1-2020

Suborbital Payload Testing Aboard Level 3 Rocket Research Platform

Pedro Llanos
Embry-Riddle Aeronautical University, llanosp@erau.edu

Sathya Gangadharan
Embry-Riddle Aeronautical University, sathya@erau.edu

Nikita Amberkar
Embry-Riddle Aeronautical University

Isachi Halphen
Embry-Riddle Aeronautical University

Melisa Mastroliberti
Embry-Riddle Aeronautical University

See next page for additional authors

Authors

Pedro Llanos, Sathya Gangadharan, Nikita Amberkar, Isachi Halphen, Melisa Mastroliberti, and Michelle Munasinghe

Suborbital Payload Testing Aboard Level 3 Rocket Research Platform

Nikita Amberkar[1], Vijay Duraisamy[2], Isachi Halphen[3], Melisa Mastroliberti[4], Michelle Munasinghe[5]
Pedro Llanos[6] and Sathya Gangadharan[7]
Embry-Riddle Aeronautical University, Daytona Beach, FL, 32114

Embry-Riddle Aeronautical University (ERAU) has launched several suborbital scientific payloads aboard Blue Origin's New Shepard in 2017 and 2019. Students continue gaining hands-on experience in rocket design and construction, and payload integration and testing of future and more mature payloads to be launched into space. A Level 3 Rocket is being designed and developed at ERAU to serve as a scaled-down model research platform for launching and testing of payloads that will be later flown in commercial suborbital platforms such as Blue Origin's New Shepard and PLD space Miura 1 rockets. Computer simulations were conducted to calculate the key parameters such as flight trajectory profiles, stability and flight velocities for different rocket motors configurations. A preliminary design of the rocket was developed using Computer-Aided Design (CAD) software. The rocket will accommodate multiple payloads (Cubesats, NanoLabs, TubeSats) designed and developed in the Payload Applied, Technology and Operations (PATO) laboratory. The rocket will be primarily constructed of carbon fiber composite as it has a high strength to weight ratio. These simulations are used to select a suitable motor for the rocket according to the flight requirements and landing restrictions. This prospective Level 3 Rocket is referred to as Suborbital Technology Experimental Vehicle for Exploration (STEVE). Rocket procedures and results from the design, simulation, construction and assembly will be presented.

I. Nomenclature

ABS = Acrylonitrile Butadiene Styrene
CAD = Computer Aided Design
Cubesat = 1U (10 cm × 10 cm × 10 cm)
ERAU = Embry-Riddle Aeronautical University
NAS = National Air Space
NanoLab = 2U (20 cm × 10 cm × 10 cm)
PATO = Payload Technology Applied Operations
STEVE = Suborbital Technology Experimental Vehicle for Exploration
TubeSat = OD (10.20 cm), ID (9.91 cm), Length = 12.7 cm
S.A.T = Society of Aviation Technicians

II. Introduction

The objective of this research endeavor is to design and build a Level 3 Rocket that can serve as a research platform for launching, testing and recovering of payloads to be flown in commercial suborbital platforms such as Blue Origin's New Shepard, Exos Aerospace's SARGE, Interorbital Systems' Neptune, and PLD space's Miura 1 rockets. The

[1] Undergraduate student, Department of Aerospace Engineering, 600 S. Clyde Morris Blvd.
[2] Ph.D. Candidate, Department of Mechanical Engineering, 600 S. Clyde Morris Blvd., AIAA Student Member
[3] Undergraduate student, Applied Aviation Sciences Department, 600 S. Clyde Morris Blvd.
[4] Undergraduate student, Department of Aerospace Engineering, 600 S. Clyde Morris Blvd.
[5] Undergraduate student, Department of Aerospace Engineering, 600 S. Clyde Morris Blvd.
[6] Assistant Professor, Applied Aviation Sciences Department, 600 S. Clyde Morris Blvd., AIAA Member
[7] Professor, Department of Mechanical Engineering, 600 S. Clyde Morris Blvd., AIAA Associate Fellow

rocket will initially be launched to measure humidity, temperature and radiation in the atmosphere. However, other electronics and educational experiments will be launched in the future. The rocket is being constructed at the Payload Applied Technology Operations (PATO) laboratory using state-of-the-art materials and manufacturing techniques, such as 3D printing and CNC machining, with multiple levels of redundancy which maximizes the payload capabilities and the safety and reliability [1] of the launch vehicle. The payload bay area is being developed in conjunction with students from a CSO 390 Payloads and Integration class to accommodate multiple payloads with various shape factors (1U, 2U cubic NanoLabs and TubeSats). This is to ensure seamless integration of the payloads that are tested for various prospective commercial flight providers after launching on our rocket. The Level 3 rocket is being developed and integrated based on the team's previous experience in designing and flying level 1 and level 2 rockets [2].

The Suborbital Technology Experimental Vehicle for Exploration (STEVE) project is a prospective Level 3 Rocket that will serve as a scaled down model of a rocket [3] in which students can use to send payload and test them. The rocket is expected to be 4.877 meters in length and 0.279 meters in diameter. It will reach a maximum altitude of 3.962 kilometers (class B airspace) for the given flight and vehicle parameters using the 98-millimeter diameter motor. The rocket has a cylindrical payload bay with a maximum capacity of 0.0716 cubic meters and can carry a payload up to 13.607 kilograms. However, our rocket is expected to fly higher than 5.486 kilometers (class A airspace) after optimization of these parameters.

Computer software, such as Open Rocket [4] and Cambridge Rocketry [5], were used to simulate the flight trajectory of the rocket and the preliminary design was developed using Computer Aided Design (CAD) software. Cambridge Sensitivity Test, which is used to analyze the flight path of the rocket, provides insight into any necessary changes required to optimize our design.

The design for the payload bay area was assigned as a class project, to a CSO 390 Payloads and Integration class at ERAU, resulting in two teams to cover total integration of the payload and its housing in the bay. The task was to design three experiments in the various 1U (10 cm x 10 cm x 10 cm), 2U (20 cm x 10 cm x 10 cm) CubeSats, and 13 cm height TubeSat compartments. Final dimensions for the inner diameter (ID) and outer diameter (OD) are 9.91 cm and 10.20 cm respectively.

The experiments within each compartment are as follows: basic telemetry, radiation sensing with no shielding, and liquid radiation sensing. These experiments are conducted to test radiation and radiation-shielding to see what methods would be best for protecting astronauts and other spaceflight participants. The main goal is to study different levels of radiation between the TubeSat and the 2U CubeSat in the same general area of the atmosphere. This data will be utilized toward future experiments and suborbital spaceflight research, allowing ERAU students to advance in the fields of science and technology. In 2017, our team [6] flew NASA's Timepix radiation sensor aboard the NASA's WB-57 aircraft to characterize the radiation at 60,000 feet (18.29 km), and registered instances spikes in the dosage during the 3.8 hours of flight (2.5 hours of cruise near 60,000 feet) of about 48 µGy.

The development of this research payload project will allow students to advance in the fields of science and technology by testing various size payloads and science experiments and utilizing the data for future efforts in the design and development of larger payloads for larger suborbital and orbital platforms. Such platforms include PLD Space's Miura 1 rocket and Blue Origin's New Shepard rocket, but also smaller payloads housed in smaller rockets, such as Exos' rocket.

III. Methodology and Preliminary Results

A. Design for Rocket

The final rocket design has seven major sections which can be seen in Fig 1. Assembly and fabrication [7] of the rocket was completed using purchased 2×2 twill carbon fiber weave tubes as well as 2×2 twill carbon fiber bulkheads and motor tube centering rings. The 2×2 twill pattern was chosen due to its higher tensile strength than other common patterns. Each rocket section is attached to the other using threaded metal rods. The motor tube [8], shown in Fig 2, will be able to hold a 150-millimeter motor [9] and was self-fabricated using 2×2 twill carbon fiber weave with Wet Systems 105-B epoxy and 206 hardeners. Using the hand lay-up method, the weave was applied to a phenolic tube, which has the necessary inner diameter for holding the rocket motor. Layers of carbon fiber weave were added to the outer diameter of the phenolic tube to obtain the correct size for mating with the centering rings. After curing, the motor tube was sanded for an accurate outer diameter and roundness. However, it was realized that the layer of carbon fiber was too thick because the carbon fiber expanded due to not being properly cured within a vacuum bag. Thus, the centering rings did not properly fit onto the motor tube. It was decided that a method must be determined to remove enough carbon fiber such that the centering rings would fit around the motor tube. There were several solutions to fix this excess of carbon fiber.

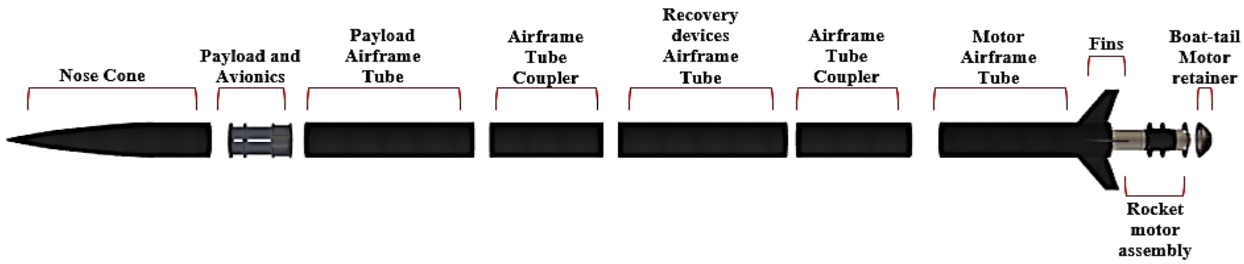


Fig 1. Design of STEVE and the sub-assemblies.

The first solution was to mill the carbon fiber using the lathe but was unsuccessful due to the bit braking off. Another solution that was attempted was sanding the tube. However, the sander did not take off enough carbon fiber efficiently. Ultimately, it was discovered that using an angle grinder and sander would take off the necessary amount of material. Before making any changes to the motor tube, the team started by measuring the outer diameter. A string was placed along the outer diameter and then measured using a measuring tape. A 4.5-inch angle grinder was used to reduce the outer diameter of the motor tube in small increments. The carbon fiber was removed by passing along the length of the area then rotating the motor tube with each pass overlapping. The process of the development of the motor tube had to be execute in a timely manner. This process was conducted slowly over the course of 5 days to avoid the angle grinder taking off too much material at once. After grinding down the carbon fiber, the diameter of the motor tube layup was small enough for all three of the centering rings to fit Fig 3.

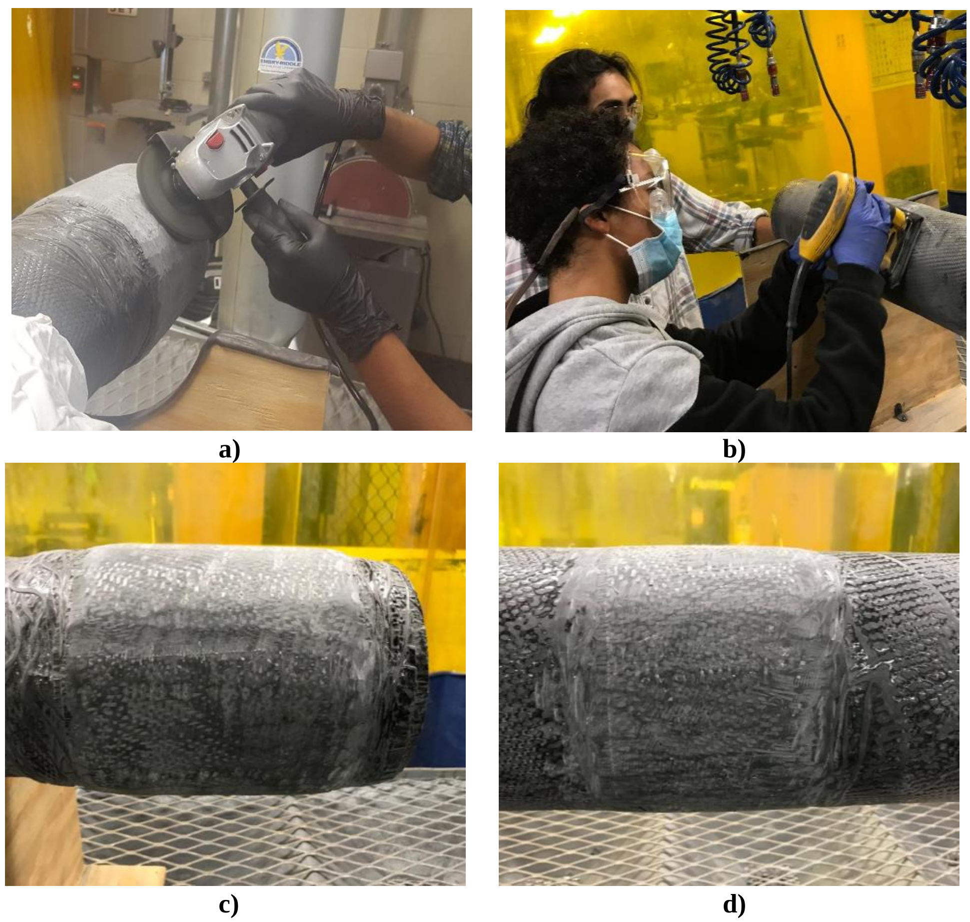
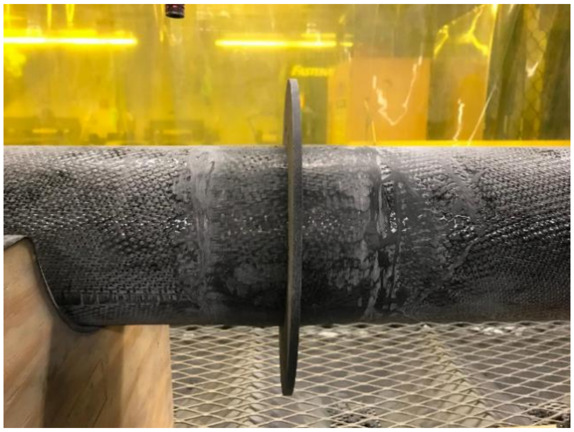


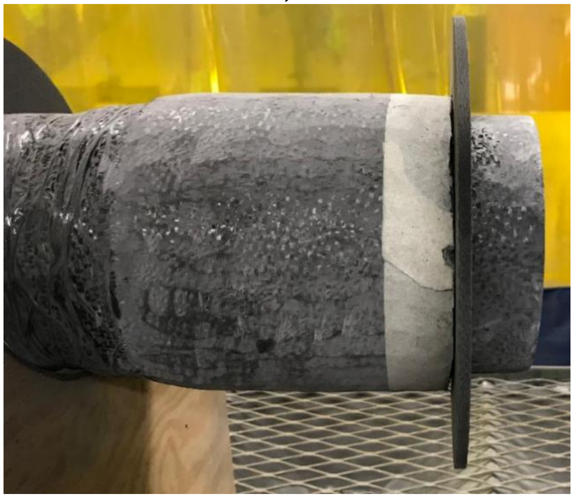
Fig 2. Initial sanding and grinding process for centering rings. a) Grinding. b) Sanding. c) Post-initial grinding. d) Post-initial sanding.

a)



b)

c)

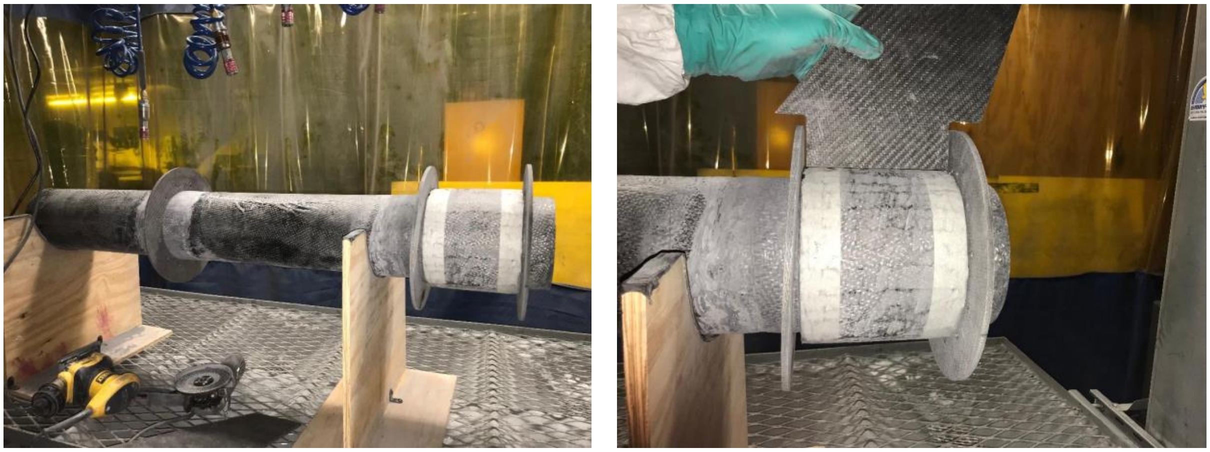


d)

e)

Fig 3. Final grinding and sanding process for centering rings. a) Final product after initial grinding. b) Fitting of first centering ring. c) First surface cut. d) Fitting of second centering ring. e) Final cut for second and third centering rings.

After the tube was sanded for a smooth finish, the centering rings were able to lie flush against the motor tube and carbon fiber layup Fig 4. In reducing the diameter of the hand layup, excess material was taken off to reduce the overall weight of the motor tube.

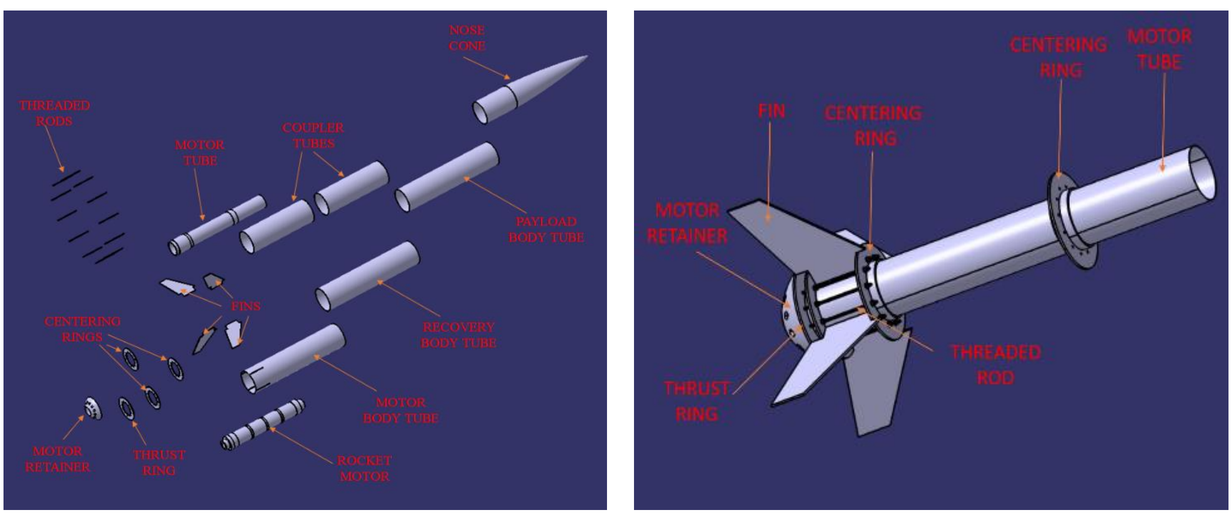


a) **b)**

Fig 4. Completed motor tube. a) Centering ring placement. b) Fin placement with centering rings.

Manufacturing of the rocket is being conducted in the College of Aviation Maintenance, where the 2×2 twill carbon fiber weave motor tube is currently being sanded using a downdraft table to allow for proper ventilation and disposal of excess material being sanded. Other parts of the rocket that require more precise measurements were machined at the College of Engineering.

The rocket fins were created with a purchased 2×2 twill weave carbon fiber plate, which was cut and sanded to the correct shape. The fins are attached to the motor tube through slots that were cut into the aft rocket tube using a rotary tool, which is called the Dremel. Alignment of the fins was ensured using a fin box. The fins were epoxied into place. A paste mixture was created using the same epoxy mixture along with Wet Systems 404-15 high-density adhesive filler to form fillets along the fins where they met the rocket tube. The nose cone will be constructed out of 2×2 twill Kevlar weave. All components of the rocket and motor are shown in Fig 5.



a) **b)**

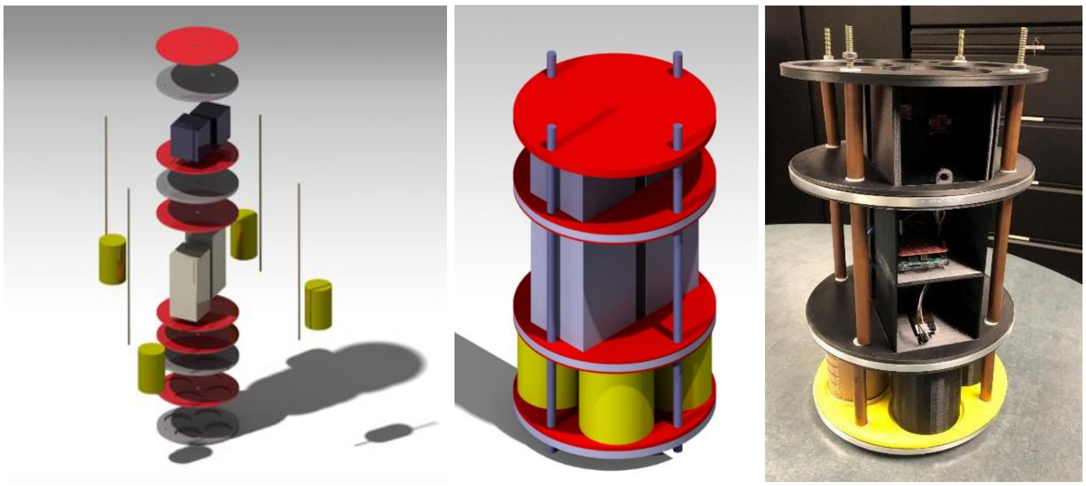
Fig 5. Detailed design view of the STEVE CAD assembly. a) Exploded view of the STEVE rocket assembly. b) Motor assembly.

B. Design and assembly of payload bay

The payload bay will contain the following electronic components: a battery as the power source, several environmental sensors to detect radiation, acceleration, temperature, humidity, altitude and pressure, an Arduino as a microcontroller, and a microSD module for data storage.

One of the payloads include a radiation shielding experiment, which utilizes water as the shielding material. The Tubesat will be designed as a shell to contain a known amount of water in its periphery. The radiation sensors will be placed inside the shielded Tubesat and a similar sensor will be utilized on the unshielded 2U cube and the data from the two sensors will be compared. Overall objective is to find out how varying the thickness of water shielding layers works as a viable barrier against radiation.

The payload bay consists of aluminum bulkheads which are key in transferring the inertial and impact loading from the payload to the airframe and the aft bulkhead transfers the loading through shear in a bonded joint to the monocoque airframe. All other bulkheads transfer loading to the aft bulkhead through the copper spacers. During preflight and the coast phase, the assembly is held in compression through preloaded locknuts on top of the forward most bulkhead and below the aft most bulkhead. The Payload design and assembly is shown in Fig 6.



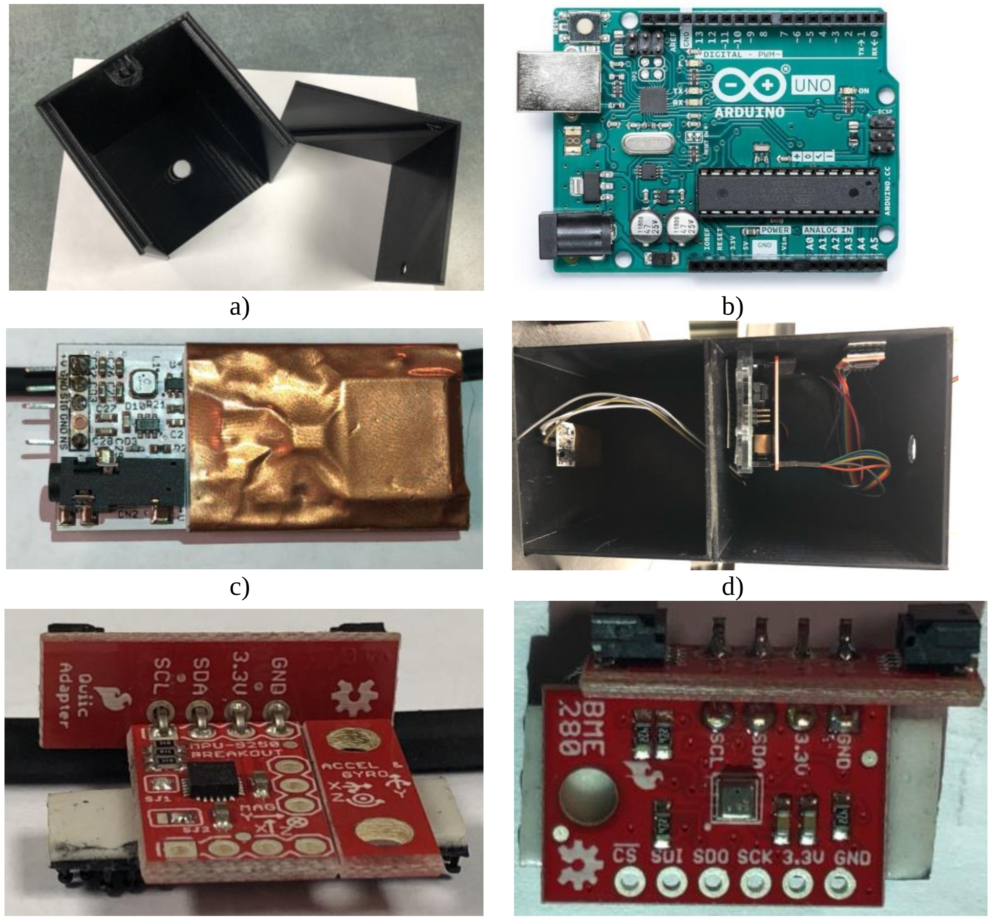
a) b) c)

Fig 6. Payload Design and final assembly. (a) Exploded CAD view of the payload bay. (b) CAD view of the payload assembly. (c) Fabricated and preliminary assembled payload bay.

Our original design of both the 1U and 2U structures utilized a two-part locking mechanism that requires screws on both sides of the structure to secure the two pieces together. Write about the structural analysis and add the pictures.

Arduino uno will be used as the microcontroller that integrates all the sensors and the software for the microcontroller will be programmed using the Arduino IDE. There will be two type 5 pocket Geiger radiation sensors used in both the 2U and TubeSats. A BME-280 atmospheric sensor will be used to measure atmospheric data in the 1U. MPU-9250 inertial measurement unit will be used to measure accelerations and gyrations in the 1U. Arduino will be housed within the 3D printed 2U. Two other sensors, BME-280 and MPU-9250, are hooked up to the Arduino using the Qwiic connect system in order to minimize the amount of soldering required to hook up the sensors. The radiation sensors will be directly soldered to the Arduino as the sensors are not compatible with the Qwiic system. The electronic components used in the payload are shown in Fig 7. Components used in the payload bay. a) 3D printed 1U cube. b) Arduino Uno. c) Radiation sensor. d) 3D printed 2U cube. e) Acceleration sensor. f) Atmospheric sensor.

The Arduino will be powered via a Universal Serial Bus (USB) type-B which will give the Arduino the required electricity to operate along with all the sensors. These sensors will use I2C communications protocol to communicate the data from the sensors to the Arduino. After the Arduino collects the data, it will use SPI communication protocols to write the data to the micro SD card. All the soldering and integration of the electronics system was conducted within the P.A.T.O. laboratory.

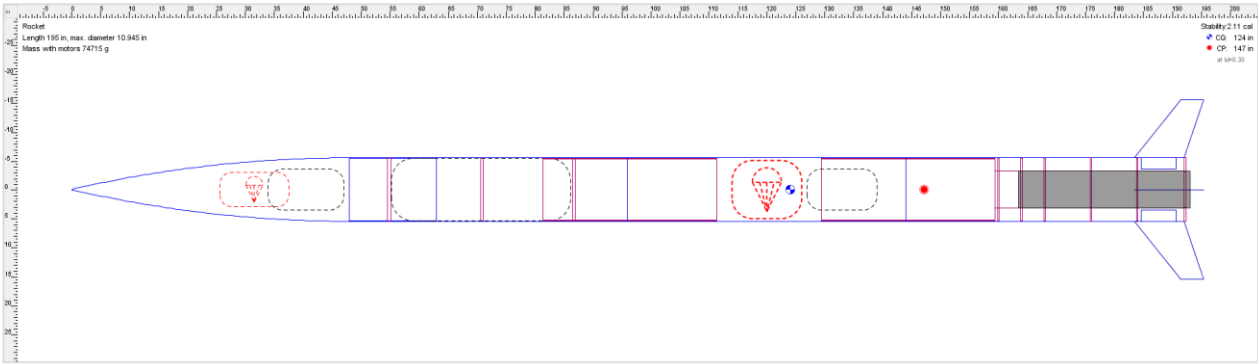


a) b) c) d) e) f)

Fig 7. Components used in the payload bay. a) 3D printed 1U cube. b) Arduino Uno. c) Radiation sensor. d) 3D printed 2U cube. e) Acceleration sensor. f) Atmospheric sensor.

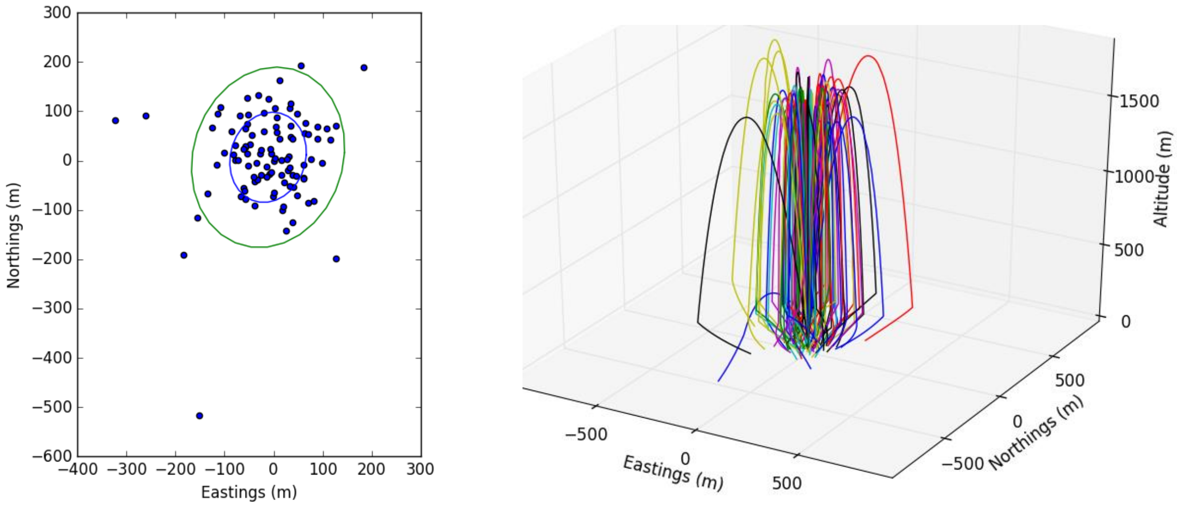
Using the Cambridge Rocketry Simulator, the team was able to simulate parachute descent, 3D flight trajectories, and splash down plots for the final rocket design with the specified 98-millimeter [10] rocket engine that was selected for the desired altitude. This software was used to compute a sensitivity analysis of the rocket trajectory based on some flight parameters, such as launch declination angle and thrust, to assess the deviation of each trajectory in altitude, easting and northing directions.

Two sets of data were simulated which consisted of five individual test trials, each consisting of 10, 50, 100, 500, and 1000 runs. The first data set simulated using the Rocketry software, pertained to our initial design in which our rocket had one coupler tube and used the payload bay area as our second coupler tube. The second data set simulated the current rocket design where there are two coupler tubes and the payload bay area are located near the nose cone. Between the two data sets there are differences that makes the flight more stable and therefore more accurate [11]. Below are two diagrams depicting the designs for the two different data sets simulated. With the two types of data sets, the mass of the payload changed. The tested masses of the payload were 10 kg, 20 kg, and 30 kg and were each conducted for five Monte-Carlo simulations (Fig 8). Using these simulations, the team was able to ascertain if the rocket design would be able to sustain up to a maximum payload weight of 30 kg while ensuring the flight path remains stable 16. Our preliminary simulations include 100 runs for each Monte-Carlo configuration.



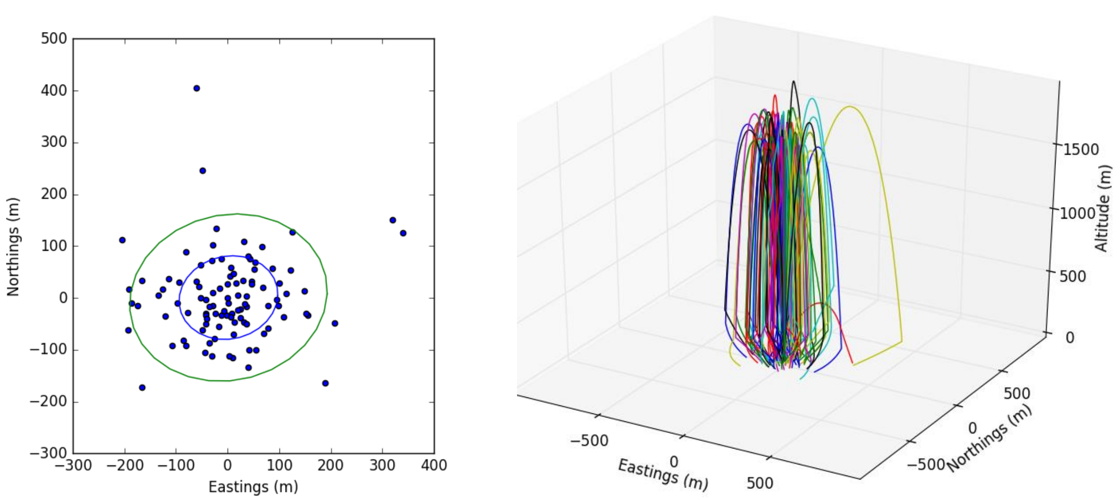
Rocket
Length 195 in, max. diameter 10.945 in
Mass with motors 74715 g
Stability:2.11 cal
CG: 124 in
CP: 147 in
at M=0.30

a)



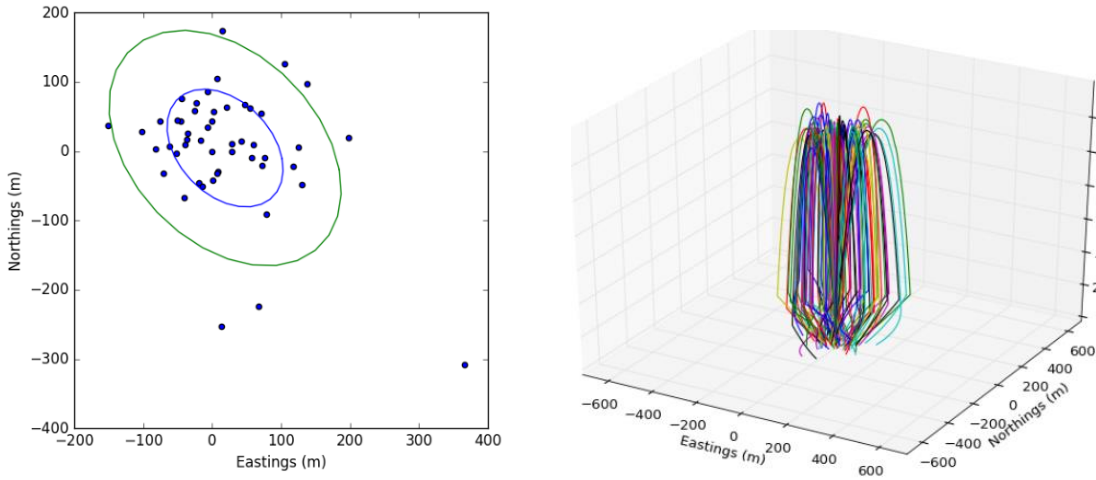
Northings (m)
Eastings (m)
Altitude (m)

b)

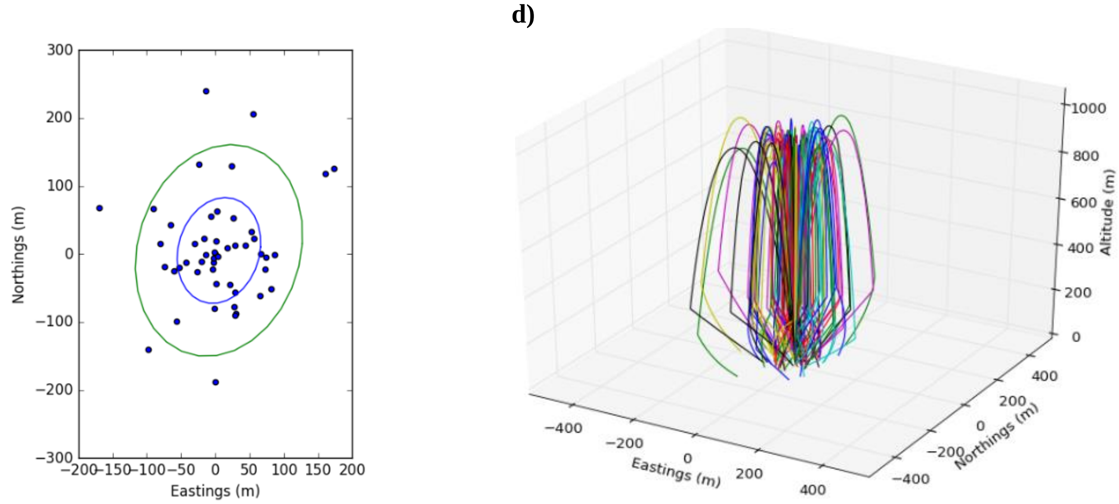


Northings (m)
Eastings (m)
Altitude (m)

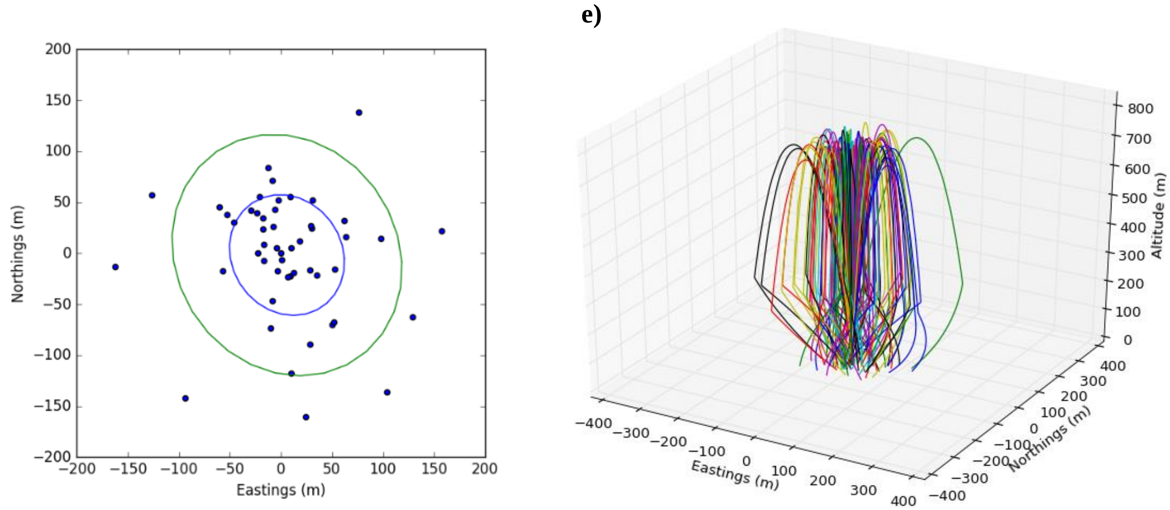
c)



d)



e)



f)

Fig 8. Splashdown plots with various payload masses. a) Cambridge Rocketry Simulator setup. Monte-Carlo splashdown plots: b) Dual coupler tube design. c) Single coupler tube design. d) Dual coupler tube with 10 kg-payload. e) Dual coupler tube with 20 kg-payload. f) Dual coupler tube with 30 kg-payload.

When comparing single and double coupler tube cases, it was observed that when the rocket has one coupler tube and utilizes the payload as a coupler tube, the flight is more stable than having two coupler tubes. In the plots, the diameter of the green circle is 400 meters and the diameter of the blue circle is 200 meters. The goal of these uncertainty plots is to maintain the flight profile in between the green and the blue circle. In the sample of diagrams for 50 runs with a mass of 10 kg, 20 kg, and 30 kg it can be concluded that the stability and accuracy changes. Through these simulations, a confidence interval can be calculated to ensure that our design will have at least a 95% confidence interval of success before any launch occurs. A 95% confidence interval is a range of values that you can be 95% certain contains the true mean of the population. Using the data exported from these simulations into an Excel data file, it sorted within specified time intervals for which each launch trajectory occurs, then tallied up the number of launches that fall within the two Gaussian ellipses. Since the exported data contains the final positioning of each launch trajectory, its exact location within the ellipses can be determined and used to calculate an overall confidence interval. Since different tests were carried out with different masses, it was observed that there were differences between these sets. While simulating the different masses, the goal is to have the trajectories within the green circle.

Flutter velocity is the speed at which vibrational harmonics within the fins begin, and any aerodynamic disturbances will cause a rapid fluttering and eventual tear-off of the fin. This will, again, lead to a loss of aerodynamic stability and loss of vehicle and payload. Rockets should be designed so that neither the divergence nor the flutter velocity are ever exceeded, with a margin of safety decided on by the designer. The results show that flutter is not expected to occur up to a flight velocity of 2.17 Mach which greatly exceeds the designed vehicle's maximum velocity. FinSim uses proven aerodynamic calculations, as well as very conservative numbers for materials' properties, and is widely used in the rocketry community to find maximum allowable velocities. If desired, and material properties are known, you can input them to get simulations better tuned to your exact flight. The maximum expected velocity of the rocket was inputted along with the dimensions and structural properties of the fins. FinSim was conducted as part of this project to ensure payload safety, as loss of vehicle will almost certainly lead to loss of payload.

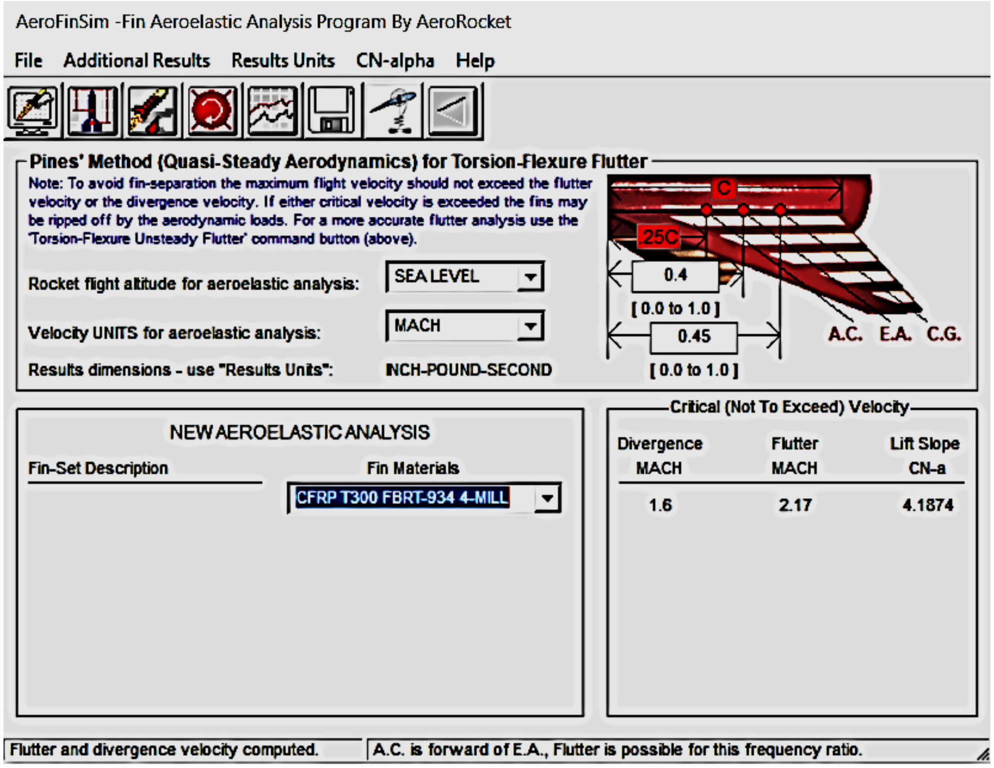


Fig 9. Fin Flutter Analysis.

A MATLAB code (see Fig 10) was developed to import data from the Cambridge Excel data sheet and obtain the overall confidence level for each payload mass. The main code block imports data from the Excel sheet and extracts only the necessary values contained within the columns of imported data. The columns extracted for the program include the iterations, time (in seconds), altitude (in meters), and distance (in meters). This code was specifically made to be modular in order for more flexibility on updates. Due to this attribute of the code, each task is separated into a different block. Overall, there are three task blocks.

The first block (see Fig 11) is the colors' radius block. This section of the code counts how many simulations runs landed within optimal range/radius. There are two optimal landing ranges, the blue circle and the green circle. The blue circle has a radius of 200 meters, which is 100% confidence interval, and the green circle has a radius of 400 meters, which has a 95% confidence interval. The block runs a for loop that cycles through the distance, in meters, column. In the loop, the data is square rooted to find the value of the distance from the center of blue circle, which is also the center of the green circle due to both being concentric. The value is then run through an if-else statement to determine which circle it lies within. If the value (x) is less than or equal to 200, then it is counted as landing within the blue circle. When x is more than 200 but less than 400, then it is counted as landing within the green circle. If it is more than 400, then the value is counted as outside the range. The distance block is the block that references the iteration block.

The second block is the iteration block (see Fig 12). This counting index block will be used as a reference in another block. Within this block, it used specifically the index column of data. The code within this section employs a loop to cycle through all the data. In the loop, the code will count how many indexes are within the imported Excel data. Then the data goes through a nested if-else statement that will compare the index count with the data. If they don't match, then it triggers the statement and it will be added to another variable. This variable is the number reference for when the index changes. This piece of data is what the distance function block uses as a reference. The last block is the distance function block.

The fin flutter analysis as illustrated in Fig 9 was carried out using the AeroFinSim software [13] used to calculate divergence and flutter velocities of fins used to stabilize rockets. Fins on a rocket are used to move the center of pressure backwards and behind the center of gravity to ensure a stable flight. However, at high enough velocities, divergence and flutter can occur. When flying, any bending in the fins are counteracted by the stiffness of the fin, with the forces going into the epoxy, and, preferably, into the airframe and motor mount. Divergence is the point at which any aeroelastic forces are equal to the restoring force provided by the fins and any twisting deformation will not be able to be restored. The twisting will continue until the fin is ripped from the airframe, leading to an asymmetric aerodynamic loading on the rocket. The result of this is a rapid loss of aerodynamic stability and likely loss of vehicle and payload.

IV. Conclusions

The knowledge of these flight parameters is critical for the integration of space vehicles into the National Air Space (NAS) to ascertain the behavior or impact it may have with the surrounding air traffic. The preliminary results predicted the mean rocket flight trajectories using Monte Carlo simulations for up to 1000 trajectories (not shown in the results sections for clarity purposes but will be presented in future work) with their probable landing zones (landing confidence bounds) indicating the predicting landing positions and Gaussian ellipses for 1 and 2 standard deviations. Through these simulations, a confidence interval can be calculated to ensure that our design will have at least a 95% confidence interval of success before any launch occurs. As of now, the outer airframe tubes of the rocket, fins, centering rings, and connecting rods have been obtained. Slots for the fins have been cut into the aft rocket section and the motor tube has been fabricated using hand layup. Finally, the payload has been designed and constructed.

For 100 runs Monte-Carlo simulation (one coupler tube with single payload), 10% of the trajectories fall outside the green, 38% between the green and blue, and 52% inside the 95% confidence interval. For the two couplers with single payload configuration, 8% of trajectories fall outside the green, 40% between the blue and green, and 52% within 95% confidence interval. For 100 runs Monte-Carlo simulation (two couplers with 10 kg-payload), 8% of trajectories fall outside the green boundary, 12% between green and blue, and 80% within 95% confidence interval. For two coupler tubes with 20 kg-payload, 7% are outside of green, 18% between blue and green and 75% within 95% confidence interval. Finally, for the 30 kg-payload configuration, 8% fall outside the green, 15% between blue and green, and 77% within 95% confidence interval. Our simulations suggest that using two coupler tubes provides better stability, yet more Monte-Carlo simulations with up to 1000 trajectories will be provided to further assess its stability. Preliminary calculations suggest that about 11% of trajectories fall outside the green, near 19% fall between the green and the blue, and about 70% are within the 95% confidence interval.

V. Future Work

Using a MATLAB code, the data collected through various runs conducted using the Cambridge Rocketry Simulator will be sorted through and the final position of each launch trajectory will be located using the northings and eastings data. Using the intervals in which the two ellipses span, the MATLAB code determined which launch trajectories and how many of them landed within these specified intervals. After determining the number of successful trajectories, the confidence interval was computed from the statistics of the observed data. This was done to ensure that a desired confidence interval, of no less than 95%, was obtained for a successful launch for the specified design. If the confidence interval calculated is any less than 95%, any changes possible to the remaining aspects of the design will be determined to increase the stability and confidence interval of the launch vehicle. Any changes made to the future design of the Level 3 Rocket can be accounted for by running new simulations on the Cambridge Rocketry Simulator. A new confidence interval will be calculated from the new set of data acquired to ensure that the flight will still be successful.

The next step will be to assemble the motor section of the rocket, followed by the fabrication of custom coupler tubes and nose cone. The couplers and nose cone will be hand laid similarly as conducted with the motor tube. Since the coupler tubes and the nose cone are going to be custom-made, more research will be done to determine the correct and more efficient way to construct the parts. Once all the segments have been made, the rocket will be assembled. All segments will be bolted together through the zinc-plated threaded rods. By first attaching the centering rings to the motor tube, a fin box will be used to help align the fins to the rocket body, and then the rocket tube. After joining those segments together, the next step would be to insert the threaded rods through the centering rings and secure them to ensure the proper structure of the rockets runs through its entirety and maintains its stability during flight. Once all the segments are attached to the motor tube, the whole motor tube, with its components, will slide into the aft section of the rocket. The centering rings will be attached to the tube to ensure that they will be able to withstand the force of the motor tube and keep it aligned during flight. The coupler tubes will connect each of the main outer rocket tubes together. Finally, the nose cone will be attached to the payload body tube.

Deployment and recovery of the flight vehicle will be aided using avionic components which are to be planned in the future. Integration and testing of the various components will be performed and presented in the manuscript. The team plans on working with the incoming CSO 390 Payload and Integration in Fall 2019 to further design input of our design. They will assist in the development of an avionics bay and recovery system that will incorporate most if not all the designs the team has planned.

Appendix

Appendix A – Block diagram of MATLAB code with corresponding functions.

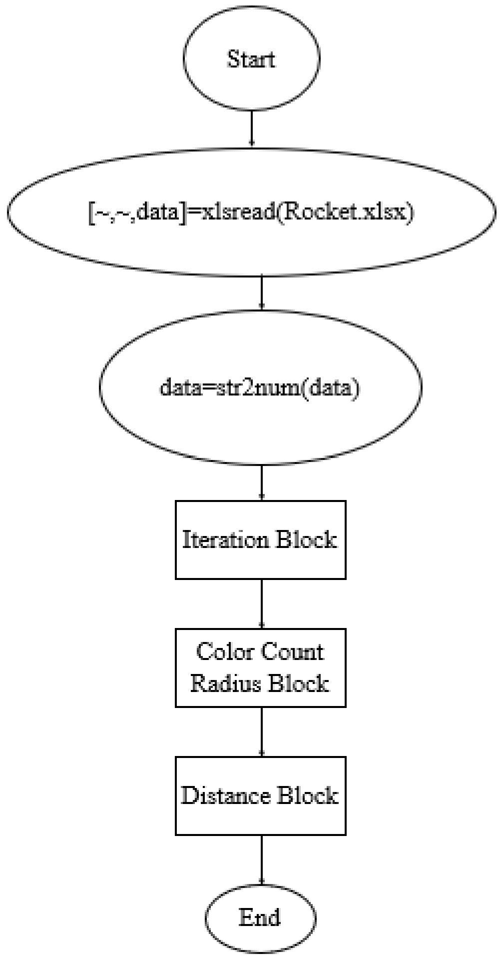


Fig 10. Main MATLAB code diagram.

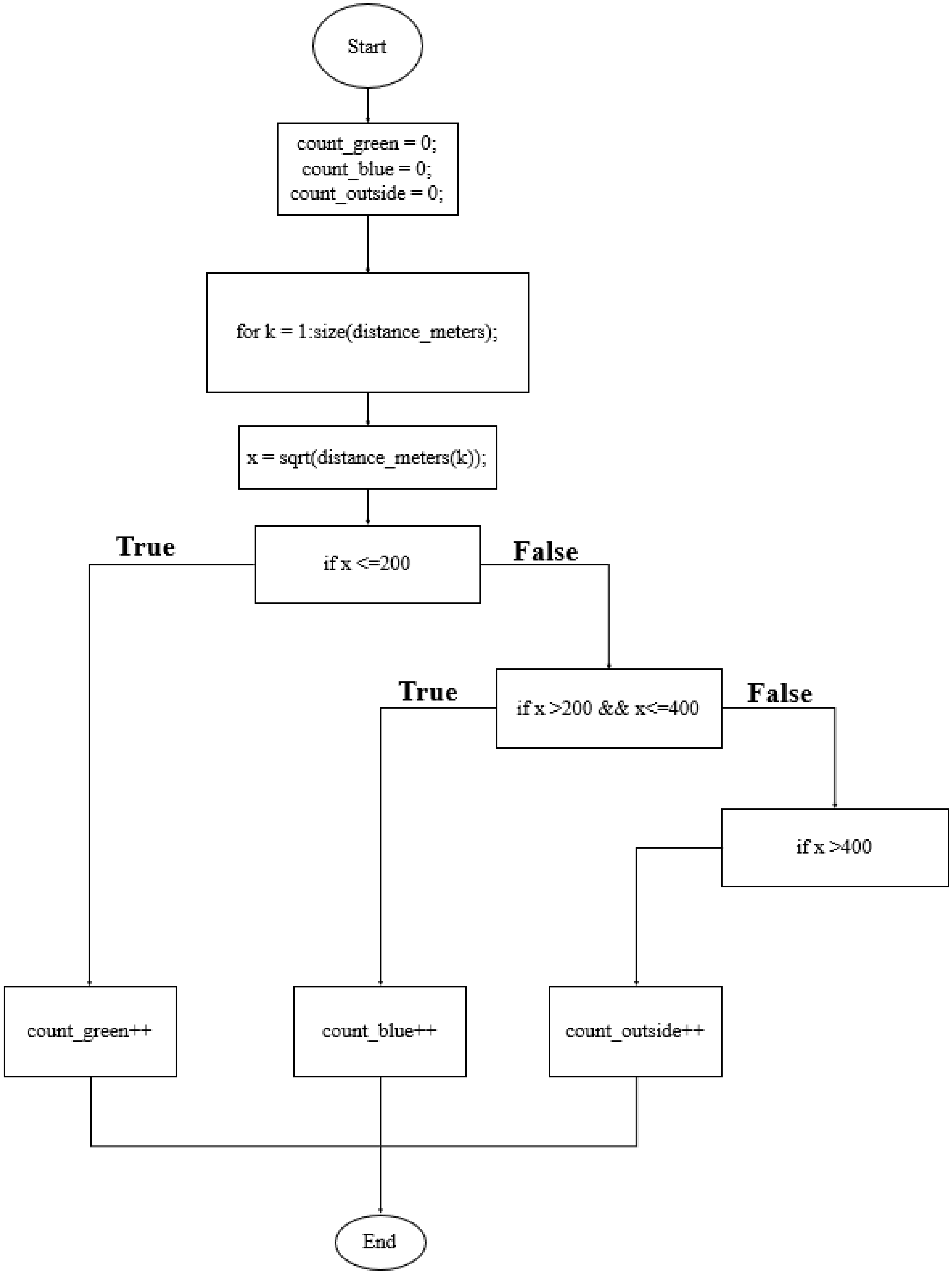


Fig 11. Color count radius function block.

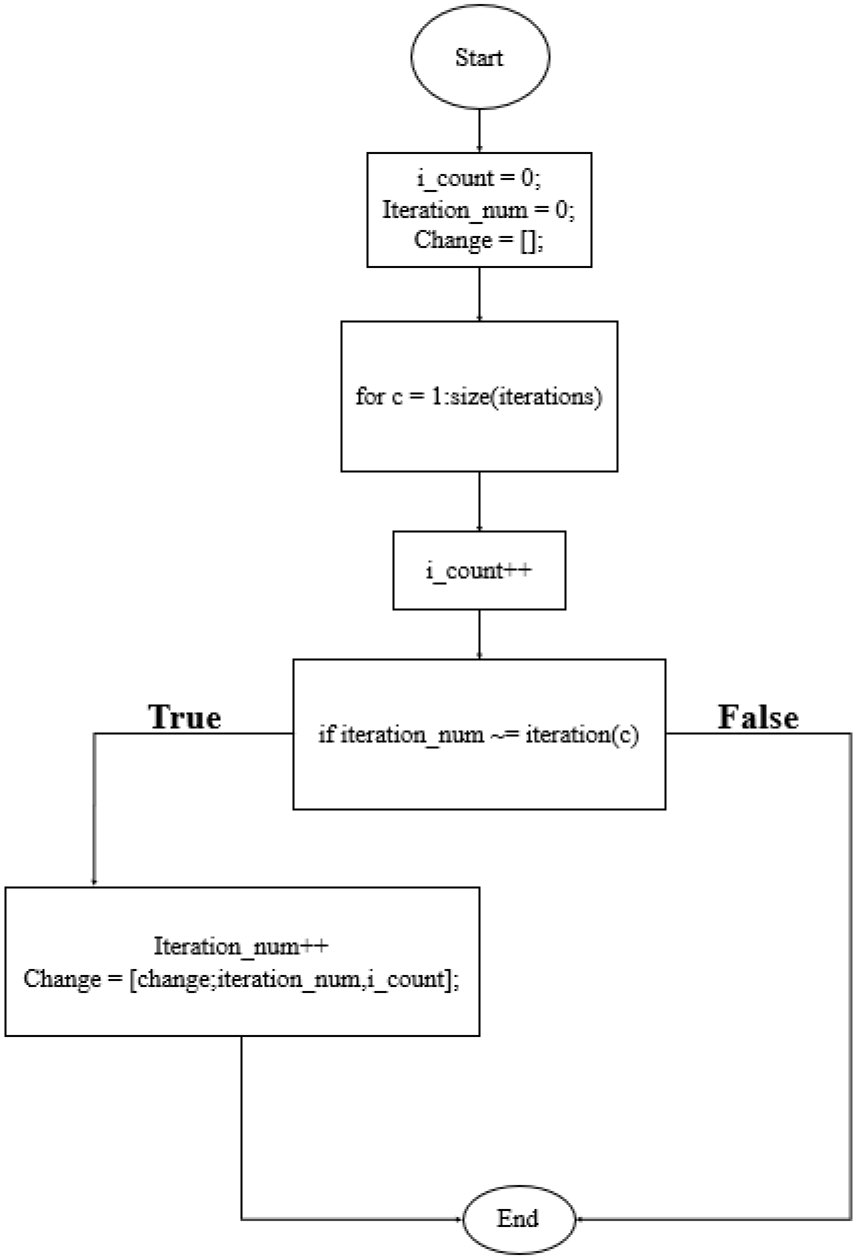


Fig 12. Iteration block.

Acknowledgments

We would like to thank the IGNITE Undergraduate Research Office and the Applied Aviation Sciences department for granting most of the funds for the construction of the rocket. We would like to thank Dr. Llanos' CSO 390 Payload and Integration class for designing the payload structure, TubeSats, CubeSats, 1U and 2U compartments in the PATO lab. We would also like to thank the National Association of Rocketry and Embry-Riddle Future Space Explorers and Developers Society (ERFSEDS) for initially guiding us on the construction of the Level 3 Rocket. We would like to thank the Department of Mechanical Engineering for their support in this project as well as the Department of Aviation

Maintenance for providing labs to manufacture various components of the rocket. We would also like to thank the Students in the S.A.T. club for helping us with the fabrication of the remaining parts.

References

[1] NAR, "National Association of Rocketry Level 3 High Power Certification Requirements," National Association of Rocketry Level 3 High Power Certification Requirements Available: https://www.nar.org/wp-content/uploads/2014/08/L3certreq.pdf. Accessed February 2019.

[2] Llanos, P., Haley, R., Gangadharan, S. N., Duraisamy, V. V., Maupin, G., & Stockton, C. (2019). Educating the Space Scientists at Embry-Riddle through Design, Build and Fly Rocketry Experience. In *AIAA Scitech 2019 Forum* (p. 0612)..

[3] Stine, G. H., & Stine, B. (2004). Handbook of model rocketry. Wiley. Accessed January 2019.

[4] Sampo Niskanen, "OpenRocket technical documentation," OpenRocket technical documentation Available: http://openrocket.sourceforge.net/techdoc.pdf. Accessed February 2019.

[5] Eerland, W., Box, S., & Sóbester, A. (2017). Cambridge Rocketry Simulator–A Stochastic Six-Degrees-of-Freedom Rocket Flight Simulator. Journal of Open Research Software, 5(1). Accessed January 2019.

[6] P. Llanos, A. Rukhaiyar, J. Nadeau, N. Nunno, K. Andrijauskaite, S. Gangadharan, Educational Experiences and Lessons Learned in the Multidisciplinary Design, Fabrication, Integration and Pre-Flight Testing of Embry-Riddle High Altitude Science Engineering Rig (ERHASER) Payload Aboard NASA's WB-57 Aircraft, ASEE

[7] Michael R. Lostoski, Jeff Szucs, and Matt Schwenning, "Structural Design and Fabrication of a Rocket," The University of Akron IdeaExchange @UAkron Available: https://ideaexchange.uakron.edu/cgi/viewcontent.cgi?article=1391&context=honors_research_projects. Accessed January 2019.

[8] "Propulsion," How do you calculate rocket engine performance?Available: http://www.qrg.northwestern.edu/projects/vss/docs/propulsion/3-how-do-you-calculate-rocket-engine-performance.html. Accessed January 2019.

[9] Coker, J., "Simulator Data," ThrustCurve Hobby Rocket Motor Simulator Data Search O5800 Available: http://www.thrustcurve.org/simfilesearch.jsp?id=1071. Accessed March 2019.

[10] Coker, J., "Rocket Motors Found," ThrustCurve Hobby Rocket Motor Search O9800 Available: http://www.thrustcurve.org/motorsearch.jsp. Accessed March 2019

[11] Barrowman, J., "Rocket Stability," Calculations Rocket StabilityAvailable: http://www.me.umn.edu/courses/me4090_summer2017/CG_and_CP_Slides.pdf. Accessed February 2019

[12] "Basic Rocket Stability - Rockets for Schools," Basic Rocket Stability Available: http://www.rockets4schools.org/images/Basic.Rocket.Stability.pdf. Accessed January 2019.

[13] "Fins for Rocket Stability," Richard Nakka's Experimental Rocketry Site Available: https://www.nakka-rocketry.net/fins.html. Accessed January 2019.