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Development of Modular High Powered Rocketry Kit for Rocketry Workshop Course

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Development of Modular High Powered Rocketry Kit for Rocketry Workshop Course

by

Justin Thomas Bump, Seth Lakota Bunt, and Sean Brendan Joyce

An Honors Capstone

submitted in partial fulfillment of the requirements

for the Honors Diploma

to

The Honors College

of

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Honors Capstone Project Director: Dr. David Lineberry

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05/03/2024

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5/3/24

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Date

TABLE OF CONTENTS

1 ABSTRACT

The goal of this project was to design, build, and fly a workshop rocket to be utilized be future students in UAH's rocket design course. This rocket was designed with the knowledge of design features from the rockets built for NASA's University Student Launch Initiative (USLI) competition that rocket design students participate in. Both the nose cone and the boat tail were 3D printed to keep costs down, and a snap ring was inserted into the boat tail to retain the motor. The only onboard electronics are an Eggtimer Quantum used to deploy the main parachute at apogee. While flown as a single separation point, this design has the capability of being flown as a dual deployment system, with the avionics bay sitting between two parachute bays. The rocket is 47.5 inches long with a 3 inch diameter body. It weighs 3.6 pounds, not including the motor, and 4.1 pounds with the H283 motor. Post flight analysis revealed the rocket's drag coefficient to be 0.652.

The rocket was flown in Olmstead, Kentucky to ensure the rocket was both safe and effective for future teams to use. The flight was successful, and the only changes made afterwards do not affect the in-flight performance. After the flight, data from the onboard altimeter was used to conduct post flight analysis to help achieve a better understanding of the rocket's parameters. After a successful flight demonstration, a set of manufacturing instructions were compiled to aid in assembly for future teams to use.

2 INTRODUCTION

The Mechanical and Aerospace Engineering department's senior design course, Rocket Design, begins the fall semester with a short workshop. In this workshop, small teams are formed to teach the basics of high powered rocketry. While details vary from year to year, the workshop rocket is usually a commercial off-the-shelf (COTS) high powered rocket kit designed for a Level 1 high power rocket motor that flies to an altitude around 2000 ft. Rocket fabrication is the most time consuming part of the workshop, taking approximately four classes periods over the course of two weeks to complete the build. While beneficial, the workshop takes time away from working towards the class's ultimate goal: competing in NASA's USLI rocket competition. The USLI competition consists of designing and building a rocket payload that flies to an altitude between 4000 to 6000 feet using a Level II high power rocket motor. Constructing a rocket that achieves a lower apogee is a safe and easy way to teach rocketry techniques before tackling this challenge. NASA's request for proposal is published before the first week of class, and the time spent building a workshop rocket delays the date in which the class's focus shifts.

The workshop is a great introduction to rockets for students that have little to no high power rocketry experience. However, typical Level 1 high power rocket kits use manufacturing techniques and design approaches that can differ from those used for larger-scale high power rockets like those seen in USLI. Therefore, the goal of this project is to create a workshop rocket that incorporates design concepts that more directly apply to the scale of rocket that will be required for the USLI competition, and that can be fully assembled in a single build period. The scratch-build workshop rocket will introduce more applicable design and manufacturing concepts and allow for more time to be put towards the USLI proposal.

Pre-designed level 1 rocket kits are simple and easy to build. As these rockets are intended to be mass produced for hobbyists, they typically only consist of a body tube, a nose cone, fins, and some form of motor retention, with more expensive ones including parachutes. The rockets are designed to be assembled over many days as the components are epoxied together two at a time and allowed for the epoxy to cure before assembling the next piece. Kit rockets are also designed to be used with a built-in motor ejection charge to deploy the recovery system instead of requiring the use of an altimeter for an electronics controlled deployment. Motor ejection charges come in a predesignated amount so there is no need for testing charge size prior to flight. These rockets also typically do not fly high enough to warrant the use of a two-stage recovery system consisting drogue parachute at apogee and a separate main parachute at lower altitude. Instead the kit rockets are designed to simply deploy their main parachute at apogee.

However, when working with rockets as seen in USLI, many of these designs are no longer applicable. When flying to heights of over 4000 feet, a two-stage recovery system is required to limit the drift of the rocket. This then requires the use of a dual deployment system, which is not compatible with using motor ejection charges for separation. Dual deployment systems utilize altimeters to deploy the main parachute at a specified lower altitude, housed in an avionics bay coupler between the two parachute bays to protect sensitive electronics from the separation charges.

To ensure a timely construction for future rocket design students, mechanical fasteners were prioritized for connection points over epoxy between parts to avoid losing days of build time waiting for epoxy to dry. Rocketry kits use epoxy because it is a cheap and easy method of connecting parts for the average person. While it is not usually an issue to have to wait between major build steps, the time sensitive nature of this class promotes looking for alternate connection methods. Another key goal of the design was to keep costs as low as possible. This allows student groups to be smaller and for every member of a workshop team to gain some experience in building a high powered rocket.

By designing a workshop rocket from scratch, design features from a larger rocket can be incorporated into a smaller one to better represent what the students will need to know for USLI. In addition, by removing the use of epoxy, the time of build can be decreased from days to an afternoon with minimal fabrication required pre-assembly. An effort was also made to keep the rocket as affordable as possible.

To achieve the goal of creating a workshop rocket that is more beneficial to the students of MAE 490, the rocket was designed, and the necessary materials were purchased before building and flying the rocket. A bill of materials and a set of building instructions were also written to aid future students in their endeavors.

3 DESIGN OF THE ROCKET

The most time consuming aspect of the assembly is waiting for epoxy to cure before moving onto following steps that could potentially disrupt the curing process. The design choices made by this team cut down the time of assembly by up to an entire week by eliminating all sources of epoxy and replacing them with mechanical connections. It is by no means unheard of for rockets to be built with minimal or no epoxy. However, rockets on the scale of what would be seen in a workshop build typically utilize epoxy because it is simple to use, and machined parts or mechanical connections are reserved for larger rockets put under greater stress during flight.

Before purchasing parts for the workshop rocket, a complete CAD model was created to represent the vehicle. An isometric view of the fully integrated CAD assembly is shown in Figure 1, as well as a sliced view in Figure 2 to better show the internal assembly. This CAD model helped to ensure interference between parts would not occur, allowed for rapid design iteration (especially of 3D printed parts), and allowed an opportunity to estimate a mass and center of gravity (CG) of the vehicle before flight. This information was incorporated into an open source rocket trajectory simulation software called OpenRocket to predict vehicle performance before parts had been ordered for the project.

The future workshop rocket incorporates features that would provide newcomers to high powered rocketry with a good basis for the design of hobby rockets. The length of the design is 47.5 inches with an internal airframe diameter of 3 inches. The design uses three fins spaced evenly around the aft airframe. Using three fins is the optimal choice for this design due to the combination of minimal weight and sufficient stability. This design has aspects that are more typical of larger rockets such as the ability for dual parachute deployment from two separation points, the nosecone and between the avionics bay and aft airframe. The inclusion of an avionics bay and electronic deployment is uncommon on kit rockets at this price point. The rocket uses multiple custom 3d printed parts, the most apparent of these are the nosecone and the boat tail. The nosecone is an ogive for aerodynamics and includes a small loop on the interior for attaching to the recovery harness. The boat tail transmits the thrust to the rest of the vehicle as well as acts as the motor retention system by using a snap ring placed beneath the motor.

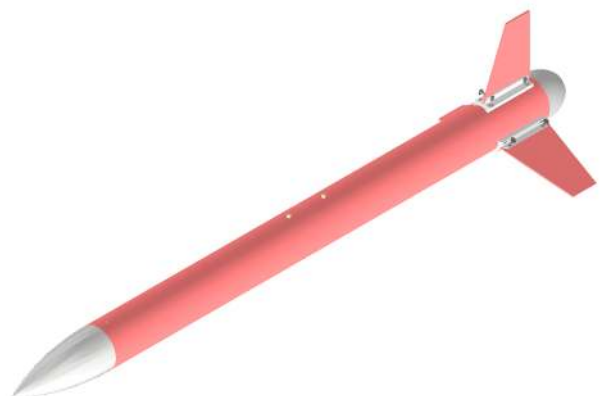


Figure 1: Isometric View of CAD Assembly

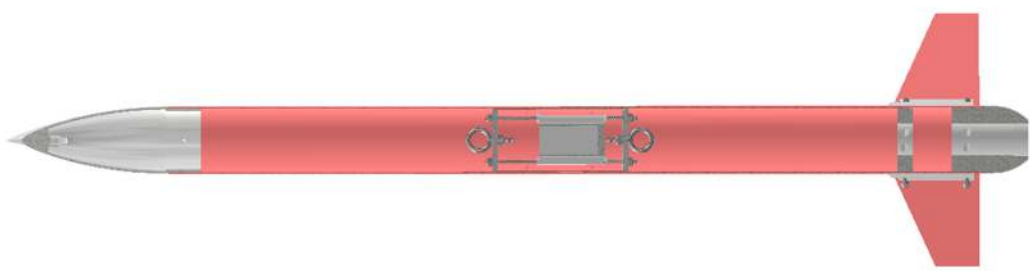


Figure 2: Sliced View of CAD Assembly

3.1 AIRFRAME

Most high powered rockets are constructed out of fiberglass, cardboard, or carbon fiber. For USLI, the length and weight of the rocket pushes teams towards fiber glass or carbon fiber as the extra strength is needed to land without risk of breaking components. However, body tubes are commonly one of the more expensive parts of the rocket, and for the purposes of the workshop cardboard was deemed strong enough to withstand the loads seen upon parachute deployment and landing. In an effort to keep costs down, the airframe was made from a material known as blue tube. Blue tube is a form of treated cardboard that is significantly easier to cut and work with in comparison to fiberglass or carbon fiber, and while not as strong as them, still results in a durable rocket for significantly cheaper. This is one of the few design choices made intentionally going against what would be done on a USLI rocket.

3.2 MOTOR ALIGNMENT AND RETENTION

For the class of motor used in workshop rockets, it is most common for motors to be aligned along the axis of the rocket using a tube that is epoxied to centering rings which hold it in place. However, there is no downside to using a motor alignment method that is typically used for more powerful rockets. Motor alignment and retention on this workshop rocket are both accomplished with a 3D printed boat tail and snap ring configuration. Figure 3 shows how the snap ring sits under the motor, keeping it in place. While a thrust plate would have been another option for motor retention consistent with larger rockets, Aeropack does not make thrust plates of this size. Therefore, a boat tail was chosen as it doubled as a connection point for the brackets.

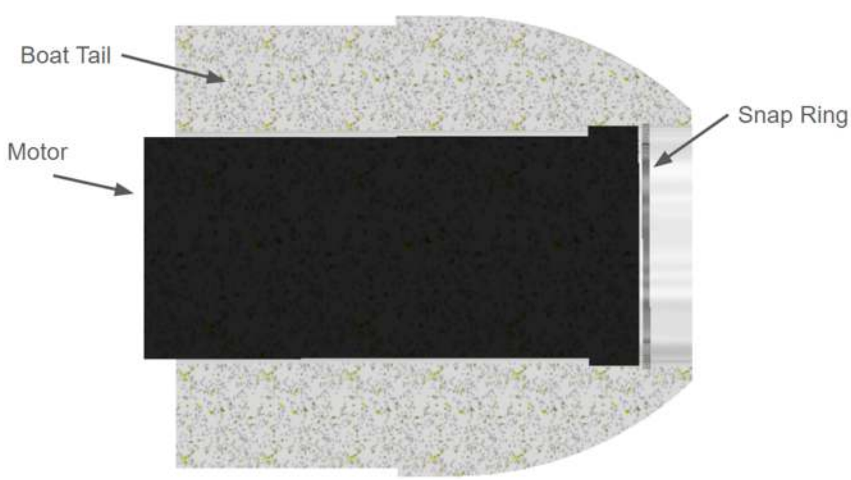


Figure 3: Boat Tail Assembly Cross Section

3.3 FINS

The design for fin attachments was inspired by this year's USLI full scale rocket. Figure 4 shows a fin bracket assembly as it sits on the workshop rocket. The bracket is held in place by self-tapping screws drilled through the aft airframe and into the boat tail/centering ring. The attachment of the fin brackets is shown in Figure 5. Chicago screws are then used to hold the fiberglass fin in the bracket's channel. This design has been tested extensively throughout the USLI season and is a reliable method of retaining fins without using adhesives such as epoxy.

Figure 4: Fin Attachment

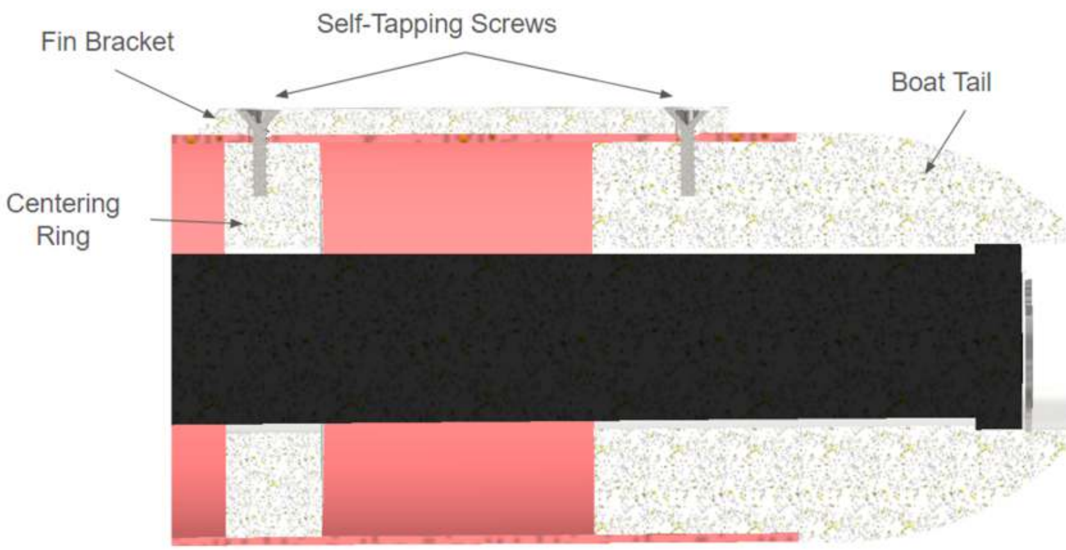


Figure 5: Fin Bracket Mounting

3.4 Centering Rings

Centering rings are used to ensure the motor stays in line with the axis of the rocket such that the thrust from the motor does not pitch the rocket to the side. There is only one centering ring present in this design, as the boat tail acts as the second one. The ring is 3D printed and held in place with self-tapping plastic screws similar to the boat tail. In the

3.5 Bulkheads

The design for the avionics bulkheads is heavily inspired by the avionics coupler design from this year's USLI vehicles which used two aluminum bulkheads connected by all-thread rods without the epoxy filet. Aluminum bulkheads would take additional manufacturing time and the extra strength compared to plastic is unnecessary for a rocket of this size, so 3D printed bulkheads were the best choice. During the black powder testing to determine separation charge sizes, these bulkheads have shown their ability to withstand the pressure differential created by the black powder charges used to separate the two rocket halves as no damage has been seen after five black powder tests with loadings between 2 and 3 grams.

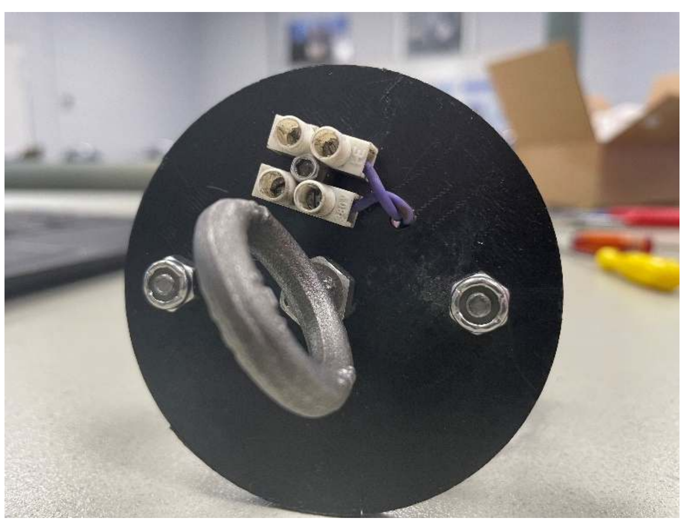


Figure 6: Forward Bulkhead Assembly

3.6 Avionics Bay

The avionics bay was designed to fit an Eggtimer Quantum altimeter into a 6 inch coupler using a similar design to the USLI rocket. 6 inches was chosen in order to have one full body tube diameter in contact with each airframe. The coupler is also fixed to the airframes with four plastic rivets, two for each airframe's connection to the coupler. The 3D printed sled has four 4-40 threaded inserts set in to help secure the altimeter. Figure 7 shows an exploded view of the avionics bay with all parts necessary before installing the wiring harnesses.

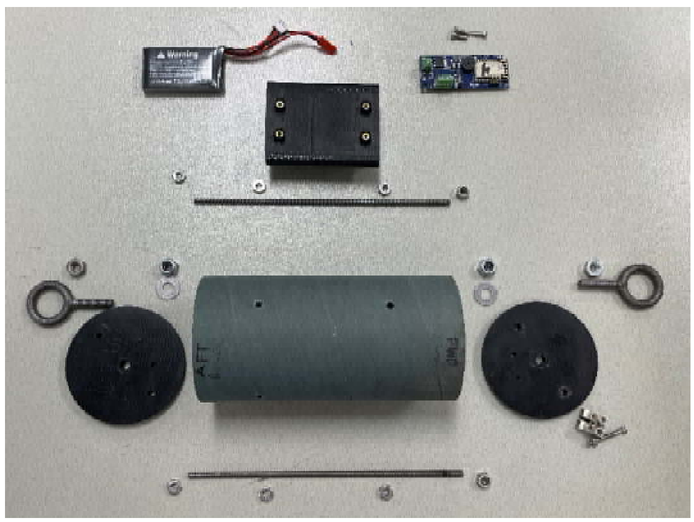


Figure 7: Avionics Bay Exploded View

The avionics bay bulkheads have five through holes. The central hole fits a 1/4 inch eyebolt to support the recovery harness. The two holes separated by 180 degrees fit the #8 all-thread rods which support the sled. The smallest of the remaining holes fits a #4 screw which secures a white terminal block to the bulkhead while the largest remaining hole allows the twisted pair wire to connect to the aforementioned terminal block. The thickness of the bulkhead is 1/4 inch, though 1/8 inch is used for the shoulder mounting.

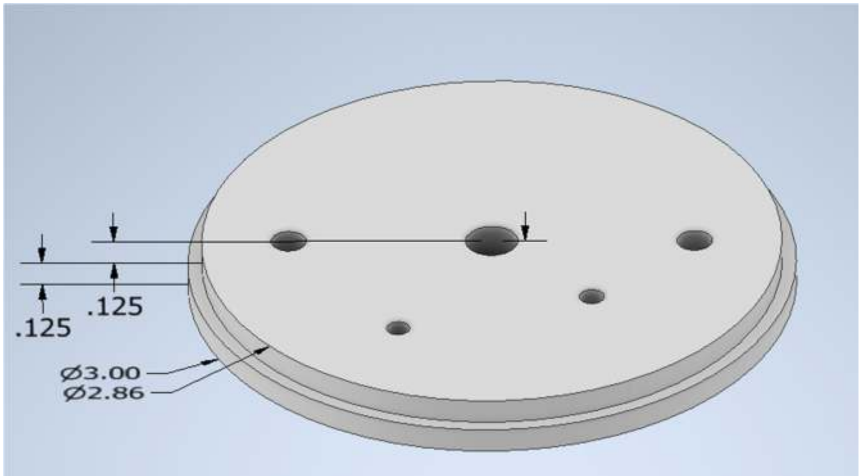


Figure 8: Avionics Bay Bulkhead

The avionics in the coupler must be capable of powering on and off externally, so a push button toggle switch was used. This push button lies in the circuit between battery positive to ground, interrupting the signal when pressed off. The button is external to the rocket and pushed through a hole drilled in the avionics bay. Other holes are also drilled in the bay as static pressure ports allowing the altimeter to sense the pressure of outside air. Pressure equalization is achieved with two 1/8" holes spaced 180 apart on opposite ends of the coupler.

3.7 NOSECONE

The design of the nosecone was based on common designs in model rocketry. The overall length of the nosecone is 9 inches with an exterior shoulder diameter of 3 inches. The shoulder has a length of one caliber, a caliber is the average diameter of the airframe so 3 inches. A common rule of thumb in hobby rocketry is to have the shoulder at separation points be at least one diameter in length. The length of the nosecone was constrained by the print height of available 3d printers which is 9.8 inches.

The nosecone acts as the primary separation point for the workshop rocket so there needs to be a method of keeping it attached to the recovery system. So, the interior of the nosecone has a loop to attach it to a quick link in the recovery shock cord. The interior of the nosecone can be seen in Figure 10. The nosecone can be attached to the upper airframe in two ways. The first way is using a friction fit and testing to confirm that separation does not occur when the rocket is held upright by the nosecone. It can also be attached with two shear pins if desired.

Figure 9: Nose Cone Isometric View

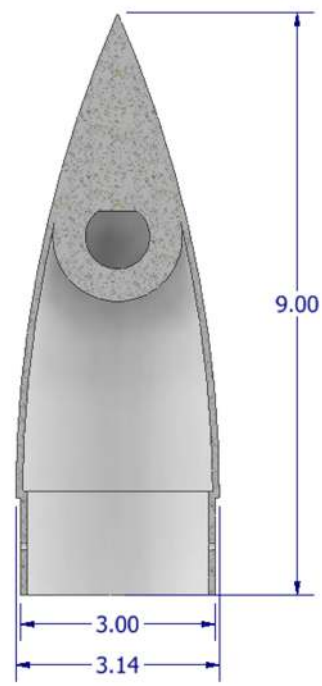


Figure 10: Nosecone Cross Section

4 CONSTRUCTION OF THE ROCKET

Prior to the construction of the vehicle, several parts had to be 3D printed. These parts include the fin brackets, centering ring, boat tail, nosecone, bulkheads, and avionics sled. Initially ABS filament was chosen for all of the 3D printed parts of the rocket because of its low cost and higher impact resistance when compared to other common 3D printed filaments. However, when construction of the workshop rocket began, the ABS capable printer was unusable, so an alternative filament material, PETG, was selected. PETG filament is similar in impact resistance to ABS and can be printed on the available 3D printers. However, PETG has a higher density than ABS, and resulted in a 20% increase in the weight of the printed parts. This increased weight was within acceptable design margins for the workshop rocket and did not necessitate a motor change for safe flight.

While the project goal was to produce a kit that could be built in a single work period, construction of the initial workshop rocket took place over the span of about 3 days. During this initial build, detailed manufacturing instructions were simultaneously developed increasing the time required for manufacturing. These instructions can be found in Appendix A, and have been separated into sections that can be worked on simultaneously to reduce the build time for the rocket. In addition, several of the initial 3D printed parts required re-prints to adjust tolerances for better fits with the airframe. These re-prints resulted in delays for the initial build that would not exist for subsequent builds. The most complicated system is the recovery electronics which require precise soldering of small electrical components. This took the most amount of time during construction. With a set of instructions containing example wiring harnesses, this build time can be reduced to a couple of hours.

The construction began with the drilling of the rivet holes in the coupler on the first day of building. After placing the airframes and coupler into a vice, four holes were drilled through the airframes into the coupler to keep the airframes pinned together during flight. These holes are shown in Figure 11. Additional holes were drilled in the upper airframe for shear pins to mount the nosecone to the rocket; these were not utilized as a friction fit was deemed sufficient. Thursday's build was postponed because the 3D printed boat tail encountered some sizing issues.

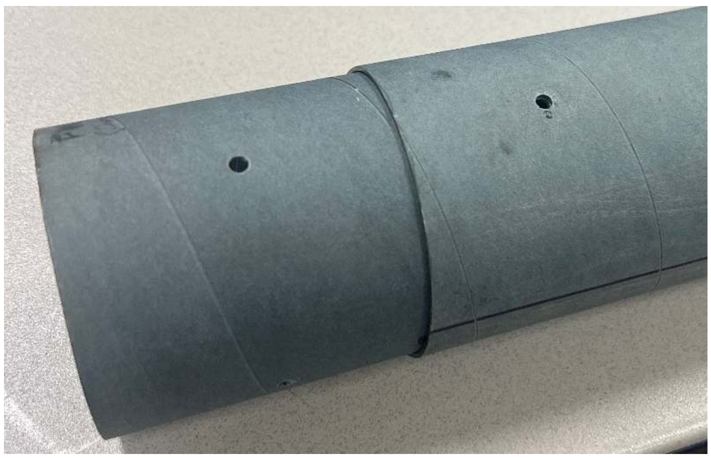


Figure 11: Rivet Holes

Construction continued two days later after a new boat tail finished printing. This is when most systems of the workshop rocket were completed including fin retention, motor retention, avionics, and recovery. Avionics and fin retention were built concurrently which took 4 hours to complete.

Fin retention was the trickiest part of the assembly due to the need to place precise holes in the aft airframe that align with holes in the boat tail. The boat tail design has since been modified to use self-tapping screws instead of bolts, so there is no longer a need to align any holes in the boat tail. This will make construction far easier in the future. The drilling of these holes began by marking a point on the aft airframe .8 inches from the aft end and inserting the boat tail such that a hole would lie beneath this point. Having the boat tail installed while drilling the holes in the airframe helps to ensure proper alignment. The boat tail has changed since the construction of the prototype so that it is now mounted using self-tapping screws instead of bolts so there is no longer a need to align holes in the boat tail. To ensure each fin brackets are mounted 60 degrees apart, a fin jig was designed post-construction. A #30 drill bit was used to make a pilot hole to guide a #18 bit through the airframe. This new hole would help in the placement of all the subsequent holes by keeping the fin bracket in place while all the other holes are drilled. The holes pattern and placement on the aft airframe is shown in Figure 12. The same technique was used to position the other two fin brackets. To ensure the brackets were evenly spaced during construction, the first fin bracket was installed and then the airframe was marked at the location of the other sets of holes in the boat tail. This proved effective, but using the new fig jigs is a better method as it holds the brackets rigid while drilling.

Figure 12: Placement of Fin Bracket Holes on the Aft Airframe

The avionics bay was constructed using the coupler that had rivet holes drilled into it on Thursday. The bay was finished by incorporating the avionics sled, Eggtimer Quantum, 2S Lipo battery, wire harnesses, and a terminal block on the forward bulkhead to support the black powder charge. Figure 13 shows an exploded view of the avionics bay. Before the avionics bay could be assembled, four heat set inserts were inserted into the avionics sled as seen in the top center of Figure 13. Next, the wire harness shown in Figure 14 is created. An additional wire harness using two 10” long wires braided together is also created to connect the altimeter to the charge as seen in Figure 15. The remainder of the avionics bay build is straightforward. The Eggtimer Quantum is secured to the av sled using four 4-40 screws. The all-thread rods are inserted through the sled and four 8-32 nuts are used to secure it in place. The bulkheads and coupler tube are also installed using two 8-32 locknuts and two 8-32 nuts.

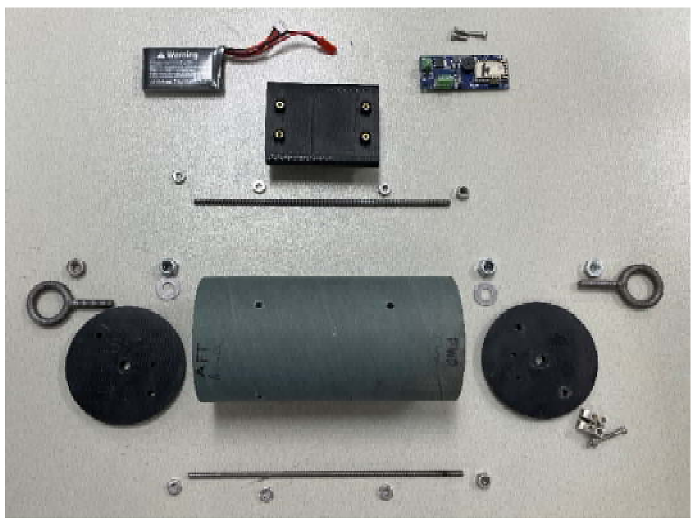


Figure 13: Avionics Bay Exploded View

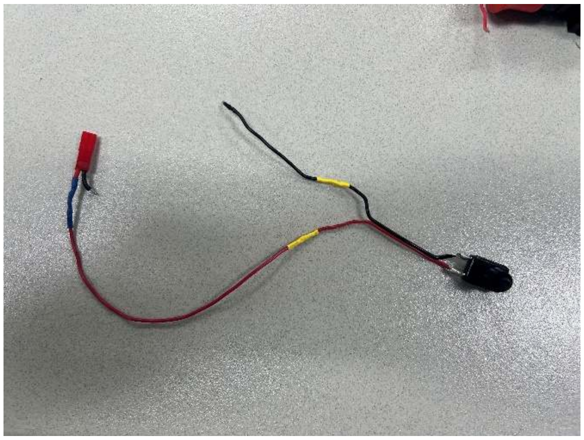


Figure 14: Wire Harness

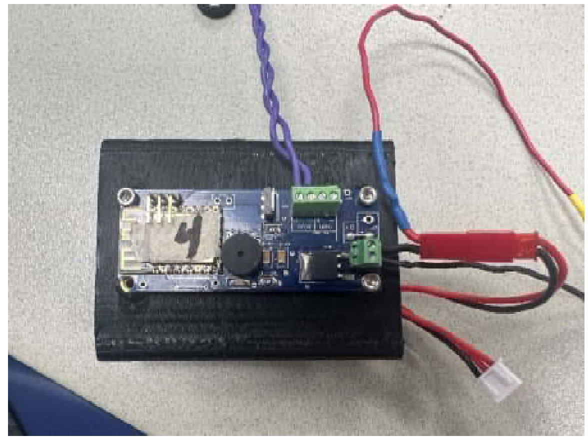


Figure 15: Eggtimer Connections

The final system of the rocket to be assembled was the recovery system which consisted of about 20 feet of nylon shock cord, a 48 inch parachute, three quick links, and a Nomex blanket. Three “figure 8 on a bight” knots were tied on the shock cord. One at each end of the cord and one about three feet away from one of the other knots. The completed shock cord is shown in Figure 16. The quick links are then attached to each of the knots and the Nomex blanket is attached to the quick link in the middle of the shock cord. The parachute is now folded and placed in the center of the Nomex blanket as shown in Figure 17.

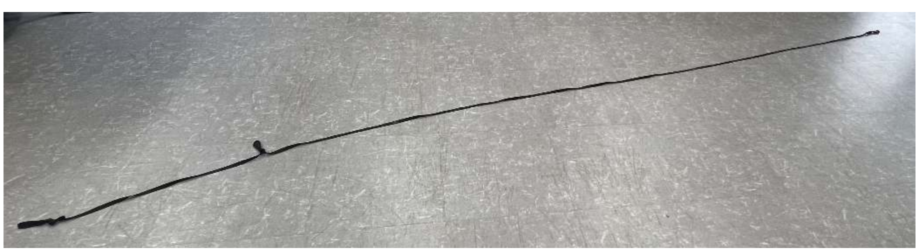


Figure 16: Tied Shock Cord

Figure 17: Folded Parachute Placed onto the Nomex Blanket

The Nomex is then folded around the parachute by folding the four corners of the Nomex towards the center while keeping it held together tightly. Once the Nomex was folded, it was checked to verify that the parachute and shroud lines were not visible from the exterior of the blanket. To make sure the shock cord did not tangle during flight, it was "z-folded" before installation into the airframe. The finished recovery harness and how it attaches to the workshop rocket are shown in Figure 18. The shock cord, Nomex bundle, and nosecone are then inserted into the upper airframe.

Figure 18: Completed Recovery Harness Attached to the Workshop Rocket

The final steps to constructing the rocket are performed at the launch field immediately preceding launch. A black powder charge, constructed from an e-match, a rubber glove fingertip, and tape, is connected to the terminal block on the forward bulkhead. Half a handful of a fire-retardant cellulose wadding is placed between the charge and shock cord to prevent singeing of the shock cord. The upper airframe is then attached to the coupler with plastic rivets. Finally, the motor is inserted into the boat tail followed by a retaining snap ring. The workshop rocket is now fully constructed and ready for launch.

5 COST ANALYSIS

Developing a low cost scratch-build rocket was an objective for the project. With lower costs, more and smaller sized teams could be incorporated into the rocketry workshop to begin the MAE 490 course. The cost breakdown shown in Table 5.1 gives a total cost of the entire rocket at $303.37. This cost includes the cost of body materials, fasteners, the altimeter, the motor, and 1 roll (46.51 cubic inches) of ABS or PET-G filament to account for the 38.232 cubic inches of printed material. This budget assumes a price per item independent from the quantity which parts are bought in. For example, a single 8-32 all-thread rod "costs" 89 cents, but it must be purchased from the distributor in a bag of 10.

Table 5.1: Cost Breakdown of Workshop Rocket

Part Description	Price Per	Price
48 inch Body Tube	$ 34.72	$ 34.72
Coupler Tube	$ 11.18	$ 11.18
1 sqft G-10 fiberglass	$ 19.80	$ 19.80
8-32 Chicago Screw 3/8"-1/2"	$ 0.72	$ 4.33
#8 Flat Head Self Tapping Screws for Plastic	$ 0.07	$ 0.89
1-1/2" Snap Ring	$ 0.59	$ 0.59
8-32 All Thread 7"	$ 0.89	$ 1.78
8-32 Locknut	$ 0.07	$ 0.14
8-32 All Thread Float Nuts	$ 0.05	$ 0.27
4-40 Socket Head Screw 3/8" long	$ 0.11	$ 0.44
4-40 Heat Set Insert	$ 0.16	$ 0.64
Eggtimer Quantum	$ 40.00	$ 40.00
500 mAh 2S Lipo battery	$ 11.99	$ 11.99
Spare 20 Gauge wire	$ 4.44	$ 4.44
Push button toggle switch J-188-1	$ 2.52	$ 2.52
1/4-20 Eyebolt 1" shank	$ 3.63	$ 3.63
18-8 Stainless Steel Washer	$ 0.06	$ 0.06
1/4-20 Locknut	$ 0.06	$ 0.06
0.161_dia_rivets	$ 0.25	$ 1.01
1/4-20 Nut	$ 0.07	$ 0.07
Shock Cord	$ 41.25	$ 41.25
main	$ 25.73	$ 25.73
Quick links	$ 1.58	$ 4.74
H283ST Motor	$ 54.99	$ 54.99
ABS/PETG Filament	$ 23.99	$ 23.99
1010 Rail Buttons	$ 2.23	$ 4.46
Nomex Blanket (1ft x 1ft)	$ 9.66	$ 9.66
Total Cost/Rocket		$ 303.37

As this rocketry kit helped team member Seth Bunt to achieve his L1 rocketry certification, it would be appropriate to compare the cost of this rocket to other commercially available L1 kits. Apogee Rockets provides a list of L1 kits on their website, and Table 5.2 below compares their basic dimensions and costs of the "JSS" workshop rocket with and without missing parts including Eggtimer Quantum altimeter and H283 motor. Only rockets capable of flying a 38 millimeter motor, the diameter of the H283, are compared. None of the kits carry an altimeter and nearly half do not have any motor retention system included. The comparison shows that the workshop rocket is similar to several kits available off the shelf when it comes budget.

Table 5.2: Cost Comparison to Kit Rockets

Kit Name	Height (in)	Diameter (in)	Base Cost	Cost w/ H283 Motor	Cost w/ Missing Parts	Manufacturer	Not included
Torrent	54	4	$ 226.95	$ 281.94	$ 321.94	Madcow Rocketry	No altimeter
Enceladus	57.3	2.6	$ 164.80	$ 219.79	$ 316.77	Mach 1	No parachutes, shock cord, motor retention, altimeter
Super DX3	63	4	$ 185.66	$ 240.65	$ 310.65	Madcow Rocketry	No motor retention, altimeter
JSS (Workshop)	47.5	3.1	$ 248.38	$ 303.37	$ 303.37	UAH	
Journey 75	48	3	$ 148.50	$ 203.49	$ 273.49	Wildman Rocketry	No motor retention, altimeter
Peregrine	68.8	4	$ 177.39	$ 232.38	$ 272.38	Apogee	No altimeter
Hi-Tech	49.75	2.63	$ 92.51	$ 147.50	$ 231.62	LOC Precision Rocketry	No motor retention system, rail buttons, Nomex, altimeter
LOC IV	47.75	4	$ 109.69	$ 164.68	$ 204.68	LOC Precision Rocketry	No altimeter
Zephyr	56.4	4	$ 104.94	$ 159.93	$ 199.93	Apogee	No altimeter

6 ROCKET SYSTEMS TESTING

To validate the design and prepare the rocket for a flight, subsystem tests were conducted. For this workshop rocket, two primary subsystems were conducted: Avionics Testing and Deployment Testing. The main goals of each test and the methods used to carry out the testing are discussed in the following sections.

6.1 AVIONICS TESTING

To ensure the functionality of the avionics before installation into the avionics bay, the sled and the forward part of the avionics coupler must be constructed first. This build uses 4-40 threaded inserts and 4-40 3/8-inch socket head cap screws to secure the Eggtimer Quantum to the sled. A wire harness, shown earlier in Figure 14, is constructed from a female JST discharge plug, about 12 inches of spare wire, and a button toggle switch. Then, drogue charge wires and battery power wires are connected to their proper Eggtimer Quantum terminal blocks, shown in Figure 15. The drogue charge wires are pulled through the forward bulkhead and screwed into a white terminal block resting on the outside of the bulkhead.

Connecting the two red discharge plugs and pressing the button toggle switch turns on the altimeter and allows the user to connect to its Wi-Fi network. In the browser, going to the web interface for the Eggtimer at 192.168.4.1 begins the avionics testing process. The initial state seen by the user should match that shown in Figure 19. Users can edit states with the “Change” and “Settings” buttons in the web interface. After the initial state meets criteria, the user will connect the open ends of the white terminal block using a resistor creating continuity across the Eggtimer’s drogue terminal. After a refresh of the web interface, the states should match that shown in Figure 21. After avionics testing states are matched, the user removes the resistor, closes the browser window, disconnects from the Wi-Fi connection, and turns off the altimeter.

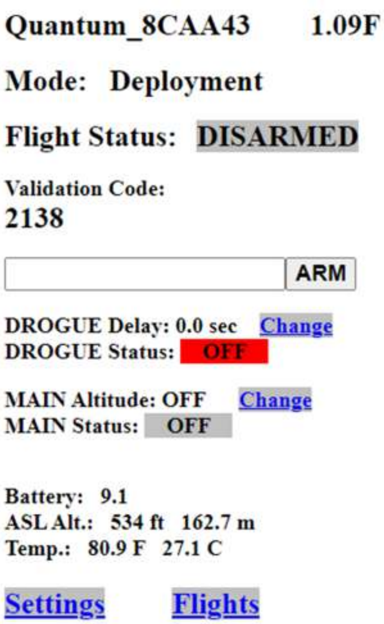


Figure 19: Initial State

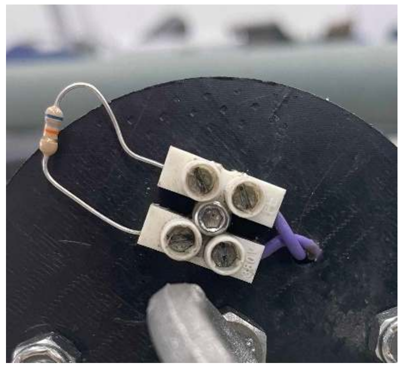


Figure 20: Bridged Terminals

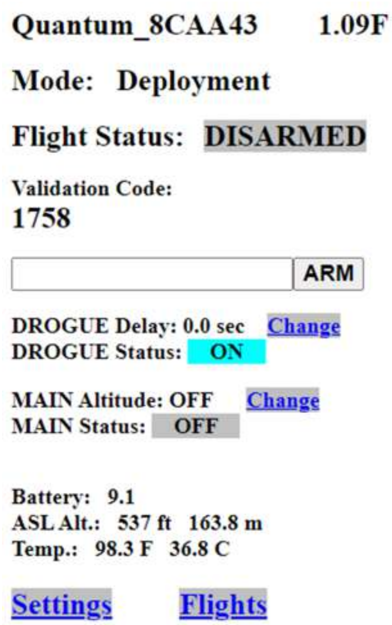


Figure 21: Final State

6.2 Deployment Testing

Black powder testing has the goal of finding the ideal amount of black powder necessary to deploy the recovery system from the rocket. For this workshop rocket, the parachute deploys from a single separation point at the nosecone. This design does allow for the possibility of using a dual deployment system, achievable with a second recovery train connecting the aft airframe to the avionics bay. In this case, black powder tests would need to be conducted to determine the amount needed to separate the lower airframe in addition to the nosecone. In a typical black powder test, increasing the charge size until a separation is seen is typical. However, the first test used 3 grams of black powder. This was an overestimate. Instead, decrementing amounts of black powder were used to find an ideal amount. Through testing it was found that about 2 grams of black powder was sufficient to separate the nosecone and upper airframe and deploy the parachute from the rocket.

7 Flight Test Results and Discussion

Following construction and successful black powder testing, the rocket flew in Olmstead, Kentucky at 2:45 PM with an Aerotech H283 motor . Flying as the “Baja Blaster”, this launch was anticipated to fly to about 1240 feet above ground level (AGL). Due to high steady winds of 14 mph and gusts of up to 25 mph on launch day, the true apogee reached was only 1004 feet AGL. With a drogue deployment 1 second after apogee, the time to ground was about 57 seconds and drift distance from the launch rail was limited to about 750 feet. Figure 22 shows the true flight profile compared to the pre-flight simulation run in OpenRocket.

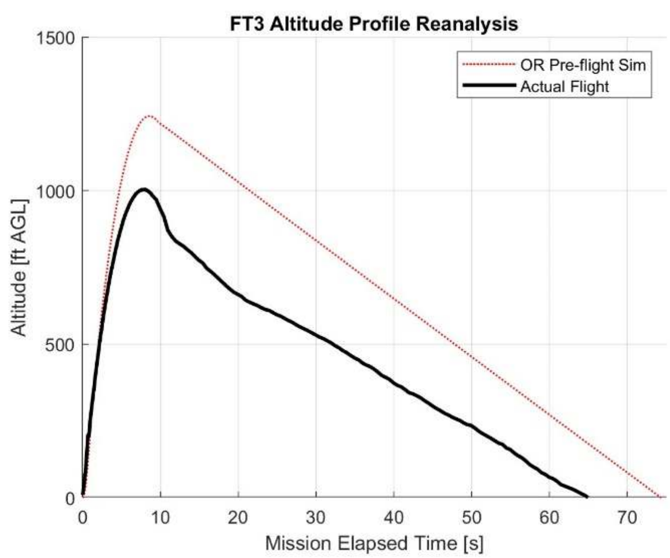


Figure 22: Predicted Versus Measured Flight Trajectory

Post flight, damage was found on the parachute. The parachute had a large tear across it, likely due to the separation charge being delayed by 1.0 seconds after apogee. This delay meant the vehicle began to nose over after apogee. The separation charge then detonated allowing the parachute to deploy upwards. During its deployment sequence, it is suspected that the parachute passed by the sharp fiberglass fins creating the tear. This theory also explains damage that was found on one of the fin brackets which appeared to have torn the front Chicago screw out of the top of the bracket. The fin bracket design had its bracket channel subsequently increased in height to avoid further damage.

Figure 23: Landing Configuration of Recovery Harness

Figure 24: Broken Fin Bracket

The results of this flight were successful and demonstrate this workshop rocket's potential as a senior design workshop rocket replacement. The unique boat tail design performed well and demonstrated its ability to retain the motor effectively in addition to the simple recovery system demonstrating its ability to bring the vehicle to ground in a safe manner. This vehicle's design also showed a major benefit for slight wear and tear situations as well. In a modular design, a single broken fin bracket can be replaced easily. In a design using epoxy, if a fin breaks, debonding it from the body would be incredibly time consuming and frustrating to handle. The discrepancy in apogee between predicted and measured is not of any concern for future teams. For the purposes of the workshop and a safe recovery, the rocket only needs to reach roughly 600 ft. Most 38 mm motors will propel the rocket to heights exceeding 1000 ft, and even a lower than expected apogee due to wind will have enough time for a parachute to open, resulting in a safe recovery.

Post flight analysis was conducted on the flight data to determine a drag coefficient for the rocket. During the coast phase between motor burnout and apogee, there are no forces acting on the rocket other than drag and gravity. Using altimeter data, the drag force was calculated and from it, a drag coefficient value of 0.652 was found. Drag coefficients of high powered rockets tend to be approximately 0.6. Therefore, while it is on the higher end, a coefficient of 0.652 is not unreasonable and is close to the predicted OpenRocket value used pre-flight of 0.61. After updating the drag coefficient in OpenRocket, a selection of 38 mm motors of varying total impulses were compared. While most H-class motors are acceptable to be used for a launch, those with longer burn times such as the H112 do not accelerate the rocket fast enough to be traveling at an acceptable velocity at rail exit. For H-class motors with low total impulses, a small burn time is required to accelerate the rocket to an acceptable speed before exiting the rail. This test flight shows that the design is safe and capable of flying with a variety of H and I class motors. However, students must still pay attention to motor specifications when making their choice.

Table 7.1: Rocket Motor Comparison

Motor	Apogee (ft)	Rail Exit Velocity (ft/s)	Max Velocity (ft/s)
H112	1634	30.2	316
H550	2239	83.4	518
I357	2559	61.5	527
I345	2841	60.6	598
I300	3096	68.1	615

8 CONCLUSIONS

In previous years, COTS workshop rockets were beneficial for students enrolled in the rocket design section of UAH's senior design courses. They served as a good introduction to rocket assembly for those that were unfamiliar with the field. However, construction of a basic workshop rocket varies greatly when compared to the typical USLI rocket constructed later in the year. By using design choices found in larger rockets, the workshop build described here will have the added benefit of teaching the class techniques that will be applicable to the USLI rocket.

Only minor changes were made to the design of the rocket post flight, all having to do with the 3D printed parts found within the rocket. The loop within the nose cone that connects to the recovery harness was moved further aftward, the fin bracket channel was heightened to increase strength, and the connections between the lower airframe and the centering ring and boat tail were changed to be self-tapping plastic screws to simplify the alignment process. A fin jig was also designed to aid in the installment of the fin brackets. None of these changes affect how the rocket flies; they were done to minimize the chances for parts to break or to save time in manufacturing. Next year's team will now have the advantage of learning many lessons that are typically learned in the subscale phase of the competition.

9 APPENDIX A: WORKSHOP ROCKET MANUAL

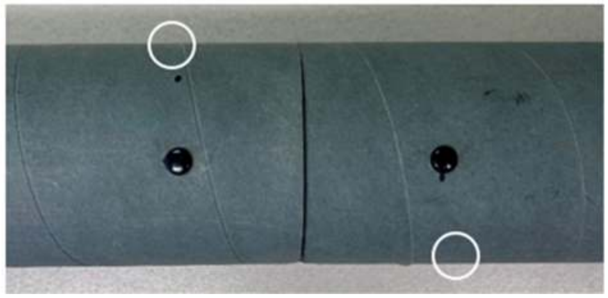
JSS Rocket Works

Construction Guide

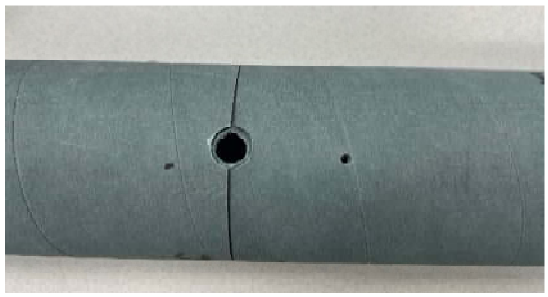
1. Preliminary Requirements
2. Required Tools
    - Phillips head screwdriver x2
    - Pliers x2
    - Diagonal cutters
    - Battery Powered Drill
    - #18 Drill Bit
    - #30 Drill Bit
    - Allen Wrench Set
    - Wet Saw
    - Soldering Iron
    - Miter Hand Saw
    - Sharpie
    - Safety Glasses
    - 3D Printed fin jigs
    - Masking or painters tape
    - Tape measure
    - Calipers
    - Ruler
3. Structural
    a. Materials
        i. 48” Length 3” Blue Tube
        ii. 8” Length Blue Tube Coupler
        iii. Nosecone
        iv. Fin Brackets x3
        v. Centering Ring
        vi. Boattail
        vii. 1’ by 1’ Fiberglass sheet
        viii. 1010 Rail Button x2
        ix. Plastic Rivets x4
        x. 5/8” #8 Phillips Flat Head Self Tapping Screws for Plastic x12
        xi. Chicago Screws x6
        xii. 2 kilograms of PET-G or ABS filament
    b. Preparation Steps
        i. Print a nose cone from PET-G or ABS
        ii. Print a boat tail from PET-G or ABS
        iii. Print a centering ring from PET-G or ABS
        iv. Print 3 external fin brackets from PET-G or ABS
    c. Airframe Construction
        i. Cut an 18” section of blue tube airframe using the miter hand saw to create the upper airframe.

ii. Cut a 19.5” section of blue tube airframe using the miter hand saw to create the aft airframe.
iii. Cut the coupler to 6” using the miter hand saw.
iv. Mark a point in the center of the coupler. Choose an end to label “Forward” and an end to label “Aft”.
v. Insert the coupler to the marked point in the upper airframe.
vi. Hold the coupler in its place relative to the upper airframe.
vii. Place the aft airframe onto the coupler and verify that the aft and upper airframes are flush. If they are not, then sand the location where they are touching and recheck.
viii. Remove the upper airframe.
ix. Tape the coupler to the aft airframe ensuring the mark on the coupler is at the end of the airframe (i.e. the coupler is inserted 3” into the aft airframe).
x. With a #18 drill bit, drill two holes 180° apart roughly 1.5” from the end of the airframe. Each hole must be drilled through the coupler and airframe as shown in the following image.

xi. Insert a plastic rivet through each hole to secure the coupler to the airframe. Remove any tape used previously.
xii. Place the upper airframe onto the coupler and re-check that the aft and upper airframes are flush.
xiii. Hold the airframes together with force and drill two more holes with a #18 drill bit through the coupler and upper airframe 1.5” away from the seam. These holes should be in-line with the aft airframe’s rivets.
xiv. Insert two plastic rivets through the new holes to secure the coupler to the upper airframe.
xv. Verify that the airframes are still flush with each other.
xvi. Drill two static pressure ports with a #30 drill bit, one through each airframe 90° away from the rivets. Drill these holes in the locations shown in the image below.



xvii. Using a 3/8” drill bit, drill a hole aligned with one of the pressure holes along the seam between the airframes (it is a good idea to drill a pilot hole with a #30 bit). After cleanup, this hole will look similar to the image below.



xviii. Remove the rivets with diagonal pliers. Remove the coupler from the assembly and clean up all drilled holes.

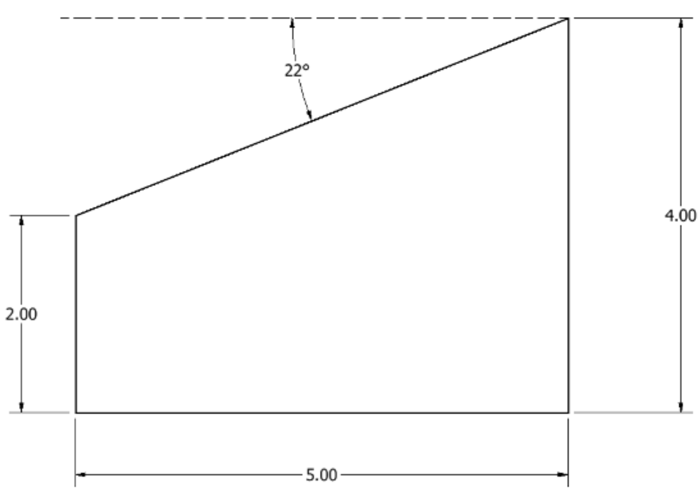
xix. Ensure your coupler looks similar to the image below.

d. Centering ring, fin brackets, and boat tail installation
   i. Attach the fin jigs to the aft end of the aft airframe.
   ii. Insert the fin brackets and align them with the fin jigs using a section of fiberglass sheet.
   iii. With the new assembly fixed in place, drill holes with a #18 drill bit in the aft airframe using the fin brackets as a guide.
   iv. Do the same for the remaining fin brackets.
   v. Remove the fin jigs and brackets. The drilled holes should look similar to the following image.

vi. Insert the centering ring until it is visible in the forward-most holes that were just drilled. The bottom face of the centering ring should be about 3 ½" from the end of the airframe; use calipers or tape measure to verify.
vii. Fully insert the boat tail into the aft airframe and align one of the fin brackets with the previously drilled holes. Use tape to hold the fin bracket to the airframe.
viii. While ensuring the boat tail remains flush with the edge of the airframe, drill the self tapping plastic screws through the lower fin bracket holes and into the plastic boat tail.
ix. Drill the self tapping plastic screws through the upper fin bracket holes and into the centering ring.
x. Repeat steps viii and ix for the remaining two fin brackets.

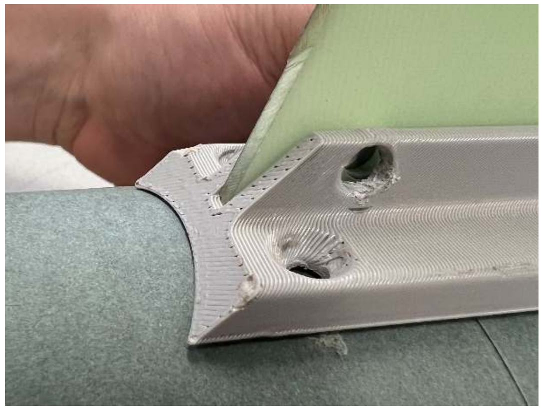
e. Fins

i. Using a sharpie and ruler, mark the outline of three fins on a sheet of fiberglass.



ii. Cut three fins from the fiberglass using a wet saw for best results. Take into account the width of the blade when cutting fins!
iii. Insert one of the fins into a fin bracket already installed on the aft airframe. Hold the aft airframe in a vice.

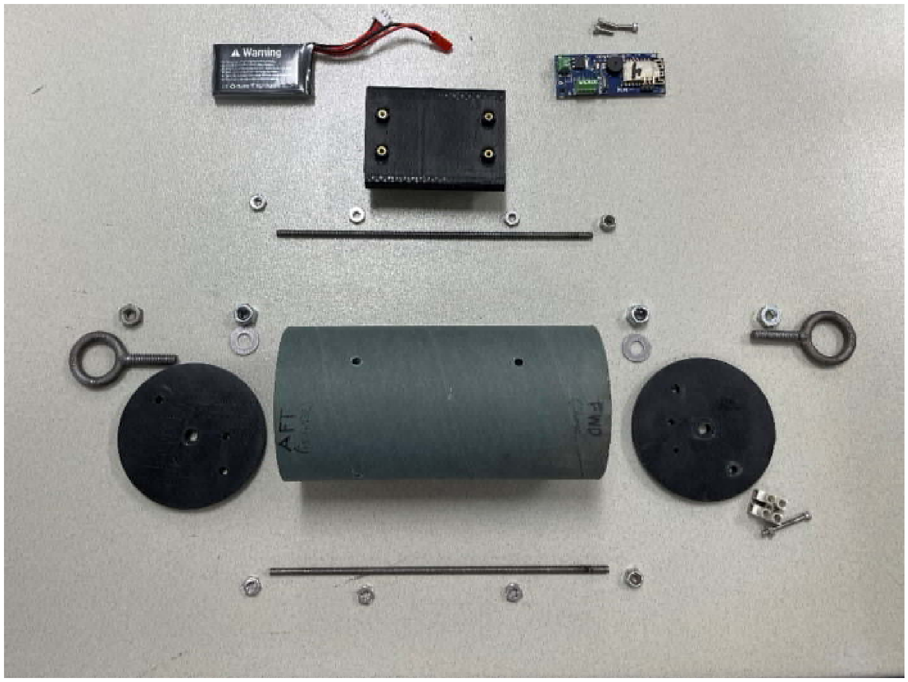
iv. While holding the fin in place with its leading edge in line with the end of the bracket channel, use the bracket as a guide to drill holes into the fin with a #10 drill bit.



Leading edge in line with end of bracket channel

v. Remove the fin from the bracket and redrill the holes with a #6 drill bit. This method prevents the drill from damaging the plastic fin bracket.
vi. Repeat steps d.iii – d.v for the remaining fins.
vii. Install the fins into their brackets with Chicago screws and tighten using two Phillips screwdrivers.

4. Avionics Bay
    a. Blown Up View

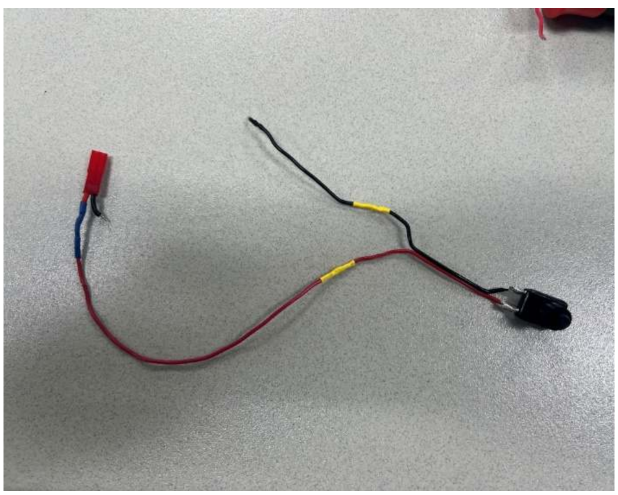


    b. Necessary Parts
        i. Coupler tube
        ii. Bulkheads x2
        iii. Eggtimer Quantum
        iv. Avionics sled
        v. 4-40 Threaded Inserts x4
        vi. 4-40 3/8-inch Socket head cap screws x4
        vii. 4-40 1-inch Socket head cap screw x1
        viii. 4-40 Nut x1
        ix. 8-32 Nuts x6
        x. 8-32 Lock nuts x2
        xi. 1/4-inch Eyebolts x2
        xii. 1/4-inch ID Washers x2
        xiii. 1/4-inch Nuts x2
        xiv. 1/4-inch Lock nuts x2
        xv. #8, 7-inch All-thread rods x2
        xvi. 2S Lipo battery
        xvii. Female JST discharge plug
        xviii. Button toggle switch
        xix. White terminal block
        xx. About 40 inches of spare wire
        xxi. Heat-shrink tubing
        xxii. Soldering iron and solder

xxiii. Resistor

c. Preparation Steps
   i. Construct the Eggtimer Quantum.
   ii. Print 2 bulkheads and an avionics sled.
   iii. Use soldering iron to set four 4-40 threaded inserts into the avionics sled.

d. Wiring Steps
   i. Before splicing (connecting) wires, slide as many pieces of heat shrink tubing as will be necessary to cover your exposed splices onto the wires. In the photo below, there are 3 pieces of heat shrink tubing.
   ii. Splice together the RED wire on the female JST discharge plug and a piece of spare wire with length of about 6 inches. Then connect the other end of this spare wire to one side of the button toggle switch.
   iii. Splice together the unconnected side of the button toggle switch and another 6 inch length of spare wire.
   iv. Cover any exposed wire splices with heat shrink tubing.
   v. Cut two spare wires to a length of about 10 inches. Tin both ends of these wires (four tinnings) and twist them together to create a twisted pair wire.



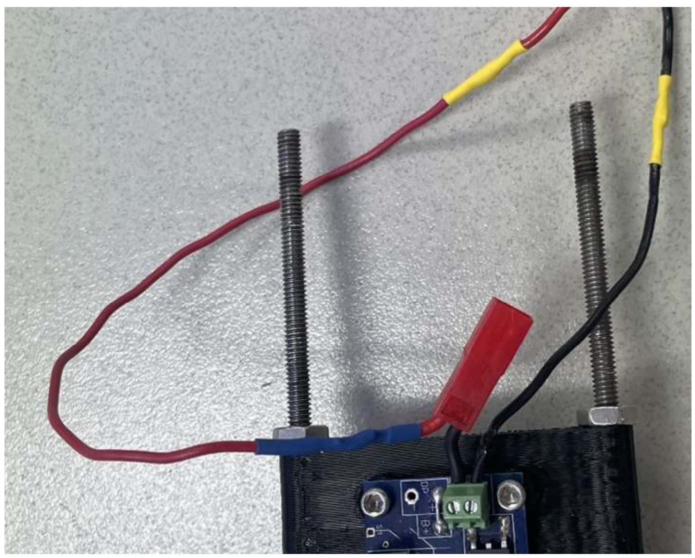
Steps d.i – d.iv

Twisted pair of wire

e. Avionics Sled Build
   i. Secure the Eggtimer Quantum to the sled with four 4-40 3/8-inch socket head cap screws. Ensure the power terminal block on the Eggtimer is nearest to the battery holder opening on the back of the sled.
   ii. Connect one end of the twisted pair wires to the drogue (labelled DROG) terminals on the Eggtimer Quantum.

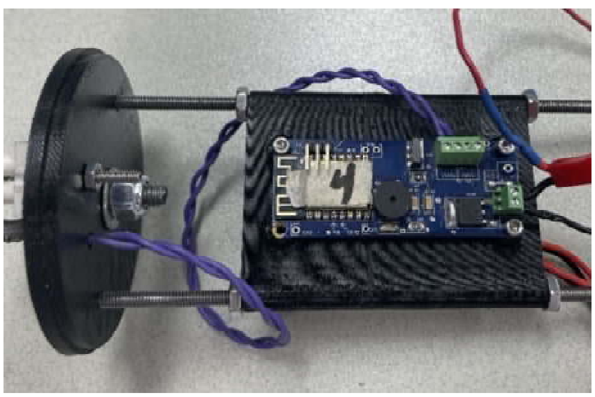
NOTE

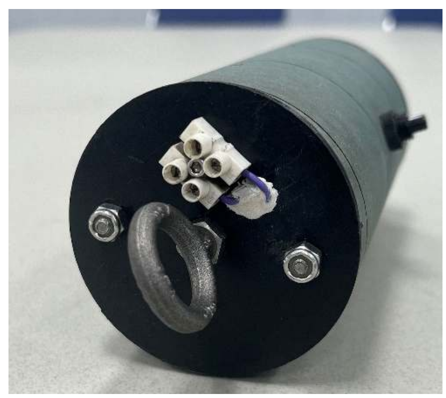
The polarity of the female JST discharge plug matters when plugged into the Eggtimer Quantum! Make sure you're plugging the BLACK end into the ground (-) terminal and the open lead from the button toggle switch into the power (+) terminal (see image below).



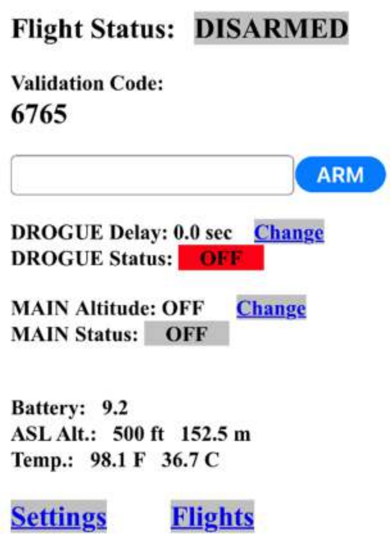
   iii. Connect the BLACK side of the female JST discharge plug to the ground (-) side of the power terminal block. Ensure this wire is connected to the terminal side closest to the center (see above note)
   iv. Connect the open lead of the button toggle switch to the power (+) side of the power terminal block.
   v. Put the 2S Lipo battery into the case on the avionics sled on the opposite side from the Quantum. Do not plug it in yet!

f. Avionics Bay Build Part 1
    i. On both bulkheads, secure eyebolts through the center hole of the bulkhead with a jam nut (1/4-inch nut) on the eye side and a locknut and washer on the other.
    ii. Put two #8 7-inch All-thread rods through the sled.
    iii. Use four 8-32 nuts (two on each rod) to secure the sled near the center of the all-thread rods.
    iv. Designate one side of the sled as the forward side. In the example build, the side opposite from the battery opening is chosen as the forward side. Slide a bulkhead onto the All-thread on this side leaving a small amount of All-thread end exposed.
    v. Secure the forward bulkhead to the All-thread using two 8-32 locknuts.
    vi. Send the twisted pair wire through the larger of the remaining two holes on the bulkhead towards the outside of the bulkhead.
    vii. Secure the white terminal block to the outside of the bulkhead with a 1-inch 4-40 Socket Head Cap screw and a 4-40 nut.
    viii. Connect the twisted pair wire to the white terminal block.
    ix. Fill the twisted pair hole with clay or a similarly malleable material.

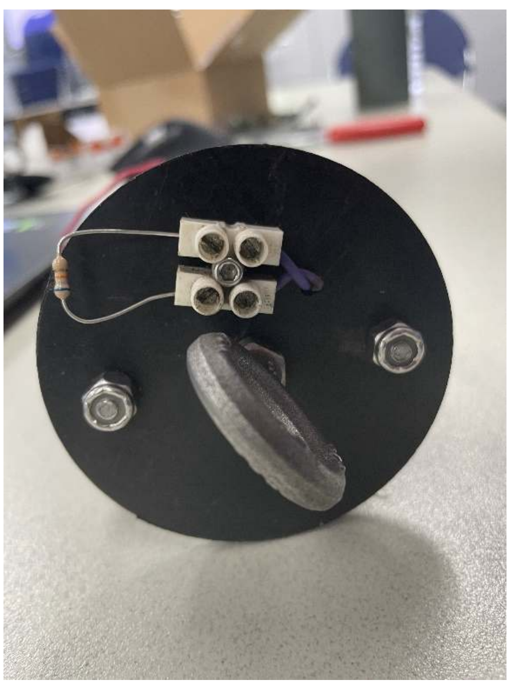


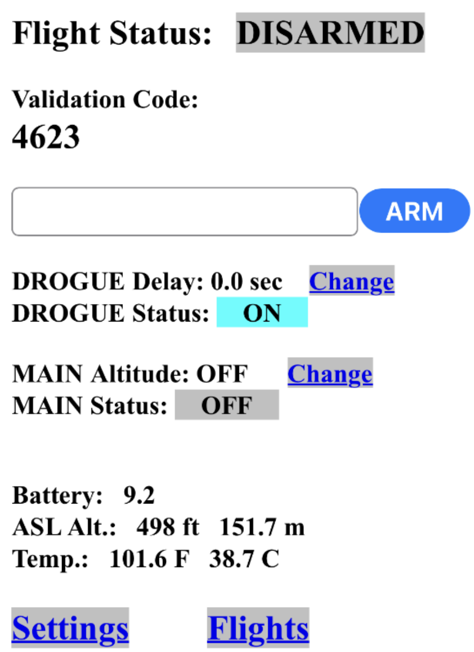


g. Test Avionics
    i. Connect the red JST plugs and press the button toggle switch to activate the altimeter.
    ii. On your phone or computer, connect to your Quantum's WiFi using the password written on the supplied packaging.
    iii. On your device's browser, go to 192.168.4.1.
    iv. Set the DROGUE Delay to 0.0 seconds and MAIN Altitude to OFF. Verify that the DROGUE Status shows **OFF** in red and that the MAIN Status shows **OFF** in gray.



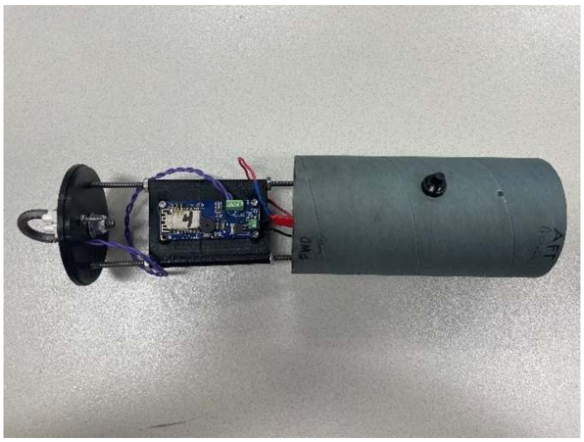
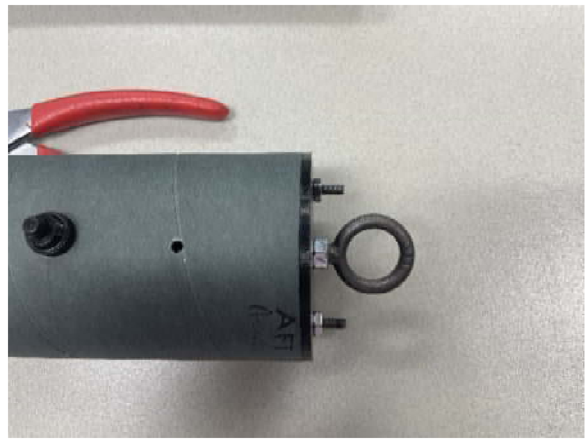
v. Use a resistor on the white terminal block to create continuity across the drogue terminal of the Quantum. Refresh the webpage and verify that the DROGUE Status shows **ON** in cyan.





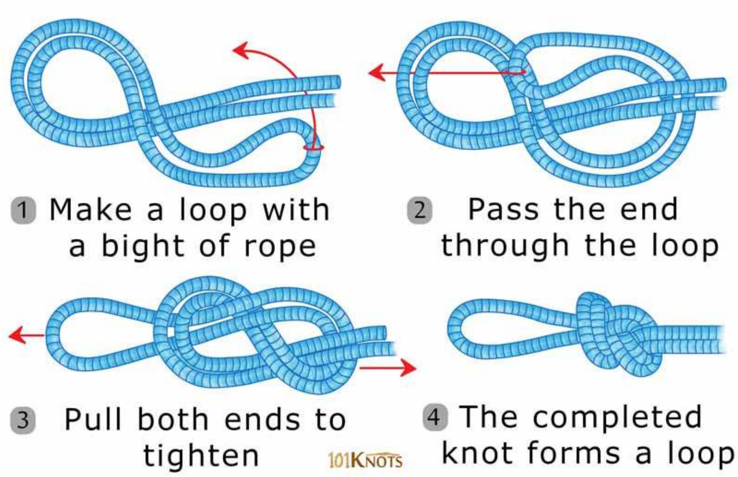
vi. If the check in step g.v passed, turn off the altimeter as follows:
vii. Close the browser window.
viii. Disconnect from the WiFi connection.
ix. Disconnect the resistor.
x. Press the button toggle switch.
xi. Disconnect the battery.

h. Avionics Bay Build Part 2
   i. Insert the button toggle switch into the large hole previously drilled in the avionics coupler. (This step will make you realize why your power wire harness should be long!)
   ii. Secure the button toggle switch with its supplied nut fastener.
   iii. Slide the avionics coupler over the sled ensuring that the previously marked “Forward” direction is against the previously assembled bulkhead.
   iv. Secure the second bulkhead to the aft side of the coupler with 8-32 nuts on the exposed All-thread.

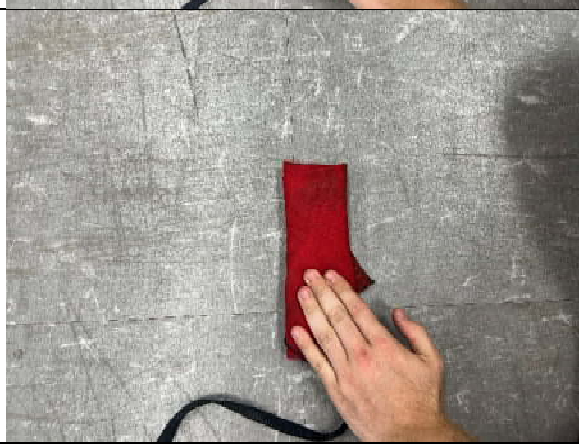



Steps h.i – h.iv

5. Recovery System
    a. Materials
        i. ~20 ft of ½" tubular nylon
        ii. Three quick links
        iii. 48" diameter parachute
        iv. 12" x 12" Nomex blanket
    b. Assembly
        i. Tie a "figure 8 on a bight" knot on both ends of the tubular nylon as shown in the diagram below:



        ii. About 12" away from one end of the nylon shock cord, tie another figure 8 on a bight, this is where the parachute will attach.
        iii. Attach a quick link to each of the knots.
        iv. Attach the Nomex blanket to the parachute attachment quick link.
        v. Fold the parachute as shown in this video (or as instructed): https://www.youtube.com/watch?v=N5l_SST5t8M
        vi. Place the folded parachute in the center of the Nomex blanket and fold it "burrito" style by folding each side of the Nomex blanket towards the center starting at the side with the quick link and going clockwise.

	
	Nomex Burrito Folding Steps

vii. Make sure the folded Nomex bundle is tight and fits into the airframe with little effort.
viii. Attach the free end of the shock cord closest to the parachute to the nose cone loop.
ix. Attach the other end of the shock cord to the eye bolt on the forward side avionics bay.
x. Bundle the shock cord as shown in the following image:

xi. The recovery harness should look like the image below.

xii. Verify the parachute shroud lines and parachute nylon are not visible outside the Nomex.
xiii. Carefully insert bundled shock cords into the forward end of the upper airframe.
xiv. While making sure the Nomex remains closed, insert it into the forward end of the upper airframe. As shown:

xv. Insert the nosecone into the upper airframe.
xvi. Verify the rocket can be held from the nosecone without separating. If this cannot be done, add tape around the nosecone shoulder to make the fit more snug.

6. Launch Day Procedures
    a. Avionics Bay
        i. Remove the aft bulkhead from the avionics bay.
        ii. Use a multimeter to verify 2S Lipo battery charge is above or equal to 7.0 V.
        iii. Connect the red JST plugs.
        iv. Reinstall the aft bulkhead.
        v. Press the button toggle switch to verify the altimeter turns on.
        vi. Press the button toggle switch again to turn the altimeter off.
    b. Energetics
        i. Get a mentor to pack a 2.0 gram black powder charge and connect it to the white terminal block on the forward bulkhead.
        ii. Get a mentor to load the motor into the aft airframe and install the retaining snap ring.
    c. On Pad
        i. Slide the vehicle onto the launch rail.
        ii. Press the button toggle switch to turn the altimeter on.
        iii. Verify in the Eggtimer webpage (192.168.4.1) that the DROGUE Status shows **ON** in cyan.
        iv. In the Eggtimer webpage, arm the altimeter by typing the validation code and pressing "**ARM**".
        v. Get a mentor to load the igniter into the motor.
        vi. Walk away from the launch pad.
        vii. Launch the rocket!