inflate. The total flight time was 62 seconds with 41 seconds of the flight being under the open main parachute. A safe ground hit velocity of 16.4 ft/s was achieved. The resulting kinetic energy was 13.8 ft-lb. Data from the initial simulations for the I-218 motor are summarized in Table 2.

It was also important to take into account what snatch loads the rocket may see upon main parachute opening. Using Figure 17 and equation 1 below the predicted snatch loads were calculated. In equation 1, ρ is the density of the air, V^2 is the velocity prior to parachute deployment, A_{ref} is the calculated area of the parachute, C_D is the estimated drag coefficient of the parachute, and C_k is the opening force factor. This graph comes from experimental data. OpenRocket predicts a high velocity descent until the main parachute opens this is because it doesn't predict drag well for a bundled main parachute. OpenRocket also assumes near instantaneous opening. These two factors weigh in to the high predicted snatch loads seen in Table 3. From previous flights it is seen that high power rockets tend to fall around 80 – 90 ft/s without a drogue due to its own body drag. Taking this into account a lower and more expected bound for snatch loads is also calculated and shown in Table 3. Also, from previous flight experience the snatch load will tend to fall a little below the average of the two bounds. So, for this initial flight, the max snatch load would likely have been around 168.35 lbf. This same calculation can be done for each simulation. It is good to know the upper bounds so that the rocket can be prepped and made to withstand the upper bound just in case an anomaly happens, and the rocket sees the upper bound force.



$$Mass\ Ratio, RM = \frac{\rho\left(A_{ref}C_d\right)^{\frac{3}{2}}}{m_t}$$

m_t is total mass of system and parachute

Figure 17 Opening Force Factor vs. Mass Ratio

$$F_{opening} = \frac{1}{2}\rho V^2 A_{ref} C_d C_k \qquad (1)$$

Table 2 Initial I-218 OpenRocket Simulation Summary

Initial Simulation Data (I-218)								
Length (in)	**Dry Mass (lbm)**	**Wet Mass (lbm)**	**Burn Out Mass (lbm)**	**Velocity Off Rod (ft/s)**	**Apogee (ft)**	**Time to Apogee (s)**	C_D	**Ground Hit Velocity (ft/s)**
72.54	4.57	5.38	4.96	94.3	2044	11.4	0.56	16.4

Table 3 Snatch Loads - Initial I-218 Simulation

Initial Snatch Loads (I-218)	
Simulated Velocity (267 ft/s)	
Calculated Ck	**Resulting Snatch Load (lbf)**
0.85	1119.5
Worst Ck	**Resulting Snatch Load (lbf)**
1.4	1843.9
Expected Velocity (90 ft/s)	
Calculated Ck	**Resulting Snatch Load (lbf)**
0.85	127.2
Worst Ck	**Resulting Snatch Load (lbf**
1.4	209.5

Figure 18 shows the altitude, velocity and acceleration profiles for this initial simulation of the rocket using the I-218. It is also interesting to compare the total rocket mass and altitude over time as seen in Figure 19. It can be seen that by about 1.5 seconds into the flight the burnout mass is reached. This is expected as the burn time for the I-218 is 1.5 seconds. At this point in time the rocket is at 350 ft and will continue traveling up to 2044 ft. Around 22 seconds into the flight the rocket reaches 700 ft and the main parachute is deployed.

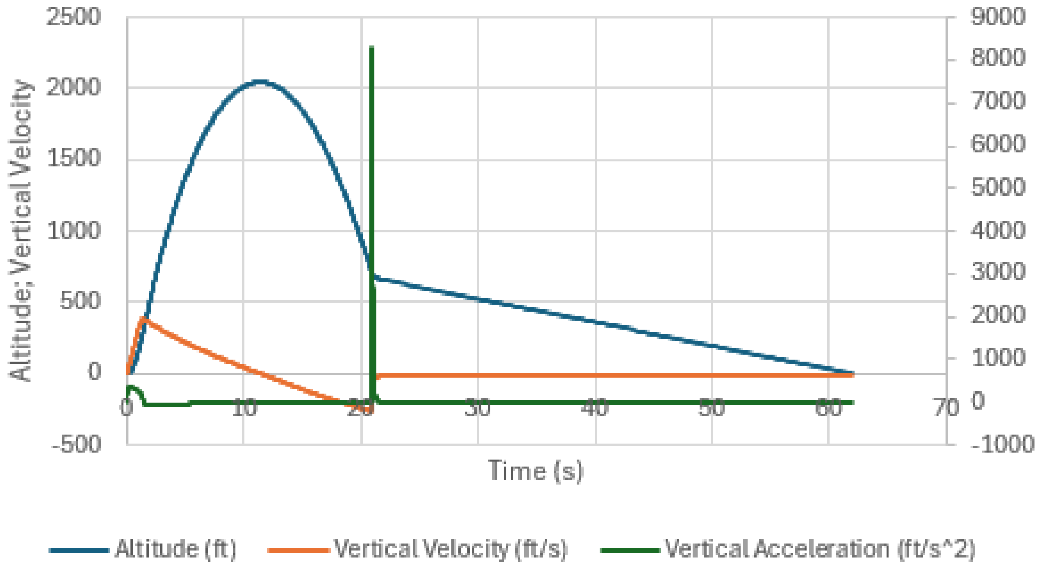


Figure 18 Initial Altitude, Velocity, and Acceleration Profile for I-218

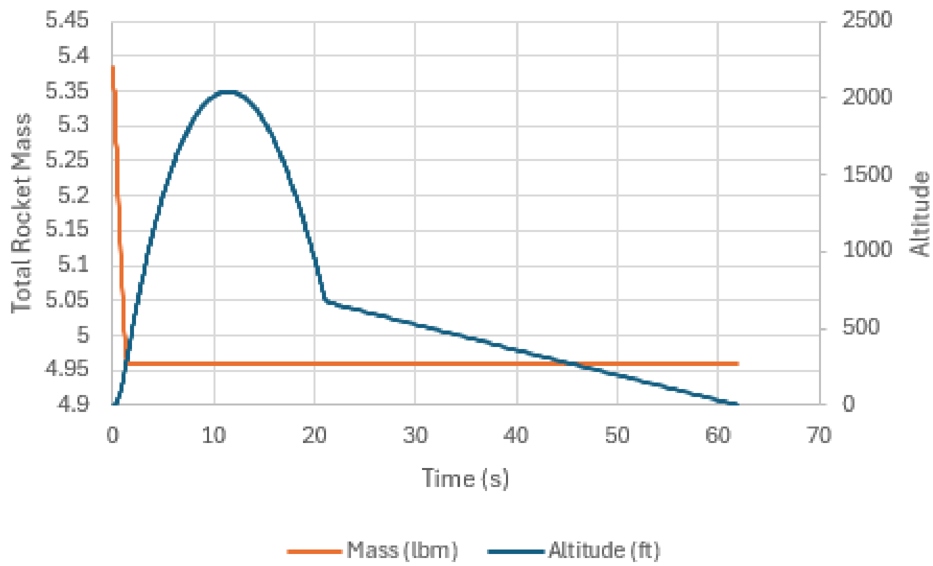


Figure 19 Initial Altitude and Total Rocket Mass Profile for I-218

Once the materials were ordered and the kit rocket arrived measurements and weights of each component were taken in order to create a more accurate model. This model resulted in a rocket that was 62.625 ft long and weighed 3.91 lb. Since it was shorter and weighed less than initial calculations the apogee increased to 2468 ft. The total flight time was 67.9 seconds. The rocket fell under the opened main parachute for 44.6 seconds. The rocket had a landing velocity of 15.46 ft/s which resulted in a kinetic energy of 10.66 ft-lb. More flight prediction data is summarized in Table 4. Table 5 shows a summary of the predicted and expected snatch loads.

Table 4 Second I-218 OpenRocket Simulation Summary

Second Simulation Data (I-218)								
Length (in)	**Dry Mass (lbm)**	**Wet Mass (lbm)**	**Burn Out Mass (lbm)**	**Velocity Off Rod (ft/s)**	**Apogee (ft)**	**Time to Apogee (s)**	C_D	**Ground Hit Velocity (ft/s)**
62.625	3.91	4.73	4.31	100.29	2468	12.29	0.51	15.46

Table 5 Snatch Loads – Second I-218 Simulation

Second Simulation Snatch Loads (I-218)	
Simulated Velocity (293 ft/s)	
Calculated Ck	**Resulting Snatch Load (lbf)**
0.82	1300.6
Worst Ck	**Resulting Snatch Load (lbf)**
1.4	2220.5
Expected Velocity (90 ft/s)	
Calculated Ck	**Resulting Snatch Load (lbf)**
0.82	122.7
Worst Ck	**Resulting Snatch Load (lbf**
1.4	209.5

Figure 20 and Figure 21 show the second simulated flight profile and takes a closer look at how the mass changes over the flight.

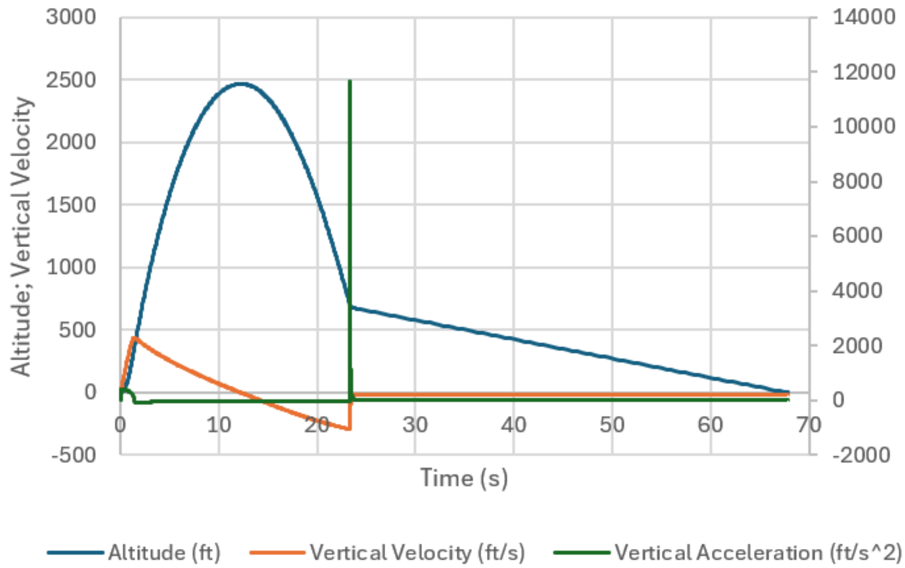


Figure 20 Second Altitude, Velocity, and Acceleration Profile for I-218

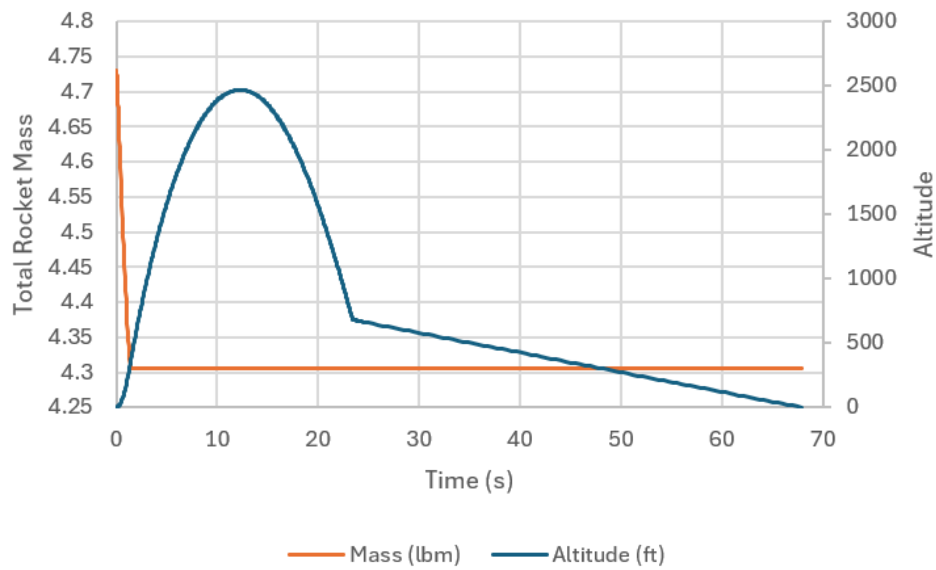


Figure 21 Second Altitude and Total Rocket Mass Profile for I-218

A final simulation was run for the I-218 motor once the rocket was fully constructed. A summary of weights is included in Table 6 below. This model uses a rocket that is 62.625 ft long and weighs 4.92 lbm without the motor. The final version of the rocket is 0.35 lbm heavier than the initial simulation mass and 1.01 lbm heavier than the second simulation mass. This was expected due to the addition of epoxy and fasteners. The rocket has a predicted stability of 5.25 with the center of gravity located 35.02 inches from the top of the nose cone and the center of pressure at 49.32 inches from the top of the nose cone. The total flight time was 59.9 seconds. The rocket fell under the opened main parachute for 40 seconds. The rocket had a landing velocity of 16.94 ft/s which resulted in a kinetic energy of 15.0 ft-lb. More flight prediction data is summarized in Table 7. Table 8 shows a summary of the predicted and expected snatch loads.

The final flight profile for the I-218 is shown in Figure 22. A final comparison of the total rocket weight and altitude over time is shown in Figure 23.

Table 6 Final Component Weights

Component	Weight (lbm)
Upper Airframe	0.34
Nose Cone Assembly	0.54
Avionics Bay	0.53
Lower Airframe Assembly	1.76
Harness	1.07

Table 7 Final I-218 OpenRocket Simulation Summary

Final Simulation Data (I-218)								
Length (in)	Dry Mass (lbm)	Wet Mass (lbm)	Burn Out Mass (lbm)	Velocity Off Rod (ft/s)	Apogee (ft)	Time to Apogee (s)	C_D	Ground Hit Velocity (ft/s)
62.625	4.92	5.74	5.31	87.53	1888	11.09	0.52	16.94

Table 8 Snatch Loads - Final I-218 Simulation

Final Snatch Loads (I-218)	
Simulated Velocity (257 ft/s)	
Calculated Ck	**Resulting Snatch Load (lbf)**
0.9	1098.2
Worst Ck	**Resulting Snatch Load (lbf)**
1.4	1708.4
Expected Velocity (90 ft/s)	
Calculated Ck	**Resulting Snatch Load (lbf)**
0.9	134.7
Worst Ck	**Resulting Snatch Load (lbf**
1.4	209.5

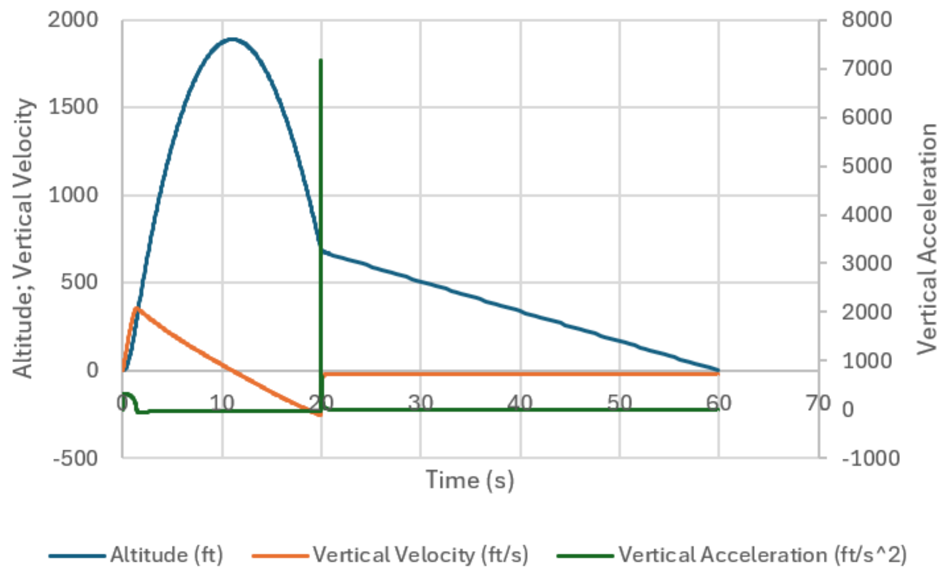


Figure 22 Final Altitude, Velocity, and Acceleration Profile for I-218

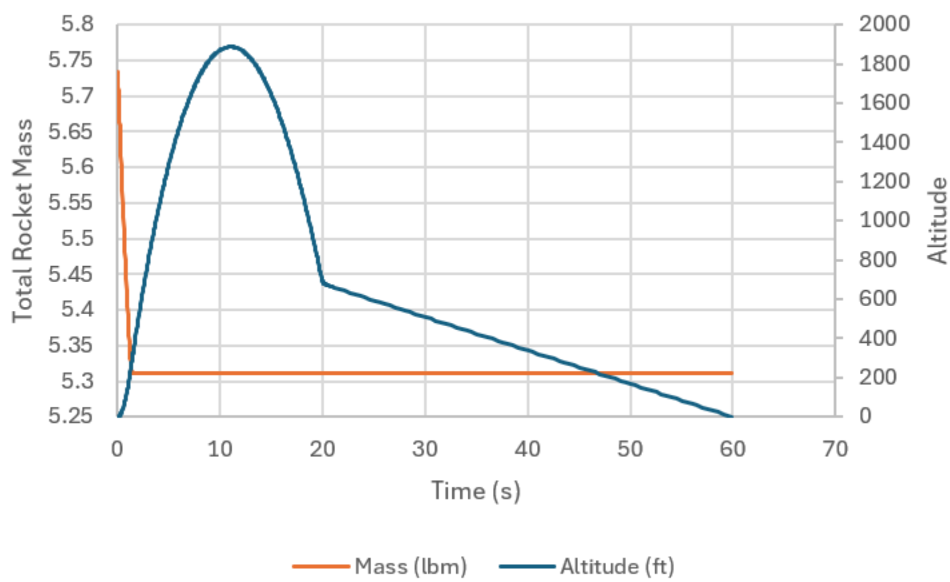


Figure 23 Final Altitude and Total Rocket Mass Profile for I-218

An initial, secondary, and final simulation were conducted for the J-420 motor. The results for the initial and secondary simulation can be found in Appendix A: Initial Simulation Data (J-420) and Appendix B: Second Simulation Data (J-420), respectively. The results from the final simulation for the J-420 are summarized below. The stability of the rocket is 4.62 cal with the center of gravity at 36.73 inches from the top of the nose cone and the center of pressure at 49.32 inches from the nose cone. The predicted final apogee for the J-420 motor is 4893 ft. It will take approximately 16.54 seconds to reach apogee. The total time of flight will be 72.8 seconds. The rocket will be descending under its main parachute for approximately 38.7 seconds. The predicted ground hit velocity of 17.3 ft/s results in a kinetic energy of 15.6 ft-lb. Table 9 contains data from the final OpenRocket simulation for the J-420. The simulated and expected snatch loads are summarized in Table 10. The expected values agree with previous flight experiences. The data gathered for this flight supports a successful flight in the future. Figure 24 and Figure 25 provide a closer look at the flight profile for the J-420 motor.

Table 9 Final J-420 OpenRocket Simulation Summary

Final Simulation Data (J-420)								
Length (in)	**Dry Mass (lbm)**	**Wet Mass (lbm)**	**Burn Out Mass (lbm)**	**Velocity Off Rod (ft/s)**	**Apogee (ft)**	**Time to Apogee (s)**	C_D	**Ground Hit Velocity (ft/s)**
62.625	4.92	6.35	5.518	122.2	4893	16.54	0.50	17.3

Table 10 Snatch Loads - Final J-420 Simulation

Final Simulation Snatch Loads (J-420)	
Simulated Velocity (410 ft/s)	
Calculated Ck	**Resulting Snatch Load (lbf)**
0.88	2733.0
Worst Ck	**Resulting Snatch Load (lbf)**
1.4	4348.0
Expected Velocity (90 ft/s)	
Calculated Ck	**Resulting Snatch Load (lbf)**
0.88	131.7
Worst Ck	**Resulting Snatch Load (lbf**
1.4	209.5

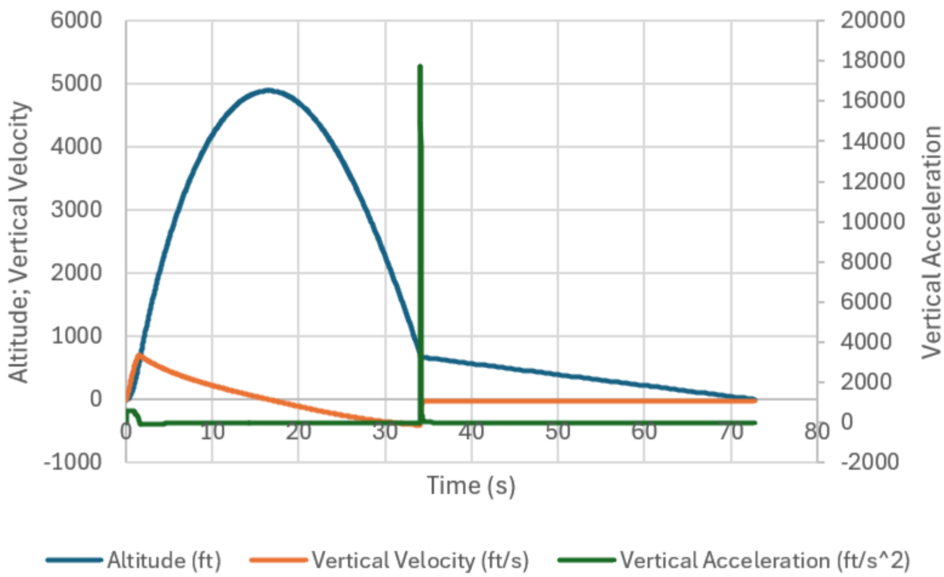


Figure 24 Final Altitude, Velocity, and Acceleration Profile for J-420

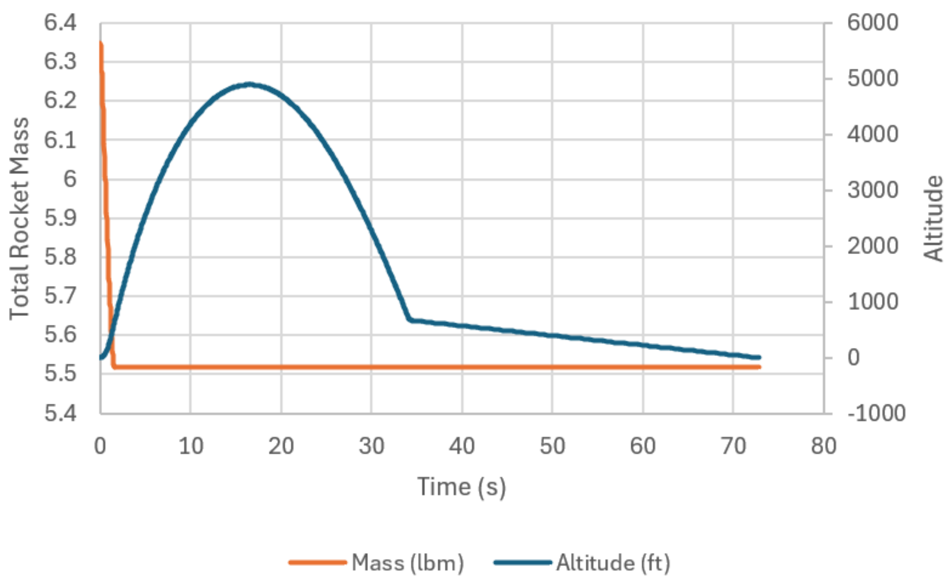


Figure 25 Final Altitude and Total Rocket Mass Profile for J-420

6. Testing

An initial test for the RunCam 6 tested the video quality of the camera as well as battery life. The camera setting was set on high at 4K at 30 FPS. The test started by using the WiFi remote feature through the RunCam app. A phone can be connected to the camera using WiFi and can be used to start and stop video, watch live video, change camera settings such as FPS and resolution, change modes and more. The 4K 30 FPS video was started on the camera from my phone at about 30 ft away. This feature worked great for about 10 minutes until my phone connected to my home WiFi which prevented my phone from working as the camera remote. After this point I could no longer see the live video on my phone screen as it was frozen. Pressing the stop recording button on the app sent me an error message that it could not connect to the camera. Even though my phone disconnected from the camera it still recorded video until I manually pressed the stop recording button on the camera itself. For future reference it would be best to forget all nearby WiFi's so that the phone does not switch over to another WiFi and cause the app to stop working. After this I started recording another 4K 30 FPS video by using the buttons on the camera. This recording lasted until the camera died at 51.5 minutes. Five minutes before the camera died it started beeping. This beeping indicated low battery. The total battery life when using the camera at 4K 30 FPS is about an hour. This agreed with the information I gathered from the RunCam 6 User Manual. The user manual also reports that the camera has a battery life of 110 minutes at 1080P at 60 FPS and 135 minutes at 1080P at 30 FPS. After pulling up the files from the SD card on the computer it was found that the 51.5-minute video was saved in small segments in order to keep the file sizes smaller. Each video was about 12 minutes and 36 seconds long. Overall the video quality was very good. The video consisted of a drive around town and a walk into the PRC. The video did not show much grain and detail could be easily seen. For the price point it is very good image quality. The audio quality is also good as well. This camera has the capabilities that it needs to record good flight videos audio and visual wise. Some screenshots from the captured video are shown below in Figure 26 through Figure 33.

Figure 26 RunCam 6 Test Photo 1

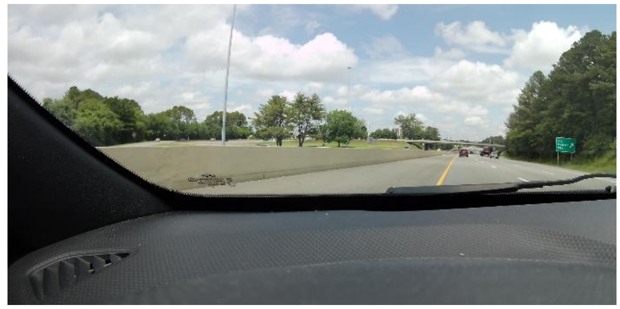


Figure 27 RunCam 6 Test Photo 2

Figure 28 RunCam 6 Test Photo 3

Figure 29 RunCam 6 Test Photo 4

Figure 30 RunCam 6 Test Photo 5

Figure 31 RunCam 6 Test Photo 6

Figure 32 RunCam 6 Test Photo 7

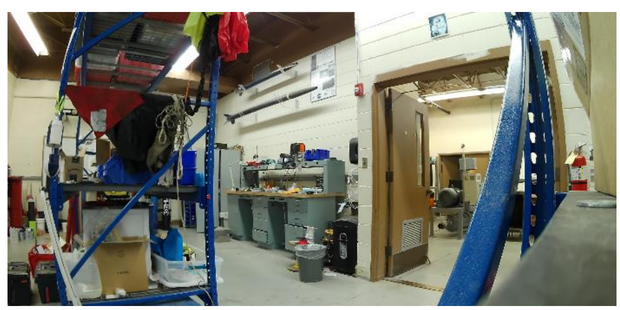


Figure 33 RunCam 6 Test Photo 8

Installing the camera shroud onto the rocket body was simple. Four holes were drilled, the shroud was placed on the rocket, screws were inserted and screwed down holding the shroud in place. The shroud fits the curvature of the rocket body very well. No adjustments were made in order to install the shroud as desired. It is also important to note that the camera shroud has the camera lens over the very edge so that the shroud does not get in the camera's field of view. Once the camera is in the shroud there is still easy access to the control buttons. Installing the camera into the shroud is very easy as well. The top curved portion of the shroud separates from the rest of the shroud so that the camera can be slid in and then the curved portion snaps back into place. Then the curved portion is screwed into place.

Black powder testing will also be conducted in order to find the proper charge size for the rocket separation charge at apogee. Two shear pins hold the separation point together. Each shear pin can withstand 50 lbf each. In order to shear the two pins it is estimated that 2 grams of black powder will be the starting test value. A black powder test is deemed successful if the body tubes separate at the desired location and the parachute is pushed out of the bay as well. In some black powder tests it has been seen that the parachute will not come out of the bay just from a black powder charge. In this case, if the parachute and harness slide out of the bay when it is tilted down then the test will be deemed successful. This case is only followed when multiple black powder tests show that the charge alone won't push the parachute out of the bay.

Finally, two flight tests will be conducted on May 18th, 2024, at the MC^2 field in Olmstead, KY pending weather. The first flight will be with the I-218 motor. After the first flight the flight video will be viewed in order to check the quality and to see if any adjustments need to be made such as modifying the placement of the camera shroud or changing video settings. The camera and its shroud along with the rocket will be inspected for any damage post flight. If everything checks out, I will take the L2 certification test and pending my passing of the test I will fly the rocket again under the J-420 motor and acquire more flight video. Once again, the rocket and camera and its shroud will be checked for any damage post flight. If minimal damage occurs and good quality flight videos are acquired, the tests will be deemed successful.

7. Project Outcome

My honors capstone project has been a great opportunity to apply all that I've learned from my senior design courses this year. I started with the workshop rockets in August 2023 and now I have come full circle by building another kit rocket but this time on my own with the ability to design it as I'd like. I have learned that time management is very important and that projects like these take a while, even if you know what you're doing for the most part. Building this rocket on my own has been a great experience. During senior design I focused on the recovery system, so I didn't do much of the manufacturing like drilling holes and such. This project has allowed me to touch on manufacturing, electronic skills, design skills, as well as allowing me to continue using the knowledge I have gained about recovery systems.

Overall, I wish I had put more time into this project so that I could make it more of my own and to be able to make a more robust system and report. I am used to working on tight schedules from the USLI competition, but this is something that I should have started sooner. I am still proud of what I have been able to accomplish in such a short time. Coupled with the USLI competition, course load, work, writing an article, and external factors I feel like I balanced everything the best I knew how to at the time. I am looking forward to continuing to put time into this project ahead of the May 18th launch. I plan to design the avionics sled, 3D print it, and install it. I also plan to make a shroud that is a "mirror" of the shroud purchased from Additive

Aerospace to help with flight dynamics and to have an easy way for future teams to use this camera without the shroud being a COTS item.

Some recommendations for future work include testing the range of the WiFi connection to the camera. This will be very important for flights. Range issues come into play if the launch pad is far away or if the rocket drifts out of range. From tests conducted even if the camera gets out of range it will keep recording – it will just have to be manually stopped from the shutter button on the camera instead of using the app to stop the recording. It would also be neat to be able to start the recording when launch is detected by an altimeter and to have it stop recording once the rocket has landed. This would make the camera very useful and much more appealing to future teams because the rocket will sometimes have to sit on the pad for hours on the day of competition which will cause the battery to run down or storage to fill up if there isn't a way to remotely start the camera right before or at launch. I would also suggest looking into the different resolutions and frames of view to see which is best during flight. I have been focused on 4k at 30 FPS. It would be nice to see how the others affect battery life and what the quality of video will be as the resolution is lowered. I would also suggest looking into EIS and GyroFlow. These should make for some amazing videos. I would also suggest looking into external power and remote control connections for the camera.

I believe future teams can gain massive insight into their flights by having a camera attached to the rocket during flight. I know having a camera would have helped us a lot this year when trying to figure out what went wrong with the recovery system. A closer view might have helped us come to conclusions about issues sooner. A camera can help give insight into a complex recovery system and into the dynamic world of high-power rocketry.

Overall, the capstone project tested the RunCam 6 and its shroud without the flight tests. The project also allowed me to completely construct a high-power rocket on my own. After submission of the capstone, the intended flight tests will be completed and L1 and L2 certifications will be sought. Post flight, the data gathered from the camera and the Quantum will be processed, summarized, and compared against predicted values.

8. Acknowledgements

I would like to thank my project advisor, Dr. Lineberry, for the opportunity to undertake this project and for his guidance. I am grateful to the Honors College as well for enriching my time here at UAH and for pushing me to be my best.

9. Appendix A: Initial Simulation Data (J-420)

Table 11 Initial J-420 OpenRocket Simulation Summary

Initial Simulation Data (J-420)								
Length (in)	**Dry Mass (lbm)**	**Wet Mass (lbm)**	**Burn Out Mass (lbm)**	**Velocity Off Rod (ft/s)**	**Apogee (ft)**	**Time to Apogee (s)**	C_D	**Ground Hit Velocity (ft/s)**
72.54	5.91	7.34	6.52	109.3	4143	15.63	0.54	21.2

Table 12 Snatch Loads - Initial J-420 Simulation

Initial Snatch Loads (J-420)	
Simulated Velocity (393 ft/s)	
Calculated Ck	**Resulting Snatch Load (lbf)**
0.95	2710.8
Worst Ck	**Resulting Snatch Load (lbf)**
1.4	3994.8
Expected Velocity (90 ft/s)	
Calculated Ck	**Resulting Snatch Load (lbf)**
0.95	142.2
Worst Ck	**Resulting Snatch Load (lbf**
1.4	209.5

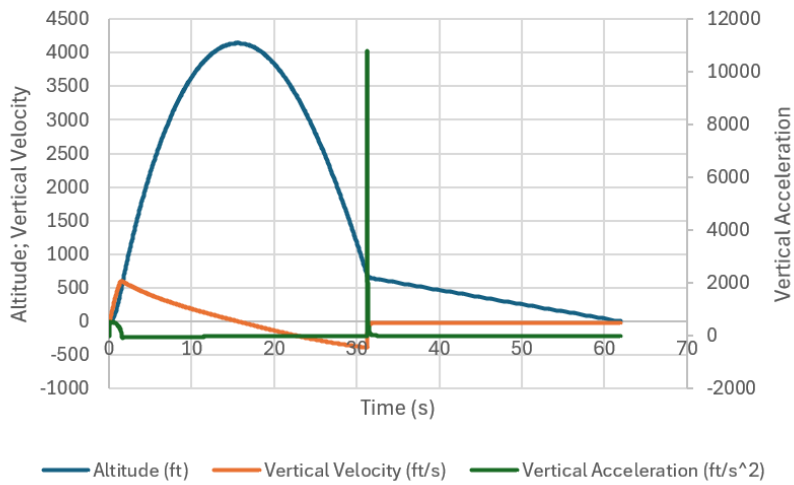


Figure 34 Initial Altitude, Velocity, and Acceleration Profile for J-420

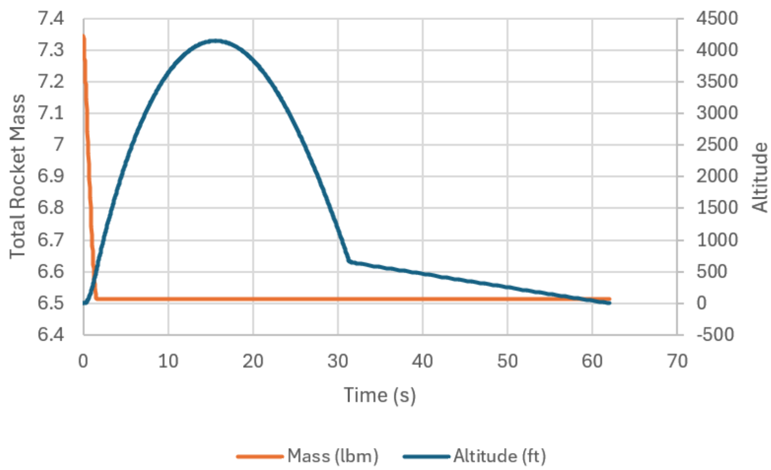


Figure 35 Initial Altitude and Total Rocket Mass Profile for J-420

10. Appendix B: Second Simulation Data (J-420)

Table 13 Second J-420 OpenRocket Simulation Summary

Second Simulation Data (J-420)								
Length (in)	**Dry Mass (lbm)**	**Wet Mass (lbm)**	**Burn Out Mass (lbm)**	**Velocity Off Rod (ft/s)**	**Apogee (ft)**	**Time to Apogee (s)**	C_D	**Ground Hit Velocity (ft/s)**
62.625	3.91	5.34	4.51	132.8	5517	16.93	0.50	15.4

Table 14 Snatch Loads - Second J-420 Simulation

Second Simulation Snatch Loads (J-420)	
Simulated Velocity (405 ft/s)	
Calculated Ck	**Resulting Snatch Load (lbf)**
0.81	2454.6
Worst Ck	**Resulting Snatch Load (lbf)**
1.4	4242.5
Expected Velocity (90 ft/s)	
Calculated Ck	**Resulting Snatch Load (lbf)**
0.81	121.2
Worst Ck	**Resulting Snatch Load (lbf**
1.4	209.5

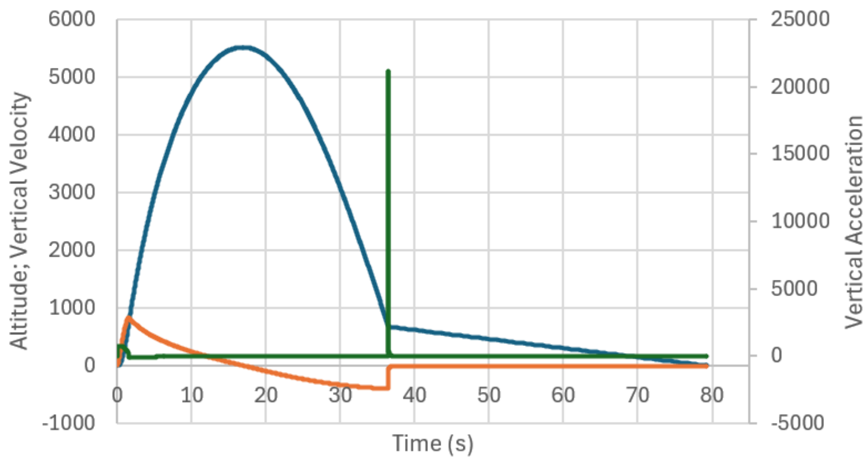


Figure 36 Second Altitude, Velocity, and Acceleration Profile for J-420

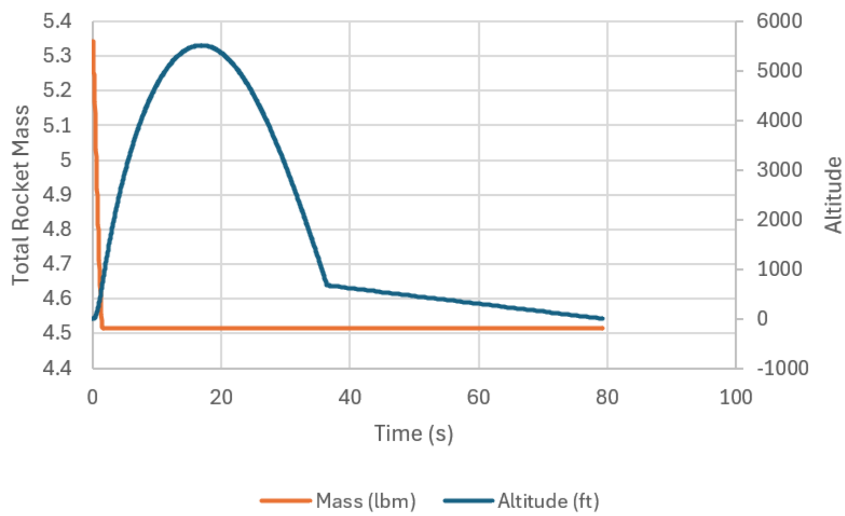


Figure 37 Second Altitude and Total Rocket Mass Profile for J-420