Gator Locator

NASA Student Launch 2022 Critical Design Review

University of Florida
Swamp Launch Rocket Team

MAE-A 324
January 3, 2022

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1. Report Summary

1.1 Team Summary

Swamp Launch Rocket Team
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1.1.1 Team Mentor

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1.1.2 Launch Dates

The team anticipates performing the final flight of the competition in Huntsville, AL at the official competition launch site. The primary launch day associated with the field is April 23, 2022, with a backup launch day of April 24, 2022. As a backup location, the team will utilize the Tripoli Tampa Rocketry Association launch site in Plant City, FL. Launches at this site will be available March 19, 2022 and April 16, 2022.

1.1.3 Hours

The total number of hours spent on the design, testing, planning, meeting, and writing of the Critical Design Review was 502 hours.

1.2 Launch Vehicle Summary

The target altitude of the launch vehicle is 4578 ft. The motor selected is the Aerotech L1090W. The nosecone section has a length of 20 in and a mass of 27 oz, the forward section has a length of 38 in and a mass of 112 oz, and the aft section has a length of 57 in and a mass of 275 oz. The total exterior length is 115 in and the total mass is 414 oz. The launch vehicle uses a dual deploy system. The selected drogue parachute is a 24 in Rocketman Parachute with a coefficient of drag of 0.97. The selected main parachute is a 72 in Fruity Chutes Iris Ultra parachute with a coefficient of drag of 2.2. The selected altimeters are a Perfectflite StratologgerCF and an Entacore AIM USB. The selected recovery harness is 25 ft long 7/16 in wide tubular Kevlar. Each separation point will have a recovery harness. A 12 ft 1515 launch rail will be used. There will be two rail buttons: one located near the center of gravity and one located near the aft end of the launch vehicle.

1.3 Payload Summary

Payload Title: Land-Mark Watney

The payload uses a hybrid inertial and image-based location tracking system. Two downward-facing cameras capture images of the terrain during ascent, which are then compared to pre-uploaded satellite images of the field using the SIFT algorithm to determine the vehicle's mid-flight location relative to known landmarks. An inertial measurement unit (IMU) continuously records acceleration and orientation data throughout the flight, which is used to calculate the displacement between the vehicle's last determined mid-flight position and final landing location.

2. Changes Made Since PDR

2.1 Changes Made to Vehicle Criteria

The lower aft airframe was lengthened by 1 in. to provide additional space for the payload bay. This change was necessary in order to properly contain the payload bay within the aft section. In addition, the aft payload bulkhead was removed to allow the electronics tubes to travel directly to the coupler with ease. Furthermore, the inner diameter of the electronics tubes was increased from 0.25 in. to 0.375 in. to allow more space for the wires. As a result, the wires could be more easily replaced if one was damaged. Finally, a slot in the lower aft airframe was added and the 0.25 in. hole for the electronics tubes was removed. This allows the cameras to be submerged partially within the airframe in order to decrease the height of the camera mounts to prevent the camera from having significant effects on the aerodynamic performance. One change was made to the Recovery System between PDR and CDR. The drogue parachute was changed from a Skyangle C3 Drogue to a 24 in. Rocketman parachute. This change was made to meet the 2500 ft drift radius requirement.

2.2 Changes Made to Payload Criteria

The 9-axis MTI-3-0I IMU with was replaced with a 6-axis ADIS16470 IMU to comply with the FAQ clarification on the prohibition of magnetometers.

The mechanical structure of the payload sled and the camera mounts were changed after testing during the subscale launch. The payload sled no longer has the rail system or the latch system. Instead, the payload sled now utilizes a retention system directly attached to the sled, using two screws and hex nuts through the forward bulkhead. This proved successful during the subscale launch and removes the need to epoxy the rail system into the payload coupler. Also, the camera is now able to slide into a slot that is cut into the airframe of the launch vehicle. This enables the camera mount to be an overall shorter height and allows for a more modular design. This decision was made to make the assembly process easier, as well as decreasing the protrusion of the mounts to minimize the aerodynamic effects on the launch vehicle.

2.3 Changes Made to Project Plan

The milestone schedule and individual subteam schedules were updated to reflect changes made during the subscale manufacturing period. The time allotted for manufacturing and testing of the subscale launch vehicle was updated to be the duration from 11/23/2021 to 12/3/2021. The primary launch date for the subscale was also changed to 12/4/2021.

Additionally, the team is welcoming a new lead for the structures subteam to the leadership team: Erik Dearmin.

3. Vehicle Criteria

3.1 Design and Verification of Launch Vehicle

3.1.1 Mission Statement and Success Criteria

The mission is to perform a successful flight that meets the team defined criteria and successfully completes the payload mission. The mission success criteria of the flight include a flight path that reached the target apogee of 4578 ft and a recoverable launch vehicle that successfully carries the payload. The launch vehicle must be able to be relaunched and must not sustain irreparable damage in order to be considered recoverable. In order to successfully carry the payload, the launch vehicle must not interfere with the payload performance.

3.1.2 Final Vehicle Design

The final launch vehicle is composed of three sections: a nosecone section, a forward section, and an aft section. There is one avionics bay, located in the forward section. There is also a payload bay, located in the aft section. The leading design was modeled in SolidWorks with each section labeled (Figure 1).

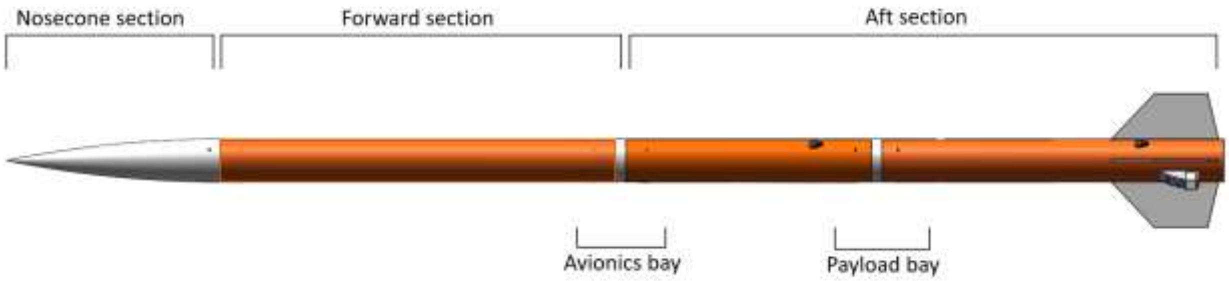
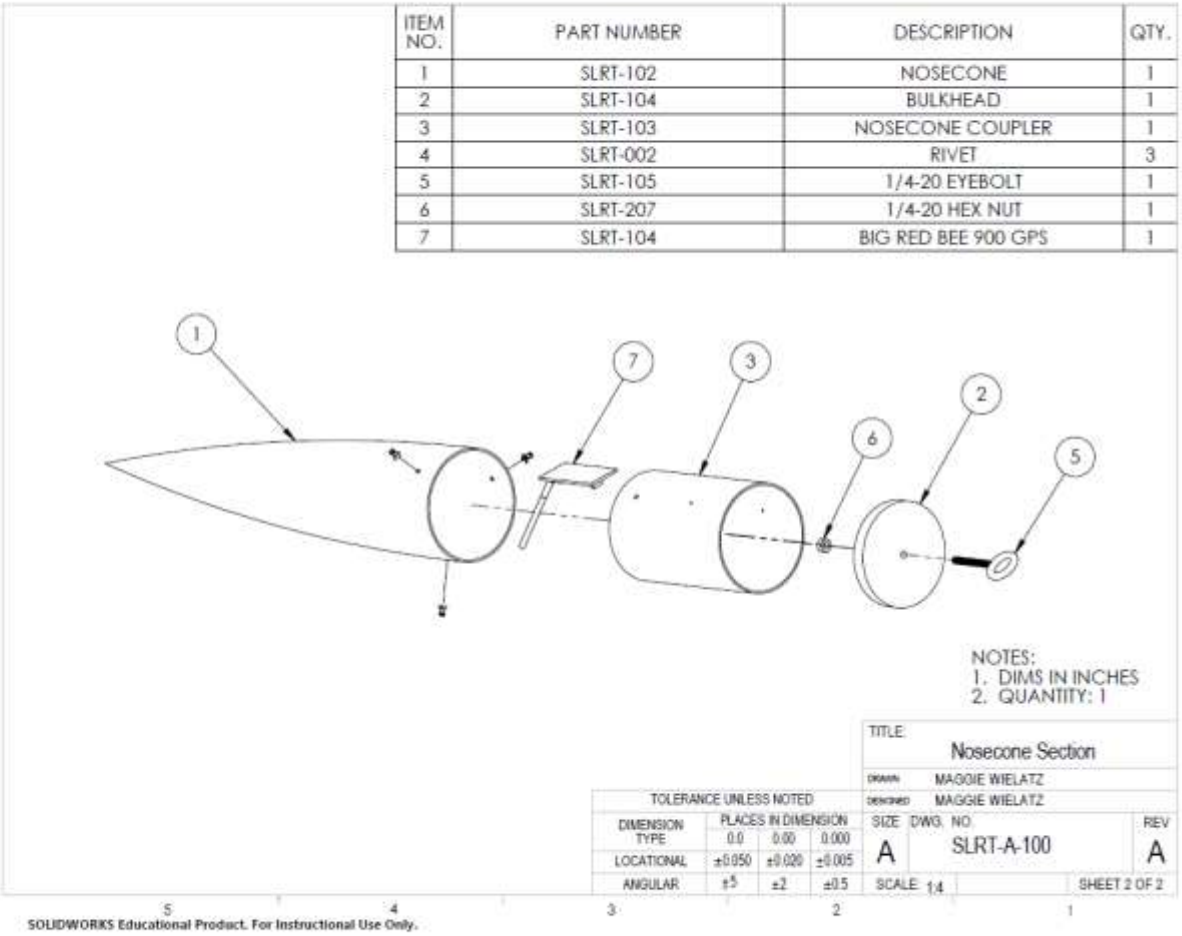


Figure 1: Full Scale SolidWorks Model

The alternative design consisted of two payload bays, one located in the nosecone coupler and one located in the aft section. It also consisted of cameras mounted on both the forward and aft sections. Since it was determined that the cameras located on the forward section would not be able to collect useful data, this design was not selected. As a result, the cameras on the forward section and the payload bay located in the nosecone coupler were not required.

3.1.2.1 Nosecone Section

The nosecone section consists of a 5:1 ogive nosecone, nosecone shoulder, and a bulkhead (Figure 2). The nosecone is 4 in. in diameter and is made of G12 fiberglass with a metal tip. The nosecone shoulder attaches to the nosecone body with three plastic rivets. The G12 fiberglass nosecone shoulder connects to the forward section with three 2-56 nylon shear pins. Within the nosecone shoulder, a type II PVC bulkhead is epoxied in place. A ¼-20 eyebolt is secured to the bulkhead with a nut and attaches to the recovery harness to keep the nosecone section connected to the forward section. A Big Red Bee 900 GPS is located in the nosecone section and is secured to the nosecone shoulder with the use of Velcro tape. Aluminum foil is also epoxied to the inside of the bulkhead to shield the rest of the launch vehicle from the GPS transmitter.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SLRT-102	NOSECONE	1
2	SLRT-104	BULKHEAD	1
3	SLRT-103	NOSECONE COUPLER	1
4	SLRT-002	RIVET	3
5	SLRT-105	1/4-20 EYEBOLT	1
6	SLRT-207	1/4-20 HEX NUT	1
7	SLRT-104	BIG RED BEE 900 GPS	1

NOTES:
1. DIMS IN INCHES
2. QUANTITY: 1

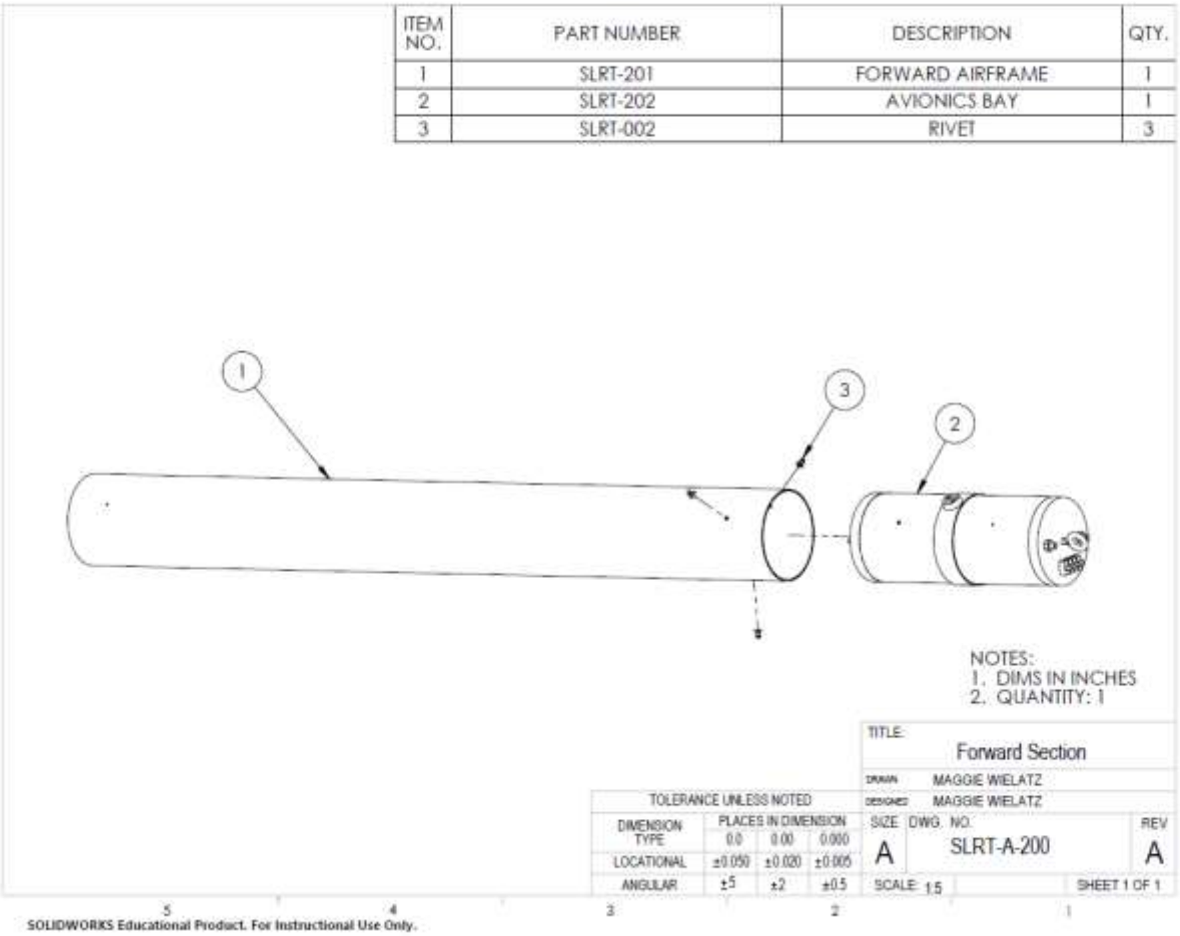
TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION 0.0	0.00	0.000
LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

TITLE: Nosecone Section
DRAWN: MAGGIE WIELATZ
DESIGNED: MAGGIE WIELATZ
SIZE: A
DWG. NO. SLRT-A-100
REV: A
SCALE: 1:4
SHEET 2 OF 2

Figure 2: Nosecone Section Assembly

3.1.2.2 Forward Section

The forward section consists of the forward airframe and the avionics bay (Figure 3). The airframe and couplers are made of G12 fiberglass. The forward airframe connects to the avionics bay with three rivets. The forward section is connected to the aft section with three 2-56 nylon shear pins that attach the avionics coupler to the upper aft airframe. The avionics bay consists of an avionics coupler, a switchband, two type II PVC bulkheads, and an avionics sled. A ¼-20 steel eyebolt connects to each bulkhead with a ¼-20 steel nut. The eyebolts attach to the recovery harnesses to keep the forward section connected to the nosecone section and aft section upon separation.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SLRT-201	FORWARD AIRFRAME	1
2	SLRT-202	AVIONICS BAY	1
3	SLRT-002	RIVET	3

NOTES:
1. DIMS IN INCHES
2. QUANTITY: 1

TITLE: Forward Section
DRAWN MAGGIE WIELATZ
DESIGNED MAGGIE WIELATZ

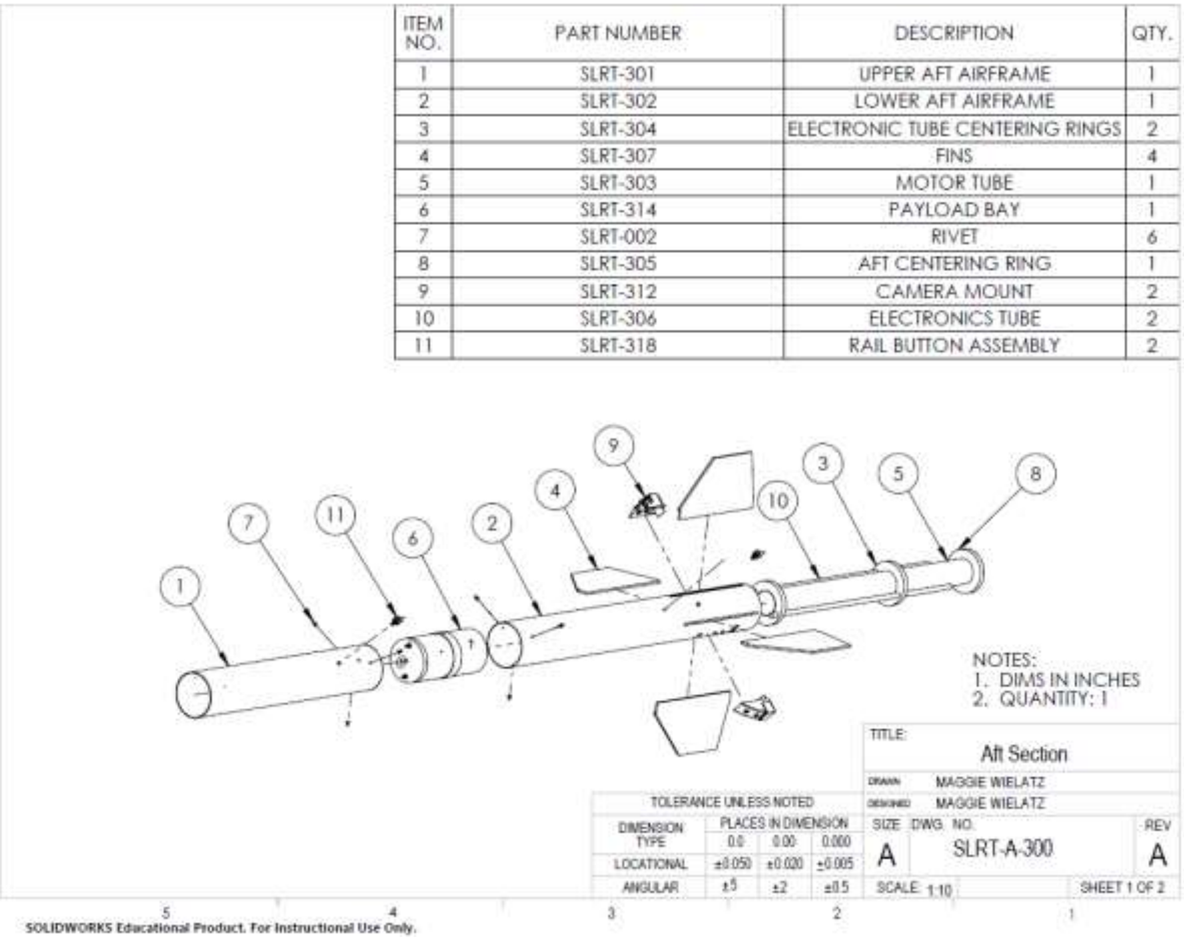
TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION 0.0	0.00	0.000
LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

SIZE A DWG. NO. SLRT-A-200 REV A
SCALE: 1:5 SHEET 1 OF 1

Figure 3: Forward Section Assembly

3.1.2.3 Aft Section

The aft section consists of upper and lower aft airframes, a payload bay, two camera mounts, a motor assembly, and fins (Figure 4). The upper and lower aft airframes are coupled to the payload bay with three plastic rivets each. The payload bay consists of a coupler, switchband, a bulkhead, and payload hardware. The payload bay is secured between the upper and lower aft airframes with three rivets connecting the coupler to each airframe. There is a ¼-20 eyebolt secured to the payload bay bulkhead that is attached to the recovery harness to keep the aft section connected to the forward section. The motor tube assembly, located in the lower aft airframe, consists of a G12 fiberglass motor tube and three plywood centering rings, and the electronics tubes. There are four structural FRP fiberglass fins that are attached through the wall of the airframe and are secured in place with epoxy. Two kraft paper electronics tubes travel from the payload bay to two slots in the sides of the lower aft airframe. The camera mounts are located over those slots and are secured in place with ¼-20 fasteners.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SLRT-301	UPPER AFT AIRFRAME	1
2	SLRT-302	LOWER AFT AIRFRAME	1
3	SLRT-304	ELECTRONIC TUBE CENTERING RINGS	2
4	SLRT-307	FINS	4
5	SLRT-303	MOTOR TUBE	1
6	SLRT-314	PAYLOAD BAY	1
7	SLRT-002	RIVET	6
8	SLRT-305	AFT CENTERING RING	1
9	SLRT-312	CAMERA MOUNT	2
10	SLRT-306	ELECTRONICS TUBE	2
11	SLRT-318	RAIL BUTTON ASSEMBLY	2

NOTES:
1. DIMS IN INCHES
2. QUANTITY: 1

Figure 4: Aft Section Assembly

3.1.3 Separation Points

There are two separation points on the launch vehicle. Black powder will be used to cause separation. The expected masses of the black powder charges are presented in grams instead of ounces to make it easier to work with when measured on a small scale (Table 1).

Ejection Charge Masses		
Ejection Charge	**Primary (g)**	**Secondary (g)**
First Separation	1.5	2.0
Second Separation	2.5	3.2

Table 1: Ejection Charge Masses

Ejection charge sizing (n) was determined using the Ideal Gas Law (Equation 1) using a required force (F), the cross-sectional area of the bulkheads (A), volume of the section (V), gas constant (R), and the burning temperature for black powder (T). The gas constant is 5.979 $\frac{ft-lbs}{slugs\,°R}$ and the temperature black powder burns at is 3307 degrees Rankin. The force used to find the black powder was a minimum of 80 lbs. It was assumed this would be sufficient to shear the 3 shear pins used at each separation point.

$$\frac{F}{A} * V = nRT$$

Equation 1

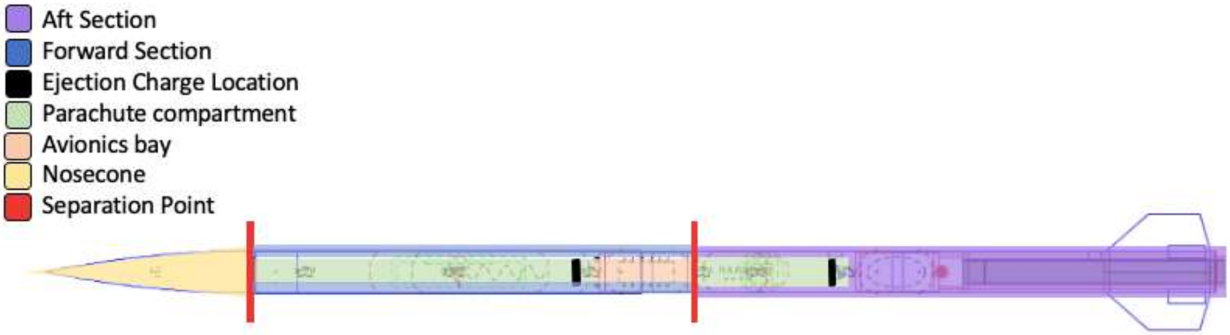


Figure 5: Separation Points

The first separation event will be between the Aft Section and the Avionics Bay with the ejection charge just forward of the Payload Bay (Figure 5). The primary ejection charge will go off at apogee and the secondary ejection charge will go off half a second after apogee. The first separation will deploy a drogue parachute stored in the aft section (Figure 6). The two sections will remain tethered with the use of a recovery harness. A parachute protector will be used to protect the drogue parachute from the hot ejection gasses. The parachute protector used for the drogue will be 24 in. square flame resistant fabric from Dino Chutes. The recovery harness will be secured to the Avionics Bay bulkhead and the Payload Bay bulkhead with an eyebolt epoxied into each bulkhead and a quick link secured to the eyebolt and recovery harness (5.1 Launch Concerns and Operation Procedures).

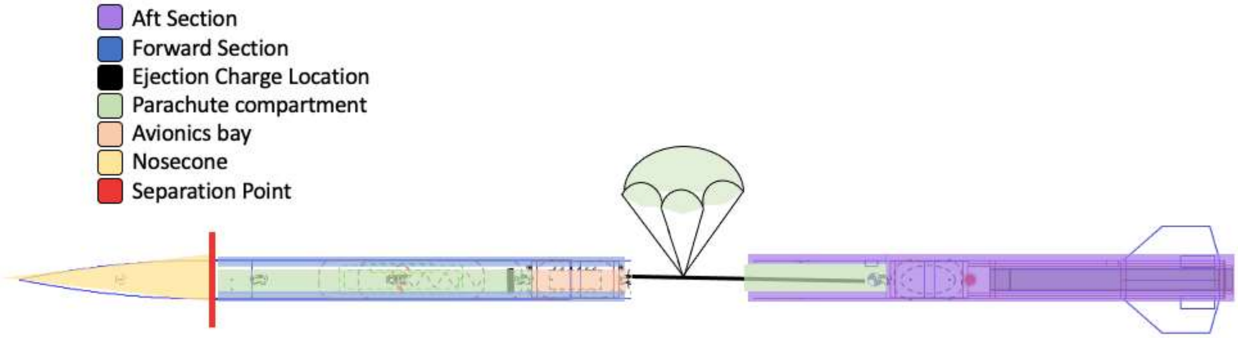


Figure 6: Drogue Separation Event

The drogue parachute will be secured to the recovery harness using a slip knot and a quick link secured to a swivel to mitigate the parachute tangling itself with the recovery harness due to the rotation of the launch vehicle below. The knot will be positioned 1/3 of the length away from the Avionics Bay to help protect against the sections colliding midair during descent (Figure 7).

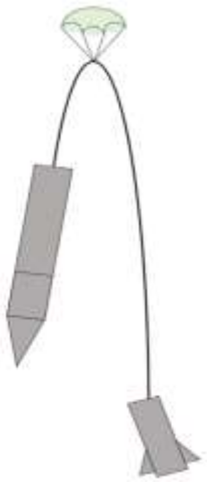


Figure 7: Launch Vehicle Under Drogue

The second separation event will occur between the Nosecone Section and the Forward Section (Figure 8). The primary altitude for this separation event is 600 ft and the secondary altitude is 550 ft. This separation will deploy a main parachute. Separating at this point with the ejection charge just forward of the Avionics Bay will utilize gravity to help pull the main parachute out of the section as the ejection charge pushes it out. A 33 in. square parachute protector from Madcow Rocketry will be used to protect the main parachute from the hot ejection gasses.

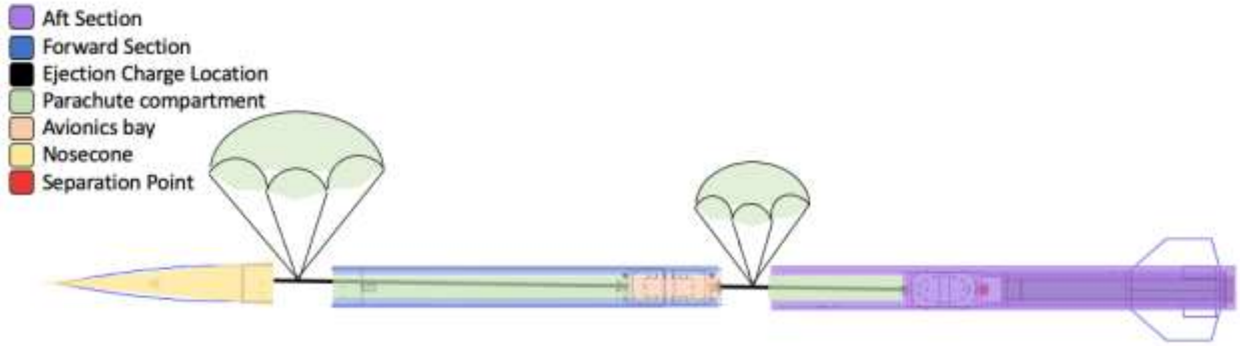


Figure 8: Main Separation Event

The second separation will use a recovery harness to secure the Nosecone Section to the Avionics Bay. The Avionics Bay will be riveted to the Forward Airframe to hold the Forward Section together during flight. The recovery harness will be secured to eyebolts epoxied into the Nosecone bulkhead and the Avionics Bay bulkhead with the use of quick links. The main parachute will be secured to the recovery harness with the use of a knot and a quick link secured to a swivel on the parachute. The knot will be tied 1/3 of the length of the recovery harness away from the nosecone. This distance will help mitigate the risk of sections colliding during flight (Figure 9).

Figure 9: Launch Vehicle Under Main

3.1.4 Manufacturing Readiness

The launch vehicle was modeled in SolidWorks and detailed design drawings were created to aid in manufacturing. Assembly drawings were also created to show how each component fit together. All members participating in any manufacturing will wear the proper PPE consisting of safety glasses, long pants, and closed toed shoes. Other safety measures will be taken depending on the material being manufactured and Safety Officer instructions.

3.1.4.1 Nosecone Section

In order to construct the nosecone section, the nosecone bulkhead needs to be manufactured and secured to the nosecone. The nosecone does not need to be manufactured because it will be purchased off the shelf. Rivet holes also need to be drilled into the nosecone body and nosecone coupler to attach them together. Shear pin holes need to be drilled into the coupler to attach it to the forward airframe. The nosecone section components can be constructed using a lathe and power tools.

3.1.4.1.1 Nosecone

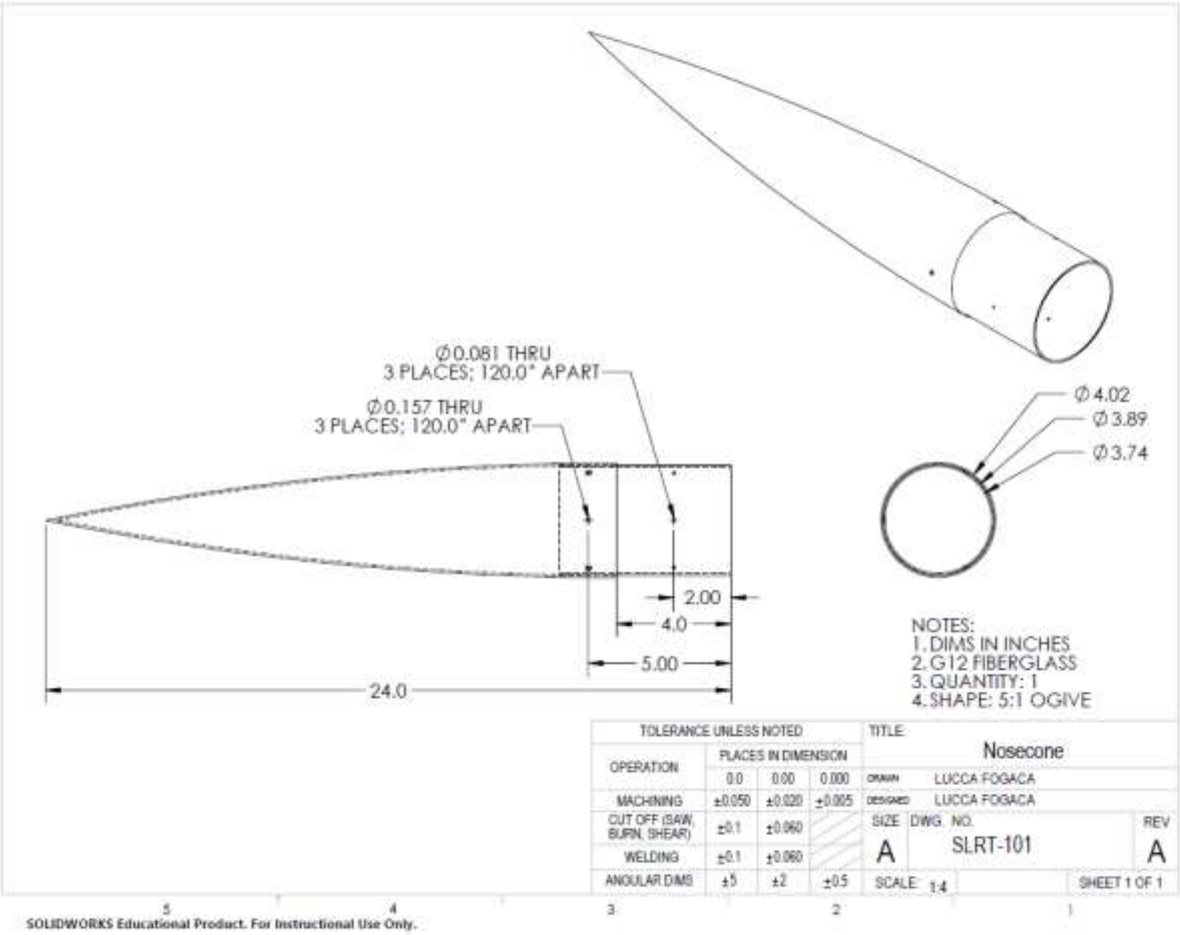


Figure 10: Nosecone Drawing

1. Mark three rivet holes 120.0° apart, 19.0 in. from the tip of the nosecone.
2. Mark a line 2.00 in. from the aft end of the nosecone coupler.
3. Mark a line 5.00 in. from the aft end of the nosecone coupler.
4. Insert nosecone coupler into the nosecone body.
5. Clamp nosecone in a vise.
6. Drill one 0.157 in hole at a rivet hole mark.
7. Use sandpaper to sand holes until smooth.
8. Insert a rivet into the drilled hole.
9. Repeat steps 6-8 until all three holes have been drilled.

3.1.4.1.2 Nosecone Bulkhead

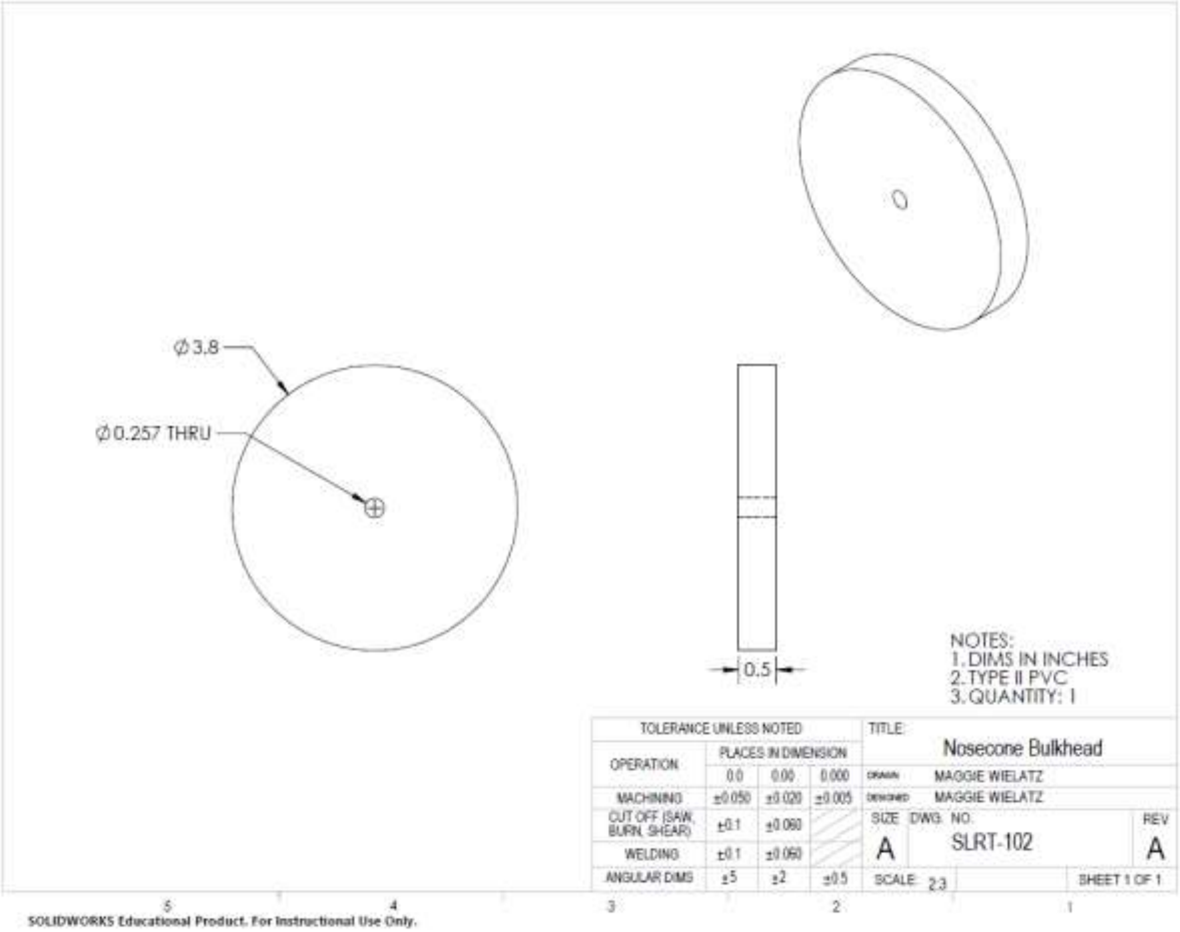


Figure 11: Nosecone Bulkhead Drawing

1. Measure raw type II PVC stock. Ensure there is at least 1 in of material to machine the part and 1 in clamp in the lathe.
2. Load stock into the chuck and clamp securely.
3. Load turning/facing tool into lathe and ensure that it is aligned with the spindle axis.
4. Turn lathe into high range and turn on machine.
5. Set the speed to 800 RPM.
6. Turn the stock using 0.100 roughing passes with the auto feed. Use oil when completing any roughing passes.
7. Change machine to low range and use auto feed to turn the part with finishing passes that are 0.020 in or less.
8. Measure the stock with a caliper between passes to ensure the part is the correct diameter.
9. Test the fit of the part with the coupler and airframe.
10. Remove the cutting tool and load a parting tool.
11. Part the bulkhead off using the parting tool while applying oil.
12. Remove the parting tool.
13. Remove the leftover stock and load the part into the chuck securely.

14. Load the center drill into the tailstock and center drill the part.
15. Remove the center drill, then load the 0.25 in drill bit into the tail stock and drill the center thru hole. Remove the 0.25 in drill bit and use the 0.257 in drill bit to drill the hole to size. Use oil for any drilling operations.
16. Sand the edges of the nosecone bulkhead in preparation for epoxying.
17. Remove the workpiece and the tools, then clean the machine.

3.1.4.1.3 Nosecone Assembly

The instructions list detailed steps explaining how to assemble the nosecone section as shown in Figure 2.

1. Attach an eyebolt to the bulkhead using a nut and apply RocketPoxy to secure in place.
2. Put on gloves in preparation for epoxying.
3. Attach an eyebolt to the bulkhead using a nut and apply RocketPoxy to secure in place.
4. Apply RocketPoxy to the interior of the nosecone coupler in the sanded area.
5. Insert the bulkhead and twist in place.
6. Apply RocketPoxy to the connection point between the coupler and the bulkhead and create a fillet.

3.1.4.2 Forward Section

The structural components of the forward section consists of the forward airframe, the avionics bay coupler and two avionic bulkheads (Figure 12). The forward section components can be manufactured using a milling machine, lathe, bandsaw, and power tools.

3.1.4.2.1 Forward Airframe

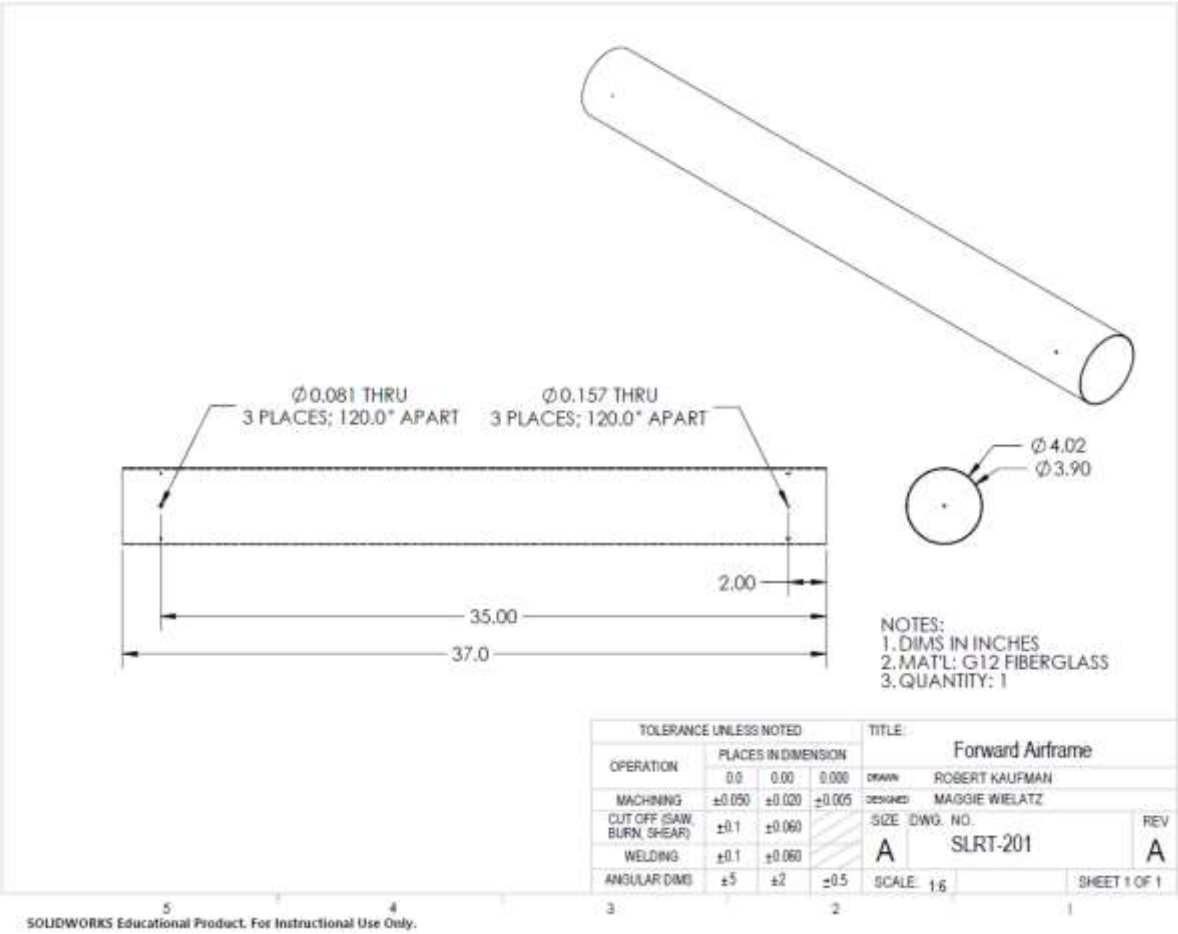


Figure 12: Forward Airframe Drawing

1. Measure 37.0 in of 4.02 in diameter fiberglass airframe.
2. Put on safety glasses and respirator.
3. Turn on vacuum and mount near cutting area.
4. Cut airframe to size using a roll-in bandsaw.
5. Clean machinery and workpiece.
6. Sand edges of the airframe to smooth the edges with 80-100 grit sandpaper.
7. Mark three shear pin holes 120.0° apart, 35.00 in from the aft end of the part.
8. Mark three rivet holes 120.0° apart, 2.00 in from the aft end of the part.

3.1.4.2.2 Avionics Coupler Switchband

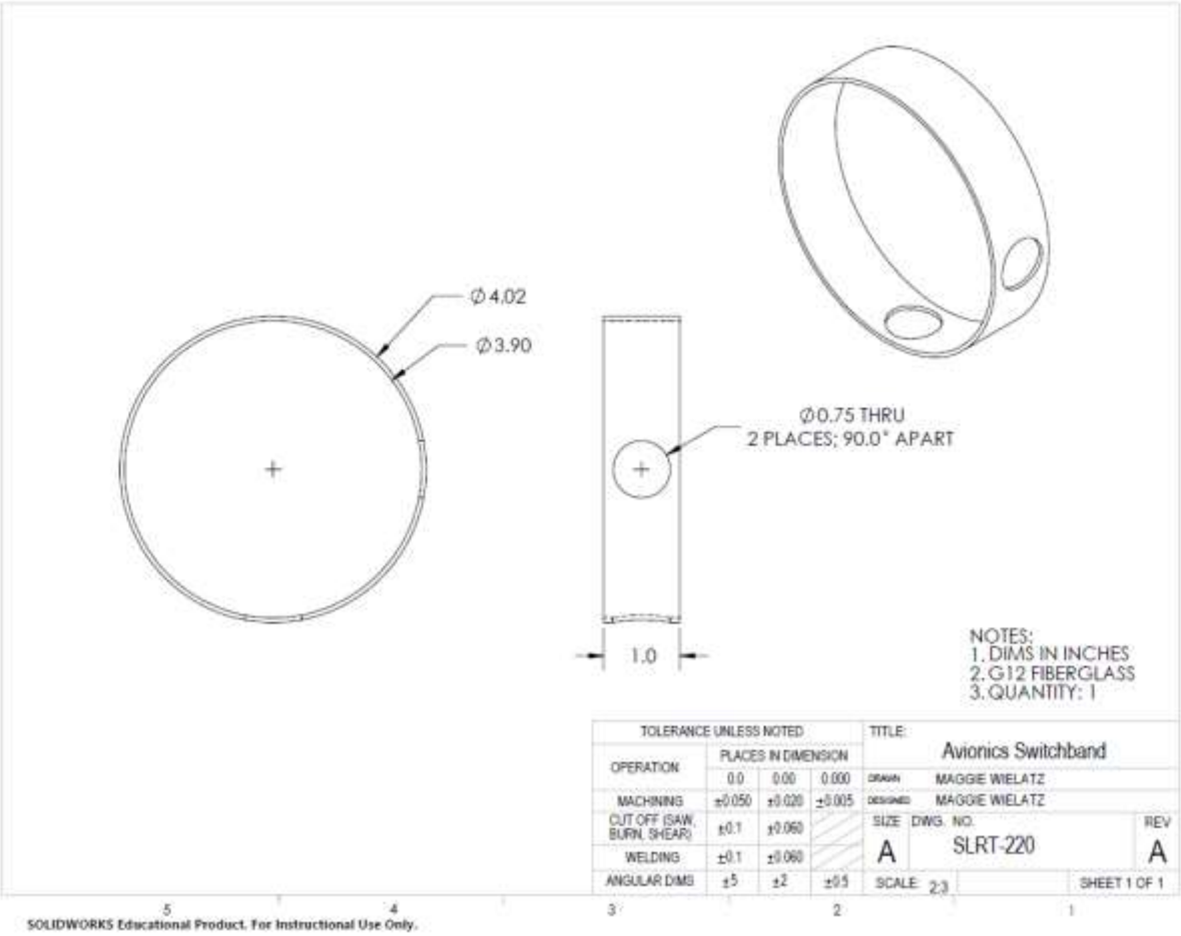


Figure 13: Avionics Switchband Drawing

1. Measure 1.0 in of 4.02 in diameter fiberglass airframe.
2. Put on safety glasses and respirator.
3. Turn on vacuum and mount near cutting area.
4. Cut airframe to size using a roll-in bandsaw.
5. Clean machinery and workpiece.
6. Sand edges of the airframe to smooth the edges with 80-100 grit sandpaper.
7. Mark two 0.75 in diameter holes, 90° apart, 0.5 in from the aft end of the part.

3.1.4.2.3 Avionics Coupler

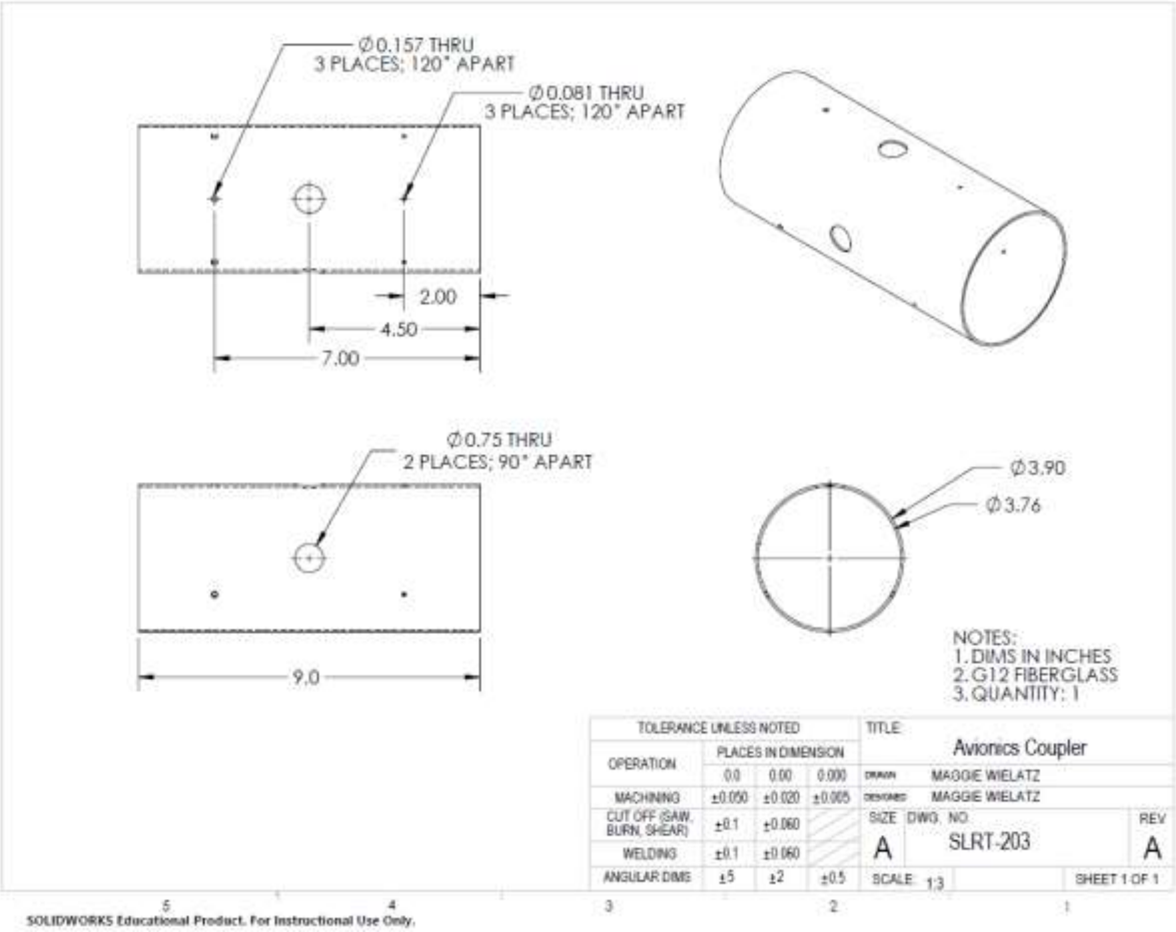


Figure 14: Avionics Coupler Drawing

1. Measure 9.0 in of 3.90 in diameter fiberglass coupler.
2. Put on safety glasses and respirator.
3. Turn on vacuum and mount near cutting area.
4. Cut coupler to size using the roll-in bandsaw.
5. Clean machinery and workpiece of fiberglass material.
6. Sand edges of the avionics coupler with 80-100 grit sandpaper to ensure a clean edge.
7. Mark three shear pin holes 120.0° apart, 2.00 in from the aft end of the part.
8. Mark three rivet holes 120.0° apart, 7.00 in from the aft end of the part.
9. Measure 1.0 in of 4.02 in diameter fiberglass airframe.
10. Cut the 1.0 in airframe to size with the roll-in bandsaw to manufacture the switchband.
11. Mark one line 4.0 in and another line 5.0 in from the aft end of the coupler for the switchband.

3.1.4.2.4 Avionics Bulkheads

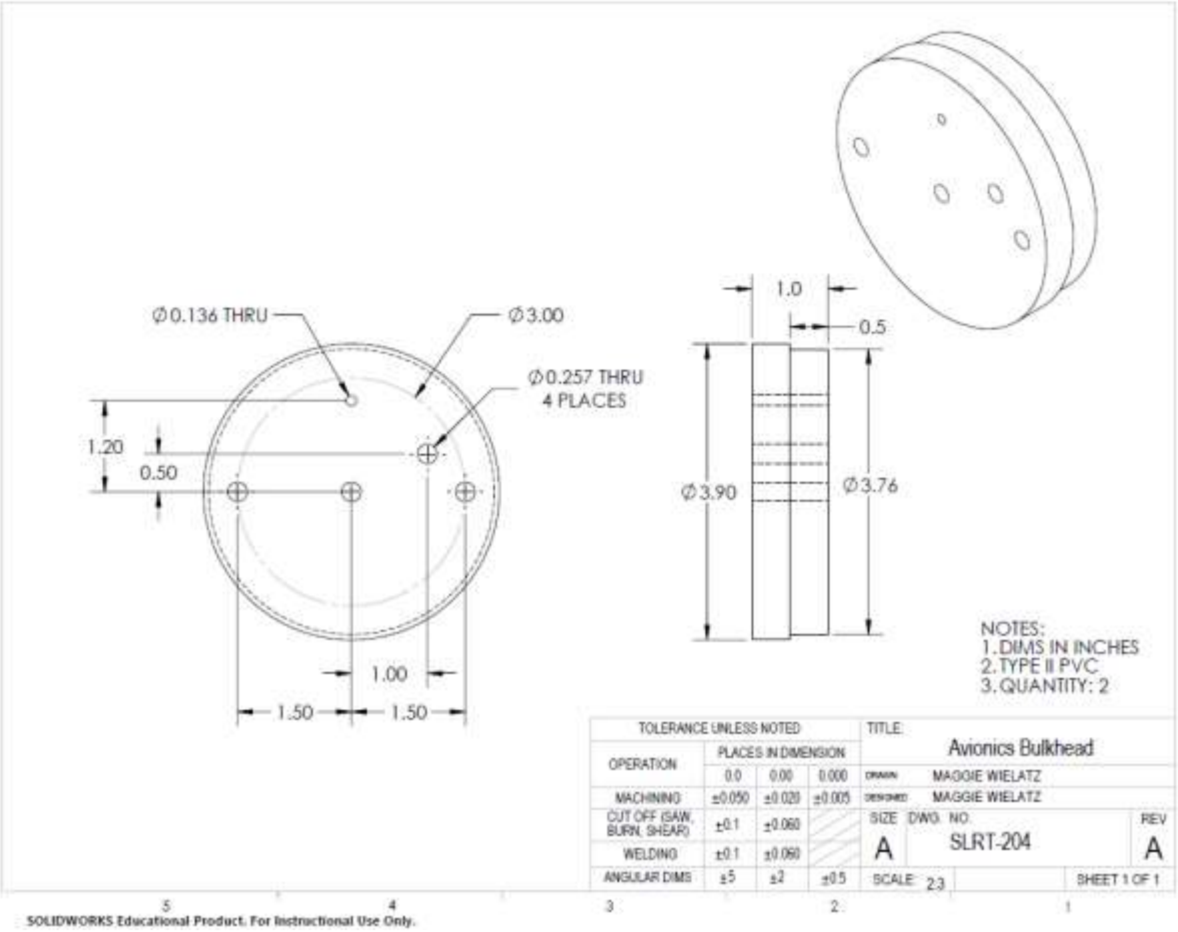


Figure 15: Avionics Bulkhead Drawing

1. Measure raw type II PVC stock. Ensure there is at least 1.75 in of stock to machine the part and 1 in to clamp in the lathe.
2. Load stock into the chuck and clamp securely.
3. Load turning/facing tool into lathe and ensure that it is aligned with the spindle axis.
4. Turn lathe into high range and turn on machine.
5. Set the speed to 800 RPM.
6. Turn the stock using 0.100 roughing passes with the auto feed. Use oil when completing any roughing passes.
9. Change machine to low range and use auto feed to turn the part with finishing passes of 0.020 in or less.
10. Measure the stock with calipers between passes to ensure the part is the correct diameter.
11. Test the fit of the part with the coupler and airframe.
12. Remove the cutting tool and load a parting tool.
13. Part the bulkhead off using the parting tool while applying oil.
14. Remove the parting tool.
15. Remove the stock and load the part into the chuck securely.

16. Load a center drill into the tailstock.
17. Center drill the center thru hole.
18. Drill the center hole up to a size of 0.257 in.
19. Remove the workpiece and the tools, then clean the machine.
20. Load the workpiece into the milling machine vise using v-blocks.
21. Load a keyless chuck into the spindle with a cylindrical edge finder.
22. Zero the part with a cylindrical edge finder against the center hole.
23. Remove the edge finder and load a 0.25 in drill bit into the chuck. Drill four thru holes.
24. Remove the 0.25 in drill bit and load a 0.257 in drill bit. Drill the four thru holes to size.
25. Remove the 0.257 in drill bit and load a 0.136 in drill bit. Drill the final thru hole to size.
26. Remove the part and tools and clean the machine.

3.1.4.2.5 Avionics Bay

1. Wear gloves in preparation for epoxying.
2. Apply RocketPoxy between the marked switchband lines.
3. Twist the switchband in place.
4. Clean off any excess epoxy.
5. Mark two key lock switch holes in two places, 90.0°apart, 4.5 in from the aft end of the part.
6. Drill the key lock switch holes in 0.25 in step-ups.
7. Sand the part until smooth with sandpaper.
8. Clean the part and tools.

3.1.4.2.6 Forward Assembly

The procedures demonstrate how to assemble the forward section as shown in Figure 3.

1. Insert the coupler into the forward airframe.
2. Clamp the airframe into a vise securely.
3. Drill one 0.081 in hole through coupler and airframe at a shear pin hole mark.
4. Use a deburring tool to sand hole until smooth.
5. Insert a shear pin into the drilled hole.
6. Repeat steps 3-5 until all three shear pin holes have been drilled.
7. Drill one 0.157 in hole through coupler and airframe at a rivet hole mark.
8. Use a deburring tool to sand hole until smooth.
9. Insert a rivet into the drilled hole.
10. Repeat steps 7-9 until all three rivet holes have been drilled.

3.1.4.3 Aft Section

The structural components of the aft section consists of the aft airframes, payload coupler, payload bulkhead, motor mount assembly and four fins. The motor mount assembly includes a motor tube and three centering rings. The necessary components can be manufacturing using a milling machine, lathe, bandsaw, abrasive waterjet, and power tools.

3.1.4.3.1 Upper Aft Airframe

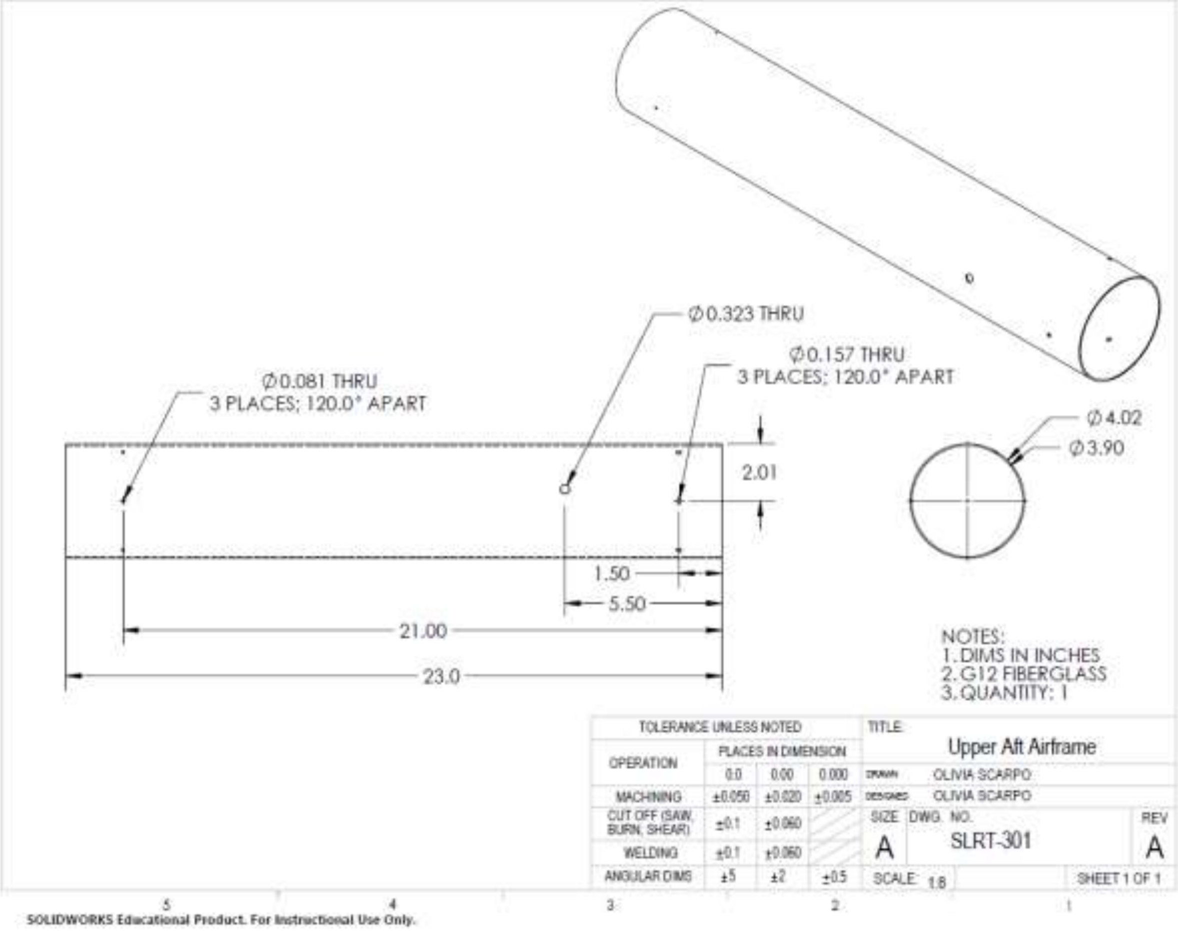


Figure 16: Upper Aft Airframe Drawing

1. Measure 23.0 in of 4.02 in diameter fiberglass airframe.
2. Put on safety glasses and respirator.
3. Turn on vacuum and mount near cutting area.
4. Cut airframe to size using the roll-in bandsaw.
5. Clean machinery and fiberglass material.
6. Sand edges of the airframe with 80-100 grit sandpaper to smooth the edges.
7. Mark three shear pin holes 120.0° apart, 21.0 in from the aft end of the part.
8. Mark three rivet holes 120.0° apart, 1.5 in from the aft end of the part.
9. Mark a rail button hole 5.5 in from the aft end of the part.
10. Drill a 0.323 in diameter hole through the rail button hole using a power drill.
11. Clean the part and tools.

3.1.4.3.2 Lower Aft Airframe

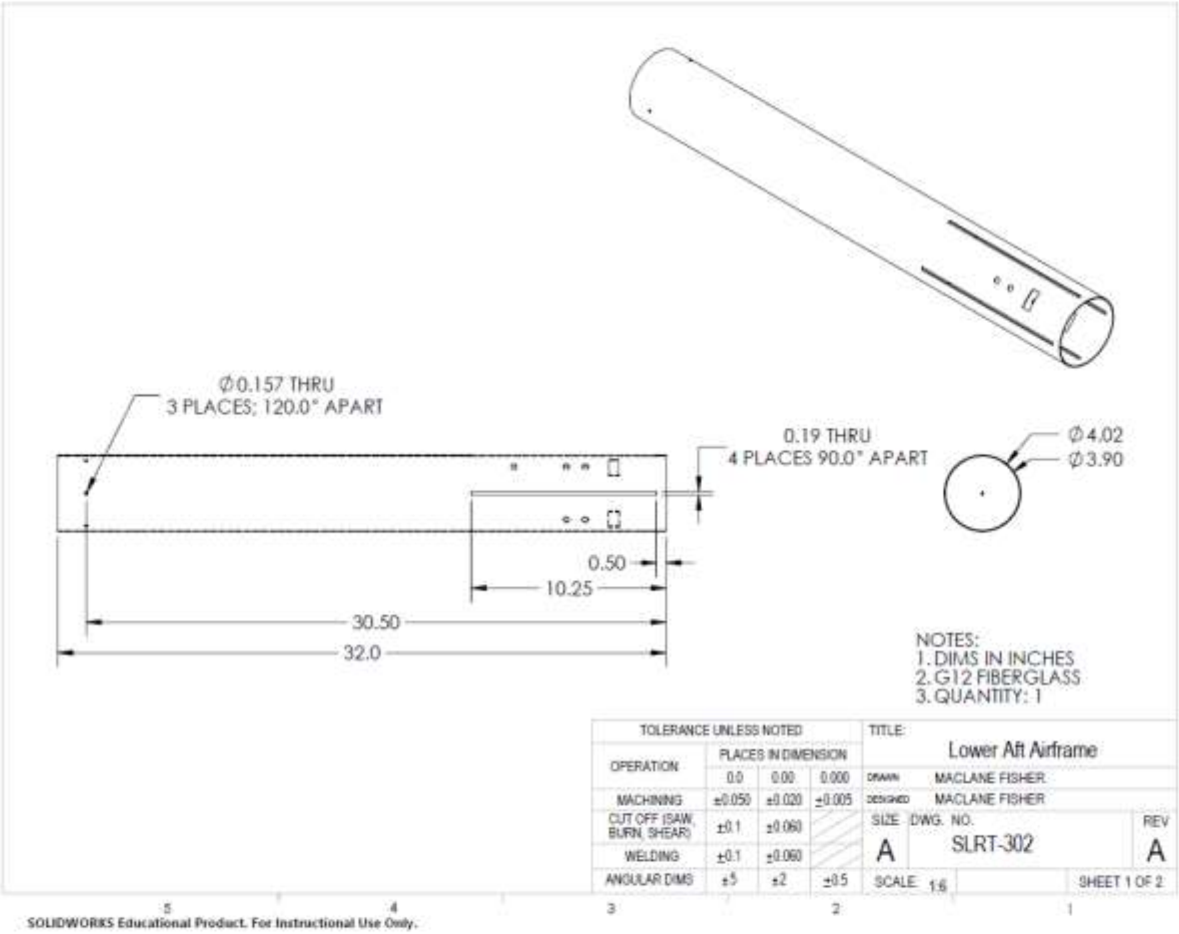


Figure 17: Lower Aft Airframe Drawing

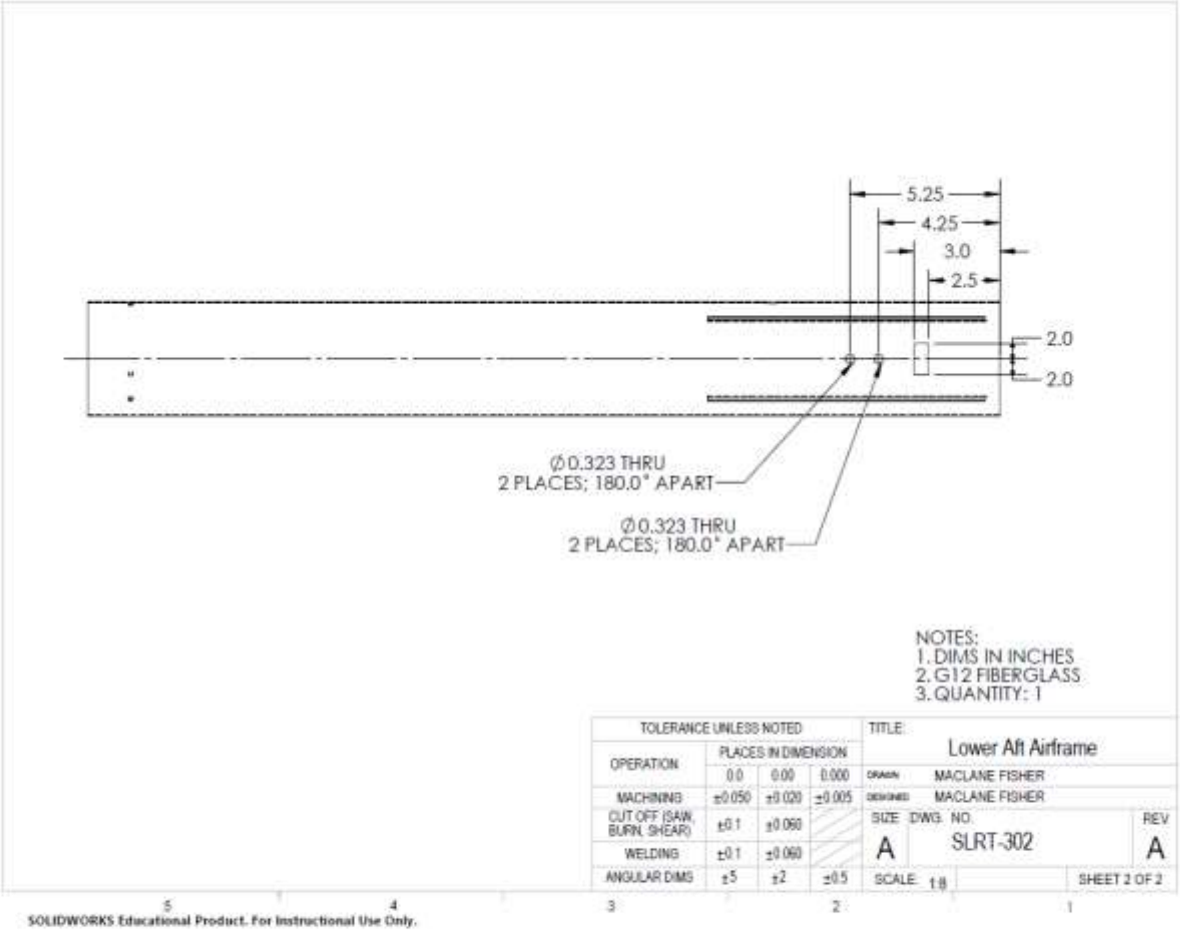


Figure 18: Lower Aft Airframe Drawing Side View

1. Measure 32.0 in of 4.02 in diameter fiberglass airframe.
2. Put on safety glasses and respirator.
3. Turn on vacuum and mount near cutting area.
4. Cut airframe to size using the roll-in bandsaw.
5. Clean machinery and workpiece of fiberglass material.
6. Sand edges of the airframe with 80-100 grit sandpaper to smooth the edges.
7. Remove respirator and turn off vacuum.
8. Mark three rivet holes 120.0° apart, 30.5 in from the aft end of the part.
9. Mark the location for a ¼-20 rail button hole 8.0 in from the aft end of the airframe, located between two fins, 90.0° from the camera mounts. (Ensure alignment with forward rail button)
10. Mark four fin slots, 90.0° apart, starting 0.5 in from the aft end of the airframe and ending 10.25 in from the aft of the airframe.
11. Mark two holes 4.25 in from the aft end of the airframe, 180.0° apart and 45.0° away from the previously marked fin slots.
12. Mark two holes 5.25 in from the aft end of the airframe, 180.0° apart and 45.0° away from the previously marked slots.
13. Mark two 0.5 in (long axis) by 4.0 in (perpendicular axis) camera slots, 180°apart.

14. Put on safety glasses and respirator.
15. Turn on vacuum and mount near cutting area.
16. Using a Dremel with a cutting wheel bit, cut out the four 9.75 in fin slots.
17. Drill four 0.323 in diameter camera mount fastener holes at the marked locations.
18. Drill a 0.323 in diameter hole for the rail button at the marked location.
19. Insert a ¼-20 t-nut and epoxy in place.
20. Drill into the rail button with a 0.302 in drill bit so the t-nut will fit.
21. Secure a 1515 rail button in place.
22. Use a Dremel with a cutting wheel to cut two 0.5 x 4.0 in camera slots 2.5 in from the aft end of the airframe.
23. Sand the fin slots with 80-100 grit sandpaper and deburr the drilled holes with a deburring tool.
24. Sand the interior and exterior near the fin slots and 5 in from the forward end of the airframe in preparation for epoxying.
25. Clean the part and tools.

3.1.4.3.3 Payload Bay Coupler Switchband

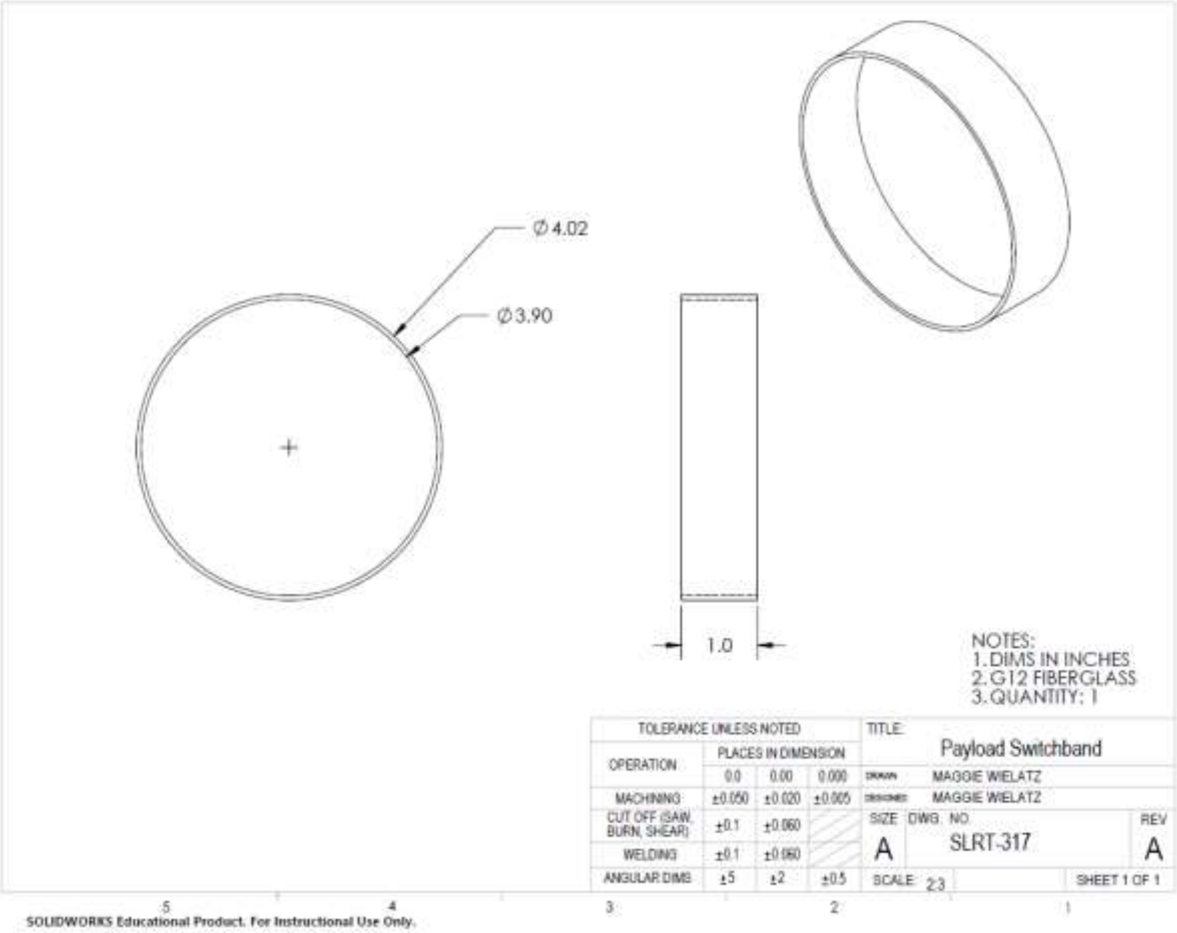


Figure 19: Payload Switchband Drawing

1. Measure 1.0 in of 4.02 in diameter fiberglass airframe.
2. Put on safety glasses and respirator.

3. Turn on vacuum and mount near cutting area.
4. Cut airframe to size using a roll-in bandsaw
5. Clean machinery and workpiece.
6. Sand edges of the airframe to smooth the edges with 80-100 grit sandpaper.

3.1.4.3.4 Payload Bay Coupler

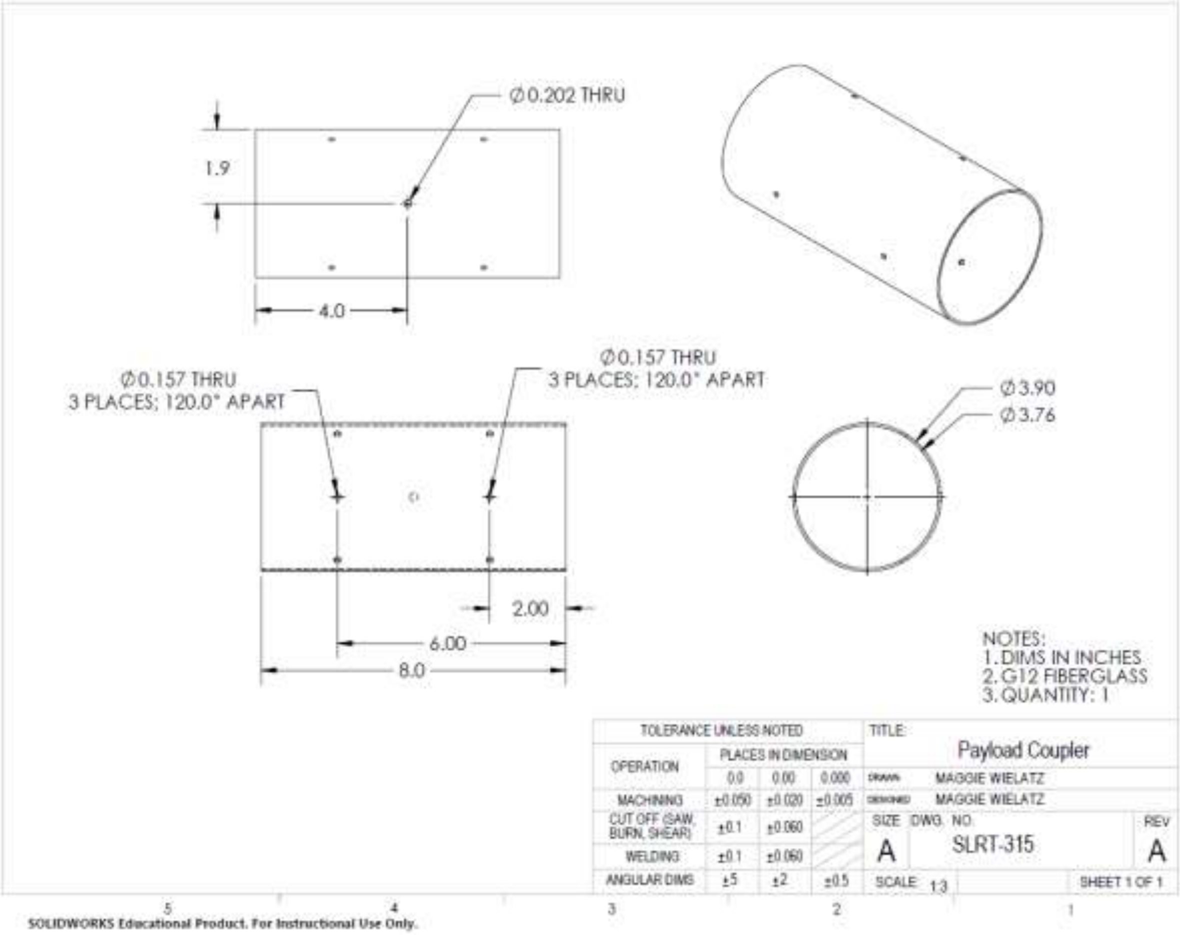


Figure 20: Payload Coupler Drawing

1. Measure 8.0 in of 3.9 in diameter fiberglass coupler.
2. Put on safety glasses and respirator.
3. Turn on vacuum and mount near cutting area.
4. Cut coupler to size using the roll-in bandsaw.
5. Clean machinery and workpiece of fiberglass material.
6. Sand edges of the avionics coupler to ensure a clean edge
7. Mark three rivet holes 120.0° apart, 2.0 in from the aft end of the part.
8. Mark three rivet holes 120.0° apart, 6.0 in from the aft end of the part.
9. Mark one line 2.0 in and another line 6.0 in from the aft end of the coupler.

3.1.4.3.5 Payload Bay Bulkhead

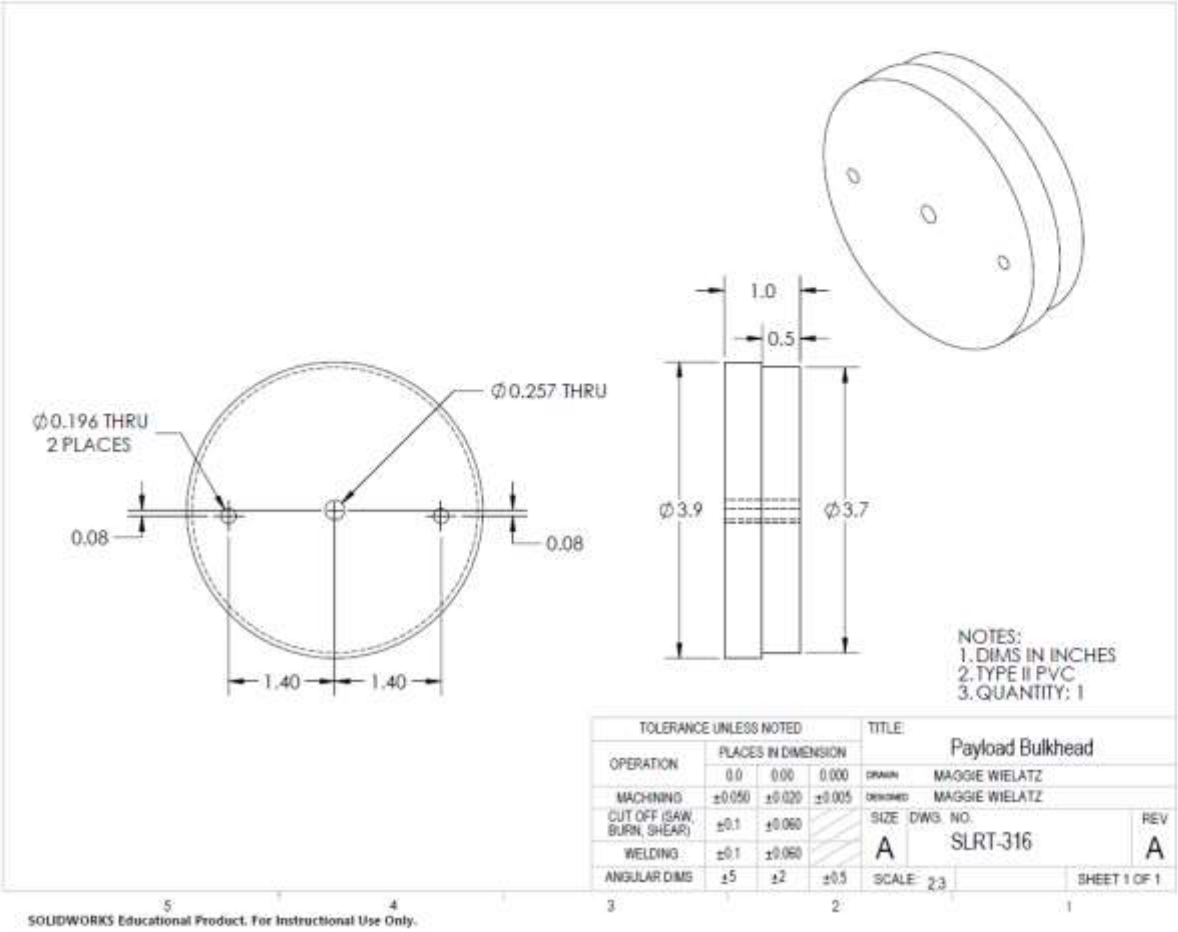


Figure 21: Payload Bulkhead Drawing

1. Measure raw type II PVC stock to ensure there is enough stock to machine the part and clamp in the lathe.
2. Load stock into the chuck and clamp securely.
3. Load turning/facing tool into lathe and ensure that it is aligned with the spindle axis.
4. Turn lathe into high range and turn on machine.
5. Set the speed to 800 RPM.
6. Turn the stock using 0.100 in roughing passes with the auto feed. Use oil when completing any roughing passes.
7. Change machine to low range and use auto feed to turn the part with finishing passes of 0.020 in or less.
8. Measure the stock with calipers between passes to ensure the part is the correct diameter.
9. Test the fit of the part with the coupler and airframe.
10. Remove the cutting tool and load a parting tool.
11. Part the bulkhead off using the parting tool while applying oil.
12. Remove the parting tool.
13. Remove the extra stock and load the part into the chuck securely.

14. Load a center drill into the tailstock and center drill.
15. Remove the center drill, then load a 0.25 in drill bit into the tail stock and drill the center thru hole. Use oil for any drilling operations.
16. Remove the 0.25 in drill bit and load a 0.257 in drill bit into the tailstock. Drill the remaining holes to size.
17. Remove the workpiece and the tools, then clean the machine.
18. Load the workpiece into the milling machine vise using v blocks.
19. Load a keyless chuck into the spindle with the cylindrical edgefinder.
20. Zero the part with a cylindrical edge finder against the center hole.
21. Drill the remaining 0.257 in thru holes in the part.
22. Remove the part and clean the machine.

3.1.4.3.6 Payload Bay

1. Put on gloves in preparation for epoxying.
2. Apply RocketPoxy between the switchband lines.
3. Twist the switchband in place.
4. Clean off any excess epoxy.
5. Let the components sent for 6 hrs.

3.1.4.3.7 Motor Tube

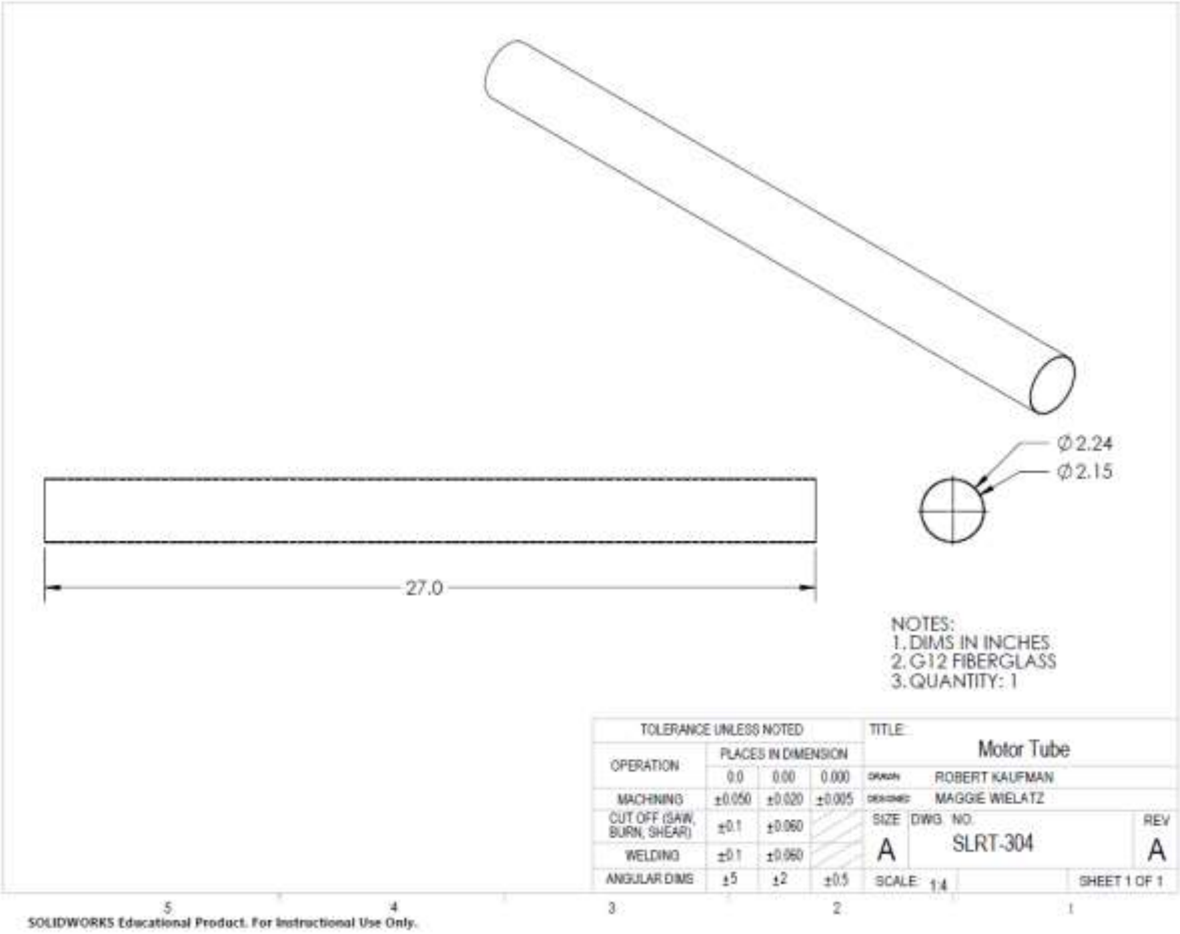


Figure 22: Motor Tube Drawing

1. Measure 27.0 in of 2.24 in diameter fiberglass motor tube.
2. Put on safety glasses and respirator.
3. Turn on vacuum and mount near cutting area.
4. Cut motor tube to size using the roll-in bandsaw.
5. Clean machinery and workpiece of fiberglass material.
6. Sand edges of the motor tube with 80-100 grit sandpaper to smooth the edges.
7. Sand epoxying surfaces at each end of the motor tube and 10.25 in from the end in preparation for making the motor mount assembly.

3.1.4.3.8 Centering Rings

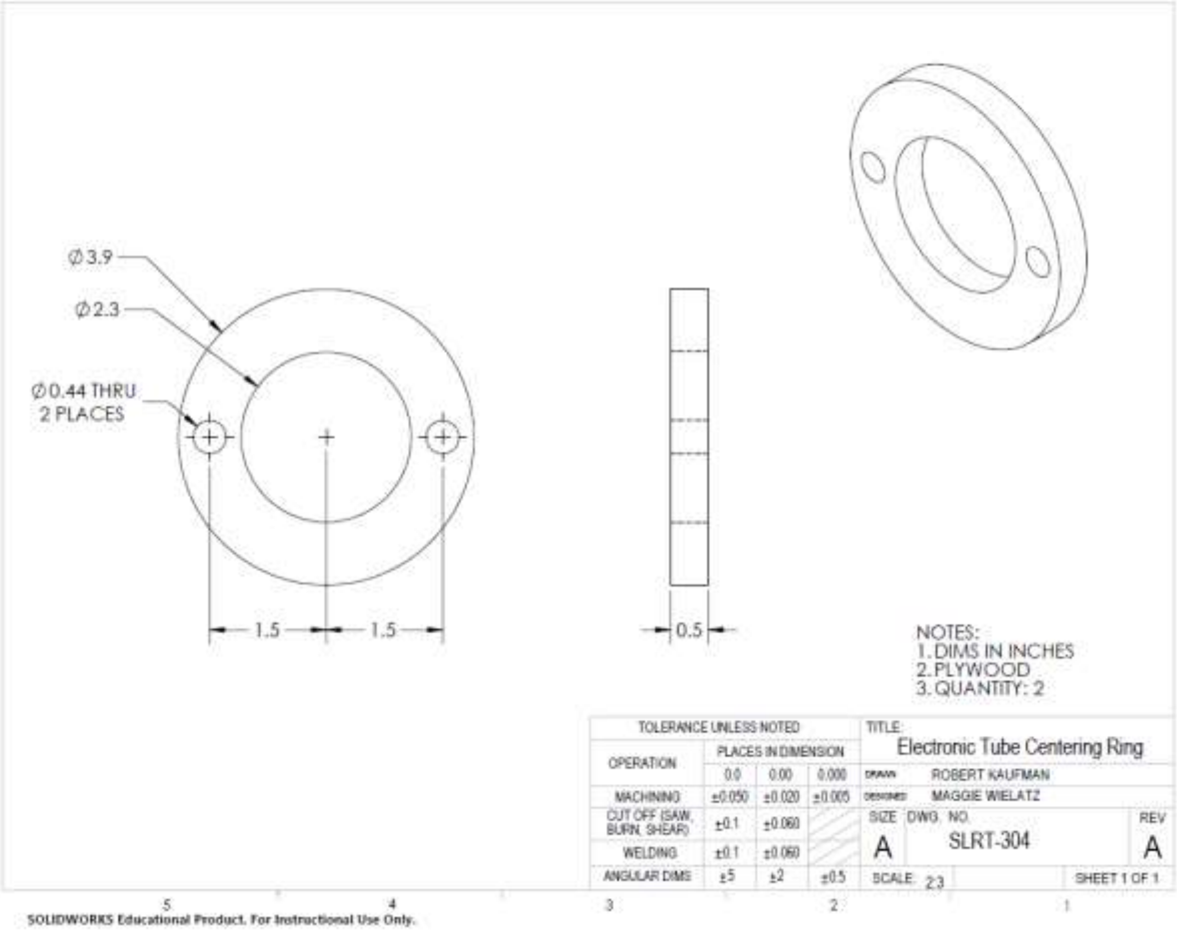


Figure 23: Electronic Tube Centering Ring Drawing

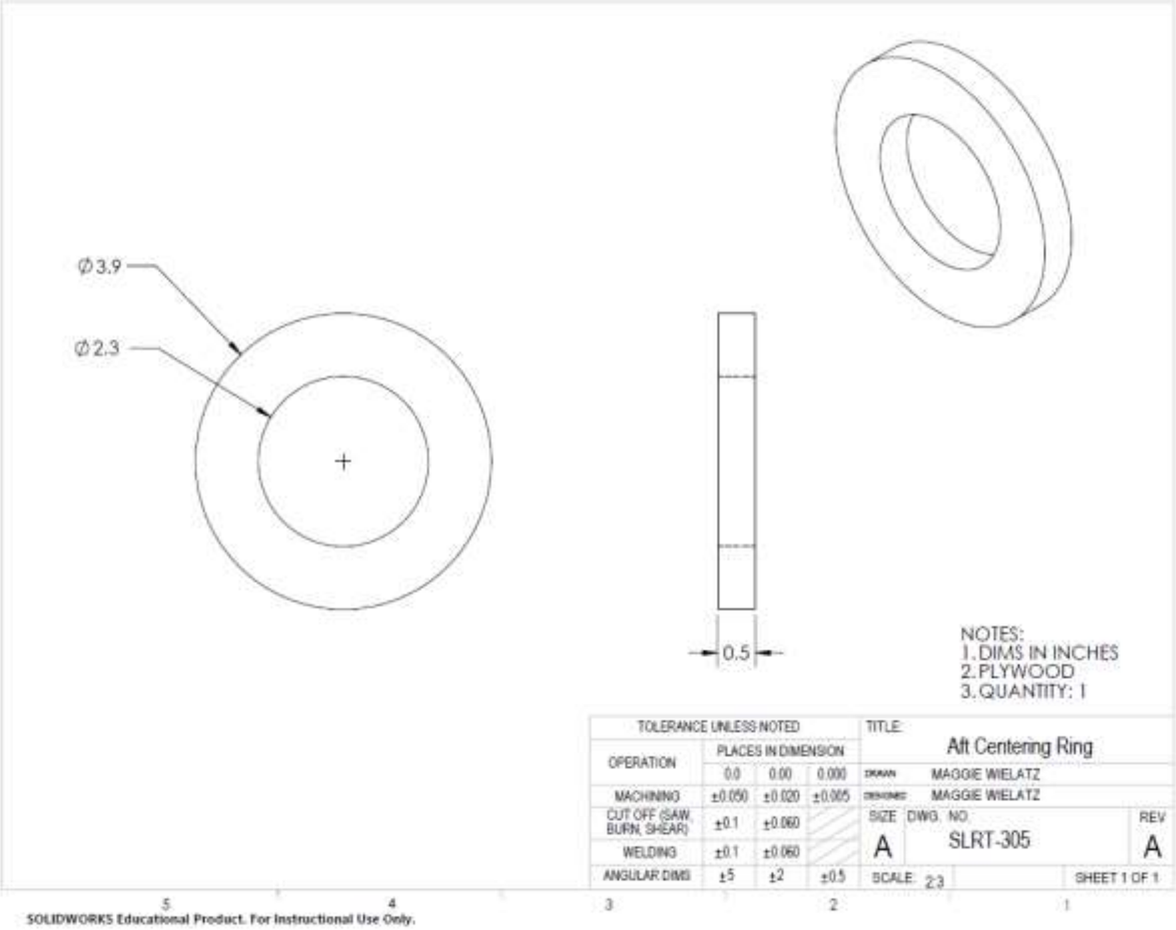


Figure 24: Aft Centering Ring Drawing

1. Model both types of centering rings in SolidWorks.
2. Export each file as a 1:1 scale dxf file.
3. Create cutting path and save ord file of the electronics tubes centering rings.
4. Open ord file in cutting software and select material type and thickness.
5. Place plywood sheet in waterjet work area.
6. Clamp the material to keep it secure while cutting.
7. Verify that the material is aligned with the x and y axes of the work area.
8. Set z axis height of the waterjet nozzle.
9. Run the waterjet and cut the predetermined path.
10. Repeat steps 1-9 for the aft centering ring.
11. Remove material and clean machinery and workspace.
12. Clean centering rings and sand with 80-100 grit sandpaper in preparation for epoxying.

3.1.4.3.9 Electronics Tubes

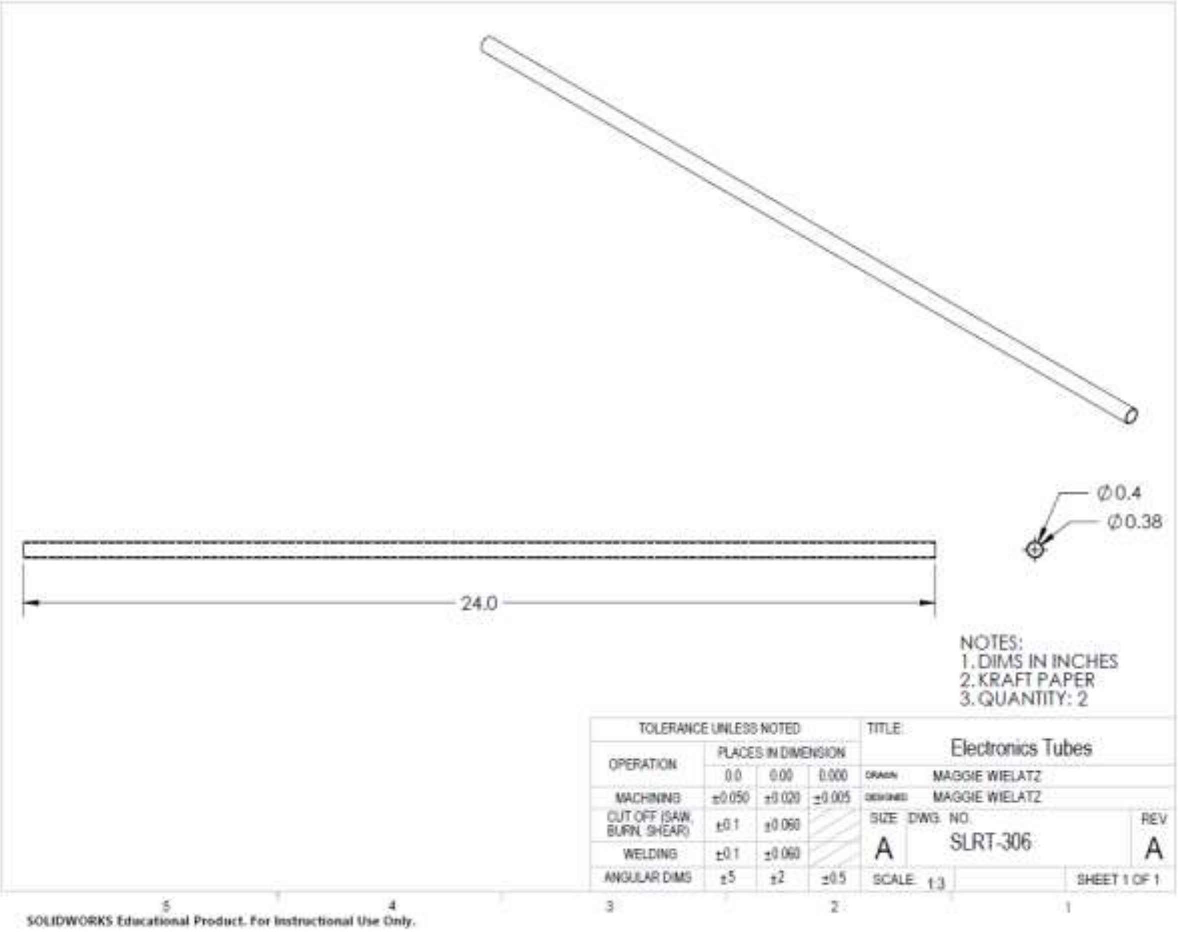


Figure 25: Electronics Tubes Drawing

1. Use a 3/8 in metal rod to make tubes with an inner diameter of 3/8 in.
2. Cut 0.5 in wide strips of 15.0 in long kraft paper.
3. Wrap a strip of kraft paper around the metal rod without overlapping any areas until 24.0 in of the rod is covered with the base layer of paper.
4. Tape the ends of the base layer to the metal rod to secure in place.
5. Mix wood glue with water in a 1:1 ratio.
6. Coat a strip of kraft paper with glue and wrap the metal rod without overlapping with itself or leaving gaps.
7. Continue wrapping the kraft paper strips until the layer has been completed.
8. Repeat steps 6-7 to create a third layer.
9. Let the tube dry for about 2 min.
10. Cut the taped ends off.
11. Remove the tube from the metal rod and clean any glue off the rod.
12. Put the tube back on the rod to allow it to dry without losing its shape.
13. Every few minutes, move the tube on the rod to prevent any residual glue from drying on the metal rod.

14. Clean materials and workspace.

3.1.4.3.10 Fins

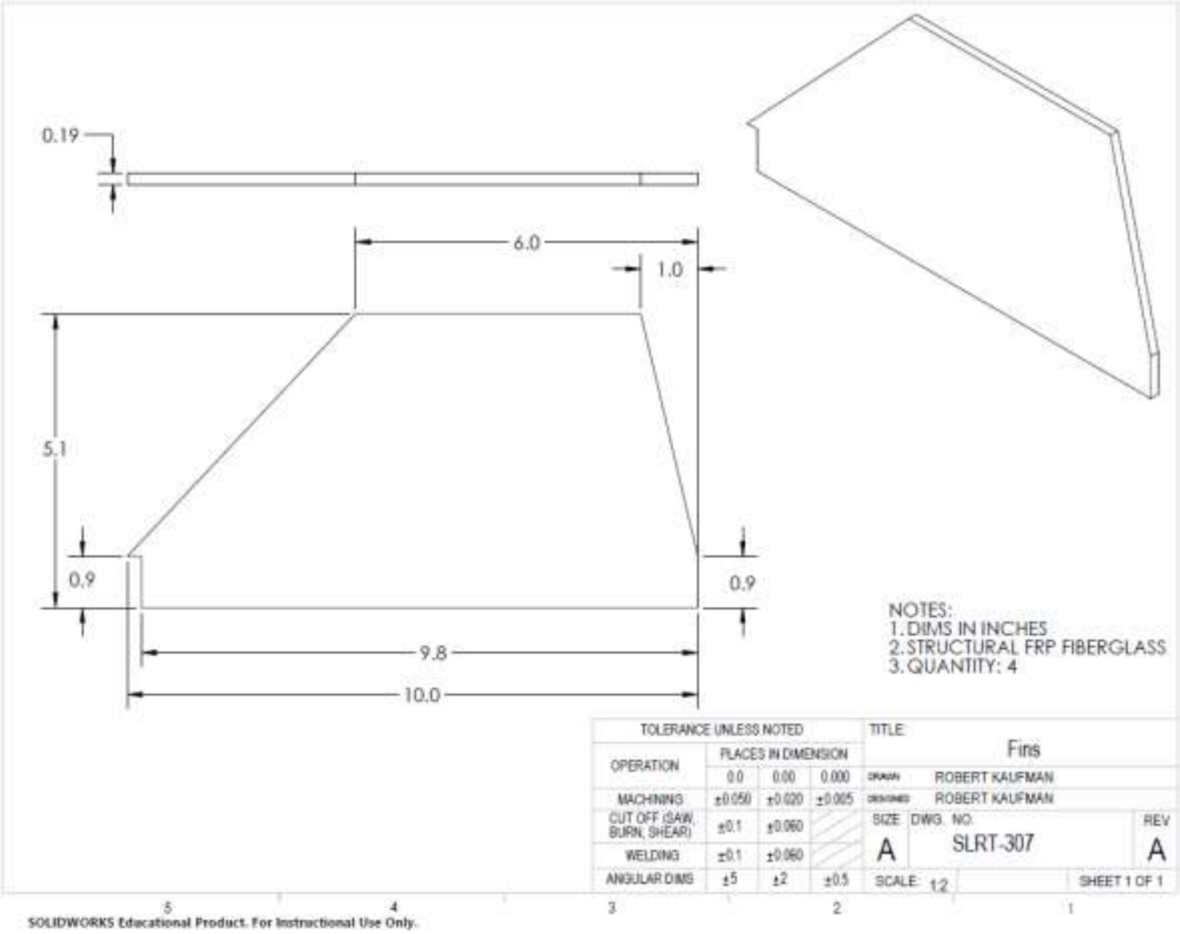


Figure 26: Fins Drawing

15. Model a fin in SolidWorks.
16. Export file as a 1:1 scale dxf file.
17. Create cutting path and save ord file.
18. Open ord file in cutting software and select material type and thickness.
19. Place fiberglass sheet in waterjet work area.
20. Verify that the material is aligned with the x and y axes of the work area.
21. Set z axis height of the waterjet nozzle.
22. Run the waterjet and cut the predetermined path.
23. Remove material and clean machinery and workspace.
24. Clean fins and sand tabs with sandpaper in preparation for fillets.

3.1.4.3.11 Motor Mount Assembly

1. Apply a layer of epoxy on the end of the motor tube.
2. Twist the forward centering ring in place flush with the end of the motor tube.
3. Twist the forward centering ring in place flush with the end of the motor tube.

4. Put on gloves in preparation for epoxying.
5. Twist the central centering ring in place 10.25 in from the aft end of the motor tube.
6. Align the electronics tubes holes in each centering ring.
7. Run the electronics tubes through the electronics tube holes to ensure proper alignment.
8. Allow epoxy to cure for 12 hours.

3.1.4.3.12 Aft Assembly

The instructions demonstrate how to assemble the aft section as shown in Figure 4.

1. Place the payload bay coupler in the upper aft airframe.
2. Secure the upper aft in a vise.
3. Drill one 0.157 in hole at a rivet hole mark.
4. Use a deburring tool to sand hole until smooth.
5. Insert a rivet into the drilled hole.
6. Repeat steps 3-5 until all three rivet holes have been drilled.
7. Place the payload bay coupler in the lower aft airframe.
8. Secure the upper aft in a vise.
9. Drill one 0.157 in hole at a rivet hole mark.
10. Use a deburring tool to sand hole until smooth.
11. Insert a rivet into the drilled hole.
12. Repeat steps 3-5 until all three rivet holes have been drilled.
13. Put on gloves in preparation for epoxying.
14. Apply a layer of JBWeld to the inside of the lower aft airframe 10.25 in from the aft end of the airframe.
15. Place the motor tube assembly in the forward end of the lower aft so that about 0.25 in is past the aft end of the airframe.
16. Before inserting the forward centering ring, apply a layer of epoxy 26.0 in from the aft end of the lower aft airframe.
17. Align the motor tube assembly in the lower aft airframe. Ensure that the electronics tubes are near the camera mount holes but do not interfere with them.
18. Allow epoxy to cure for 12 hours.
19. Apply epoxy to the points on the motor tube where the fins will make contact.
20. Allow the epoxy to cure for 12 hours.
21. Design and 3D print a fin can to align the four fins 90° apart.
22. Use a fin can to align the fins and hold them in place while the epoxy sets.
23. Apply painter’s tape on the lower aft airframe about 0.25 in from the edges of the fin slots.
24. Apply painter’s tape on the fins about 0.25 in from where the fins meet the airframe.
25. Apply painter’s tape around the outer diameter of the airframe above and below the fin slots.
26. Apply RocketPoxy to create two fillets where the upper two fins make contact with the motor tube.
27. Apply RocketPoxy to create two fillets where the two lower fins make contact with the interior of the airframe.
28. Apply RocketPoxy to the exterior of airframe where the fin makes contact with the airframe.
29. Smooth the exterior fillets with a popsicle stick.
30. Allow the epoxy to set for at least 6 hours.

31. Repeat steps 25-29 four times until all fillets are set after rotating the airframe to ensure the fin fillets are oriented so that the fillets will remain in place.

3.1.4.4 Overall Vehicle Assembly

1. Place the nosecone coupler in the forward airframe.
2. Secure the forward in a vise.
3. Drill one 0.081 in hole at a shear pin hole mark.
4. Use a deburring tool to sand hole until smooth.
5. Insert a shear pin into the drilled hole.
6. Repeat steps 3-5 until all three shear pin holes have been drilled.
7. Place the avionics coupler in the upper aft airframe.
8. Secure the upper aft in a vise.
9. Drill one 0.081 in hole at a shear pin hole mark.
10. Use deburring tool to sand hole until smooth.
11. Insert a shear pin into the drilled hole.
12. Repeat steps 3-5 until all three shear pin holes have been drilled.
13. Attach the upper aft to the lower aft by connecting each airframe to the payload coupler with three rivets.
14. Ensure the aft rail button aligns with the forward rail button mark on the upper aft.
15. Drill a 0.323 in diameter hole for the forward rail button.
16. Insert a ¼-20 t-nut and epoxy in place with RocketPoxy.
17. Drill into the rail button with a 0.302 in drill bit to increase the size in preparation for securing it to the t-nut.
18. Secure a 1515 rail button to the t-nut.
19. Ensure each component connects to each other securely.
20. Wet sand the exterior of the launch vehicle.
21. Prime and paint the launch vehicle.

3.1.5 Design Integrity

3.1.5.1 Fin Suitability

A trapezoidal fin design was selected because it provided the optimal stability to move the center of gravity up since the payload bay will move it down. A four fin arrangement was selected due to the resulting symmetry, which was needed in order to orient two cameras 180° apart. 3/16 in thick fiberglass was selected because this thickness yielded the desired stability. The fins were designed to be attached through the wall of the airframe to the motor tube to provide more points of connection and ensure the fins are attached securely.

3.1.5.2 Material Suitability

The three main materials to be utilized in the construction of the launch vehicle are fiberglass, type II PVC, and plywood.

The main characteristics that provided the basis for which G12 fiberglass was selected were its compressive/tensile strength, RF transparency for the GPS locater, and its durability. Therefore, it serves as the main material in the launch vehicle. Fiberglass makes up the entire airframe (G12) and the fins (structural FRP) as it can withstand landing impacts and the aerodynamic stresses endured by the vehicle during flight multiple times without losing its physical characteristics or weakening. Additionally, G12 fiberglass is waterproof, so the likely scenario of landing in a wet area will not lead to warping or deterioration of the airframe. This characteristic is desirable as it makes assembly, disassembly and reassembly of the launch vehicle easy and repeatable, as the airframe sections retain their ability to seal and connect with each other.

All bulkheads in the launch vehicle are made of type II PVC as it has superior durability and tensile strength when compared to plywood. This strength is necessary as the bulkheads need to endure multiple ejections and subsequent tensile stresses caused by hanging on the shock cords. Additionally, type II PVC can be more easily machined to a high level of precision than plywood. This is to yield bulkheads that provide a tight seal, so the ejection charge gases do not escape through potential gaps in the airframe connections.

Plywood is utilized in the construction of internal structural elements in the lower aft airframe. The centering rings that secure the motor tube in place are all constructed of plywood. These components serve to center the motor and transfer the motor's thrust to the airframe. Therefore, plywood's sufficient shear strength and low density allow it to withstand the motor thrust while simultaneously not adding unnecessary weight to the aft assembly.

3.1.5.3 Motor Retention

A 54 mm RMS-54/2560 motor casing is used and is located in the motor tube. The motor remains centered within the launch vehicle due to the three centering rings that keep the motor tube aligned vertically. Each centering ring is epoxied to both the motor tube and the airframe. The forwardmost centering ring is located at the forward end of the motor tube. The central centering ring is located flush with the forward end of the fin tab and the aftmost centering ring is flush with the aft end of the fin tab. A 4 in 54 mm thrust plate is attached to the aftmost centering ring by screwing it in place with three 10-24 fasteners. An Aero Pack 54 mm motor retainer can be secured to the thrust plate using six 6-32 screws.

3.1.5.4 Final Mass Estimates

A mass table of the overall launch vehicle with predicted weights for each component was created (Table 2).

Nosecone Section		
Subsystem	**Component**	**Mass (oz)**
Structures	Nosecone with shoulder	20
Avionics and Recovery	GPS	0.8
Structures	Nosecone bulkhead	4.8
Structures	Eyebolt	1.0
Total		**27**
Forward Section		
Subsystem	**Component**	**Mass (oz)**
Structures	Forward airframe	32.2
Avionics and Recovery	Parachute protector	5.0
Avionics and Recovery	Main parachute	13.4
Avionics and Recovery	Recovery harness	16
Structures	Coupler and switchband	9.9
Structures	Bulkheads	9.6
Avionics and Recovery	Eyebolts	2

Avionics and Recovery	Avionics hardware	24
Total		**112**
Aft Section		
Subsystem	**Component**	**Mass (oz)**
Structures	Upper aft airframe	20
Structures	Lower aft airframe	28
Structures	Rail Buttons	0.7
Avionics and Recovery	Drogue parachute	6
Avionics and Recovery	Parachute protector	1.0
Avionics and Recovery	Recovery harness	16
Payloads	Electronics tubes	0.6
Structures	Epoxy (fillet estimate)	22
Structures	Motor tube	10
Structures	Centering rings	4.4
Structures	Forward closure	3.1
Structures	Aft closure	3.0
Structures	Motor casing	13.5
Structures	Thrust plate	4.8
Structures	Motor retainer	2.3
Flight Dynamics	Motor	66.4
Structures	Fins	33
Structures	Coupler and switchband	8.9
Structures	Bulkhead	4.8
Payloads	Payload hardware	20
Payloads	Cameras	5.4
Payloads	Eyebolt	1.0
Total		**275**
Launch Vehicle Assembly		
Overall Total		**414**

Table 2: Mass Table

3.1.6 Design Justification

3.1.6.1 Material Selection

Alternative materials were evaluated using decision matrices for each component. The following qualitative score assignments were used when evaluating qualitative objectives (Table 3).

Qualitative Score Assignments:	
great	10
good	8
okay	6
fair	4
poor	2

Table 3: Qualitative Score Assignments

3.1.6.1.1 Nosecone

Nosecone			**Polypropylene**			**G12 Fiberglass**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Cost	0.20	USD/lb	48.35	10.0	2.00	79.95	6.05	1.21
Density	0.35	lb/in^3	0.033	4.93	1.72	0.067	10.0	3.50
Tensile strength	0.45	ksi	6.50	0.57	0.25	115.0	10.0	4.50
Overall value					3.98			**9.21**

Table 4: Nosecone Material Decision Matrix

Two different materials were considered and were evaluated based on cost, density and tensile strength (Table 4). Despite polypropylene exhibiting superior cost-effectiveness, the material properties were the deciding factor between polypropylene and G12 Fiberglass. The nosecone is the first part of the launch vehicle to disturb the airflow in flight, so it is necessary for the nosecone to retain its precise aerodynamic shape. Additionally, the nosecone must be able to withstand forces from ejection events, from the shock cord and from landing impacts. It is also desirable to have a center of mass that is oriented forward of the center of pressure, so G12 Fiberglass' higher density, when compared to polypropylene, is another reason it scored higher. Therefore, the density and tensile strength of G12 fiberglass were the reasons for selecting it as the nosecone material.

3.1.6.1.2 Airframe and Coupler

Airframe/couplers			**G12 Fiberglass**			**Blue tube**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Cost	0.20	USD/in	1.95	3.54	0.71	0.83	8.31	1.66
Density	0.25	lb/in^3	0.067	6.87	1.72	0.059	7.80	1.95
Compressive strength	0.40	ksi	37.1	10.0	4.00	5.08	1.37	0.55
Machinability	0.15	resources required	Okay	6.00	0.90	Good	8.00	1.20
Overall value					**7.33**			5.36
Airframe/couplers			**Quantum tube**			**Phenolic**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Cost	0.20	USD/in	0.81	8.52	1.70	0.69	10.0	2.00
Density	0.25	lb/in^3	0.048	9.65	2.41	0.046	10.0	2.50
Compressive strength	0.40	ksi	18.2	4.92	1.97	13.5	3.63	1.45
Machinability	0.15	resources required	Good	8.00	1.20	Good	8.00	1.20
Overall value					7.28			7.15

Table 5: Airframe/couplers Decision Matrix

Four different materials were considered and were evaluated based on cost, density, compressive strength, and machinability (Table 5). The airframe and couplers require high compressive strength to withstand the dynamics of flight and landing, and while Blue Tube, Quantum Tube, and Phenolic demonstrate superior characteristics in cost, density, and machinability, they do not possess as much strength. G12 Fiberglass however does possess high compressive strength. The superiority of G12 in strength as a material gives it the highest composite score in the decision matrix, and thus is the material selected for the airframe and couplers.

3.1.6.1.3 Motor tube

Motor tube			**G12 Fiberglass**			**Blue tube**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Cost	0.20	USD/in	1.20	3.33	0.67	0.40	10.0	2.00
Density	0.25	lb/in^3	0.067	6.87	1.72	0.059	7.80	1.95
Compressive Strength	0.40	ksi	37.1	10.0	4.00	5.08	1.37	0.55
Machinability	0.15	resources required	Okay	6.00	0.90	Good	8.00	1.20
Overall value					**6.62**			3.70
Motor tube			**Quantum tube**			**Phenolic**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Cost	0.20	USD/in	0.96	4.17	0.830	0.71	5.63	1.13
Density	0.25	lb/in^3	0.048	9.58	2.40	0.046	10.0	2.50
Compressive Strength	0.40	ksi	18.23	4.92	1.97	13.5	3.63	1.45
Machinability	0.15	resources required	Good	8.00	1.20	Good	8.00	1.20
Overall value					5.57			5.15

Table 6: Motor Tube Materials

Four materials were judged based on cost, density, compressive strength and machinability (Table 6). These materials were G12 fiberglass, blue tube, Quantum tube, and phenolic tube. G12 Fiberglass was ultimately selected as the material for the motor tube based on its high tensile strength and density. The motor tube encases the motor casing and motor and therefore experiences intense tensile stress during flight and thus must be able to withstand these forces. It additionally needs to be heat resistant, which G12 fiberglass is. Since G12 fiberglass can withstand these forces, but also possesses a superior density, it scored highest in the decision matrix, and thus was selected.

3.1.6.1.4 Bulkheads

Bulkheads			**Structural FRP Fiberglass**			**Plywood**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Density	0.10	lb/in^3	0.065	3.23	0.32	0.021	10.0	1.00
Tensile Strength	0.40	ksi	13.5	10.0	4.00	4.50	3.33	1.33
Manufacturing time	0.15	min	16.00	4.38	0.66	7	10.0	1.50
Assembly	0.35	ease of assembly	fair	4.00	1.40	Fair	4.00	1.40
Overall value					6.38			5.23
Bulkheads			**Type II PVC**					
Objective	Weighting Factor	Parameter	Mag.	Score	Value			
Density	0.10	lb/in^3	0.049	4.29	0.43			

Tensile Strength	0.40	ksi	7.54	5.59	2.23
Manufacturing time	0.15	min	40.0	1.75	0.26
Assembly	0.35	ease of assembly	Great	10.00	3.50
Overall value					**6.43**

Table 7: Bulkheads Decision Matrix

Three materials were judged based on density, tensile strength, manufacturing time and ease of assembly (Table 7). The materials were structural FRP fiberglass, plywood and Type II PVC. The final selected material for the bulkheads was determined to be Type II PVC. Using PVC as a material has the advantage of only consisting of one piece to construct the bulkhead. The alternative materials would require epoxying two separate components together to assemble the bulkhead. Furthermore, PVC is unlikely to have defects and can sufficiently seal the coupler from the rest of the launch vehicle. Therefore, Type II PVC was selected as the bulkhead material for its ease of assembly and material strength.

3.1.6.1.5 Centering rings

Centering rings			**Structural FRP Fiberglass**			**Plywood**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Density	0.25	lb/in^3	0.065	3.23	0.81	0.021	10.0	2.50
Shear strength	0.45	ksi	21.5	10.0	4.50	5.00	2.33	1.05
Manufacturing time	0.30	min	13.00	3.85	1.15	5	10.0	3.00
Overall value					6.46			**6.55**

Centering rings			**Type II PVC**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value
Density	0.25	lb/in^3	0.049	4.29	1.07
Shear strength	0.45	ksi	1.50	0.70	0.31
Manufacturing time	0.30	min	25.0	2.00	0.60
Overall value					1.99

Table 8: Centering Rings Decision Matrix

For the centering rings, three materials were judged based on density, shear strength and manufacturing time (Table 8). Those materials were structural FRP fiberglass, plywood and Type II PVC. Based on the evaluation criteria, plywood was selected as the final material for the centering rings. Although plywood has a lower shear strength than fiberglass, it is still sufficiently strong. The centering rings were designed with two holes for the electronics tubes to pass through, causing the creation of stress concentrations in those areas. However, the holes were only designed in the forward and central centering rings. Since the motor transfers most of the force to the airframe through the aft centering ring, rather than the two forwardmost centering rings, the stress concentrations are negligible. Additionally, plywood is less dense of a material than fiberglass, meaning that the plywood used must be thicker to have a similar strength. As a result, the higher thickness of the plywood design had a greater cross-sectional area of contact with the airframe and a more reinforced epoxy bond. Therefore, plywood was the optimal material for the centering rings.

3.1.6.1.6 Fins

Fins			**Structural FRP Fiberglass**			**Plywood**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Cost	0.15	USD/ft^2	14.39	2.85	0.43	4.10	10.0	1.50
Density	0.20	lb/in^3	0.065	3.23	0.65	0.021	10.0	2.00
Shear strength	0.45	ksi	21.5	10.0	4.50	5.00	2.33	1.05
Manufacturing time	0.10	min	8.20	7.34	0.73	6.02	10.0	1.00
Overall value					**6.31**			5.55

Table 9: Fins Decision Matrix

Two materials were judged based on their cost, density, shear strength and manufacturing time (Table 9). These two materials were structural FRP fiberglass and plywood. Structural FRP fiberglass was chosen for the fin material based on the vastly superior shear strength when compared to plywood. The fins need to withstand the shear forces endured when impacting the ground upon landing. Since structural FRP fiberglass is approximately four times stronger than plywood in shear, it earned a higher score in the decision matrix. Therefore, it was selected as the material for the fins.

3.1.6.1.6 Epoxy

G5000 RocketPoxy was selected as the binding agent for the fins due to its superior malleability. Other epoxies, such as JBWeld, harden very quickly and are very difficult to smooth out upon application. Therefore, as the exterior fillets that secure the fins need to be smooth and aerodynamic, RocketPoxy was selected. RocketPoxy was also used for the interior fin connection points except for those on the motor tube. For fin connections and centering ring connections to the motor tube, JBWeld was used. This is because these connections must be able to withstand the heat produced by the motor, and JBWeld can withstand this heat.

3.1.6.2 Dimensional Justification

The selected airframe has a nominal outer diameter of 4.0 in. It was selected as the payload, avionics systems, parachutes, motor system and all associated electronics would fit within an airframe of this diameter. A larger airframe diameter would provide an unnecessary amount of extra space and would yield additional weight and complexity. The forward, upper aft and lower aft airframe have the same inner and outer diameters of 3.90 in and 4.02 in, respectively.

The nosecone dimensions are derived from the constraints of an ogive style nosecone with a base outer diameter of 4.02 in. The nosecone length was constrained by the available off the shelf parts.

The switchband length of 1.0 in was selected as it only needs to frame the holes for the key-lock switches, which are 0.75 in diameter holes, and provide a flush mating point between airframe sections. Therefore, a 1.0 in switchband was deemed sufficient to provide this mating point and frame the key-lock switch holes.

The forward airframe length of 37 in was selected because it is of a sufficient magnitude to house the forward half of the avionics bay, the main parachute, the main parachute protector, insulation material, the nosecone shoulder, the nosecone ejection charges, and the parachute shock cords within an inner diameter of 3.90 in. This length also provides space to account for the somewhat indeterminate dimensions of the parachute and insulation material.

The avionics bay length of 9 in was chosen to effectively house the avionics systems sled, batteries, and associated wiring. Additionally, this dimension provides a length of one body diameter for the airframe to encase, giving the connection point between the forward airframe and the avionics bay adequate structural strength. The forward and aft bulkheads are designed to fit into the avionics bay while acting as an end cap. Their outer thickness is 0.5 in. This dimension was selected on the basis that 0.5 in is sufficient to protect the avionics systems from the concussion of the black powder ejection charges.

The upper aft airframe length of 23 in was selected as that length is long enough to house the forward half of the payload bay, the aft half of the avionics bay, the drogue parachute, ejection charges, insulation material and the drogue parachute shock cord within an inner diameter of 3.90 in while also providing enough room to account for the uncertainty associated with the dimensions of the drogue parachute and insulation material.

The payload bay length of 8 in was selected so the payload, batteries, and associated electronics could be safely housed within the payload bay. This dimension also provides a sufficient length of tube for the upper aft airframe to encase so the connection point between the upper aft airframe and the payload bay possesses adequate structural strength.

The lower aft airframe length of 31 in was selected so the aft half of the payload bay, motor casing, motor tube, motor tube centering rings and wiring raceways can all be effectively housed within the 3.90 in inner diameter of the aft airframe.

3.1.6.2.1 Fin Flutter Velocity Calculations

The fin root chord and tip chord of 10 in and 5 in respectively, along with the height of 4 in were selected as this trapezoidal fin design provides a stability that meets the requirements of the NASA SL competition. The stability these fins provide is a maximum of 4.75 cal. The thickness of 0.187 in was selected based on the fact that the thickness possesses necessary strength to withstand normal impact forces upon landing.

An approximation for the fin flutter velocity of the fins is calculated using the Flutter Boundary Equation described in Apogee Peak of Flight Issue 291, which uses a modified version of the same equation found in NACA Technical Paper 4197 by using the shear modulus of the fin material instead of the torsional modulus. Fin flutter is predominantly a function of fin thickness, shape, and material choice (Equation 2). The equation is scripted in MATLAB allowing the team to rapidly determine fin flutter velocities for different fin configurations. The fin flutter analysis uses standard sea level values for pressure and speed of sound. Values used for the calculation of the fin flutter velocities for the launch vehicle's fins are provided in Table 10.

$$V_f = a\sqrt{\frac{\frac{G}{1.337AR^3P(\lambda+1)}}{2(AR+2)\left(\frac{t}{c}\right)^3}}$$

Equation 2

Variables for Flutter Boundary Equation			
Name	**Variable**	**Value**	**Unit**
Speed of Sound	a	1144.1	ft/s
Shear Modulus	G	435113	lbs/in^2
Aspect Ratio	AR	0.5667	-
Air Pressure	P	14.696	lbs/in^2
Thickness	t	0.1875	in
Chord	c	15	in
Tip:Root Chord ratio	λ	0.5	-

Table 10: Variables for Flutter Boundary Equation

The fin flutter velocity for the full-scale launch vehicle is determined to be 1031.79 ft/s. The max velocity of the launch vehicle during flight is 619 ft/s, representing a factor of safety of 1.67. The resulting factor of safety was deemed acceptable for stable flight.

3.1.6.3 Component Placement Justification

The GPS that will be used to verify the location of the launch vehicle will be located in the nosecone of the launch vehicle to distance it from the ejection charges and altimeters. The GPS is also located in the nosecone to make it easier to shield the altimeters from the GPS with the use of Aluminum foil on the Nosecone Bulkhead.

A drogue parachute is located in the upper aft airframe and a main parachute is located in the forward airframe. The main parachute is located more forward than the drogue parachute because it is heavier and will move the center of gravity of the launch vehicle slightly more forward than if the drogue parachute was more forward than the main parachute.

Two cameras located 180° apart are used to collect image data throughout flight. They need to be located near the aft end of the launch vehicle in order to collect the images. Since the cameras have wires that need to connect to the payload bay, the payload bay is located in the aft section. The two kraft paper tubes are located in the lower aft airframe and run through the two forwardmost centering rings in order to house the wires. The aft section consists of two airframes with the payload bay coupled between them. Two airframes are used to improve the ease of access to the payload bay during launch preparation.

There are two rail buttons. The forwardmost rail button is located at the launch vehicle's center of gravity and the aftmost rail button is located between the two aftmost centering rings. The forwardmost rail button location was selected to ensure a more stable launch off the launch rail. The aftmost rail button location was selected to ensure the launch vehicle remains stable as it exits the rod.

The fins are located at the aft end of the launch vehicle in order to move the center of pressure behind the center of gravity and increase the launch vehicle's stability. The fin tabs are flush with the two aftmost centering rings, which help keep them in place.

3.2 Subscale Flight Results

3.2.1 Scaling Factor

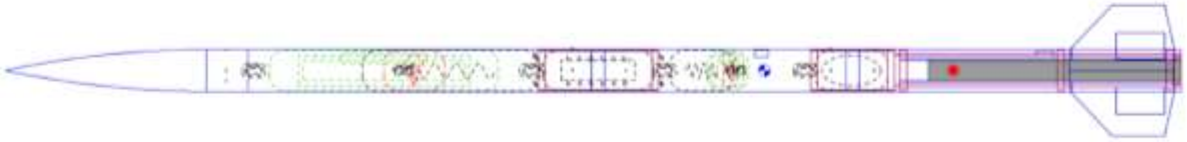


Figure 27: Subscale OpenRocket Model

The premise of achieving aerodynamic similarity between the subscale model with the full scale model implies and demonstrates the success of the full scale model by conducting experiments on a similar system. While it is difficult to achieve complete similarity, the subscale model strived to achieve geometric, kinetic, and dynamic similarity where possible (Figure 27). Due to the competition's 75% maximum guideline for scaling dimensions, geometric similarity was prioritized initially. Dynamics similarity was not achieved; however, a few circumstances justified that the results were valid for analysis. When both dynamic similarity and geometric similarity are achieved, kinematic similarity is also achieved therefore it was not prioritized directly.

Geometric similarity exists when the two models look exactly alike in shape yet have different dimensions that are scalable to another. To create geometric similarity, the launch vehicle diameter was scaled by a factor of 75% to arrive at a nominal diameter of 3 inches. Similarly, the launch vehicle length was scaled by a factor of 75% for a length of 87 inches. The overall shape of the launch vehicle was kept constant as both subscale and full-scale models had Ogive nosecones, and the same trapezoidal fin shapes. This allows the general aerodynamic effects to be reciprocated between both models because all angles, and flow directions are preserved. The motor mount tube, centering rings, bulkheads, motor casing, and closures were also scaled down to fit the 3" diameter. Furthermore, the same rail buttons, eyebolts, quick links, shear pins, and rivets were used for the subscale as the full scale. A part of the launch vehicle that was unable to maintain geometric similarity were the external camera mounts due to the space required to fit the cameras. Moreover, the desired nosecone was not delivered in time so the intended material of the nosecone changed from the planned fiberglass to a plastic nosecone. However, this did not affect the scaling factor for the nose cone. Finally, the motor retainer used was a screw-on retainer that needed to be glued to the motor tube and does not match the same retention system intended for full scale. However, the manufacturer did not have the same retention system available for the 38mm motor tube therefore the motor retention system was limited to what was available.

To achieve dynamic similarity, the velocity of the launch vehicle was the biggest factor. This is largely determined by the thrust to weight of the launch vehicle, and the motor selection. The motor used in the full-scale will be an Aerotech L1090W providing a thrust to weight ratio of 9.2. The motor used in the subscale was an Aerotech J570W providing a thrust to weight ratio of 6.84 where the mass of the subscale is 7.5 kg. Therefore, the thrust to weight ratio was unable to be maintained constant due to difficulties finding motors for the specified diameter of the subscale. The avionics weight used in the subscale was equal to the avionics weight used in the full scale. Therefore, a motor with a larger thrust would have been needed to replicate the full scale. However, the only motors available for 3” diameter body tube were 38mm motors or smaller. Most other 38mm motors were unable to provide the over 1000 N of initial thrust needed to make the thrust to weight ratios equivalent. The Aerotech J570W was one of the few 38mm motors that allowed for the capability to reach a thrust to weight ratio of 6.84. Due to this, the target altitudes were also adjusted and were not able to be scaled. However, to estimate the drag coefficient in the future the rail exit velocities were considered. In the instance where the rail exit velocities were equivalent, the models would be the most dynamically similar allowing us to understand useful information about how to use a method of determining the drag coefficient.

The subscale parachutes were selected to try and best imitate the descent rates of the full scale launch vehicle. The drogue parachute for the susbscale was selected to be a 24 in Rocketman parachute with a coefficient of drag of 0.97. Since the construction and flight of the subscale vehicle, this drogue parachute has also become the drogue parachute for the full scale launch vehicle. At the time of designing and selecting the drogue parachute, the Skyangle C3 was still the drogue parachute and provided a slower descent rate for the full scale launch vehicle. The 24 in. Rocketman parachute provided a simulated descent rate of 68.3 ft/s about 14 ft/s slower than the drogue descent rate of the full scale launch vehicle. The main parachute of the subscale launch vehicle was selected to be the 60 in Rocketman Elliptical Parachute with a coefficient of drag of 1.6. This parachute provided a simulated descent rate of 22.5 ft/s. This is about 5 ft/s faster than the chosen full scale main parachute. This provides a simulated kinetic energy for the aft section of 71 ft-lbs. This is only 9 ft-lbs over the predicted kinetic energy for the full scale aft section

A subscale payload was flown within the subscale launch vehicle. The subscale payload was a prototype, testing the mechanical structures of the payloads design. To appropriately scale down the payload in accordance with the subscale launch vehicle design, the payload bay was set to a total length of 6.25 in. Since the payload bay was shorter than the full-scale, the payload design had to be slightly altered to fit in the new payload bay. During this design phase, it was realized that the payloads design for full-scale could be greatly simplified following the subscales design. The subscale flight was then used as a test for the new mechanical structure’s designs. The retention system of the payload and the camera mounts were changed during the subscale design. The new designs were more modular and made assembly more efficient. The subscale flight was a success, with all the mechanical structures performing as planned. Electronics were placed on board, but no electronics or software was tested during the subscale flight. The electronics were used to test the mechanical structure’s ability to house and protect the electronics during flight. The design changes made during the subscale launch directly affected the design of the full-scale payload, where many of the changes were incorporated.

3.2.2 Launch Conditions and Simulation

The successful launch occurred at the first attempt on where the following launch conditions were noted (Table 11):

Subscale Launch Conditions	
Wind	1.2 m/s
Launch Angle	5 deg
Launch Rod Length	98 in
Latitude	26.8 N
Longitude	-81.3 E
Elevation	24 ft
Temperature	17 ˚ F
Pressure	1 atm

Table 11: Subscale Launch Conditions

An OpenRocket Simulation was run under these conditions yielding an apogee altitude of 2,028 ft. The altitude with respect to time was simulated (Figure 28). The total velocity and total acceleration were also simulated (Figure 29, Figure 30).

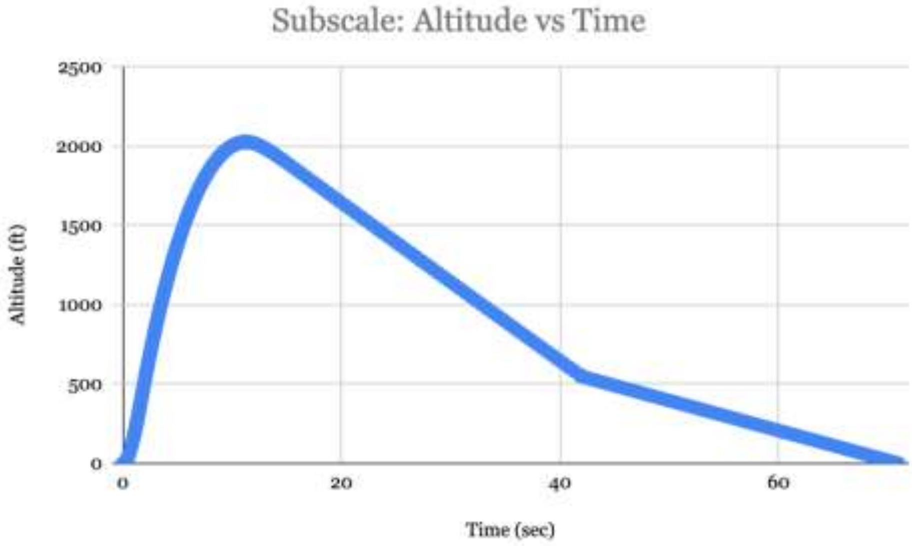


Figure 28: Subscale Altitude vs. time

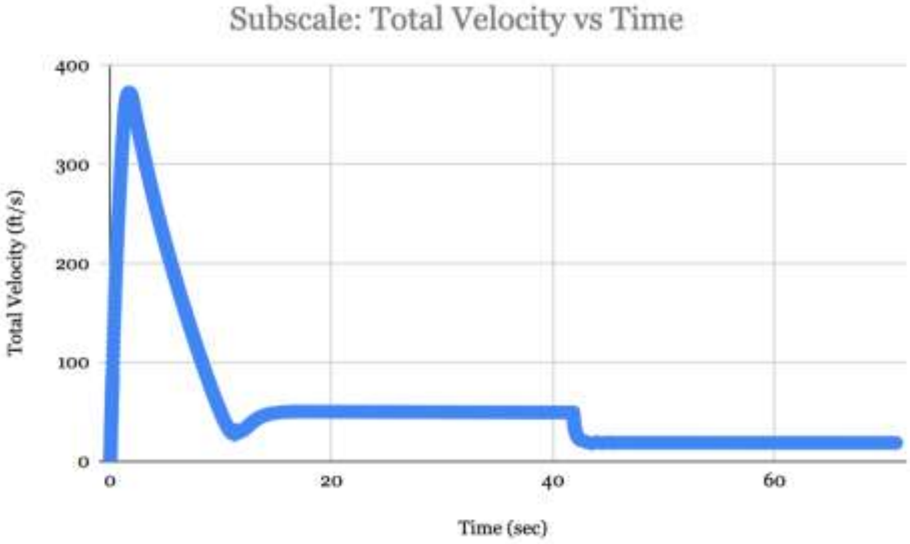


Figure 29: Subscale Velocity vs. Time

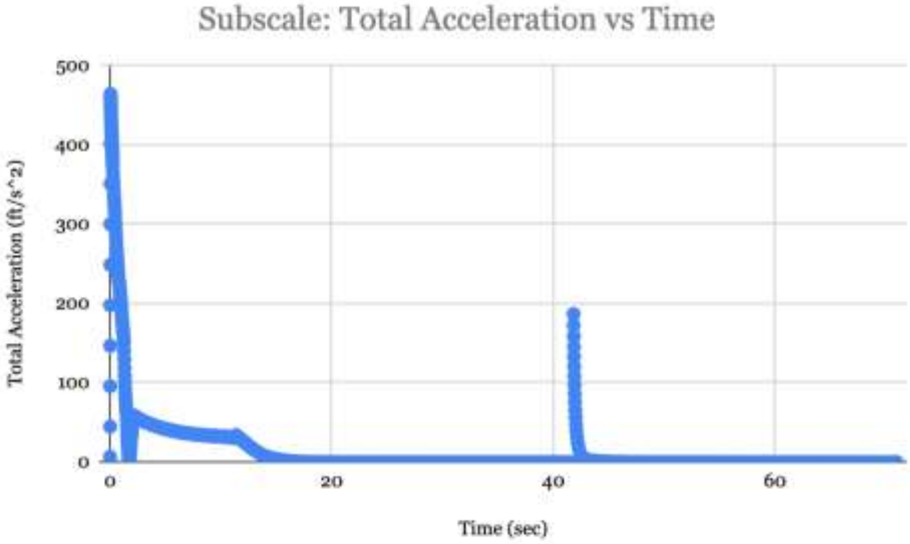


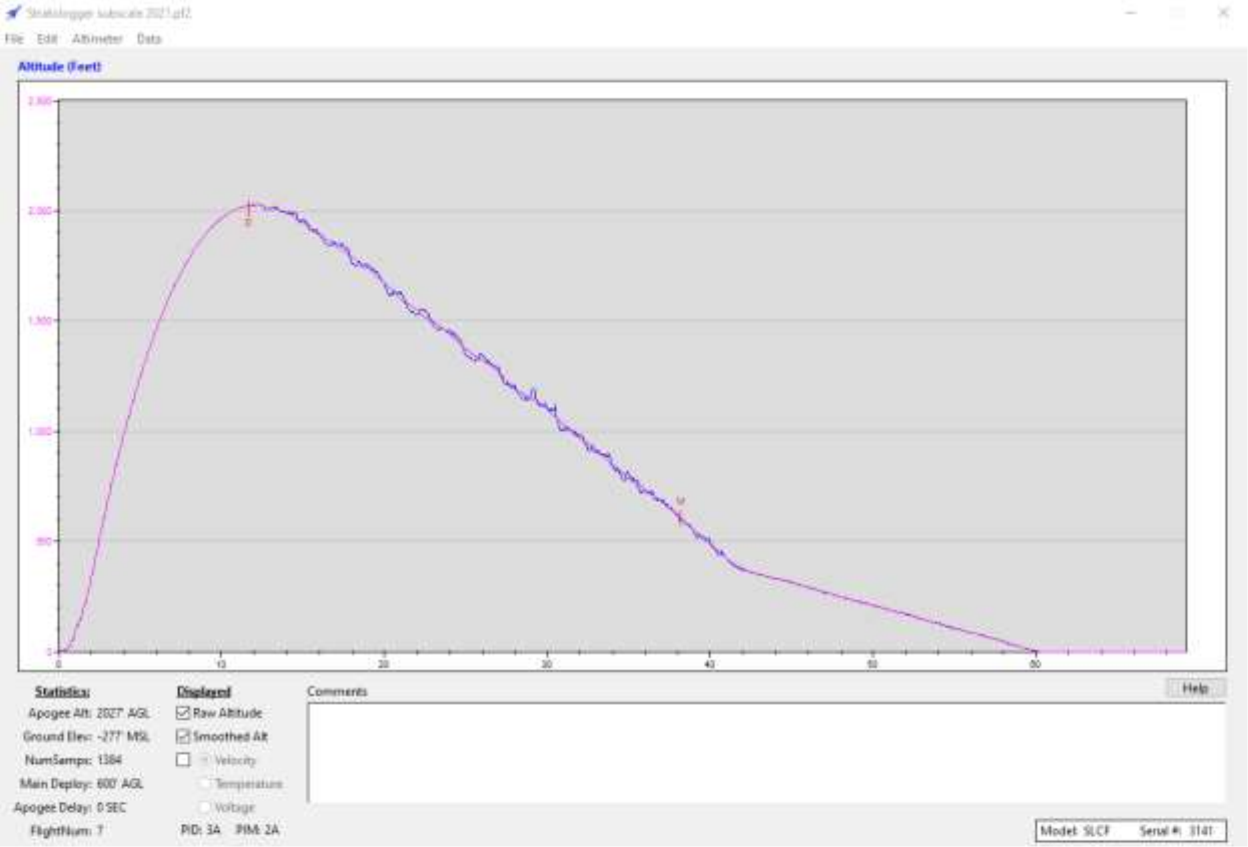
Figure 30: Subscale Acceleration vs. time

3.2.3 Subscale Flight Analysis

The experimental apogee altitude fell 1 foot shorter than that predicted by the simulation, with a recorded apogee of 2,027 ft. The relative error to the modeled simulation is negligible however differs due to the imperfect wind model that cannot be accurately predicted. However, implementing multiple simulations would allow the simulated data to be more robust to represent the experimental data. A few measurements confirmed the accuracy of the model. One being the location of the center of gravity, which matched the simulated center of gravity. The last being the accurate weight measurements pulled from manufacturer websites and confirmed on delivery of products. This combination paired with protective manufacturing techniques prepared a model that accurately represented the subscale launch vehicle. While inconsistencies with surface finish and possibly with manufacturing are likely to exist, minimizing inconsistencies allowed the subscale to replicate the simulated model.

3.2.3.1 Flight Data

The first subscale test was a success, and the recorded apogee was 2,027 ft. The altitude of the launch vehicle with respect to time was measured (Figure 31) as well as the velocity of the launch vehicle with respect to time (Figure 32). Compared to the simulated profiles, the altitude profile matches pretty similarly. However, the recorded velocity profile shows oscillations in the velocity of the launch vehicle that the simulated velocity profile does not reflect. This may be due to the fact that OpenRocket does not consider the variable changes of velocity that occurs when the drogue parachute is deployed. When the drogue is deployed, the paired with the parachute causes changes in direction and magnitude of the recorded velocity. These changes may even be emphasized due to the sensitivity of the sensors.



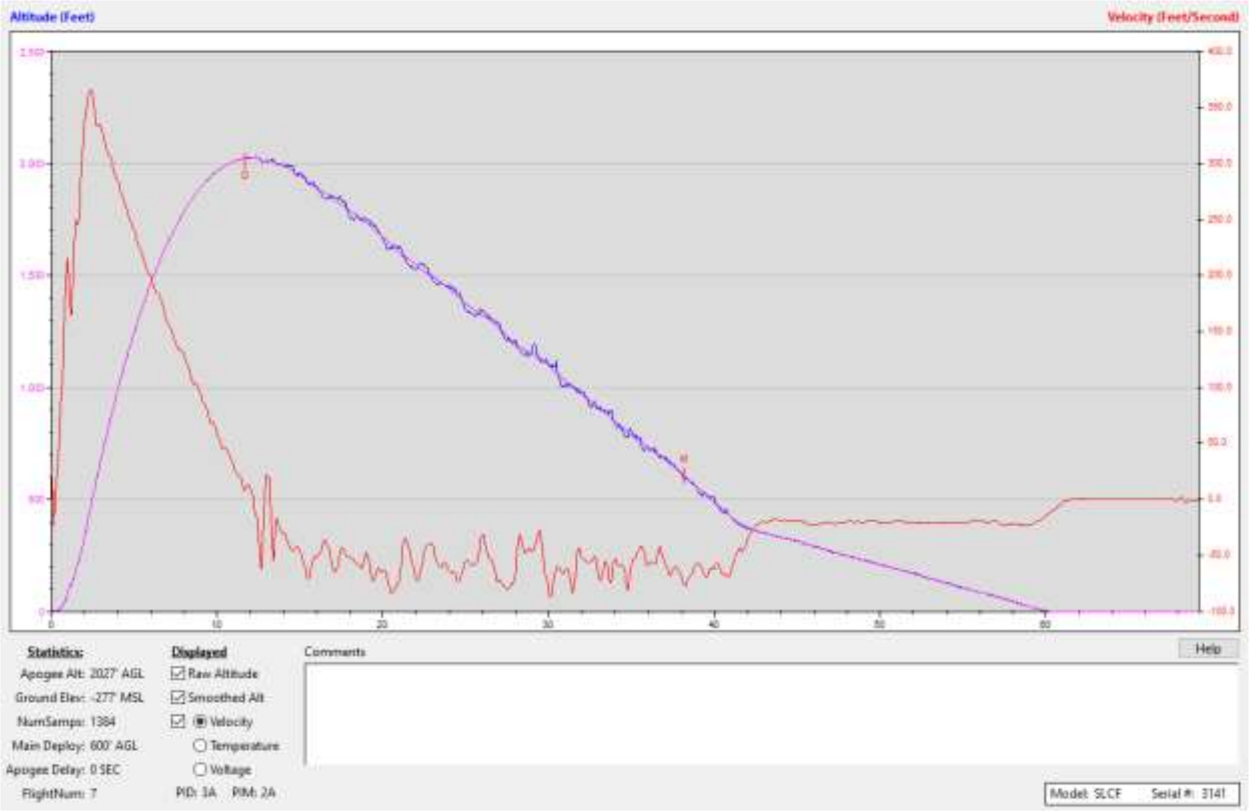
Statistics:
Apogee Alt: 2027' AGL
Ground Elev: -277' MSL
NumSamps: 1384
Main Deploy: 600' AGL
Apogee Delay: 0 SEC
FlightNum: 7

Displayed
☑ Raw Altitude
☑ Smoothed Alt
☐ ○ Velocity
○ Temperature
○ Voltage
PID: 3A PIM: 2A

Comments

Model: SLCF Serial #: 3141

Figure 31: Subscale Resulting Altitude vs. Time



Statistics:
Apogee Alt: 2027' AGL
Ground Elev: -277' MSL
NumSamps: 1384
Main Deploy: 600' AGL
Apogee Delay: 0 SEC
FlightNum: 7

Displayed
☑ Raw Altitude
☑ Smoothed Alt
☑ ● Velocity
○ Temperature
○ Voltage
PID: 3A PIM: 2A

Model: SLCF Serial #: 3141

Figure 32: Subscale Resulting Velocity vs. Time

3.2.3.2 Drag Coefficient Estimation

To determine the drag coefficient, the subscale drag coefficient cannot be used because dynamic similarity and kinematic similarity were not entirely maintained. Instead, the subscale data validated the processes of using both OpenRocket and MATLAB to determine a drag coefficient. In particular the method of altitude backtracking was implemented to both processes. First, the actual height of the rocket was considered based on the data from the altimeter. Next, a simulation using a fixed coefficient of drag (0.75) was run. Then, compare the altitude that is predicted by either OpenRocket or MATLAB against the altitude recorded by the altimeter. Finally, adjust the coefficient of drag accordingly where if the simulation underestimates the altitude then decrease the coefficient of drag. Keep iterating till the final coefficient of drag matches the actual altitude that was recorded. This process validated that the back-tracked coefficient of drag was about 1.53. This value was predicted by OpenRocket (1.51) and validated by MATLAB (1.55), therefore it validated that using the simulations available can be used to accurately determine the drag coefficient of the full scale. Using this method, the full scale's coefficient of drag is estimated to be 0.97.

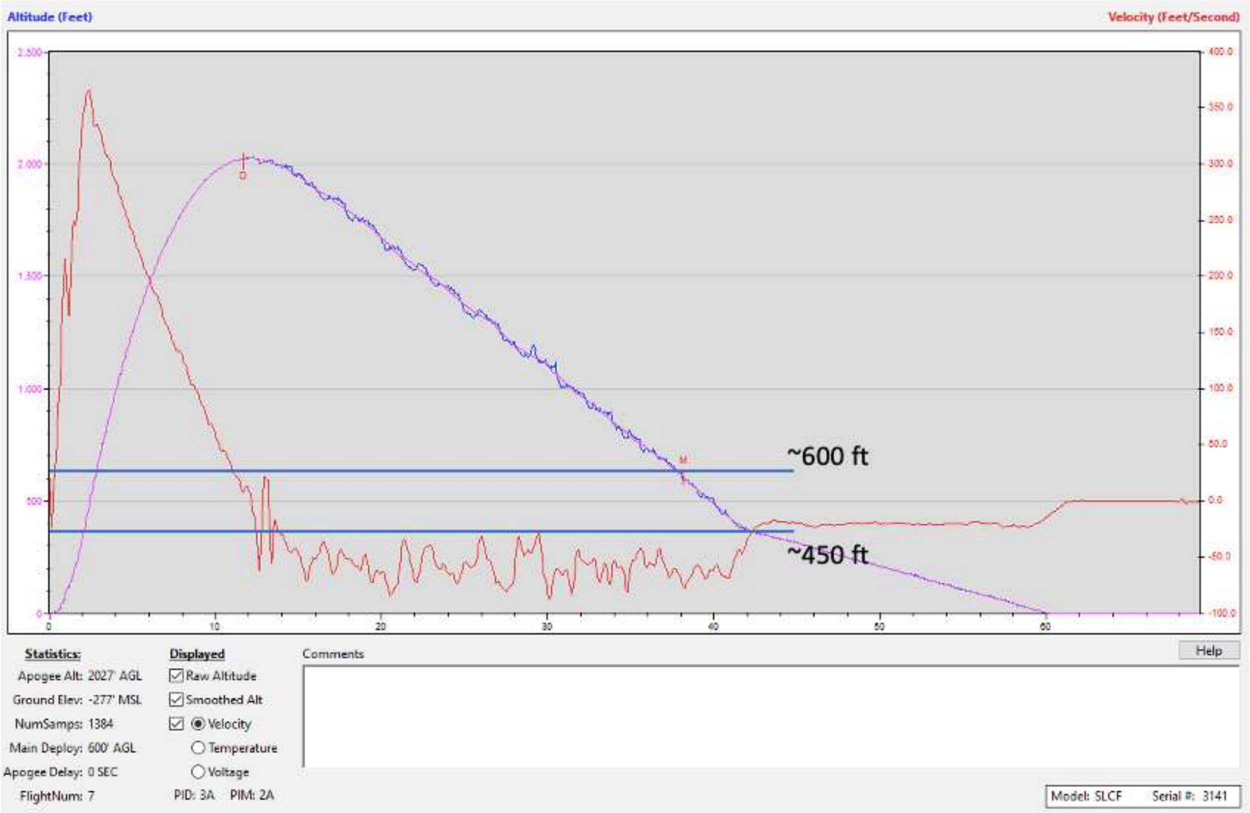
3.2.4 Impact on Full Scale Design

The successful subscale flight validated many different aspects from modeling to manufacturing. Understanding the precautions that were taken, such as taking into account the epoxy weight and accurate masses pulled from the manufacturer, has indicated value to the team. It will further be implemented when preparing the full scale launch vehicle. One of these notes that will be used for full scale is measuring all masses and dimensions throughout the process of developing the launch vehicle. This allowed plenty of time to reduce the margin of errors that occur. The mounting of the keylock switches inside of the Avionics Bay instead of mounted directly to the switch band made assembly much simpler on the field than expected.

The subscale results indicate that the design of the fins, as well as the overall dimensions/shape of the launch vehicle will be favorable. The subscale results also indicate the importance of ensuring the camera mounts do not protrude too far, as they increase the drag of the launch vehicle. This will be addressed in the full scale launch vehicle.

3.2.5 Descent Analysis

Both parachutes successfully deployed during the launch, the altimeter data suggested that the main parachute may not have fully deployed until the secondary ejection charge went off. The primary ejection charge went off around 600 ft, but there was no major change in descent rate until around 450 ft, about 100 ft below the secondary ejection charge's programmed altitude (Figure 33). The delay in deployment suggests that the primary ejection charge may have not been sufficient to cause separation. The full scale ejection charges will be increased to account for this potential risk. The additional time it took for the parachute to inflate may be due to the tight packing of the main parachute in the subscale airframe. The drogue and main parachutes also performed as predicted with an average drogue descent rate around 60-70 ft/s and an average main descent rate around 20 ft/s. The altimeter data suggests there were large variation in the velocity of the launch vehicle. This may be due to wind blowing against the barometer on the altimeter and changing the perceived altitude as the launch vehicle swung violently during descent.



Statistics:

Apogee Alt: 2027' AGL

Ground Elev: -277' MSL

NumSamps: 1384

Main Deploy: 600' AGL

Apogee Delay: 0 SEC

FlightNum: 7

☑ Raw Altitude

☑ Smoothed Alt

☑ ● Velocity

○ Temperature

○ Voltage

PID: 3A PIM: 2A

Model: SLCF Serial #: 3141

Figure 33: Subscale Deployment Data

The GPS was functional for the subscale flight. It was not able to be mounted in the Nosecone Section due to part ordering difficulties encountered during subscale construction. It was mounted in the Payload Bay alongside the payload prototype electronics and was able to successfully transmit the launch vehicle's location (Figure 34). The GPS will not be located in the Payload Bay for the full scale launch vehicle.

Figure 34: GPS

The wind speed at the launch field were no greater than 5 mph for the subscale launch. This is one of the reasons the launch vehicle did not experience significant drift during descent. It only drifted about 670 ft from the launch site (Figure 35).

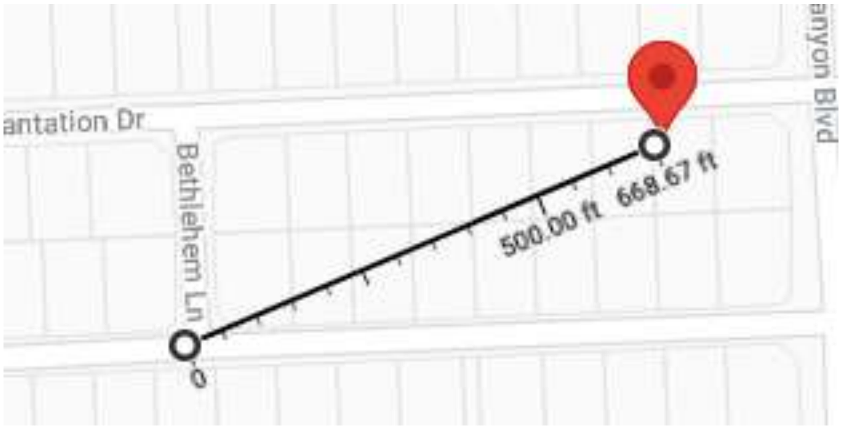


Figure 35: Subscale Drift Results

3.3 Recovery Subsystem

The recovery subsystem consists of parachutes, recovery harnesses, eyebolts, ejection charges, altimeters, and a GPS. The parachutes' sizing and descent rate were verified using the OpenRocket simulation developed by the Flight Dynamics Subteam.

3.3.1 Selected Components

The selected components were compared to alternatives in the Preliminary Design Review. Final selected components are presented.

3.3.1.1 Main Parachute

The main parachute was selected using a decision matrix during PDR (Table 12). This selection was verified using the mission performance predictions.

Main Parachute			**84" Iris Ultra Fruity Chutes**			**72" Iris Ultra Fruity Chutes**			**72" Rocketman Elliptical**			**Large Skyangle C3**			**60" Rocketman Elliptical**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
cost	0.2	USD	297.00	3.9	0.8	246.80	4.7	0.9	135.00	8.5	1.7	139.00	8.3	1.7	115.00	10.0	2.0
descent rate	0.35	ft/s	15.4	1.2	0.4	17.7	10.0	3.5	20.2	1.4	0.5	20.1	1.4	0.5	24.4	0.5	0.2
weight	0.1	oz	19.0	5.2	0.5	13.3	7.4	0.7	12.6	7.9	0.8	34.0	2.9	0.3	9.9	10.0	1.0
shroud lines	0.35	qualitative	great	10	3.5	great	10	3.5	good	8	2.8	good	8	2.8	good	8	2.8
Overall Value					**5.2**			**8.7**			**5.8**			**5.2**			**6.0**

Table 12: Main Parachute Decision Matrix

The main parachute that was selected for this design is the 72 in. Fruity IFC. This parachute was selected because it fits a variety of criteria that benefit the design. The coefficient of drag for the parachute is 2.2. In the OpenRocket simulation, this parachute provided a descent rate of 17.5 ft/s, a descent rate close to the target 18 ft/s. The shroud lines of this parachute are made from 400 lb Spectra cord, and are sufficiently strong to support the launch vehicle and the predicted deployment load. The parachute weights 13.3 oz and has a surface area of 47.5 ft^2.

3.3.1.2 Drogue Parachute

The drogue parachute was selected to be the Skyangle C3 drogue using a decision matrix during PDR (Table 13). This selection had to be changed to meet the 2500 ft drift radius requirement. The Skyangle C3 drogue has a descent rate 1.3 ft/s below the target descent rate. This caused the launch vehicle to descend for a longer amount of time and drift outside of the launch field radius.

Drogue Parachute			**18" Elliptical Fruity Chutes**			**24" Rocketman**			**24" Elliptical Fruity Chutes**			**Skyangle C3 Drogue**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
cost	0.2	USD	62.30	4.4	0.9	28.5	9.6	1.9	64.00	4.3	0.9	27.50	10.0	2.0
descent rate	0.35	ft/s	85.7	2.3	0.8	80.7	10	3.5	66.3	0.9	0.3	78.7	10.0	3.5
weight	0.1	oz	2.1	10.0	1.0	2.8	7.5	0.8	2.2	9.5	1.0	3.1	6.8	0.7
shroud lines	0.35	qualitative	Good	8	2.8	Good	8	2.8	Good	8	2.8	Great	10	3.5
Overall Value					**5.5**			9.0			**4.9**			**9.7**

Table 13: Drogue Parachute Decision Matrix

The selected drogue parachute is the 24” Rocketman parachute. With a descent rate of 80.7 ft/s, it does not cause the launch vehicle to drift outside of the launch field (3.6.1.2 Drift Calculations). The shroud lines are sewn 6 in up the canopy to minimize the risk of tearing during deployment. This parachute was selected due to it having the second highest overall score in the decision matrix, and it fitting the descent performance requirements.

3.3.1.3 Recovery Harness

The recovery harness for the launch vehicle is a 25 ft. long 7/16 in. wide tubular Kevlar. The recovery harness meets the team requirement of being at least 2.5 times the length of the launch vehicle. The Kevlar recovery harness was also chosen over other materials because of its high heat resistance when compared to nylon alternatives. Some of the recovery harness will be exposed to hot ejection charge gasses, and the heat resistance will help it maintain strength. The 7/16 in. thickness of the recovery harness will also help mitigate tearing of the airframe due to rubbing along the edge of the airframe as the parachutes deploy. The separated sections will be tethered using one recovery harness each. A total of two recovery harnesses will be used.

3.3.1.4 Hardware

The hardware chosen by the team was a 304 Steel Eyebolt with Shoulder with 0.75” inner diameter. It has a width of 1 inch and a length of 3 inches and weighs 0.998 oz. The small size of the eyebolt, when compared to similar U-bolts, reduces the space within the rocket that it will take up, freeing up that space to be used for terminal blocks or wire holes. It has a carrying capacity of 500 lbs. which is sufficiently strong for the launch vehicle’s weight of 375.5 oz after motor burnout and the expected deployment load of the main parachute (3.6.1.4 Predicted Deployment Load). The recovery harness will be secured to the eyebolts with the use of a quick link. The quick links that will be used are 9/32 in. thick and 2 inches long in an oval shape. They have a carrying capacity of 1000 lbs.

3.3.1.5 Altimeters

The altimeters were selected using a decision matrix during the PDR (Table 14). This selection has not changed.

Altimeter			**Entacore AIM Altimeter**			**Telemetrum Altimeter**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Volume	0.2	in^3	1.4	5.4	1.1	1.8	4.1	0.8
Weight	0.2	oz	0.4	7.5	1.5	0.7	4.2	0.8
Cost	0.3	USD	121.20	5.8	1.7	363.50	1.9	0.6
Resolution	0.3	ft	1	6.7	2.0	0.67	10.0	3.0
Overall Value					**6.3**			**5.2**
Stratologger CF			**EasyMega Altus Metrum**			**EasyMini Altimeter**		
Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
0.8	8.9	1.8	1.9	3.9	0.8	0.75	10.0	2.00
0.4	7.9	1.6	0.5	6.0	1.2	0.3	10.0	2.00
70.00	10.0	3.0	300.00	2.3	0.7	96.93	7.2	2.16
1	6.7	2.0	0.67	10.0	3.0	unknown	0.0	0.0
		8.4			**5.7**			**6.2**

Table 14: Altimeter Decision Matrix

The altimeters selected for the full scale launch vehicle are a Perfectlite StratloggerCF and an Entacore AIM. The StratologgerCF will be the primary altimeter and the Entacore AIM will be the secondary altimeter. Both altimeters are capable of dual deploy and recording flight data. Both altimeters will be powered by independent 9 volt batteries. These altimeters had higher scores when compared to the alternatives in the cost and size categories. These altimeters also have the two highest overall scores in the matrix.

3.3.1.6 Switch

A keylock switch was selected to be the arming method for the altimeters inside the avionics bay. The keylock switch was chosen over a push button due to its use of a unique insert to have an open or closed circuit. A push button would require protections against accidental arming with a cover or housing. These protections would make it more difficult when the time came to arm the altimeters but would be a necessary safety precaution. The keylock switch makes it difficult to accidentally arm due to handling of the launch vehicle, and it will minimize the risk of power loss due to in flight forces when it is locked on.

3.3.1.7 GPS

The selected GPS for the launch vehicle is a Big Red Bee 900. It has a transmission range of 6 miles. It is not connected to the payload system in any way. The Big Red Bee 900 uses a 904 MHz channel frequency to transmit the location of the launch vehicle to the receiver. The transmitter uses a LiPo battery and is expected to last 6 hours on a full charge. The Big Red Bee 900 was chosen over the Big Red Bee 70 cm 100 mW GPS due to the latter requiring an amateur license to operate.

3.3.2 Redundancy in the System

There are two altimeters present in the Avionics Bay. They are wired separately from each other and powered by their own batteries. The secondary altimeter has a half second time delay on the first separation ejection charge, and a 50 ft delay on the second separation ejection charge. The delays on the secondary ejection charges are to ensure that the airframe is not over pressurized or damaged. The secondary chargers are also 25% larger than the primary charges in case the primary charges fail to cause separation. This design allows for redundancy by maintaining separation electronically and through time between the primary and secondary events throughout the descent (Figure 36).

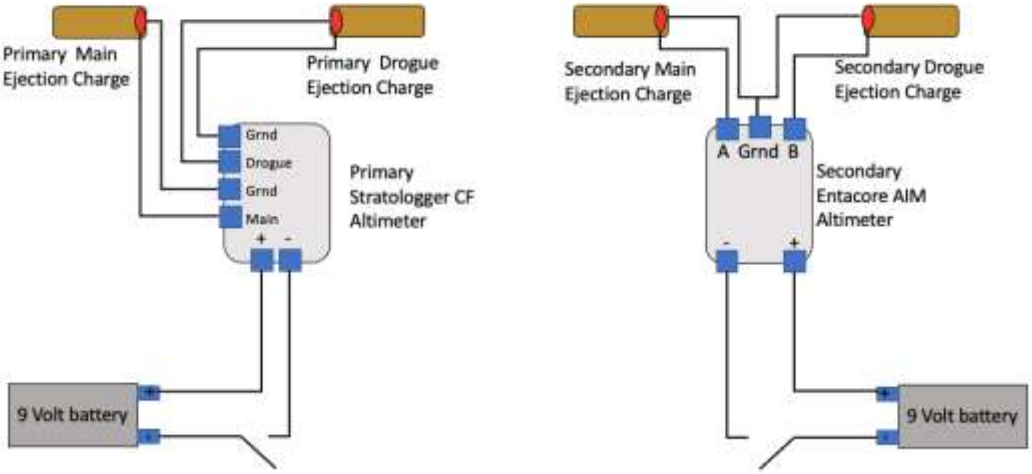


Figure 36: Altimeter Redundancy

3.4 Mission Performance Predictions

3.4.1 Launch Vehicle Parameters

An OpenRocket simulation was used to simulate the launch vehicle's performance. OpenRocket is a software that allows the user to model the rocket and numerically integrate the acceleration to the rocket's position and orientation during a time step and update the time. The software accomplishes this by computing atmospheric conditions, airspeed, angle of attack, and wind directions and then computing the aerodynamic forces and moments, effect of motor thrusts, masses, and moment of inertias to determine linear and rotational acceleration of the rocket.

The launch vehicle simulation parameters including the weights and overall dimensions are as shown illustrated in Table 2 and Section 1.2. The simulation is also shown in Figure 37.

Figure 37: Full Scale Launch Vehicle OpenRocket Simulation

3.4.2 Flight Profile Simulations

The flight simulation assumes the predicted flight conditions in Huntsville, Alabama (Table 15) Based on the simulation the launch vehicle achieves an apogee of 4579 ft, given these conditions (Figure 38). This apogee is 1 ft higher than the target apogee that was declared. It is estimated that 350 g would need to be added as ballast to reach the target altitude where 186 g would be added to the nose cone and 190 g would be added to the aft section. This value was determined through simulations of ballast distributions from 100 g to 500 g. The maximum velocity is 627 ft/s reaching a Mach number of 0.56 (Figure 39). The simulated velocity of the vehicle at rail exit is 88.6 ft/s when the Aerotech L1090W is used and the ground hit velocity is 17.7 ft/s. The maximum acceleration is 325 ft/s^2 (Figure 40).

Launch Conditions in Huntsville, Alabama	
Wind	10 mph
Launch Angle	5 deg
Launch Rod Length	144 in
Latitude	34.6 °N
Longitude	-86.7 °E
Altitude	800 ft
Temperature	62 °F
Pressure	1 atm

Table 15: Launch Conditions in Huntsville, AL

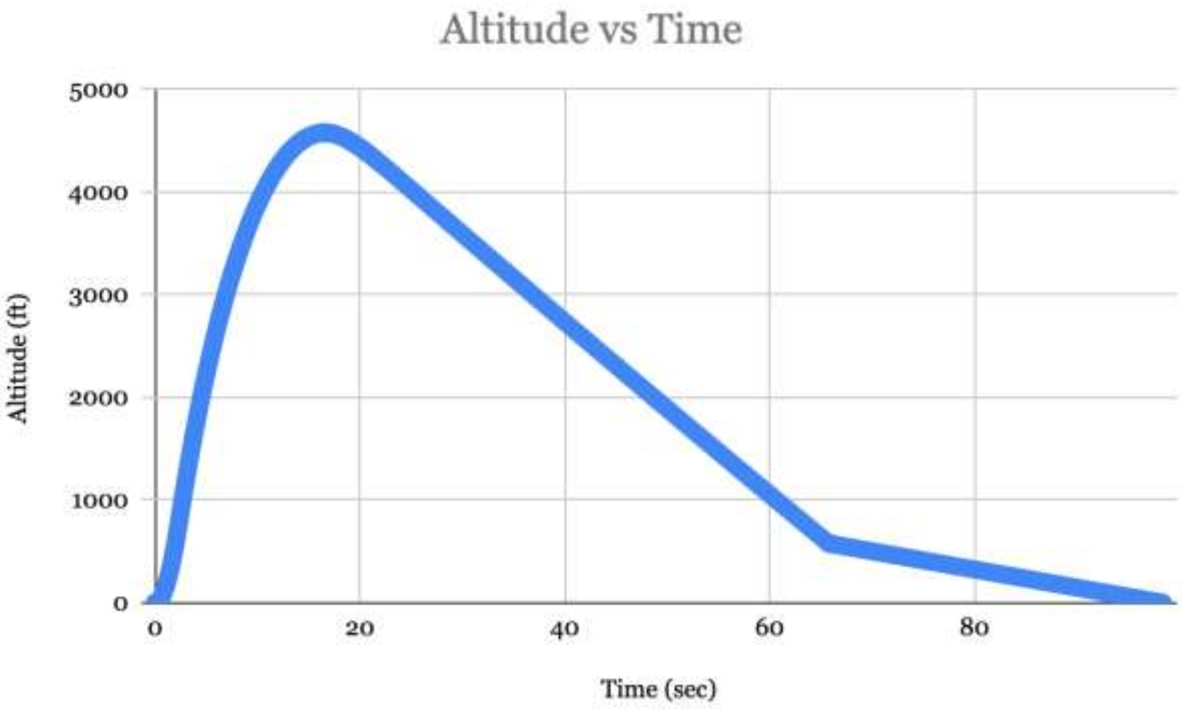


Figure 38: Simulated Altitude vs. Time

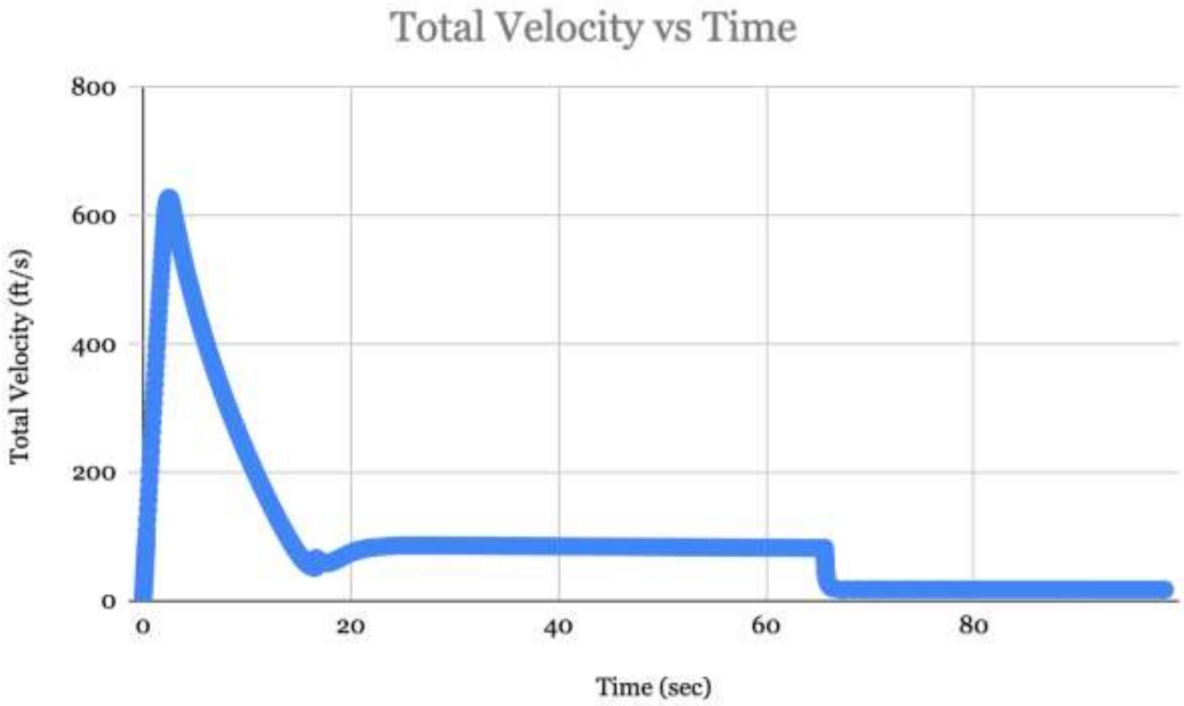


Figure 39: Simulated Total Velocity vs. Time

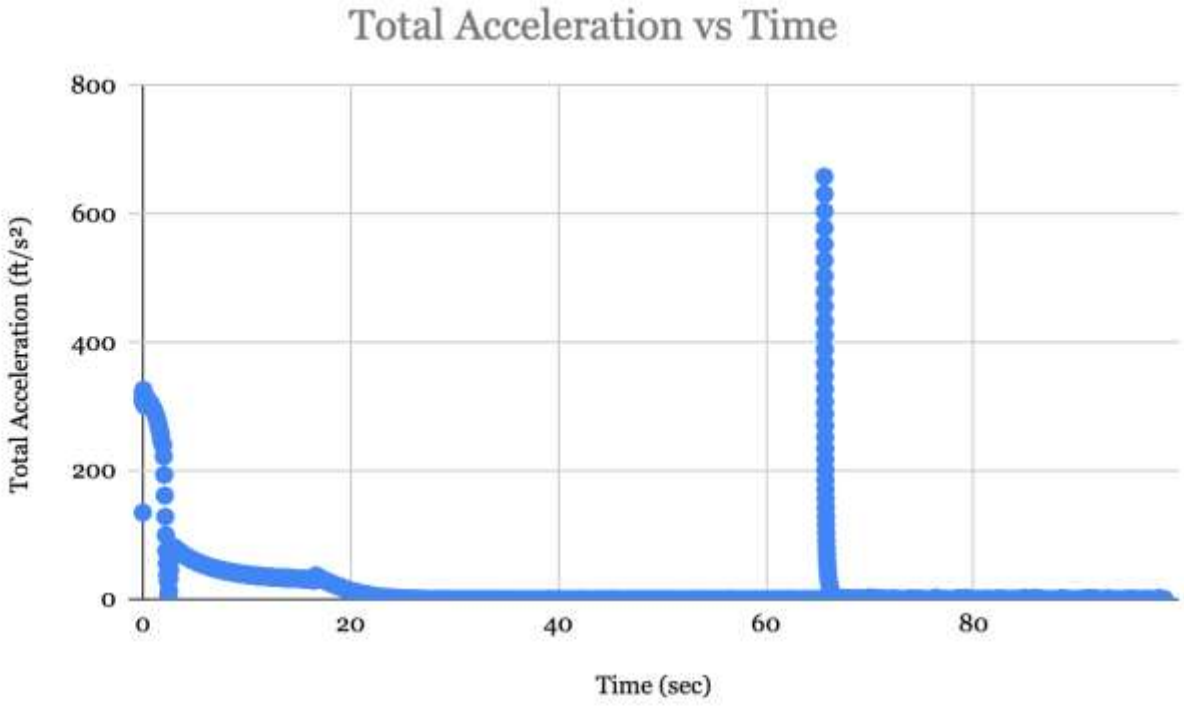


Figure 40: Simulated Acceleration vs. Time

3.4.2.1 Motor Thrust Curve

The selected motor is the Aerotech L1090W motor. It was chosen to prioritize the launch vehicle's safety and to reach the target altitude. The motor choices were restricted to 58 mm in diameter and a maximum 25in. in length. The alternative motor options were the Cesaroni L1030 motor, and the Cesaroni L640 motor. Aerotech was chosen over the alternative motors as it best achieves the team's safety priority and is most accessible for launches.

The Aerotech L1090W has a total impulse of 2736 N-s, and a maximum thrust of 1334 N. The maximum thrust occurs at the launch rod to propel the launch vehicle at 88.6 ft/s. The motor uses 1400 grams of propellant to produce a burn time of 3 seconds (Figure 41). The total weight of the launch vehicle is 428 oz, and the thrust-to-weight ratio is 9.2, fulfilling the competition's requirement of a minimum thrust-to-weight ratio of 5.

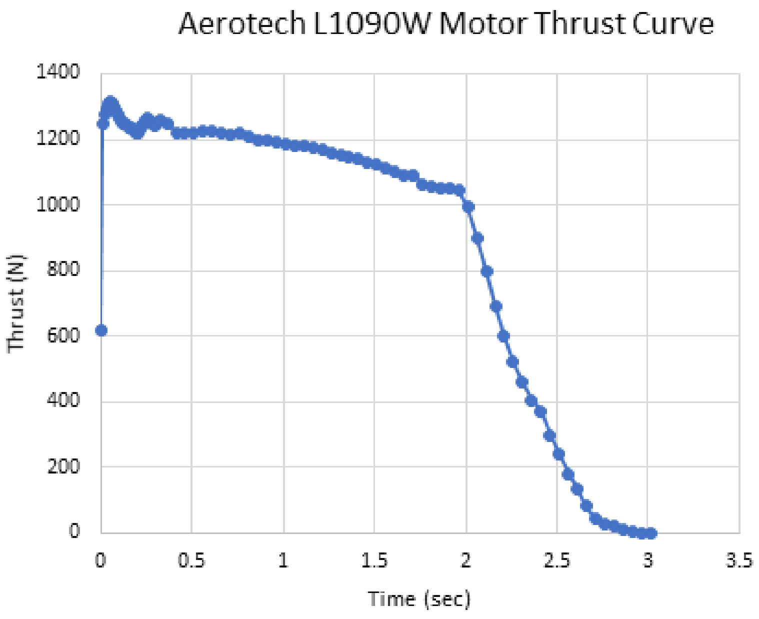


Figure 41: Motor Thrust Curve

3.4.3 Simulation Verifications: Monte Carlos Results

The predicted apogee was estimated using a MATLAB Monte Carlo Simulation to confirm the accuracy of the OpenRocket calculations. It was also used to validate those results to be precise and to ensure robustness of the design. The MATLAB simulation used random values of wind profiles ranging from 0 mph to 20 mph and it was run a total of 10,000 times to predict the range that the altitude will remain between. All other parameters matched the parameter used in the OpenRocket Simulation. The figure indicates the average predicted performance of the Gator Locator (Table 16). The probability weight is the percentage chance that the combination of launch angle and wind condition is likely to occur. The values were assigned by allocating the most likely condition with the largest probability and determining the rest accordingly. The values were allocated as results of the Monte Carlo Simulation and considering the climate of the launch site. While the launch angles for the simulated conditions in the table include 0 and 2.5 degrees, the launch angle will be between 5 to 10 degrees on the launch day as the competition requires. However, the analysis uses these given angles to ensure proportional altitude changes between launch conditions.

Average Altitude			
Launch Angle	Wind Condition	Probability Weight	Predicted Altitude
0	0 mph	5%	4687 ft
2.5 deg	5 mph	10%	4658 ft
5 deg	10 mph	70%	4579 ft
7.5 deg	15 mph	10%	4458 ft
10 deg	20 mph	5%	4312 ft
Average Altitude			**4566.9 ft**

Table 16: Monte Carlo Results

3.4.4 Stability Margin

The launch vehicle is stable when the center of pressure is located at least 1 body caliber behind the center of gravity. The center of gravity of the motor is located 76.42 in. from the tip of the rocket. The center of pressure of the motor is located 92.12 in. from the tip of the nose cone. Therefore, at the launch pad, the static stability margin would be 2.05. The static stability of the launch vehicle when it is clearing the launch rod is 2.2 calibers, fulfilling the competition's requirement of 2 calibers off the launch rod. During the flight, the stability gradually increases to 4.25 calibers, due to the reduction of mass in the motor. However, the stability reaches a maximum of 4.75 calibers, at burnout, due to the increase in velocity and a minimum of 2.1 due to the decrease in velocity as it reaches apogee (Figure 42). The oscillations indicate the simulated wind gusts on the launch vehicle.

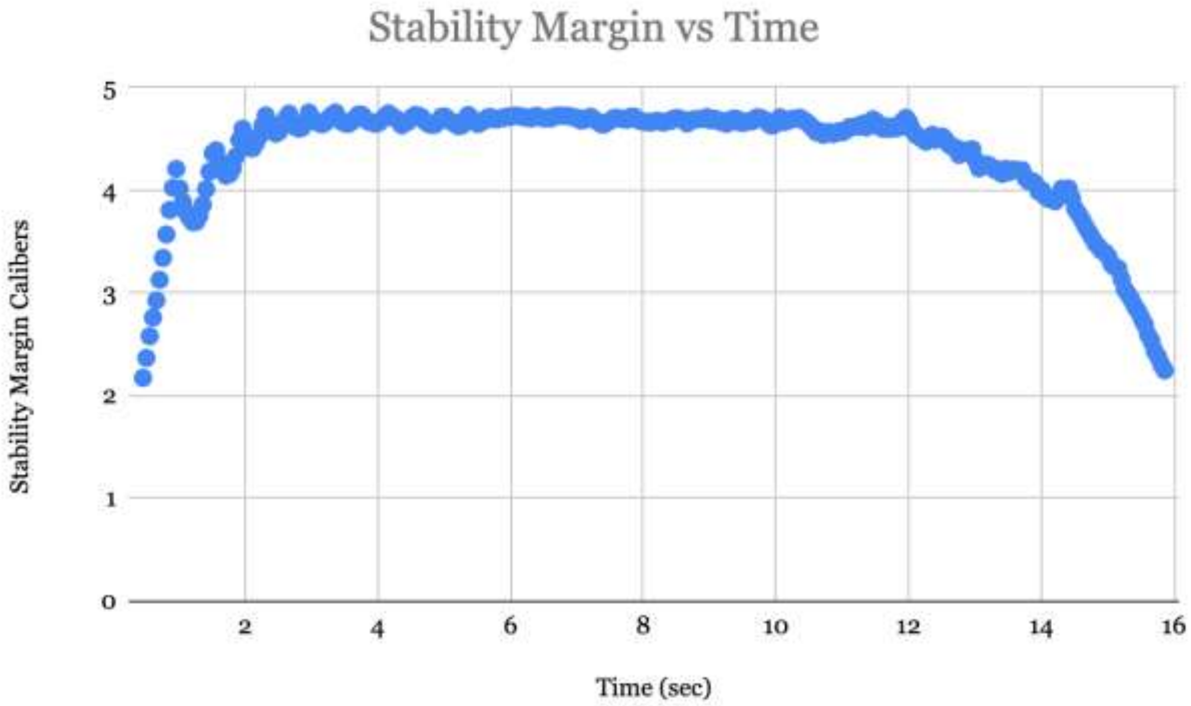


Figure 42: Simulated Stability Margin vs. Time

3.4.5 Descent Predictions

Descent predictions were performed using three calculations methods. First, an OpenRocket simulation was used to find the drogue descent rate at main parachute deployment and the main parachute descent rate at ground hit. These descent rate values were then plugged into an Excel spreadsheet to roughly calculate the desired values. A MATLAB ordinary differential equation solver was also used to simulate the parachutes' descent with the launch vehicle. When variables are used with no subscript it refers to the launch vehicle or flight as a whole (Figure 43).

Table of Variables	
h_i	Altitude
t_i	Time
v_i	Descent rate
m_i	Mass
X_i	Drift
KE_i	Kinetic energy
s_i	Area of parachute
C_i	Coefficient of drag

ρ	Density
g	Acceleration due to gravity
V	Wind speed

Figure 43: Table of Variables

"i" subscripts to be replaced by object or element the value is describing

3.4.5.1 Descent Time Calculations

The OpenRocket simulation did not calculate time from apogee to ground hit directly, but did calculate the total flight time and the time to apogee. The time to apogee was subtracted from the total flight time to find the descent time of the launch vehicle.

$$t = t_{total} - t_{apogee}$$

Equation 3

The OpenRocket simulation provided a descent rate for the drogue parachute and for the main parachute. The target apogee, 4578 ft, was used as the apogee in the spreadsheet calculations. The programmed altitude for the primary ejection charge for the second separation event was used as the altitude that the main parachute deployed. Descent time was calculated.

$$t_{drogue} = \frac{h_{apogee} - h_{main}}{v_{drogue}}$$

Equation 4

$$t_{main} = \frac{h_{main}}{v_{main}}$$

Equation 5

$$t = t_{drogue} + t_{main}$$

Equation 6

The MATLAB simulation uses the ode23 function to solve the ordinary differential equation produced by the balancing of forces on the launch vehicle during descent where velocity is the first derivative of altitude. The weight of the launch vehicle will be balanced by the drag force produced by the parachutes. The solver produces a table of time values and the corresponding altitude. The solver stops finding more points once the altitude is at ground level. The final time value is then outputted as the descent time of the launch vehicle.

$$0 = \begin{cases} -mg + \frac{1}{2}\rho v^2 s_{drogue} C_{drogue} & h_{main} < h \leq h_{apogee} \\ -mg + \frac{1}{2}\rho v^2 s_{main} C_{main} & 0 \leq h \leq h_{main} \end{cases}$$

Equation 7

Descent Time Results		
OpenRocket simulation	t_{total}	99.2 s
	t_{apogee}	16.3 s
	t	82.9 s
Spreadsheet calculation	t_{drogue}	34.1 s
	t_{main}	48.2 s
	t	82.3 s
MATLAB simulation	t	82.5 s

Table 17: Decent Time Results

The OpenRocket Simulation predicted the longest descent time of 82.9 s. The Spreasdsheet calculation predicted the shortest with a descent time of 82.3 s for a difference in descent times of 0.6 s. The difference in descent time is most likely due to the different solvers that the two methods are using. The OpenRocket simulation is also able to vary the air density with altitude in accordance with the International Standard Atmosphere where as the MATLAB simulation uses a constant air density of 0.076 pounds per foot cube. All calculated descent times fall within the competition required 90 s descent time (Table 17).

3.4.5.2 Drift Calculations

The OpenRocket simulation provides a plot of lateral distance vs time (Figure 44). The simulation does not have a setting to ensure that apogee is reached directly over the pad. This is corrected for by adding the peak lateral distance reached around apogee to the final lateral distance reported by the simulation.

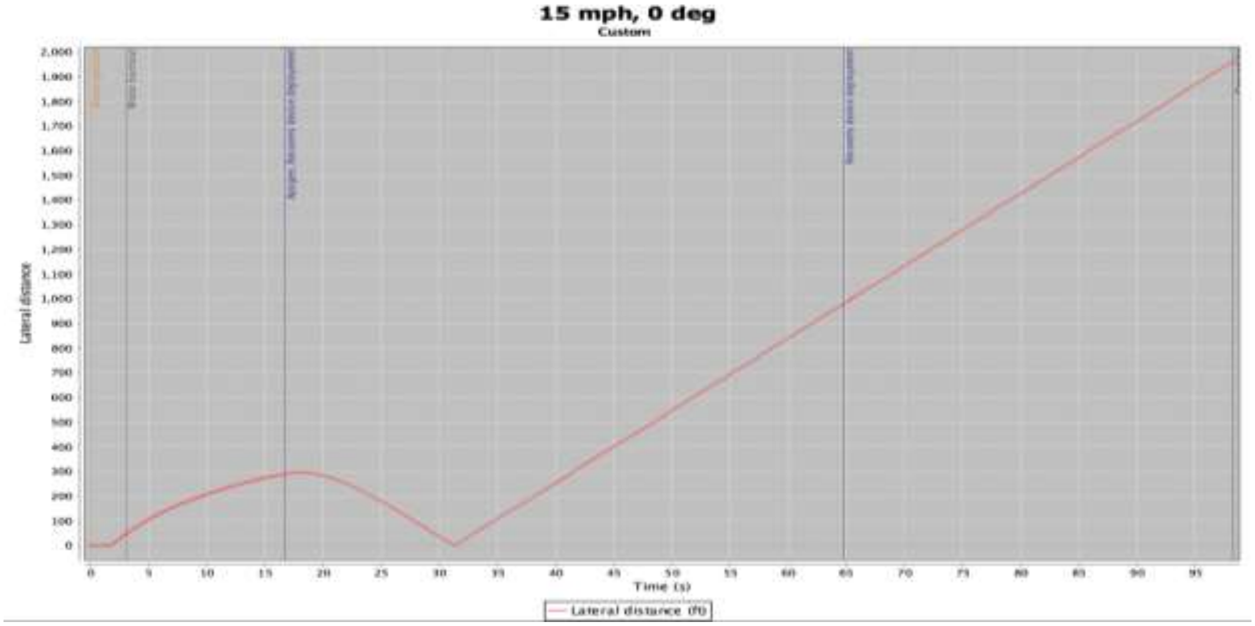


Figure 44: Drift Example

The spreadsheet and MATLAB simulation multiply the descent time by the wind speed to find total drift.

$$X = V * t$$

Equation 8

Drift Calculation Results					
Wind Speed	**0 mph**	**5 mph**	**10 mph**	**15 mph**	**20 mph**
Drift at apogee (ft)	7	200	360	465	550
Final drift (ft)	NA	360	775	1225	1655
Openrocket total (ft)	7	560	1135	1700	2205
Spreadsheet (ft)	0	604	1207	1811	2414
MATLAB (ft)	0	607	1214	1820	2427

Table 18: Drift Calculation Results

The OpenRocket simulation consistently had the lowest lateral drift total when compared to the Spreadsheet calculation method and the MATLAB calculation method. This may be in part due to the difficulty of graphically determining the distance traveled. The slight differences between the Spreadsheet and MATLAB method are most likely due to the slight differences between the OpenRocket and MATLAB solvers that find altitude over time. The final drift calculations are all within the 2500 ft radius, the largest being 73 ft below the maximum drift allowed by the competition (Table 18).

3.4.5.3 Kinetic Energy Calculations

The OpenRocket simulation does not calculate the kinetic energy of the launch vehicle. The spreadsheet calculation calculates the kinetic energy at ground hit using the ground hit descent rate from the Openrocket simulation. The MATLAB simulation uses the velocity it solved for to find the kinetic energy. Both methods use the masses presented in the mass table (TABLE #). Both the spreadsheet and the MATLAB calculation methods assume that the separated sections are descending at the velocity of the main parachute’s descent rate during ground hit. It is also assumed that horizontal velocity is negligible at ground hit.

$$KE_i = \frac{v_{main}^2 * m_i}{2}$$

Equation 9

Kinetic Energy Calculation Results			
Section	**Nosecone**	**Forward**	**Aft**
Spreadsheet (ft-lbs)	10.1	34.0	68.2
MATLAB (ft-lbs)	10.3	34.8	70.0

Table 19: Kinetic Energy Calculation Results

The kinetic energy does not vary much between the two methods of calculation. This may be due to the solvers having very similar parameters around ground level since the MATLAB simulation makes the assumption that the air conditions are always at ground level. Both calculation methods result in kinetic energy below the maximum allowed by the competition. The maximum, 70.0 ft-lbs, is 5 ft-lbs below the maximum allowed 75 ft-lbs (Table 19).

3.4.5.4 Predicted Deployment Load

The predicted load at deployment was calculated by dividing the change in kinetic energy by the distance traveled during that change. The kinetic energy during drogue descent of each separated section was found. The Aft Section will always have the highest kinetic energy if it is assumed all sections are traveling at the same velocity due to it having the largest mass. The change in kinetic energy was found by subtracting the kinetic energy during drogue descent from the kinetic energy during main descent. This was then divided by 50 ft. 50 ft was chosen as the expected distance the launch vehicle would travel between main parachute deployment and full inflation by exporting altitude velocity data from the OpenRocket simulation and finding the difference between 600 ft, the main deployment altitude, and the altitude at which the simulation reported the launch vehicle reached the main parachute descent rate. 50 ft is also considered reasonable due to the performance of the subscale flight.

$$\text{Load} = \frac{\Delta KE}{d}$$

Equation 10

Predicted Deployment Load	
$KE_{Drogue\ aft}$	1457.8
ΔKE (ft-lbs)	1389.6
d (ft)	50
Load (oz)	**444.7**

Table 20: Predicted Deployment Load

The predicted deployment load is 444.7 oz or an additional 27.8 lbs of force on the recovery equipment. The total force expected on the recovery harness, quick links, and eyebolts is about 50 lbs. All recovery components are rated for higher carrying capacities and are expected to perform well under these conditions (Table 19).

4. Payload Criteria

4.1 Design of Payload Equipment

The payload uses image and inertial data to determine the vehicle's final landing location. Images of the launch field are collected during flight, which are compared against pre-uploaded satellite reference images using the SIFT algorithm to determine the vehicle's mid-flight location. To calculate the displacement between the image capture location and landing location, an inertial measurement unit continuously records acceleration and orientation data during flight. For this calculation, the vehicle's velocity after landing is assumed to be zero. Using the vehicle's landing velocity as a known reference, rather than the vehicle's starting velocity, reduces the inertial navigation time and thus reduces the accumulated displacement error.

The selected design alternative uses two downward-facing external cameras on the aft airframe of the launch vehicle (Figure 45). Images are captured during ascent, with images captured near the vehicle's apogee prioritized for processing. This image collection window was selected because the launch vehicle is stable and near orthogonal to the launch field during ascent. During drogue descent, the aft section of the launch vehicle experiences volatile rotations and translations, drastically decreasing the possibility of obtaining an accurate image of the launch field. During main descent, the aft section's motion is more stable, providing a possibility of obtaining a clear image of the launch field. However, main descent occurs at a low altitude, reducing the field of view of the image and any identifiable portions of the launch field. Due to these image capturing windows, location analysis of the rocket will primarily occur during ascent, with any descent image analysis being conducted as a redundancy.

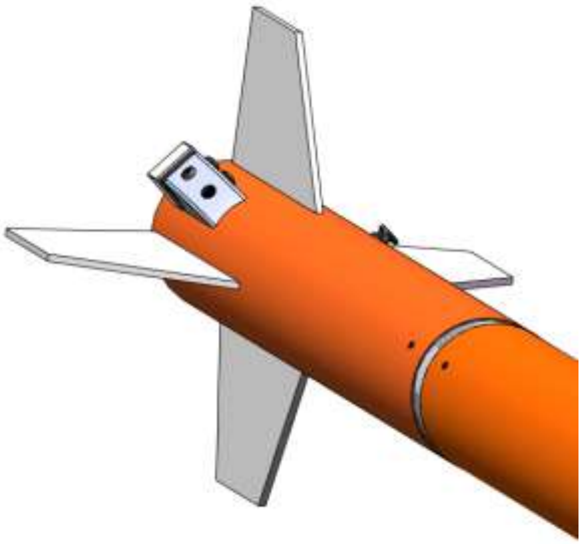


Figure 45: External Camera Mounts on Launch Vehicle

Upon landing, the payload begins scoring images based on multiple criteria including its timestamp, state, altitude, angle of image and number of keypoints. Keypoints are points in the image that help define how it stands out. The highest scoring image is analyzed to determine the rocket's location at the time of image capture. The payload processes the camera and IMU data and to determine the final location of the rocket relative to the numbered grid. The landing location's grid box number is transmitted to a ground station, where it is displayed on an LCD screen and recorded to an SD card.

4.1.1 Selected Design Alternatives

4.1.1.1 Selected Software Components

Multiple image comparison algorithms were considered before choosing SIFT. Initially, a Modified Convoluted Neural Network (CNN) approach was considered. While having a higher degree of accuracy than SIFT, this was computationally expensive at a reasonable cost for an embedded system, making it non-viable for this mission. Thus, SIFT was chosen as the location detection algorithm.

4.1.1.2 Selected Electronic Components

4.1.1.2.1 Camera Selection

Camera alternatives were evaluated by resolution, area, power consumption, and cost (Table 21). The Arducam OV5642 module features a 1080p resolution at 30 frames per second, 1.26 in^2 area, 1500 mW power consumption, and cost of 39.99 USD. The Arducam is the most suitable alternative because it has the highest resolution and smallest size.

Camera			**Arducam OV5642**			**MT9D111**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Cost	0.1	USD	39.99	2.50	0.25	9.99	10.0	1.0
Size	0.2	in^2	1.26	10.0	2.00	2.48	5.10	1.02
Resolution at 30 fps	0.4	Columns x Rows	1920x1080	10.0	4.00	800x600	2.31	0.93
Power consumption	0.3	mW	1500	1.49	0.45	223	10.0	3.0
Overall value					**6.70**			5.95

Table 21: Camera Decision Matrix

4.1.1.2.2 Inertial Measurement Unit Selection

Inertial Measurement Units were evaluated by zero-g offset and cost (Table 22). The ADIS16470 features a zero-g offset of 4 mg and a cost of 328.90 USD. The ADIS16470 is the most suitable alternative because it offers the lowest zero-g offset, thus offering the lowest displacement error.

Inertial Measurement Unit			**ADIS16470**			**MPU-6881**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Zero-g Offset	0.9	mg	4	10.0	9	80	0.5	0.45
Price	0.1	USD	328.90	0.36	0.03	11.77	10	1.0
Overall Value					**9.03**			**1.45**

Inertial Measurement Unit			**BHI260AB**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value
Zero-g Offset	0.9	mg	20	2.0	1.8
Price	0.1	USD	15.30	7.69	0.77
Overall Value					**2.57**

Table 22: IMU Decision Matrix

4.1.1.2.3 Processor Selection

Processors were evaluated by CPU performance, board size, power draw, and cost (Table 23). The Raspberry Pi 4 features a CPU performance of 28200 millions of instructions per second (MIPS), as measured by the Dhrystone integer benchmark. The Raspberry Pi 4 has a 7.38 in^2 board size, a 12.5 W maximum power draw, and a cost of 149.99 USD. The Raspberry Pi 4 is the most suitable alternative because it offers sufficient CPU performance with the smallest board size and power draw.

Payload Computer			**Raspberry Pi 4 Model B**			**TI TMDXSK437X**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Cost	0.1	USD	149.99	8.50	0.85	249.00	5.12	0.51
CPU Performance	0.4	DMIPS	28200	5.17	2.07	2500	0.46	0.18
Board Size	0.2	in^2	7.38	10.00	2.00	14.7	5.00	1.00
Maximum Power Draw	0.1	W	12.50	10.00	1.00	12.50	10.00	1.00
User Friendliness	0.2	Experience	Great	10	2.00	Good	8	1.60
Overall Value					**7.92**			**4.29**
Payload Computer			**BeagleBone AI**			**TI SK-TDA4VM**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Cost	0.1	USD	127.43	10.00	1.00	199.00	6.40	0.64
CPU Performance	0.4	DMIPS	22857	4.19	1.68	54520	10.00	4.00
Board Size	0.2	in^2	7.45	9.90	1.98	20.3	3.63	0.73
Maximum Power Draw	0.1	W	15.00	8.33	0.83	15.00	8.33	0.83
User Friendliness	0.2	Experience	Okay	6	1.20	Okay	6	1.20
Overall Value					**6.69**			**7.40**

Table 23: Payload Computer Decision Matrix

4.1.1.2.4 Barometer Selection

Barometers were evaluated by accuracy and cost (Table 24). The Grove 101020068 has an accuracy of 0.01 mbar at a cost of 21.90 USD. This barometer was selected because it provides the greatest accuracy of all evaluated alternatives.

Barometer			**Grove 101020068**			**Grove 101020812**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Cost	0.1	USD	21.90	2.97	0.30	6.50	10.00	1.00
Range	0.45	mbar	300-1200	9.00	4.05	300-1200	9.00	4.05
Accuracy	0.45	mbar	0.01	10.00	4.50	0.06	1.67	0.75
Overall Value					**8.85**			**5.80**
Barometer			**MIKROE-2665**			**SEN0226**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Cost	0.1	USD	15.00	4.33	0.43	8.80	7.39	0.74
Range	0.45	mbar	260-1260	10.00	4.50	300-1100	8.00	3.60
Accuracy	0.45	mbar	0.10	1.00	0.45	0.12	0.83	0.37
Overall Value					**5.38**			**4.71**

Table 24: Payload Barometer Decision Matrix

4.1.1.3 Selected Mechanical Alternatives

4.1.1.3.1 Attachment Method

The payload sled has a Raspberry Pi and battery compartment being mounted directly to the sled. Since the sled is made from 3D printed PETG filament, different attachment methods were considered (Table 25). Ultimately, threaded inserts for plastic were chosen as the desired attachment method. This was due to the durability of the threaded inserts, allowing the repeated attachment and removal of fasteners without damaging the plastics structural integrity. Also, threaded inserts for plastic had a greater resistance to failure compared to the other methods.

Sled PCB Attachment			**Embedded Nuts**			**Threaded Inserts (Heat-Staking)**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Material Cost	0.15	USD	7.5	10.0	1.5	9.0	8.3	1.2
Reliability	0.40	N	Good	8.0	3.2	Great	10.0	4.0
Manufacturability	0.15	hours	4.0	5.0	0.8	2.0	10.0	1.5
Modularity	0.30	fasteners	4.0	5.0	1.5	4.0	5.0	1.5
Overall Value					**7.0**			**8.2**

Sled PCB Attachment			**Rail Slide**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value
Material Cost	0.15	USD	12.0	6.3	0.9
Reliability	0.40	N	Poor	2.0	0.8
Manufacturability	0.15	hours	4.0	5.0	0.8
Modularity	0.30	fasteners	2.0	10.0	3.0
Overall Value					**5.5**

Table 25: Attachment Method Decision Matrix

4.1.1.3.2 Payload Sled and Retention System

The payload sled chosen for the final design is an iteration of the previous design, with modifications to the retention system and attachment method to the payload coupler. The previous design utilized a rail system that was epoxied into the payload coupler with a beam cutout that allowed the payload sled to slide onto it, along with a latch system to secure the sled to the rail system. The permanent nature of epoxy raised concerns regarding any errors made during installation of the rail system, as well as overall strength of the adhesion. The current retention system was designed, manufactured, and tested during the subscale launch. The current design utilizes 10-24 style fastener attachment points near the rear of the payload sled, which directly connect to the forward bulkhead. This design removed the need for epoxy, an additional rail or latch, and is more modular than the previous design. This design was successful on the subscale launch, securing the payload to the forward bulkhead and payload coupler throughout flight, and not showing any signs of fatigue after landing. The modularity of the selected payload sled design was useful during the subscale launch, where assembly and disassembly was simple using the two-fastener design.

4.1.1.3.3 Camera Mounts

The camera mount design is an iteration of the previous design, with modifications made to the camera housing and camera cover. An issue realized during the subscale launch was room for mounting the camera to the camera housing. To account for this, the camera housing now has a more open design in the camera mount location. Also, spacers were added to ensure a more flush fit between the camera mounts PCB and the camera housing. Another issue realized during the subscale launch was the effect of the camera mounts protrusion on the aerodynamics of the launch vehicle. To rectify this, a slot was opened in the airframe and in the camera housing to allow the camera to slide into the airframe as well as be mounted lower on the camera housing. This resulted in a shorter overall height of the camera mounts, reducing the aerodynamic effects on the launch vehicle. The camera covers design was slightly altered to fit the camera housing better, resulting in a shorter camera mount.

4.1.2 System Level Design

4.1.2.1 Mechanical Structures

The payload sled assembly is utilized to house the Raspberry Pi, batteries, and associated electronics needed to power the payload. The payload sled assembly is comprised of two components: the payload sled and the battery compartment (Figure 46). The payload sled has an overall length of 7.00 in, width of 3.30 in and height of 2.87 in, allowing the sled to fit smoothly into the payload coupler, which has an inner diameter of 3.76 in (Figure 47). All the components and electronics are attached to the sled using M2.5 and 10-24 style threaded inserts for plastic, which was chosen using a decision matrix (Figure 48). Wires from the payload sled assembly will travel down the aft airframe inside of the craft paper tubes, eventually reaching the camera mounts, enabling the cameras to get the power they need to operate.

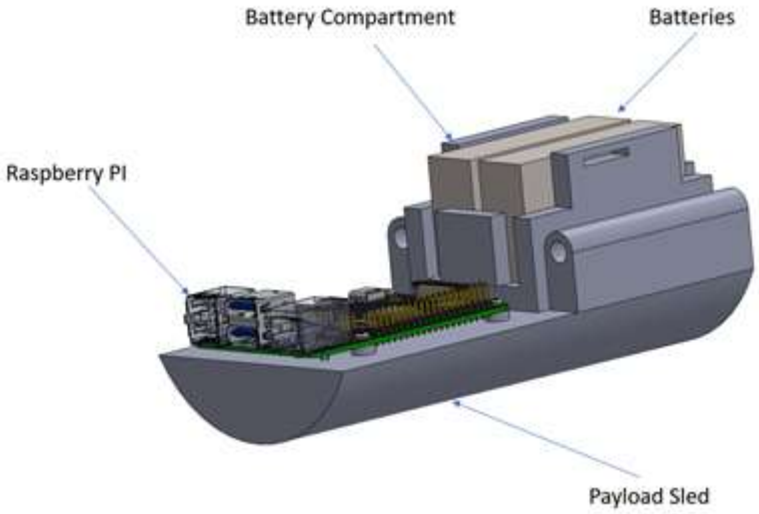


Figure 46: Payload Sled Assembly

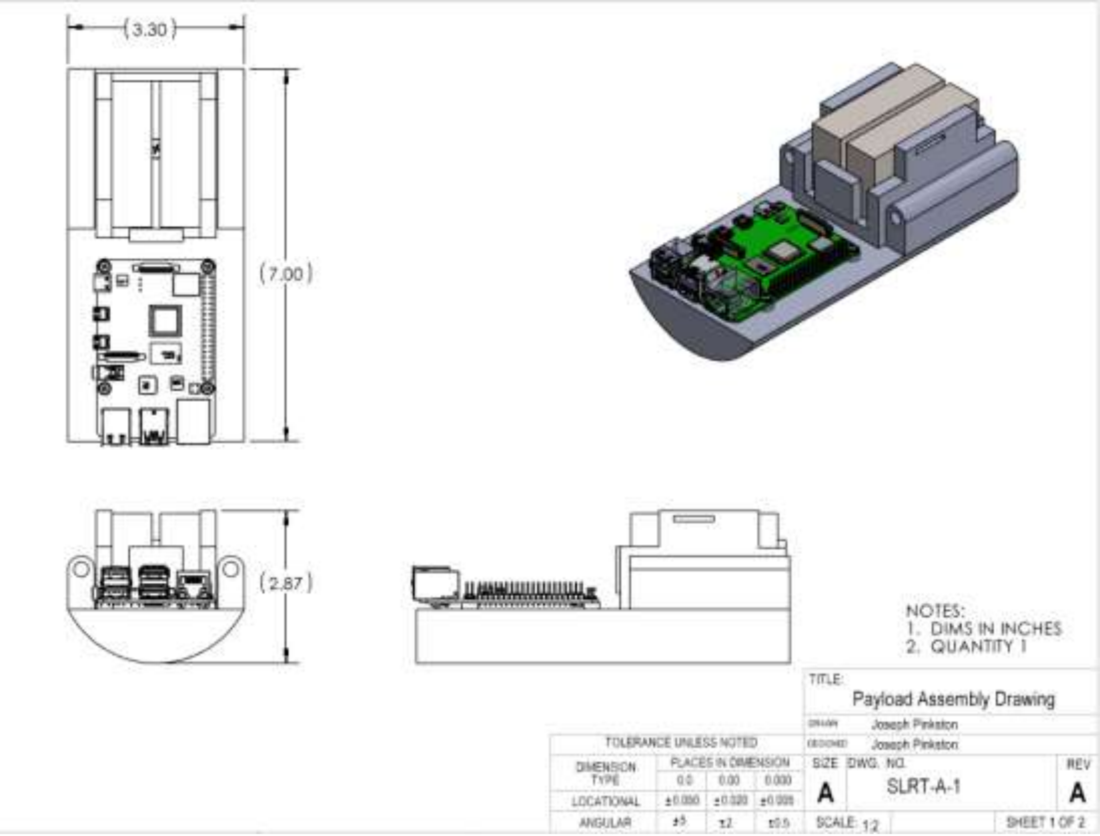
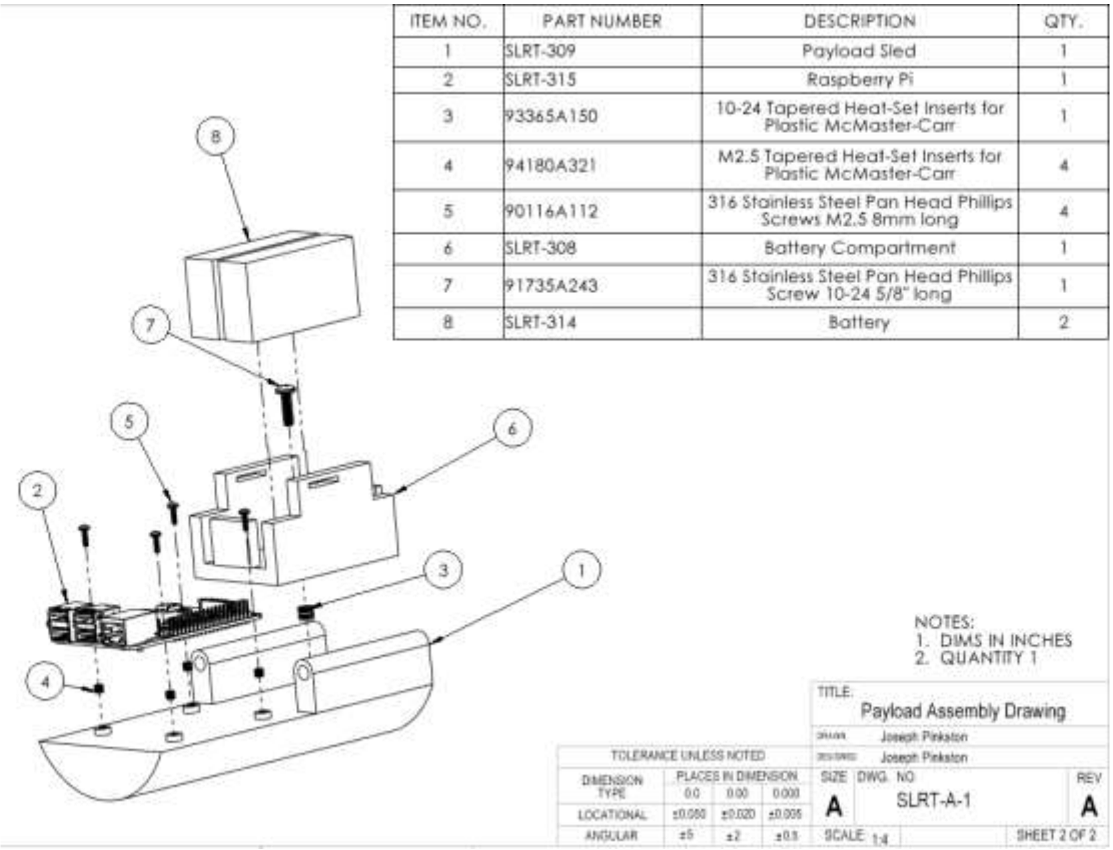


Figure 47: Payload Assembly Drawing



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SLRT-309	Payload Sled	1
2	SLRT-315	Raspberry Pi	1
3	93365A150	10-24 Tapered Heat-Set Inserts for Plastic McMaster-Carr	1
4	94180A321	M2.5 Tapered Heat-Set Inserts for Plastic McMaster-Carr	4
5	90116A112	316 Stainless Steel Pan Head Phillips Screws M2.5 8mm long	4
6	SLRT-308	Battery Compartment	1
7	91735A243	316 Stainless Steel Pan Head Phillips Screw 10-24 5/8" long	1
8	SLRT-314	Battery	2

TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION		
	0.0	0.00	0.000
LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

Figure 48: Payload Assembly Drawing Exploded View

4.1.2.1.1 Payload Sled Design

The payload sled is the primary structure that provides the support for the electronics and batteries needed for the payload. The payload sled is 3D printed from PETG filament using Prusa 3D printers provided by the University of Florida. The payload sled allows the Raspberry Pi, battery compartment, and retention system to be mounted to it using standard fasteners and clearance holes (Figure 49). For all the hole locations, threaded inserts for plastic will be utilized for the fasteners to grip onto. The threaded inserts for plastic were the best fastening method because fasteners can be removed and inserted many times without damaging the structural integrity of the plastic. Also, threaded inserts for plastic are a simple installation, using the correct soldering iron and soldering tip.

The mounting holes for the Raspberry Pi are designed to fit the M2.5 threaded inserts for plastic, set at a diameter of 0.151 in (Fig …). On these mounting holes, small spacers will be utilized to ensure the underside of the Raspberry Pi does not interfere with the sled. A battery compartment only has one mounting location, so a larger fastener was needed to withstand the forces during flight. The battery compartment will utilize a 10-24 style fastener, with a clearance hole diameter of 0.277 in to fit the 10-24 style threaded insert for plastic (Fig …). The final hole designation in the payload sled is for the retention system. The retention system also utilizes 10-24 style fasteners and the 10-24 style threaded insert for plastic, and thus has a through hole of diameter 0.277 in (Figure 50). Additionally, two holes will be drilled into the bottom of the payload sled, to ensure the sled does not interfere with the rivets that connect the payload coupler to the aft airframe. During assembly, the payload sled is attached to the payload coupler, and the rivets are placed into the coupler to secure it. During this process, the rivet holes will show where the payload sled will interfere with the rivets. These locations will be marked on the payload sled and holes will be drilled. These holes have a large tolerance as their purpose is simply to ensure the rivets can fit into the payload coupler bay without the sled interfering (Figure 51). The overall length of the payload sled is 7.00 in, width of 3.30 in and the height is 2.02 in.

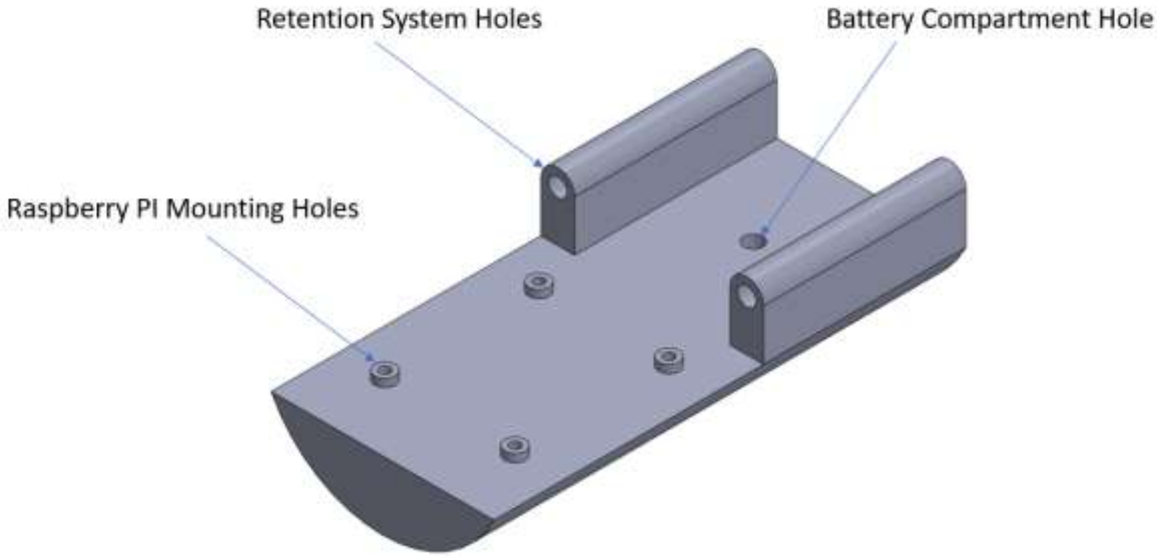


Figure 49: Payload Sled

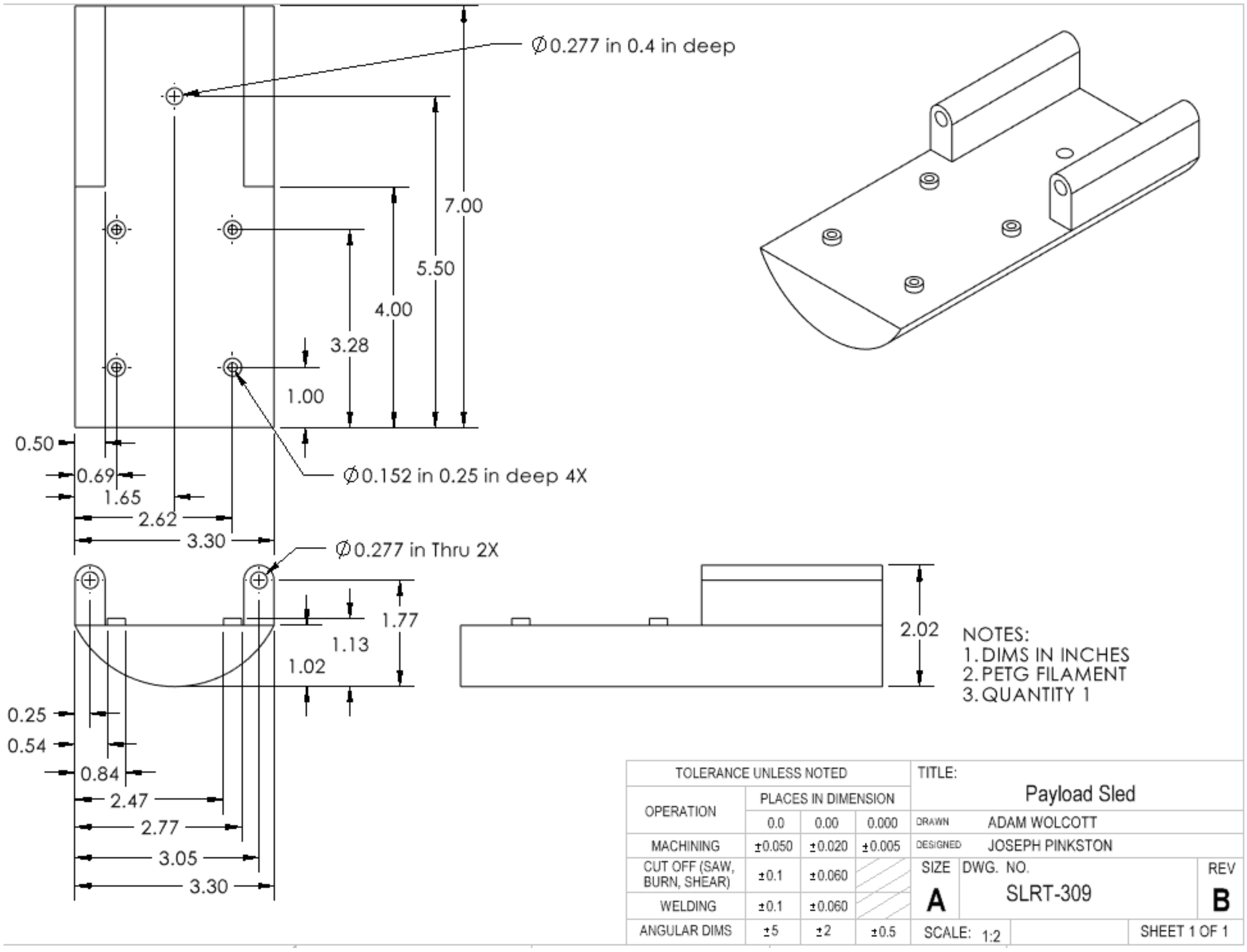


Figure 50: Payload Sled Drawing

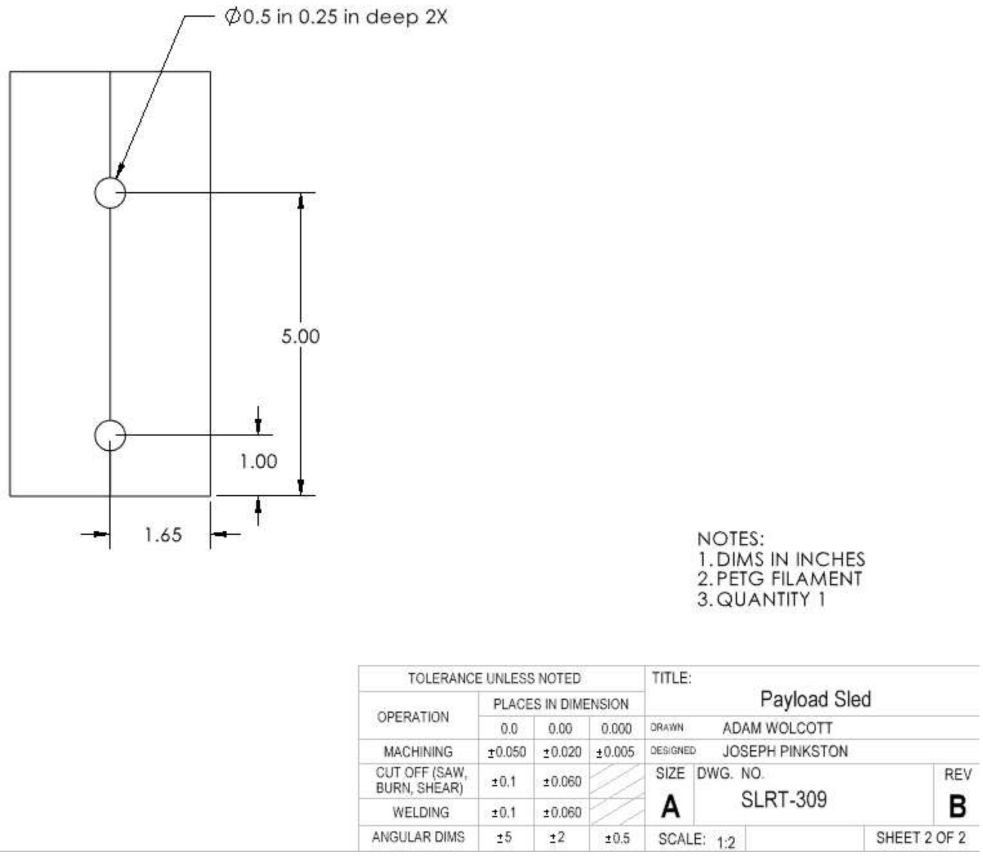


Figure 51: Payload Sled Bottom View

4.1.2.1.2 Battery Compartment Design

The battery compartment is the structure that houses and provides support for the two Lithium-Ion batteries used on the payload. The battery compartment is 3D printed from PETG filament using Prusa 3D printers provided by the University of Florida. The battery compartment thru hole of 0.277 in diameter allows for the 10-24 style fastener to attach the battery compartment to the payload sled (Figure 52). To secure the batteries, walls along the edges of the compartment were made to ensure the battery could not move. To isolate the battery completely, slots were designed into the sides of two walls to allow Velcro to pass over the top of the batteries. This method was tested during the subscale launch, and was successful, as the batteries were secure in their compartment after flight and no connections were lost. The battery compartment has an overall length of 3.1 in, width of 2.25 in and height of 1.85 in (Figure 53).

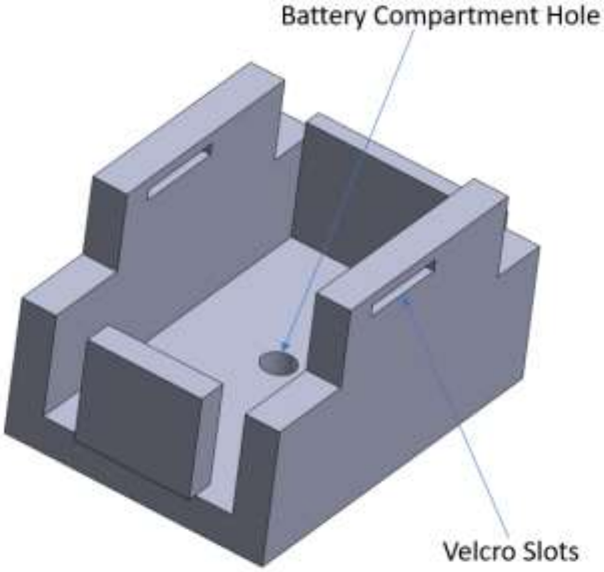


Figure 52: Battery Compartment

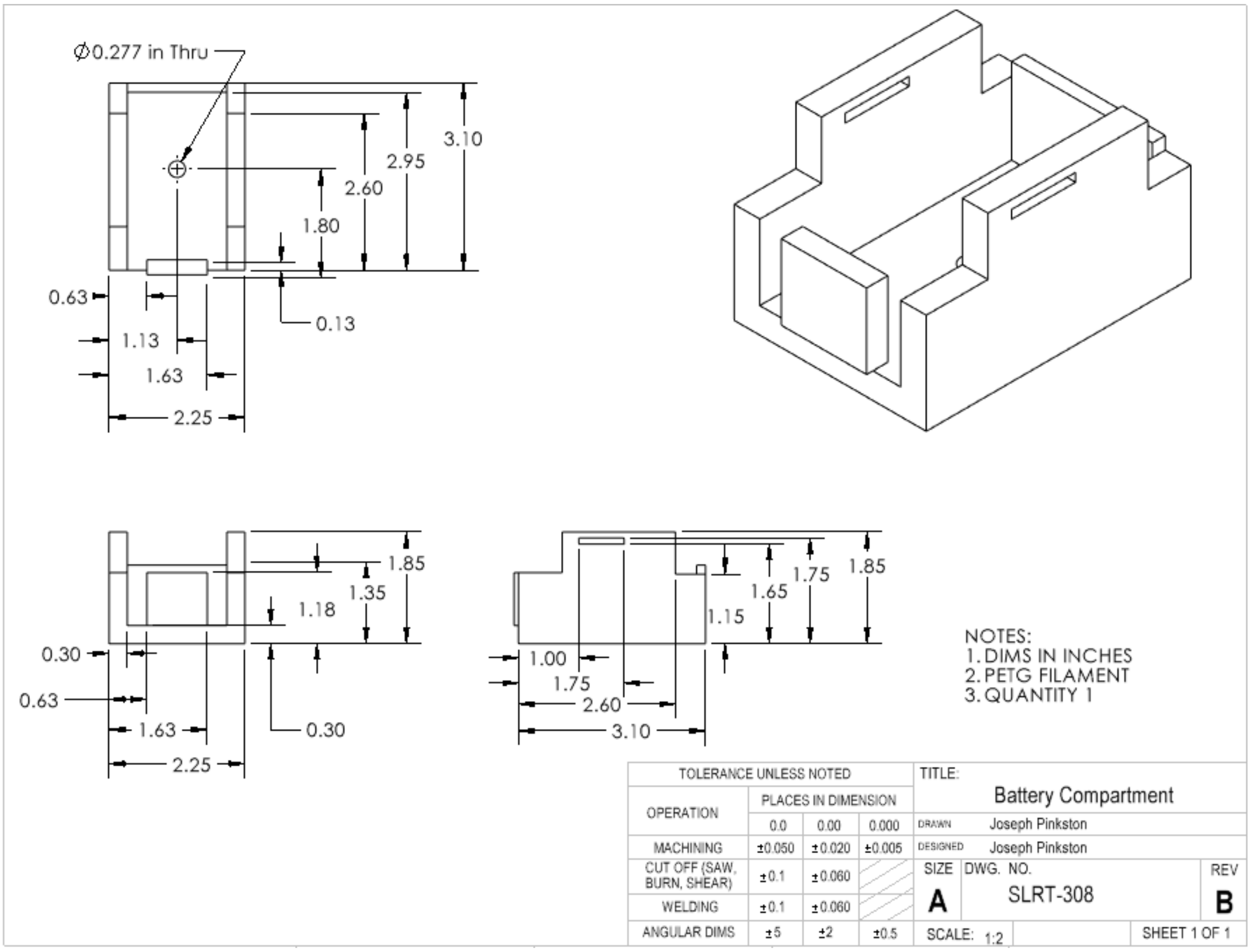


Figure 53: Battery Compartment Drawing

4.1.2.1.3 Camera Mounts Assembly Design

To use image processing, two downward facing cameras are mounted to the aft section of the launch vehicle using a camera mount assembly. The camera mount assembly is comprised of the camera housing and the camera cover mated together using fasteners and hex nuts (Figure 54). The camera is mounted to the camera housing using standard M3.0 fasteners and hex nuts (Figure 55). The camera mount's purpose is to securely mount the camera along the aft of the launch vehicles airframe, allowing the camera to take a steady and clear image of the launch field during ascent, especially near apogee. The camera mount is designed to be aerodynamic, allowing the air to flow over the top of the mount smoothly, minimizing the effects of drag on the mount's structures and the camera. The use of a camera cover allows for the assembly of the camera onto the camera housing to be easily accessed, and then shield the camera using the camera cover. This makes removing and attaching the camera easy, if any changes need to be made prior to launch or on the launch field. The camera mounts overall height is 1.41 in, width of 1.48 in and an overall length of 3.71 in (Figure 56).

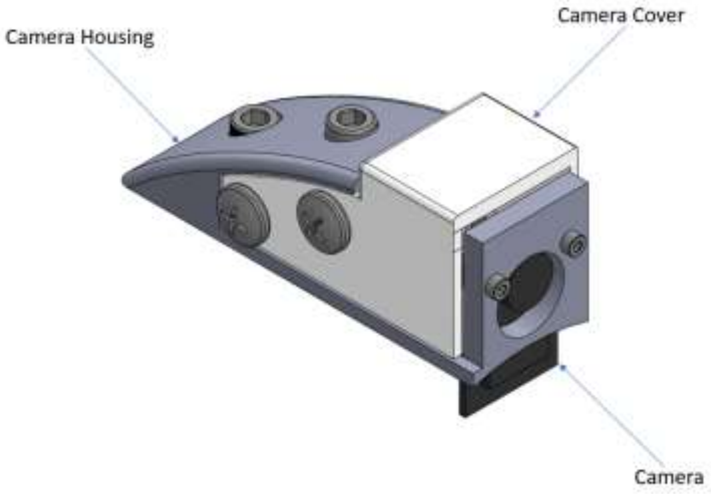


Figure 54: Camera Mount Assembly

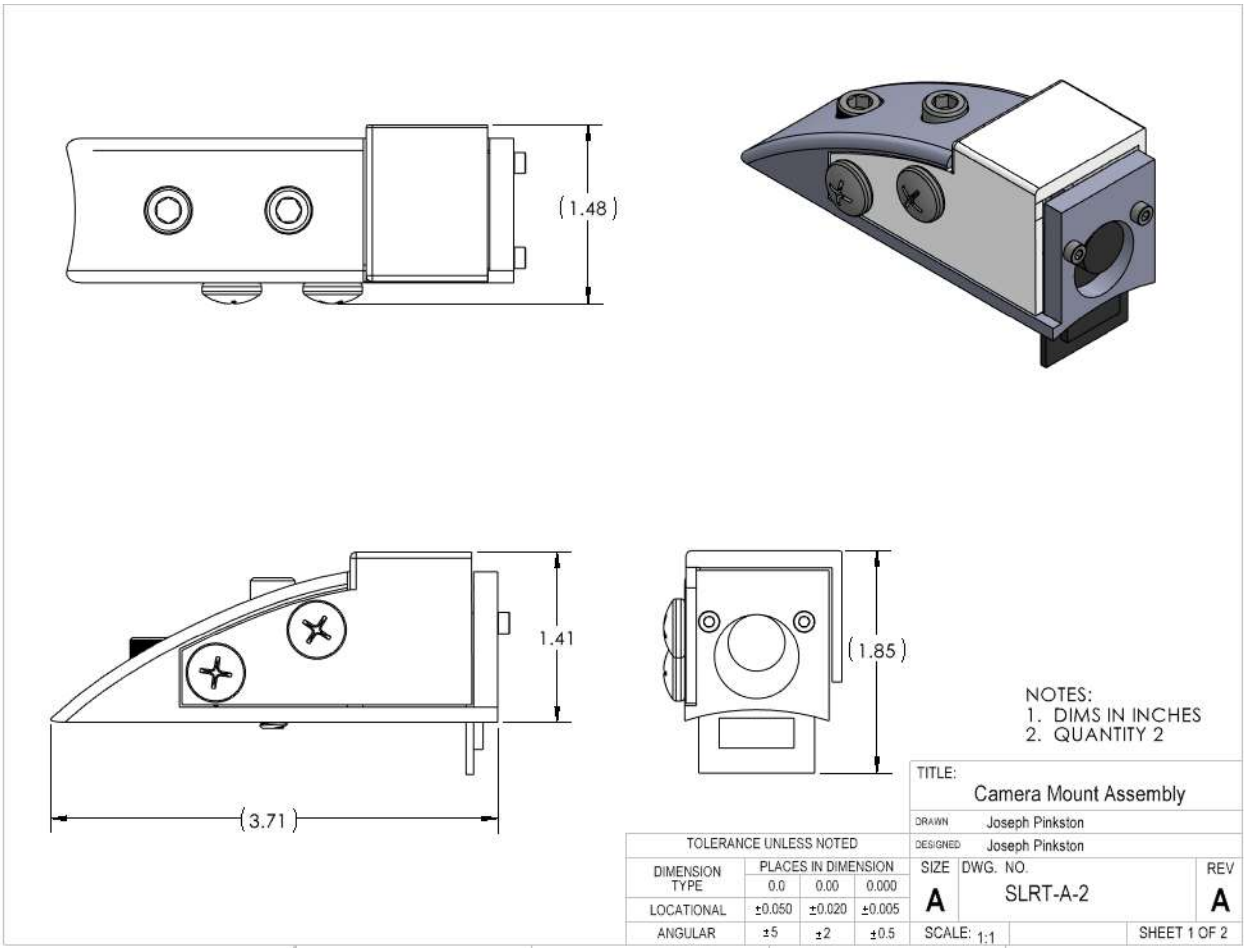
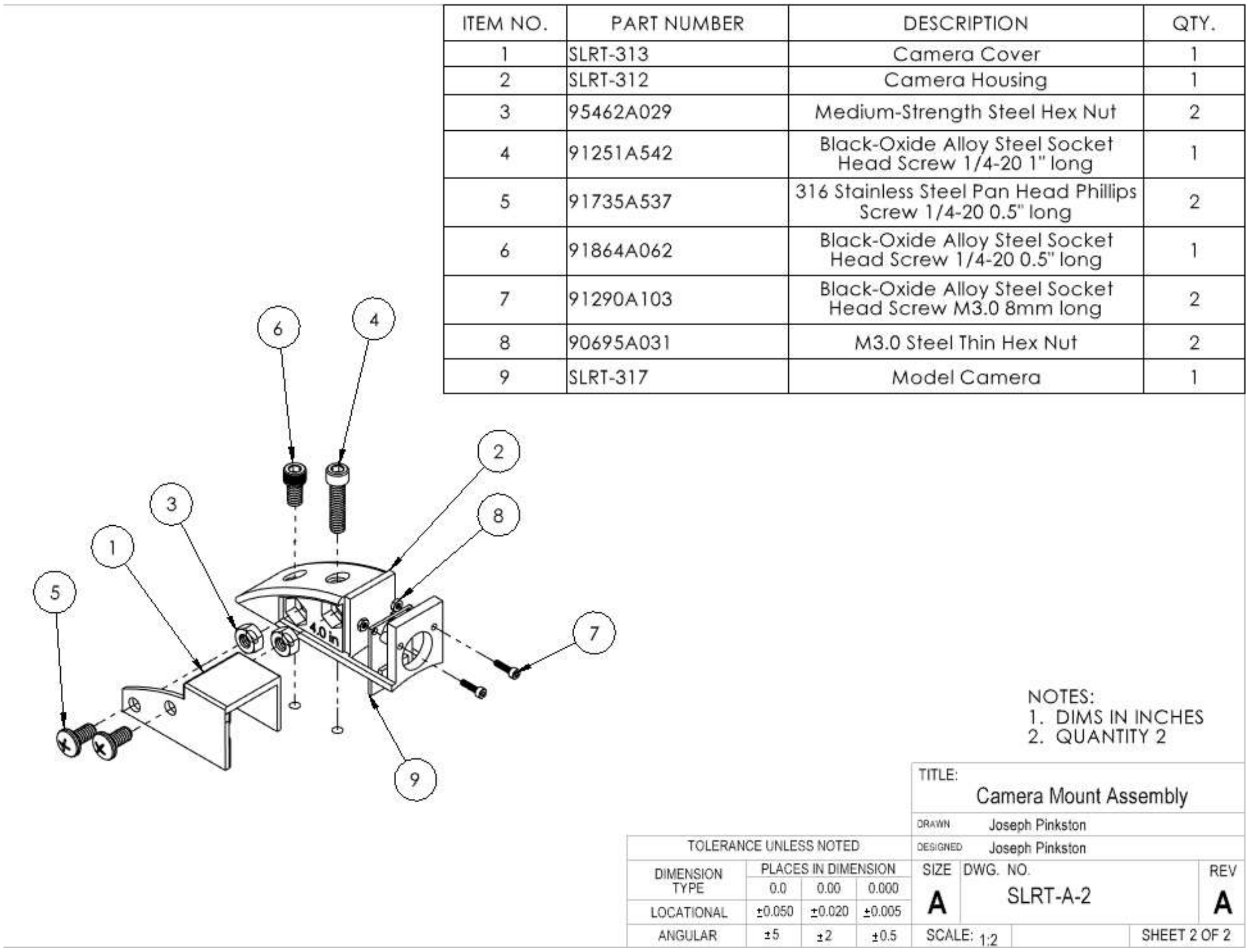


Figure 55: Camera Mount Assembly Drawings



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SLRT-313	Camera Cover	1
2	SLRT-312	Camera Housing	1
3	95462A029	Medium-Strength Steel Hex Nut	2
4	91251A542	Black-Oxide Alloy Steel Socket Head Screw 1/4-20 1" long	1
5	91735A537	316 Stainless Steel Pan Head Phillips Screw 1/4-20 0.5" long	2
6	91864A062	Black-Oxide Alloy Steel Socket Head Screw 1/4-20 0.5" long	1
7	91290A103	Black-Oxide Alloy Steel Socket Head Screw M3.0 8mm long	2
8	90695A031	M3.0 Steel Thin Hex Nut	2
9	SLRT-317	Model Camera	1

NOTES:
1. DIMS IN INCHES
2. QUANTITY 2

TITLE: Camera Mount Assembly
DRAWN Joseph Pinkston
DESIGNED Joseph Pinkston
SIZE A
DWG. NO. SLRT-A-2
REV A
SCALE: 1:2
SHEET 2 OF 2

TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION		
	0.0	0.00	0.000
LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

Figure 56: Camera Mount Assembly Exploded View

4.1.2.1.4 Camera Housing Design

The camera housing's function is to house and provide structural support to the camera during flight and landing. The camera housing is 3D printed from PETG filament using Prusa 3D printers provided by the University of Florida. During subscale testing, it was realized that mounting the camera to the previous design was extremely difficult, as the mounting location was a very tight fit, restricting the use of fasteners. This resulted in the current camera housing design, where the top portion of the camera's mounting location is completely open (Figure 57). This enables the attachment of the camera to the camera housing with ease, without sacrificing the structural integrity of the camera housing.

The camera housing has three different types of holes for fasteners, camera spacers, and a camera lens slot. The camera mount holes are the two 0.255 in diameter thru clearance holes needed for the ¼-20 style fasteners used to mount the camera housing to the launch vehicles aft airframe. Inside of the aft airframe are two T-nuts that the fasteners will be screwed into, securing the camera housing to the launch vehicle. The camera cover holes are two 0.26 in diameter clearance holes needed for the two ¼-20 fasteners used to attach the camera cover to the camera housing. Inside of the section, there are cutouts for a ¼-20 style hex nut. These hex nuts are epoxied into the camera housing, ensuring the connection between the camera cover and the camera housing is secure, rather than relying on the threads to grip to the camera housings plastic. The camera PCB holes are two 0.118 diameter thru holes, used for the two

M3.0 style fasteners to attach the camera's PCB mount. The camera is attached to the camera housing using two M3.0 fasteners and hex nuts. This attachment method was tested during the subscale launch and was successful at keeping the camera mounted throughout the flight. To ensure the cameras PCB mount is perfectly flat against the camera housing, spacers were implemented into the camera housings design. Since the camera only has two mounting locations at the top of its PCB mount, the spacers ensure that the connection is secure. Finally, to allow the lens a clear image of the launch field, a 0.7 in diameter thru hole is used for the camera lens to capture the images. The camera housing has an overall length of 3.71 in, width of 1.20 in and height of 1.25 in (Figure 58).

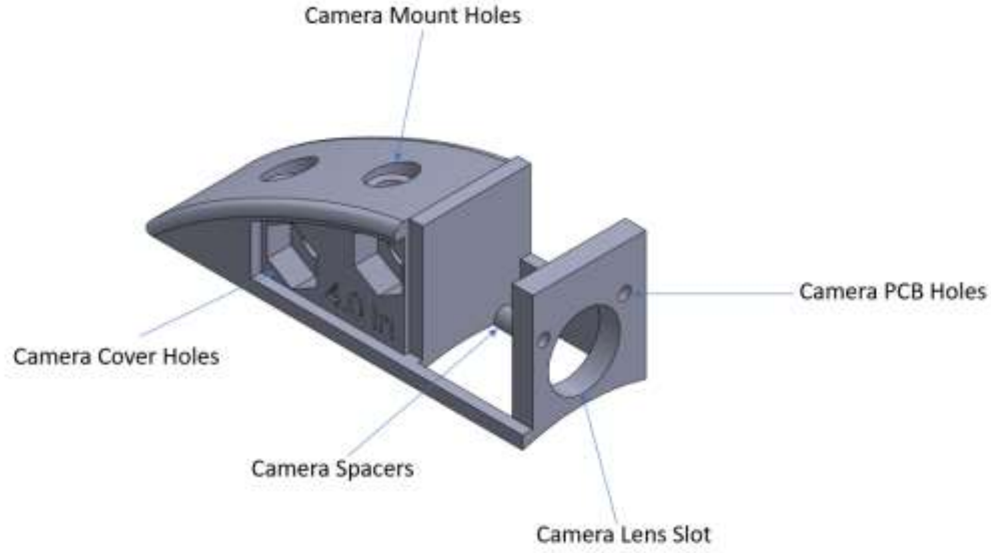


Figure 57: Camera Housing

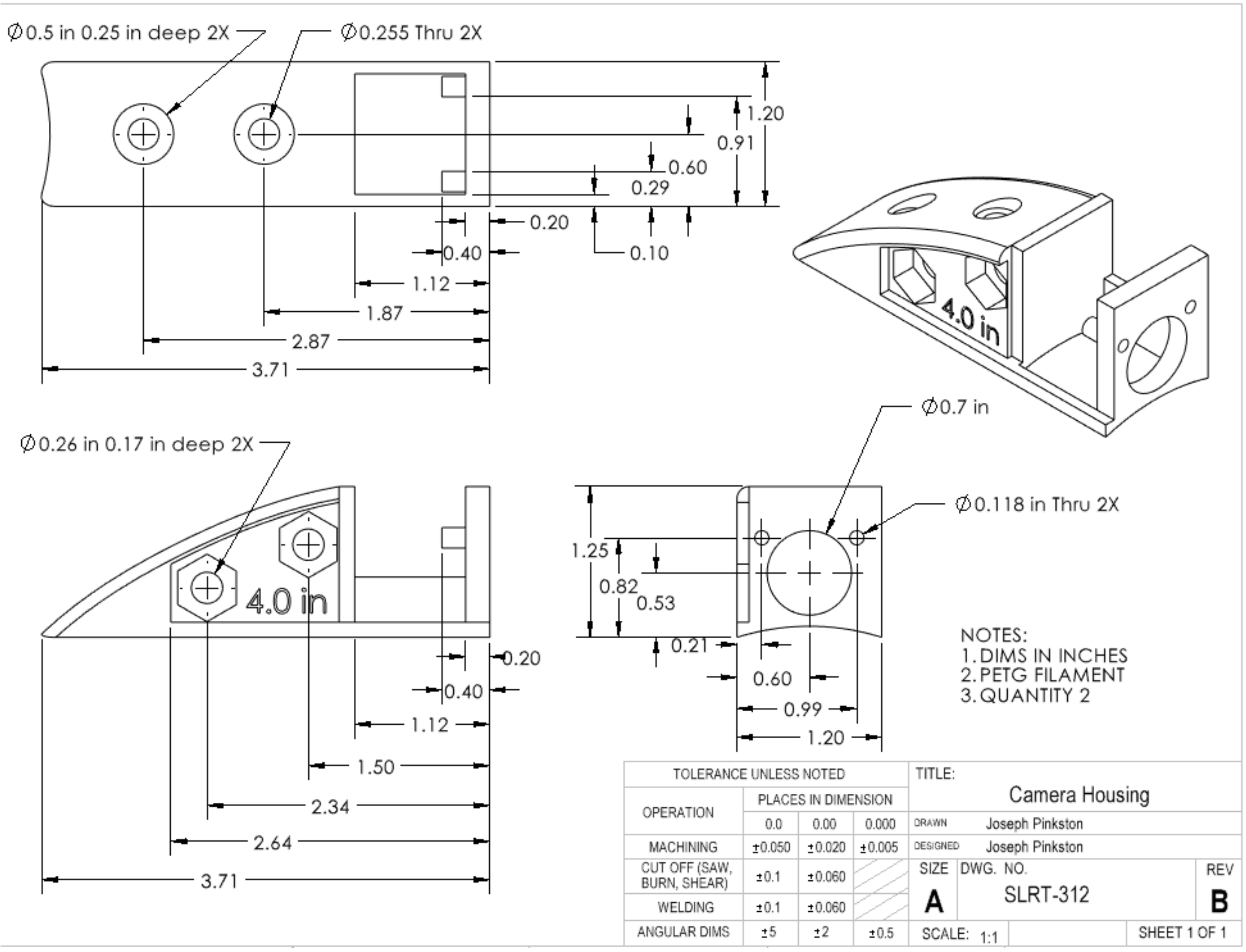


Figure 58: Camera Housing Drawing

4.1.2.1.5 Camera Cover Design

The camera covers function is to seal the camera housing from the aerodynamic forces the camera would experience during flight. The camera cover allows the air to flow over the top of the camera housing and camera, to ensure the camera is kept steady for the image taking process. The camera cover is 3D printed from PETG filament using Prusa 3D printers provided by the University of Florida. The camera cover has two 0.26 in diameter thru holes used to allow the ¼-20 style fasteners to mate the camera cover to the camera housing (Figure 59). The camera cover has an overall length of 2.41 in, width of 1.30 in and height of 1.27 in (Figure 60).

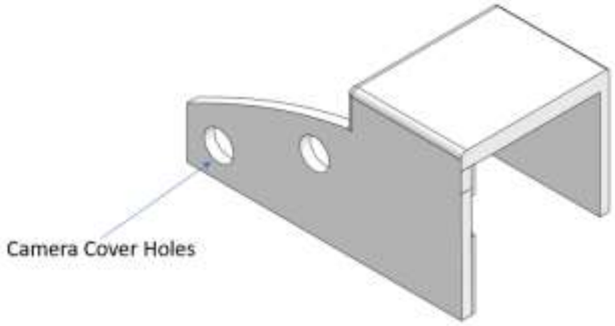
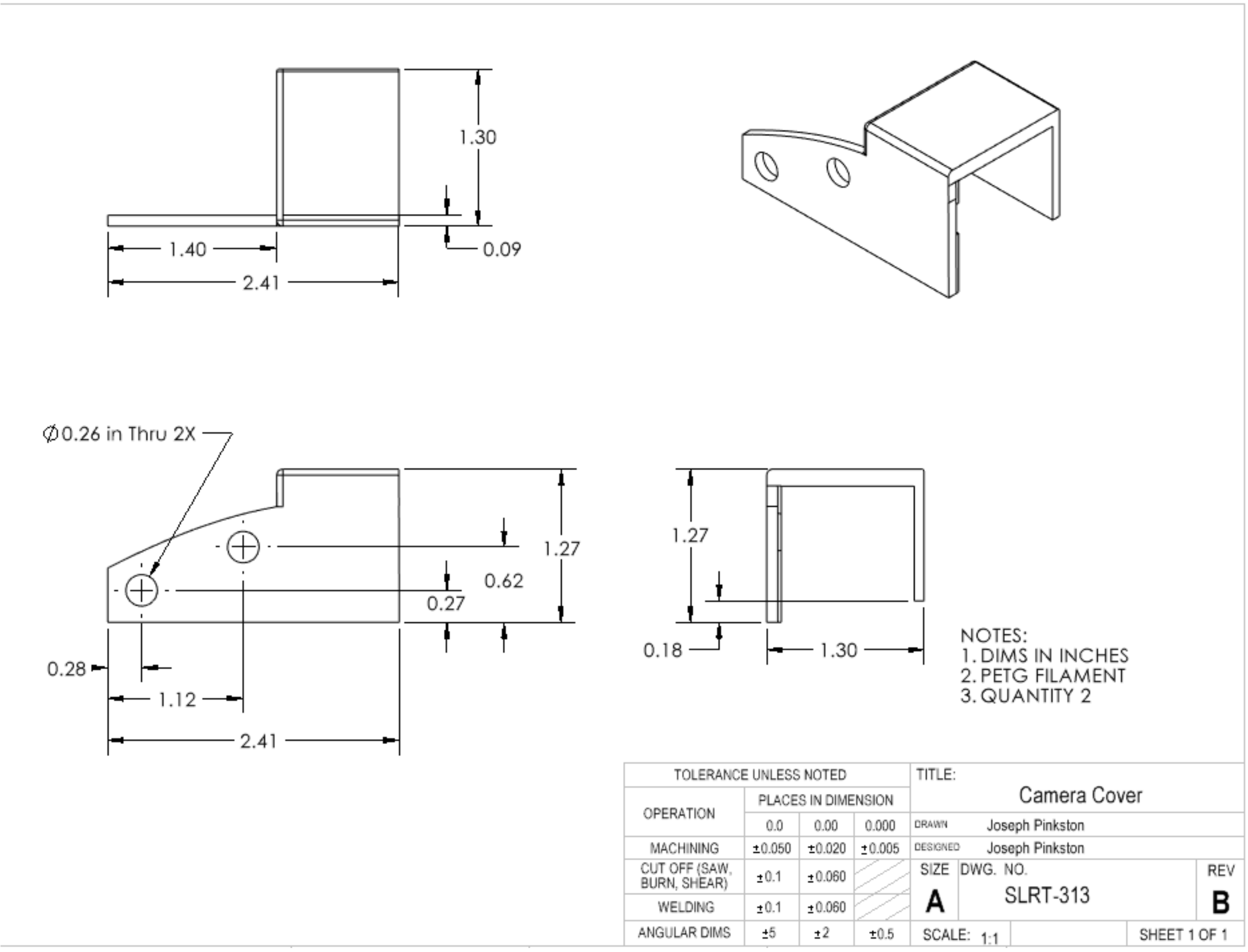


Figure 59: Camera Cover



NOTES:
1. DIMS IN INCHES
2. PETG FILAMENT
3. QUANTITY 2

TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

TITLE:	Camera Cover	
DRAWN	Joseph Pinkston	
DESIGNED	Joseph Pinkston	
SIZE A	DWG. NO. SLRT-313	REV B
SCALE: 1:1		SHEET 1 OF 1

Figure 60: Camera Cover Drawing

4.1.2.1.6 Payload Retention System Design

The payload retention system is comprised of the payload assembly, the forward bulkhead, 10-24 style fasteners and their corresponding hex nuts. As stated previously, the payload sled is designed for two 10-24 style fasteners and their corresponding clearance holes designed for the retention system. These clearance holes allow a 10-24 style fastener to pass through them, along with a 10-24 style threaded insert for plastic (Figure 61). The fasteners and hex nuts attach the payload assembly to the forward bulkhead, securing it to the payload coupler (Figure 62). Removal of the payload sled from the launch vehicle only requires the payload coupler to be removed, the hex nuts to be unfastened and then the removal of the payload assembly is possible. This retention system was designed for the subscale launch and was tested and implemented. The retention system was successful during launch and landing of the launch vehicle, securing the payload assembly inside of the payload coupler without any damage to the components. Also, the modularity of the retention system was very useful. Removing the payload assembly to make changes to the batteries and electronics was simple, requiring the removal of only two hex nuts and their fasteners.

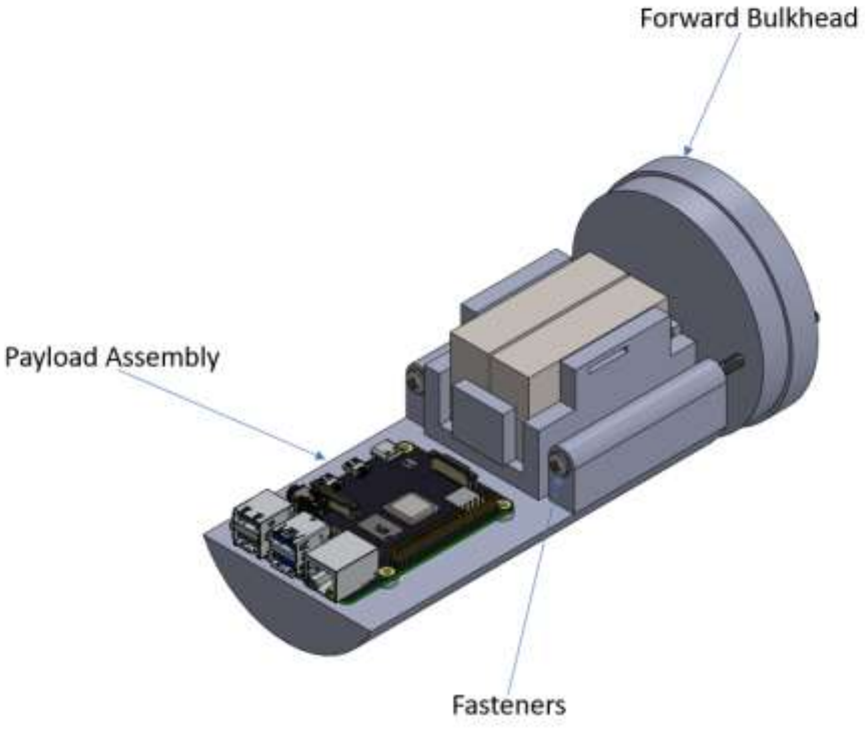


Figure 61: Payload Retention System

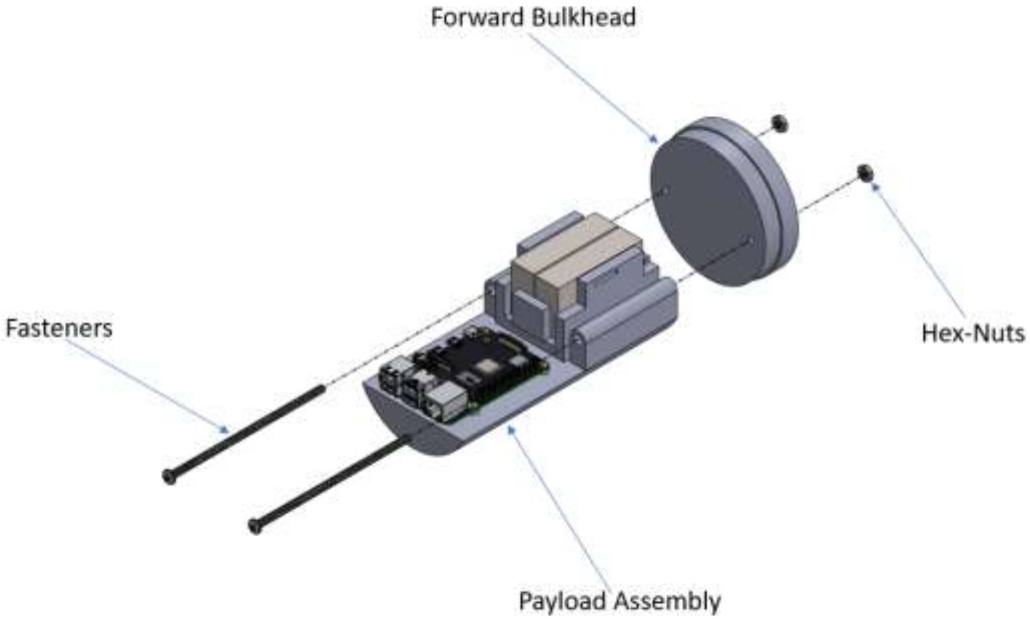


Figure 62: Payload Retention System Exploded View

4.1.2.2 Payload Integration into Launch Vehicle

The payload is comprised of three different main components: the payload assembly, the electronics tubes, and the camera mounts. To power the camera mounts, wires are run from the payload assembly to the camera mounts along the aft section of the launch vehicle via craft paper tubes, which pass through the centering rings. The payload assembly consists of the payload sled and its electronics, the payload coupler, and the forward bulkhead. The camera mounts consist of the camera housing, camera cover, and the camera. The camera mounts are mounted to the aft airframe using ¼-20 style fasteners and their corresponding T-nuts. To ensure the wires are safely connected to the camera mounts, craft paper tubes of 0.375 in diameter are epoxied to the centering rings, reaching from the payload assembly to the camera mounts (Figure 63).

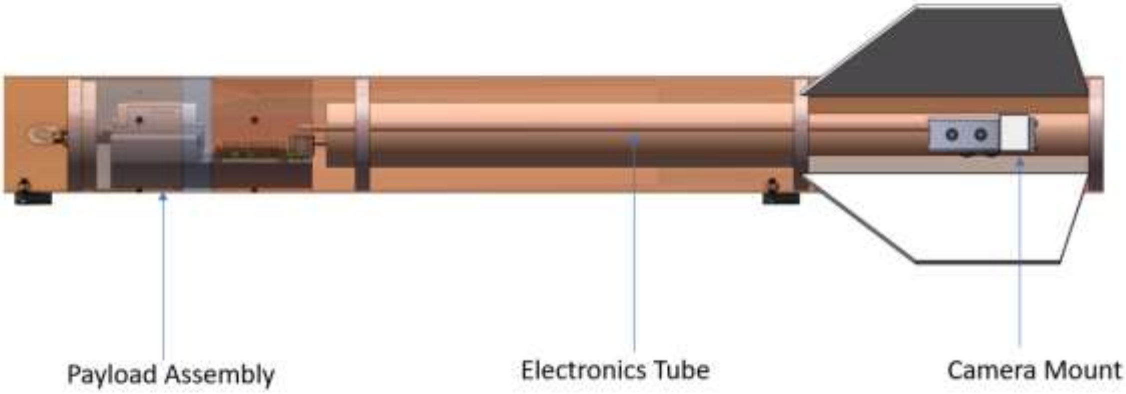


Figure 63: Payload Integration

4.1.2.3 Payload and Camera Mounts Mass Tables

The payload assembly consists of the payload sled, battery compartment, two camera mounts, associated electronics, and fasteners. The camera mount consists of the camera cover, camera housing, and the camera. The payload assembly has a total mass of 18.4 oz and the camera mounts each have a mass of 2.3 oz (Table 26).

Component	Mass (oz.)
Payload Sled	13.8
Battery Compartment	3.5
Payload Fasteners	1.1
Camera Mount Fasteners	0.7
Payload Assembly	18.4
Camera Mount	1.6
Camera Mount Assembly	2.3
Raspberry Pi 4	6.77
7.4 V Lithium-Ion Batteries	1.94
OV5642 Cameras	0.64
Printed Circuit Board	0.71
XBee Radio	0.32
Inertial Measurement Unit	0.07
Barometer	0.04
Wiring	0.35
Electronics Assembly	10.19

Table 26: Payload and Camera Mounts Mass Table

4.1.3 Payload Electronics

The payload contains a processor, inertial measurement unit, barometer, and two cameras. The interconnection between each electrical component is shown in Figure 64.

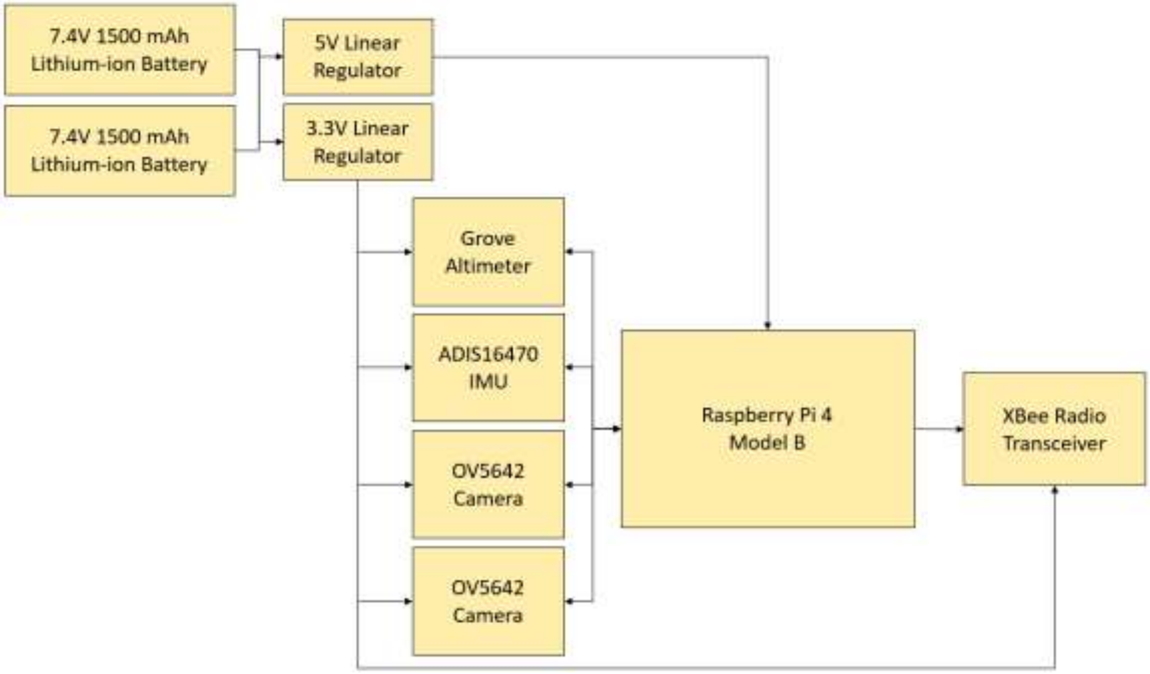


Figure 64: Payload Electronics Block Diagram

4.1.3.1 Power System

The payload is powered by two 7.4V lithium-ion batteries connected in parallel. Each battery has a capacity of 1500 mAh, resulting in a total capacity of 3000 mAh.

Power supplied by the 7.4V lithium-ion batteries is passed through a 3.3V and a 5V linear voltage regulator. The 3.3V regulator distributes power to the cameras, IMU, barometer, and XBee transceiver. The 5V regulator supplies power to the Raspberry Pi 4.

A 10 µF ceramic capacitor, and 220 µF electrolytic capacitor are placed on the input and output terminals respectively of each linear voltage regulator. These capacitors are used to reduce power ripple on each supply line, thereby reducing noise on each sensor’s output.

4.1.3.2 Electronic Component Interface

The Raspberry Pi 4 connects to the cameras, IMU, barometer, and XBee transceiver via its GPIO pins. Data is transferred between the Raspberry Pi and XBee transceiver via the Universal Asynchronous Receiver/Transmitter (UART) pins, RxD and TxD. The Raspberry Pi interfaces with the OV5642 cameras using the Inter-Integrated Circuit (I2C) and Serial Peripheral Interface (SPI) communication pins. The Grove altimeter sends data to the Raspberry Pi 4 via I2C, while the ADIS16470 IMU communicates with the Raspberry Pi 4 using SPI (Figure 65).

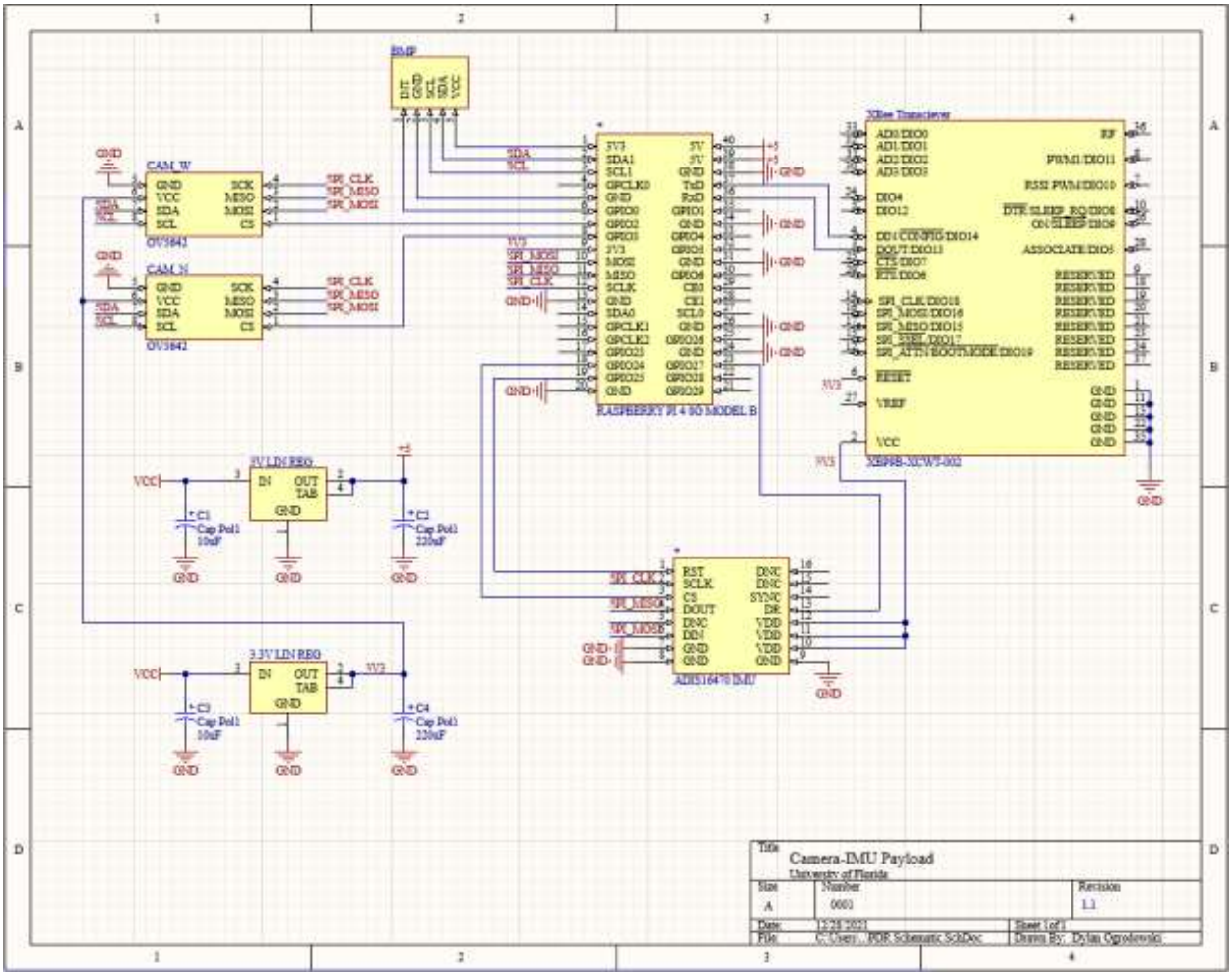


Figure 65: Payload Electronics Schematic

4.1.4 Ground Station Electronics

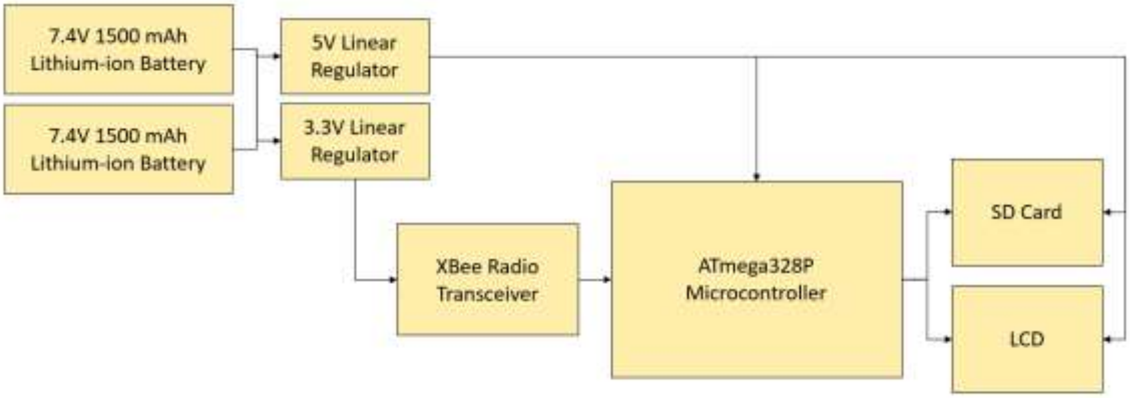


Figure 66: Ground Station Block Diagram

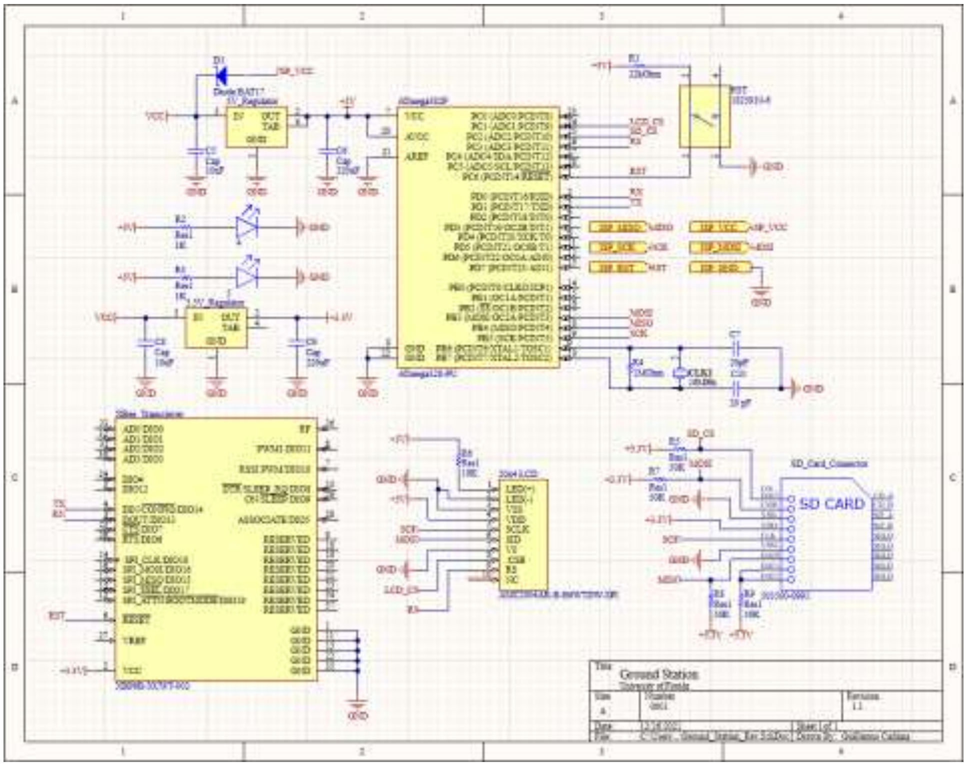


Figure 67: Ground Station Schematic

The ground station consists of an ATmega328P microcontroller, XBee radio transceiver, LCD screen, and an SD card interface (Figure 66).

The ground station’s input power is supplied by two 7.4 V 1500 mAh lithium-ion batteries. The battery’s voltage is passed through two linear voltage regulators to create 5V and 3.3V power lines.

ATmega328P microcontroller is used to coordinate data received from the XBee radio transceiver and data sent to the LCD and SD Card reader (via SPI). A reset switch is connected to the microcontroller's reset pin should it ever be needed.

The LCD reader is supplied with 5V and is controlled by the microcontroller. The display will show the radio connection status and, when received, grid coordinates of the rocket.

The SD card interface is supplied with 3.3V stores the coordinates of the rocket (Figure 67).

4.2 Software Design

4.2.1 Overview

The payload software refers to the program running on a Raspberry Pi. This program will calculate the final landing location of the rocket by using the images and Inertial Measurement Unit (IMU) data collected during the flight.

The images taken during flight will be compared to a pre-uploaded image of the launch field. This comparison will be done using the Scale-Invariant Feature Transform (SIFT) algorithm in OpenCV. This will help us identify a location of the rocket. The IMU data from that location will then be compared to the IMU data after landing to find the final landing location of the rocket. All the processing starts after landing is detected. Once the location is detected, all processing stops, and the Raspberry Pi starts transmitting the landing location coordinates based on the uploaded gridded map (Figure 68).

Figure 68: Completed Gridded Map of Competition Field (image credit: Google Maps)

4.2.2 Image and IMU data collection and storage

4.2.2.1 Images

Images will be taken by the 2 cameras attached to the rocket and will be stored on board the payload in an SD card. The images will be stored in ".png" format. The images will be labelled with its order number (The first image taken will be "1.png"). Since images will be collected from 2 cameras with different Field of View (FOVs), the images will be stored in 2 separate folders, with each folder holding images taken from a particular camera. Each folder will have a ".txt" file will be constantly updated with the image label and its respective timestamp.

4.2.2.2 IMU

The IMU data will be constantly collected and updated to a ".csv" file. The csv file will contain the timestamp, altitude, and orientation data.

4.2.3 Image analysis

The images are used to determine a location of the rocket. This location will be used as a reference point. Before analyzing the images, the data must be loaded in from the files. The time stamp data and the image label are first loaded into an array. The image label serves as the index. Next, the IMU data is loaded into a multidimensional array by timestamp. The timestamp is then compared to the timestamp of the images and the image label is assigned to the IMU data. The capture states are assigned simultaneously (Table 27).

Capture State	Criteria
Best	2500ft – 4000ft (During Ascent)
Good	1000ft – 2500ft (During Ascent)
Fair	<1000ft
Poor	Over Cloud Cover

Table 27: Capture States

Once this is done, the image comparison begins. The comparison is done in order of capture state. If an image match is found with ~150 keypoint matching, we stop analyzing. First, the image is run through the SIFT algorithm, to generate SIFT points (which are special keypoints and help in feature matching) and compare them to the pre-uploaded image of the launch field (Figure 69). If a good enough match is found, the program moves on to location detection. If not, it moves on to the next image.

Figure 69: Image of Launch Field with SIFT Points Generated (image credit: Google Maps)

4.2.4 Location detection by image

Once a good enough match is found, location detection is performed. This is done by utilizing the pre-uploaded image and the matched image to find the location. For this, the matched image is first run through SIFT algorithm again. The distance between the principal point of the camera (center point of the image) and the cluster of keypoints is calculated using openCV. We assume that the location of the principal point is the location of the rocket. Then, we account for the vertical tilt. The vertical tilt is defined as the angle between the ground and the vertical axis of the launch vehicle. Vertical tilt will be corrected by using measures to correct tilt errors in photogrammetry. Trigonometry will be employed, and the angles will be used to calculate the deviation. This is accounted for in the formula we use below.

To determine the size of the image, the real width of the image will be calculated using Equation 11 where FoV_{lens} is the field of view of the camera lens. The real width is defined as the distance from one end of the image to the other.

The formula for calculating the distance and accounting for tilt is:

$$Altitude \times (\tan\left[\frac{FoV_{lens}}{2} + tilt_{camera}\right] + \tan\left[\frac{FoV_{lens}}{2} - tilt_{camera}\right])$$

Equation 11

This real width will then be used to scale the distance between the principal point and the reference point on the map to get the real distance.

4.2.4.1 Orientation detection

A magnetometer was initially used to determine directional orientation. This was replaced with orientation detection by using the taken images. This can be done by comparing the location data of the rocket at different times. This is done by comparing the principal points of consecutive images and keypoints at the same location. The trend of direction will help us know which way the rocket is going and help us calculate its directional orientation.

After we find the orientation, we can resume location detection. We now use the orientation data from the IMU and pair it with the orientation information calculated to find the final location of the rocket.

4.2.5 Final location detection by IMU

The horizontal acceleration data from the reference location and the final location and values between will be used to calculate the displacement between the 2 locations. Since we will have the reference location detected on map due to our imaging system, the final landing location of the rocket can be calculated after the displacement is found. The location will be plotted on the map and the grid box number will then be identified on the gridded map using OpenCV.

4.2.6 Software Program Flow

On the launch pad, the Raspberry Pi is in an idling state. The IMU is turned on pre-flight. The Raspberry Pi detects flight utilizing the IMU and turns on. It then starts collecting and storing images. After landing, the images are all stored along with their timestamp, state, altitude, angle of image and number of Keypoints. After this, analysis is begun. Upon identifying the location, the grid location is transmitted to a ground station (Figure 70).

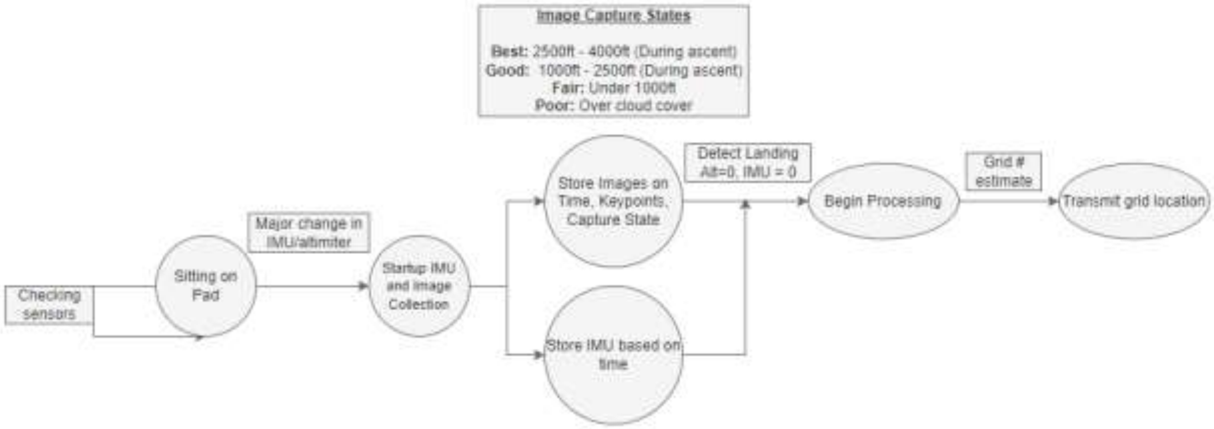


Figure 70: Payload Software Flow

5. Safety

5.1 Launch Concerns and Operation Procedures

If any responsible lead is unable to attend a launch, their replacement must be approved by the Project Manager and the responsible lead. This change must also be communicated to Safety Officers. If the individual tasked with performing the checklist verification is unable to attend a launch, their replacement must be approved by both Safety Officers and the Project Manager.

5.1.1 Avionics and Recovery Preparation

5.1.1.1 Relevant Personal Protective Equipment

None

5.1.1.2 Authority

Responsible Lead: Collin Larke (Avionics and Recovery Lead)

Checklist Verification: Raymond Pace (Secondary Safety Officer)

5.1.1.3 Critical Testing Prior to Launch Date

Test 6 – Parachute Drag Analysis

Test 7 – Recovery Altimeter Resolution Test

Test 20 – Parachute Packing Demonstration

Test 21 – Parachute Opening Demonstration

5.1.1.4 Parachute Preparation Procedure

1. Attach swivel and D-link to parachute.
2. Put slip knot in recovery harness, about 1/3 of the length away from one of the ends.
3. Secure D-link on swivel to slip knot, wrench tight.
4. Attach other ends of recovery harness to their respective eye bolts, wrench tight.
5. Fold parachute from gore to gore, until all gores folded. All shroud lines should be aligned.
6. Do one Z-fold of the shroud lines inside parachute after folding from gore to gore is complete.
7. Do one Z-fold of parachute.
8. Fold the parcel in half.
9. Roll each side of the parcel as tight as possible.
10. Place in center of the parachute protector.
11. Z-fold recovery harness alongside parachute in protector.
12. Fold ends of parachute protector in, and roll parachute and recovery harness inside protector.

Verify parachute properly folded; failure to do so may lead to hazard L.1.

	Responsible Lead	Checklist Verification
Drogue Parachute Folded	________________	____________________
Main Parachute Folded	________________	____________________

5.1.1.5 Avionics Bay Preparation Procedure

Check altimeter settings and verify deployment altitudes/delays

- ☐ Primary Drogue Deployment - At apogee
- ☐ Primary Main Deployment - At 600 ft
- ☐ Secondary Drogue Deployment - Delayed 0.5 s from apogee
- ☐ Secondary Main Deployment – At 550 feet

1. Plug in current mean altitude above sea level for the Entacore AIM to calibrate for ground level
2. Verify that batteries are plugged in in the correct orientation by powering on each altimeter with no charge plugged in. Expect 5-30 milliamps of current through the output terminals for each altimeter.
   - ☐ Primary Altimeter battery installed properly
   - ☐ Secondary Altimeter battery installed properly
3. Ensure altimeters and batteries are secured to the avionics bay sled.
4. Pass threaded rods through the forward bulkhead and the avionics sled.

   Verify sled is oriented correctly, failure to do so will require disassembly of completed bay

   - ☐ Verify correct orientation
5. Pass wires through the wire hole in the forward bulkhead and secure to one side of the terminal block for primary and secondary charges.
6. Pass wires for the aft bulkhead ejection charges through the avionics bay coupler section.
7. Secure the wires to their respective altimeter terminals and the terminal blocks on the outside of the aft bulkhead.
8. Nest the bulkheads into the avionics bay coupler, ensuring keylock switch is accessible through switch band.
9. Secure bulkheads with hex nuts, wrench tight.
10. Place clay around wire and threaded rod holes as needed to prevent ejection gases from entering and escaping through avionics bay.

	Responsible Lead	Checklist Verification
Avionics Bay Prepared	____________________	______________________

5.1.2 Camera Preparation

5.1.2.1 Relevant Personal Protective Equipment

None

5.1.2.2 Authority

Responsible Lead: Joseph Pinkston (Payload Mechanical Lead)

Checklist Verification: Raymond Pace (Secondary Safety Officer)

5.1.2.3 Critical Testing Prior to Launch Date

Test 25 – Launch Rehearsal

Test 34 – Vibrational Resistance Test

Test 35 – Payload Drop Test

Test 36 – Strength of Camera Mount Test

5.1.2.4 Payload Camera Mount Preparation Procedure

1. Mount camera to the camera housing using fasteners and hex nuts, tightening hex nuts with a wrench.
2. Place camera and camera housing onto airframe, allowing the camera to slide into the camera slot cut into the airframe. Camera housing holes must line up with the designated T-Nuts.
3. Attach camera housing to airframe using fasteners and the T-Nuts that the camera housing slides onto.
    - ☐ Camera housing attached
4. Attach camera cover housing using fasteners and the previously glued hex nuts, enclosing the camera housing and the camera.

Verify complete assembly with fully retained camera.

	Responsible Lead	Checklist Verification
Cameras Mounted	______________________	_________________________

5.1.3 Payload Bay Preparation

5.1.3.1 Relevant Personal Protective Equipment

- Non-synthetic clothing to prevent static buildup

5.1.3.2 Authority

Responsible Person: Dylan Ogrodowski (Payload Electronics Lead)

Checklist Verification: Jason Rosenblum (Primary Safety Officer)

5.1.3.3 Critical Testing Prior to Launch Date

Test 25 – Launch Rehearsal

Tests 39-44, 46 – Payload Components Functionality Demonstrations

Test 45 – Wire Tube Inspection

Test 47 – Payload Data Compilation Test

Test 48 – Payload Transmission Range Test

Test 49 – IMU Drift Analysis

5.1.3.4 Payload Bay Preparation Procedure

1. Secure two lithium ion batteries to the sled with Velcro straps.
2. Connect lithium ion batteries to the payload power input terminal.
   Verify that the payload has established a radio connection to the ground station via the ground station's display.
    - ☐ Radio Connection Established
3. Connect both camera harnesses to marked terminals on PCB.

☐ Camera Harnesses Connected

4. Insert two mounting screws to the payload sled.
5. Insert the payload sled into the payload coupler.
6. Pass the two mounting screws through the payload bulkhead and secure with nuts.
7. Pack clay around each nut to seal the payload bay.
   Failure to seal payload bay may lead to hazard L.2.

	Responsible Lead	Checklist Verification
Payload Bay Prepared and Sealed	____________________	______________________

5.1.4 Ejection Charge Preparation

5.1.4.1 Relevant Personal Protective Equipment

- Non-synthetic clothing to prevent static buildup
- Non-sparking spatula
- Non-sparking dish
- Non-sparking wooden dowel

5.1.4.2 Authority

Responsible Lead: Brida Gibbons (Testing Lead)

Checklist Verification: Raymond Pace (Secondary Safety Officer)

5.1.4.3 Critical Testing Prior to Launch Date

Test 11 – Full scale Main Parachute Ejection Demonstration

Test 12 – Full scale Drogue Parachute Ejection Demonstration

5.1.4.4 Ejection Charge Preparation Procedure

VERIFY CORRECT ENERGETIC AND AMOUNTS REQUIRED FOR ALL EJECTION CHARGES FROM CHARGE TESTS:

☐ Energetic: Black Powder
☐ Forward Avionics Bay Forward Bulkhead Primary Charge: 2.50 grams
☐ Forward Avionics Bay Forward Bulkhead Backup Charge: 3.20 grams
☐ Forward Avionics Bay Aft Bulkhead Primary Charge: 1.50 grams
☐ Forward Avionics Bay Aft Bulkhead Backup Charge: 2.00 grams

REMOVE ANY IGNITION SOURCES PRIOR TO PREPARING CHARGES. REMOVE ALL OTHER MATERIALS FROM WORK AREA. RELEASE ANY STATIC BUILDUP PRIOR TO HANDLING ENERGETIC. FAILURE TO DO SO MAY CAUSE HAZARD L.3.

Necessary Materials:

☐ Energetic (Above)
☐ 4 Premade E-Matches
☐ Fire-Resistant Insulation
☐ Electronic scale

- ☐ Non-sparking metal dish
- ☐ Non-sparking spatula
- ☐ Small wooden dowel
- ☐ Masking tape
- ☐ Writing Utensil

Ejection charges must be made one at a time to ensure correct amount of energetic is packed in each charge. During preparation, box for corresponding charge must be checked as work is performed.

1. Place small electronic scale on level surface.
2. Place metal dish onto scale and zero the scale.
    - ☐ Avionics Bay Forward Bulkhead Primary Charge: 2.50 grams
    - ☐ Avionics Bay Forward Bulkhead Backup Charge: 3.20 grams
    - ☐ Avionics Bay Aft Bulkhead Primary Charge: 1.50 grams
    - ☐ Avionics Bay Aft Bulkhead Backup Charge: 2.00 grams
3. Using a spatula, add energetic into metal dish until appropriate amount is measured.
4. Pour energetic into cardboard cylinder of premade e-match.
5. Insert fire-resistant insulation into cylinder and compress insulation using small wooden dowel.
    - ☐ Insulation packed in Forward Bulkhead Primary Charge
    - ☐ Insulation packed in Forward Bulkhead Backup Charge
    - ☐ Insulation packed in Aft Bulkhead Primary Charge
    - ☐ Insulation packed in Aft Bulkhead Backup Charge
6. Fold top of cylinder down and seal with masking tape.
7. Label charge with the corresponding energetic, amount, location, and primary/backup.
    - ☐ Avionics Bay Forward Bulkhead Primary Charge: 2.50 grams
    - ☐ Avionics Bay Forward Bulkhead Backup Charge: 3.20 grams
    - ☐ Avionics Bay Aft Bulkhead Primary Charge: 1.50 grams
    - ☐ Avionics Bay Aft Bulkhead Backup Charge: 2.00 grams
8. Initial below for each charge and repeat steps 1-7 for each required ejection charge.

	Responsible Lead	Checklist Verification
Forward Bulkhead Primary Charge		
Forward Bulkhead Backup Charge		
Aft Bulkhead Primary Charge		
Aft Bulkhead Secondary Charge		

5.1.5 Rocket Assembly Preparation

5.1.5.1 Relevant Personal Protective Equipment

- Non-synthetic clothing to prevent static buildup

5.1.5.2 Authority

Responsible Lead: Erik Dearmin (Structures Lead)

Checklist Verification: Jason Rosenblum (Primary Safety Officer)

5.1.5.3 Critical Testing Prior to Launch Date

Test 11 – Full scale Main Parachute Ejection Demonstration

Test 12 – Full scale Drogue Parachute Ejection Demonstration

Test 25 – Launch Rehearsal

5.1.5.4 Rocket Assembly Procedure

Necessary Materials:

- ☐ Nosecone body
- ☐ Nosecone coupler
- ☐ Forward airframe
- ☐ Assembled avionics bay
- ☐ Assembled payload bay
- ☐ Upper aft airframe
- ☐ Lower aft assembly
- ☐ 6 shear pins
- ☐ 12 rivets
- ☐ Wrench
- ☐ Pliers
- ☐ Flathead screwdriver
- ☐ 4 quick links
- ☐ Insulation

1. Assemble nosecone section.
    - ☐ Use 3 rivets to connect nosecone body to the nosecone coupler
2. Assemble aft section.
    - ☐ Feed recovery harness through upper aft section and connect quick link to payload bay
    - ☐ Use 3 rivets to connect upper aft airframe to payload bay
    - ☐ Use 3 rivets to connect payload bay to lower aft assembly
3. Connect avionics bay to aft section
    - ☐ Connect recovery harness in aft section to avionics bay with a quick link
    - ☐ Place ejection charge in bottom of aft section

    Ensure wires of ejection charge are accessible and shorted while the lead is not touching any surface.

- ☐ Place insulation in aft section
- ☐ Pack drogue parachute into aft section
- ☐ Wire ejection charge to avionics bay
- ☐ Use 3 shear pins to secure aft section to avionics bay

4. Connect forward airframe to nosecone.
   - ☐ Connect recovery harness in forward section to nosecone section using a quick link
   - ☐ Place insulation in forward section
   - ☐ Pack main parachute in forward section
   - ☐ Use 3 shear pins to secure forward section to nosecone section
5. Assemble forward section
   - ☐ Connect recovery harness to avionics bay using a quick link
   - ☐ Pack main parachute into forward airframe
   - ☐ Place insulation into forward airframe
   - ☐ Place ejection charge in forward airframe

Ensure wires of ejection charge are accessible and shorted while the lead is not touching any surface.

- ☐ Wire ejection charge to avionics bay
- ☐ Use 3 rivets to connect the forward airframe to the avionics bay

	Responsible Lead	Checklist Verification
Rocket Assembled	______________________	______________________

5.1.6 Motor Preparation

5.1.6.1 Relevant Personal Protective Equipment

- Non-synthetic clothing to prevent static buildup

5.1.6.2 Authority

Responsible Person: Jimmy Yawn (Team NAR/TRA Mentor)

Checklist Verification: Jason Rosenblum (Primary Safety Officer)

5.1.6.3 Critical Testing Prior to Launch Date

None

5.1.6.4 Motor Preparation Procedure

1. Grease O-rings and Threaded Sections.
2. Insert Propellant grains into Propellant Sleeve.
   a. Should be flush with end of side opposite to Aerotech logo.
3. Prepare the Delay grain.
   a. Press the inside of the delay grain cap for proper fit.
   b. Put the spacer into the delay grain cap.
   c. Slide the delay grain inside.

    d. Put the Delay Grain O-ring on the lip of the delay grain, avoiding getting grease on the grain.

4. Insert the delay grain into the forward closure.

Verify delay grain inserted

- ☐ Delay Grain Inserted

5. Insert Aft and Forward Seal Disks to the ends of the Propellant.
    a. Use the aluminum forward seal disk for bigger motors.
6. Insert Aft O-ring (Thick) onto the aft seal disk.
7. Insert Forward O-ring (Thin) onto forward seal disk.

Verify seal disks and O-rings inserted

- ☐ Aft Seal Disk and O-Ring Inserted
- ☐ Forward Seal Disk and O-Ring Inserted

8. Screw on forward closure halfway.
9. Put nozzle on aft closure.
10. Screw on aft closure with nozzle in center circle halfway.
11. Screw in both closures until fully sealed.
12. Add a small diamond-shaped cut to the nozzle plug so igniter can fit through; put it on the nozzle.

IGNITER MUST NOT BE INSERTED INTO MOTOR UNTIL ON THE PAD

	Responsible Lead	Checklist Verification
Motor Prepared (w/o Igniter)	____________________	____________________

5.1.7 Setup on Launch Pad

5.1.7.1 Relevant Personal Protective Equipment

- Non-synthetic clothing to prevent static buildup

5.1.7.2 Authority

Responsible Individuals: Jimmy Yawn (Team NAR/TRA Mentor) and Collin Larke (Avionics and Recovery Lead)

Checklist Verification: Megan Wnek (Project Manager)

5.1.7.3 Critical Testing Prior to Launch Date

None

5.1.7.4 Setup on Launch Pad Procedure

VERIFY ALL SETUP CHECKLISTS ARE COMPLETE BEFORE BEGINNING LAUNCH PAD SETUP:

- ☐ Ejection charge checklist

☐ Payload preparation checklist
☐ Avionics preparation checklist
☐ Motor preparation checklist
☐ Rocket preparation checklist

Follow directions from the Range Safety Officer at all times.

1. Verify correct launch rail
   ☐ 15-15 rail
   ☐ 12 ft
2. Load launch vehicle on launch rail
3. Arm altimeters using keylock switch
   ☐ Altimeters armed
   ☐ Continuity confirmed

Responsible Leads Checklist Verification

Vehicle on Pad ________________ ________________ _________________________

5.1.8 Igniter Installation

5.1.8.1 Relevant Personal Protective Equipment

- Non-synthetic clothing to prevent static buildup

5.1.8.2 Authority

Responsible Person: Jimmy Yawn (Team NAR/TRA Mentor)

Checklist Verification: Megan Wnek (Project Manager)

5.1.8.3 Critical Testing Prior to Launch Date

None

5.1.8.4 Igniter Installation Procedure

VERIFY LAUNCH PAD SETUP CHECKLIST IS COMPLETE BEFORE IGNITER INSTALLATION

☐ Launch pad setup checklist complete

1. Insert igniter all the way into the motor until the igniter touches the end of the motor.

Ensure that the wire does not lower throughout the following processes

2. Put the igniter through the small hole in the nozzle plug, and seat nozzle plug into nozzle.
3. Strike the alligator clips together to ensure they are not powered.
4. Using alligator clips, clip the wire on its tip (about 1/4 in of wire) and then wrap the remaining wire around the alligator clip

Ensure alligator clips and igniter wires are not touching the metal launch rail stand

Responsible Lead Checklist Verification

Igniter Installed ____________________ ______________________

5.1.9 Launch Procedure

5.1.9.1 Relevant Personal Protective Equipment

- Non-synthetic clothing to prevent static buildup

5.1.9.2 Authority

Responsible Lead: Megan Wnek (Project Manager)

Checklist verification: Jason Rosenblum (Primary Safety Officer) and Raymond Pace (Secondary Safety Officer)

5.1.9.3 Critical Testing Prior to Launch Date

None

5.1.9.4 Launch Procedure

VERIFY IGNITER INSTALLATION CHECKLIST IS COMPLETE BEFORE BEGINNING LAUNCH CHECKLIST

☐ Igniter installation checklist completed

Follow directions from the Range Safety Officer at all times.

1. Assemble payload components
   ☐ Payload checklist completed
2. Assemble avionics bay
   ☐ Recovery checklist completed
3. Assemble launch vehicle
   ☐ Rocket preparation checklist completed
4. Prepare motor
   ☐ Motor preparation checklist completed
5. Insert assembled motor into motor tube of launch vehicle
   a. Motor inserted
   b. Thread motor retainer onto motor assembly

Line of motor must remain clear of all persons.

6. Find rocket center of gravity
   ☐ Balance rocket horizontally until center of gravity is found
7. Check stability of launch vehicle
   ☐ Stability is 2.0 or higher at rail exit
   ☐ Thrust to weight ratio of 5:1 or higher
   ☐ Velocity off rail of 52 fps or higher
8. Bring launch vehicle to launch pad
   ☐ Launch pad checklist completed
   ☐ Igniter installation checklist completed

9. Launch
   - ☐ Follow all Range Safety Officer instructions
   - ☐ Verify all personnel are at least 300 ft from launch pad
   - ☐ Verify pad area is cleared for 100 ft around launch pad
   - ☐ Verify windspeed is less than 20 mph
   - ☐ Verify airspace is clear
   - ☐ Verify continuity with igniter

	Responsible Lead	Checklist Verifications	
Launch Ready	________________	______________	________________

An immediate launch can occur once lead and verifications sign off, pending RSO final approval.

5.1.10 Troubleshooting

5.1.10.1 Relevant Personal Protective Equipment

- Non-synthetic clothing to prevent static buildup

5.1.10.2 Authority

Responsible Lead for Misalignment and Altimeters: Collin Larke (Avionics and Recovery Lead)

Responsible Person for Motor Issue: Jimmy Yawn (Team NAR/TRA Mentor)

Checklist Verification: Either Safety Officer (Jason Rosenblum or Raymond Pace)

5.1.10.3 Critical Testing Prior to Launch Date

None

5.1.10.4 Troubleshooting Procedure

5.1.10.4.1 Avionics bay misaligned

1. Disassemble avionics bay
   - ☐ Avionics bay disassembled
2. Check for improper component placement
   - ☐ Avionics sled installed backwards or upside down
   - ☐ Wrong bulkheads used on avionics bay
   - ☐ Improper wiring of avionics components
3. Reassemble avionics bay
   - ☐ Avionics bay assembly procedure completed

	Responsible Lead	Checklist Verification
Avionics Bay Properly Aligned	________________	__________________

5.1.10.4.2 Altimeters do not have continuity or do not turn on

1. Disassemble avionics bay
   - ☐ Avionics bay disassembled
2. Check all wiring for loose connections
   - ☐ Altimeter connections

- ☐ Terminal connections
- ☐ Battery connections

3. Reassemble avionics bay
   - ☐ Avionics bay assembly procedure completed

	Responsible Lead	Checklist Verification
Altimeter Troubleshooting Complete	______________________	______________________

5.1.10.4.3 Motor fails to ignite

1. Wait 60 seconds before approaching launch pad
2. Disarm altimeters
   - ☐ Altimeters disarmed
3. Remove old igniter
4. Install new igniter
   - ☐ Igniter installation procedure completed

	Responsible Lead	Checklist Verification
Igniter Troubleshooting Complete	______________________	______________________

5.1.11 Post-Flight Inspection

5.1.11.1 Relevant Personal Protective Equipment

- ☐ Gloves – determination will be made by Safety Officers if rocket's recovery location requires gloves

5.1.11.2 Authority

Responsible Leads: Megan Wnek (Project Manager)

Checklist Verification: Jason Rosenblum (Primary Safety Officer)

5.1.11.3 Critical Testing Prior to Launch Date

None

5.1.11.4 Post-Flight Inspection Procedure

Identify and make team aware of any environmental hazards in recovery area prior to approaching rocket. Only leads may approach rocket for recovery and inspection.

- ☐ Area safe and only necessary personnel recovering rocket

1. Locate ejection charge wiring to verify all charges properly detonated

   Note: If undetonated, wait an additional minute before approaching vehicle
2. Listen for and take audio recording of altimeter beeps (for maximum altitude)
   - ☐ Altitude recorded: _____
3. Turn off keylock switches
   - ☐ Switches off
4. Inspect launch vehicle for external damage and proper parachute deployment (Take pictures)

   Observations: ____

5. Lift rocket from ground, 1 person holding each section, ensuring that no section is stuck or shock cord tangled. **Caution: Do not hold aft airframe by motor retainer, this may result in burns**
6. Carefully move rocket back to prep area.
7. Remove D-Links.
8. Open avionics bay and payload bay.
9. Inspect bays and bulkheads for ejection debris.

Observations: ____

	Responsible Lead	Checklist Verification
Post-flight inspection complete	____________________	______________________

5.2 Safety and Environment

Personnel hazards were quantified using a total score given by the product between the severity and likelihood of each hazard (Table 28).

	Severity (S)	Likelihood (L)
1	No injury obtained	Extremely Unlikely
2	Very minor injury	Unlikely/low probability
3		
4	Minor injury	
5		Likely
6	Moderate injury	
7		Highly likely/high probability
8		
9	Severe injury or death of personnel	
10		Extremely likely/almost certain

Table 28: Personnel Risk Assessment Chart

A hazard with a low severity and likelihood will receive a lower score than a hazard with a large difference between severity and likelihood. Furthermore, a hazard with a high severity and likelihood will receive a higher score than hazards with inconsistent severity and likelihood scores. Thus, quantifying scores using this method accurately shows the significance of the hazards present while completing the project. The scores have been color coded to visually represent the importance of each hazard (Table 29).

		Likelihood									
Severity		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	1	1	2	3	4	5	6	7	8	9	10
	2	2	4	6	8	10	12	14	16	18	20
	3	3	6	9	12	15	18	21	24	27	30
	4	4	8	12	16	20	24	28	32	36	40
	5	5	10	15	20	25	30	35	40	45	50
	6	6	12	18	24	30	36	42	48	54	60
	7	7	14	21	28	35	42	49	56	63	70
	8	8	16	24	32	40	48	56	64	72	80
	9	9	18	27	36	45	54	63	72	81	90
	10	10	20	30	40	50	60	70	80	90	100

Table 29: Risk Assessment Score Chart

5.2.1 Chemical Hazards

Chemical hazards are those posed by the team's chemical inventory. The personal protective equipment (PPE) and storage requirements for mitigating each hazard were identified using the material safety data sheets (MSDS) of each chemical (Table 30).

ID	Hazard	Cause	Effect	S	L	Score	Mitigation & Verification
C.1	Irritant contacts skin	Working with epoxy resin	Skin redness, itching, other moderate irritation	4	6	24	Use alternative adhesive if materials allow. Wear liquid-proof, chemical resistant gloves and full-body covering clothing when handling. Verification: PPE and MSDS located in MAE-C and SDC; Multiple team members must be present when using epoxy to ensure proper use of epoxy and PPE
C.2	Irritant contacts eyes	Working with epoxy resin	Eye redness, moderate irritation	6	3	18	Use alternative adhesive if materials allow. Wear chemical goggles when applying epoxy. Verification: PPE and MSDS located in MAE-C and SDC; Multiple team members must be present when using epoxy to ensure proper use of epoxy and PPE

C.3	Exposure to noxious fumes	Working with epoxy resin	Headache, nausea, dizziness, respiratory irritation	6	4	24	Use alternative adhesive if materials allow. Use in well ventilated area. Limit use of curing agents which cause additional vapors due to heat. When process produces heat or heat is applied, wear respirator. Verification: PPE and MSDS located in MAE-C and SDC; Multiple team members must be present when using epoxy to ensure proper use of epoxy and PPE
C.4	Uncontrolled detonation of black powder	Heat, or flame ignites black powder	Severe burns	8	2	16	Store black powder in cool, dry conditions until use. Wear metal-free and non-static producing clothes when handling. Release static buildup prior to beginning work. Verification: Ejection Charge Preparation Procedure - Checklist Verification (5.1.4.4); PPE and MSDS located in MAE-C and SDC.
C.5	Spray paint can explodes	Heat or flame causes can to explode, can is pierced	Severe burns, shrapnel injuries	8	2	16	Store in a cool, well-ventilated area away from sunlight. Verification: MSDS located in MAE-C and SDC.
C.6	Spray paint aerosol combusts	Heat, sparks, flames, or other ignition sources ignite aerosol	Severe burns	6	3	18	Use away from any heat sources, flames, sparks, and other ignition sources. Verification: MSDS located in MAE-C and SDC.
C.7	Spray paint aerosol contacts skin	Working with spray paint	Skin irritation, allergic reaction	4	7	28	Wear protective gloves and clothing when handling. Work outdoors or in a well-ventilated area. Wash hands and other exposed areas after handling. Verification: PPE and MSDS located in MAE-C and SDC.
C.8	Spray paint aerosol contacts eyes	Working with spray paint	Serious eye irritation	6	4	24	Wear eye or face protection when handling. Verification: PPE and MSDS located in MAE-C and SDC.

C.9	Spray paint aerosol is inhaled	Working with spray paint	Respiratory irritation, drowsiness, dizziness	7	3	21	Work outdoors or in a well-ventilated area. Wear face protection and respirator when handling. Verification: PPE and MSDS located in MAE-C and SDC.

Table 30: Chemical Hazards Chart

5.2.2 Manufacturing Hazards

Manufacturing hazards are those posed by team activities during the manufacturing process. The hazards and mitigations were identified using the operator's manuals of each machine (Table 31).

ID	Hazard	Cause	Effect	S	L	Score	Mitigation & Verification
M.1	Blade contacts skin	Improper use of bandsaw, hand saw, box cutter, or any other cutting tool.	Severe cuts, loss of extremities	8	3	24	Keep hand out of the path of the blade. Use a sacrificial handle when workpiece is too small to hold. Any member performing manufacturing work must be trained on proper machine use. Verification: Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.2	Spinning tool or workpiece contacts person	Improper use of Dremel, drill press, or any other rotating piece of machinery.	Severe skin laceration, physical trauma	8	3	24	Keep hands at least six inches away from cutting area. Any member performing manufacturing work must be trained on proper machine use. Do not wear gloves while operating powered tools. Do not wear jewelry or loose articles of clothing and tie up long hair when machining. Verification: Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.3	Person contacted by airborne tool or workpiece	Improper clamping of workpiece during machine work; improper grip on tool in use	Skin laceration, physical trauma	6	3	18	Ensure proper clamping of workpiece and tool in machine. At least two clamps used when clamping any workpiece for machining. When using a vise, tighten vise jaws with proper force. Any member performing manufacturing work must be trained on proper machine use. Verification: Clamps are located near each piece of manufacturing equipment. Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.4	Skin contacts sharp tool	Handling sharp tools with bare hands	Skin lacerations	3	5	15	Cover sharp edges with a rag when handling. Any member performing manufacturing work must be trained on proper machine use.

							Verification: Rags are located at team manufacturing sites. Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.5	Skin contacts sharp edge of workpiece	Handling workpieces with burrs recklessly	Skin lacerations	2	5	10	Carry newly machined parts with a rag. Deburr workpiece as soon as machining is finished. Any member performing manufacturing work must be trained on proper machine use. Verification: Rags are located at team manufacturing sites. Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.6	Skin contacted by pressurized water	Leak in waterjet system, hand too close to jet stream when cutting	Severe skin laceration	8	2	16	Stand a safe distance from the pressurization system when active. Do not put any body parts near cutting zone while waterjet is running. Any member performing manufacturing work must be trained on proper machine use. Verification: Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.7	Extended exposure to loud processes	Unprotected hearing while operating loud machinery	Hearing loss	6	5	30	Wear hearing protection when operating loud machinery. Any member performing manufacturing work must be trained on proper machine use. Verification: Ear plugs and ear muffs are located at team manufacturing sites. Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.8	Non-manufacturing team member exposed to loud processes	Operation of loud machinery without warning	Hearing loss	6	4	24	Verbally warn any nearby people before making any sudden loud noises or starting manufacturing work. Any member performing manufacturing work must be trained on proper machine use (includes awareness of other individuals) Verification: Ear plugs and ear muffs are located at team manufacturing sites. Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC.
M.9	Inhalation of fibrous particles in air from manufacturing	Machining fiberglass releases fibrous particles in the air	Respiratory irritation, potential lung damage	6	7	42	Work in a well-ventilated area. Wear respirators when machining fiberglass. Verification: Respirators are located at team manufacturing sites. Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and

							the SDC. At least 2 members must be present during manufacturing work.
M.10	Fibrous particles from manufacturing contact eyes	Machining fiberglass releases fibrous particles into the air	Eye irritation, potential blindness	6	7	42	Work in a well-ventilated area. Wear safety goggles when machining fiberglass. Verification: Safety goggles are located at team manufacturing sites. Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.11	Small particles from manufacturing contact eyes	Cutting or drilling creates chips that can go airborne	Eye irritation, potential blindness	6	7	42	Wear safety goggles or safety glasses with side shields when machining materials other than fiberglass. Verification: Safety goggles and safety glasses with side shields are located at team manufacturing sites. Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.12	Hot soldering iron contacts skin	Improper handling of soldering iron	Burn	5	2	10	Soldering will be performed in controlled environment. When not in use, iron will be stored properly in stand. Soldering will only be performed by individuals trained and approved by Dylan Ogrodowski (Payload Electronics Lead). Verification: Proper soldering iron stand located in SDC. Dylan maintains a list of approved individuals that is shared with Safety Officers.
M.13	Inhalation of fumes from soldering	Inhalation of soldering iron fumes	Respiratory irritation	3	6	18	Work outdoors or in a well-ventilated area. Soldering will only be performed by individuals trained and approved by Dylan Ogrodowski (Payload Electronics Lead). Verification: Dylan maintains a list of approved individuals that is shared with Safety Officers.

Table 31: Manufacturing Hazards

5.2.3 Launch Hazards

Launch hazards are those posed by team activities throughout launch preparation, launch, and vehicle retrieval (Table 32).

ID	Hazard	Cause	Effect	S	L	Score	Mitigation & Verification
L.1	Falling debris	Shock cord fails	Falling debris hits person	9	1	9	Properly fold parachute and check shock cord and motor retainer connections. Verification: Parachute Preparation Procedure - Checklist Verification 5.1.1.4
		Motor retainer fails					
		Parachute fails to deploy properly	Vehicle hits person at high rate of speed; severe injury or death	10	2	20	Complete ejection charge testing to verify proper shearing of shear pins Fold parachute properly and verify it will not get stuck inside airframe. Verification: Parachute Preparation Procedure - Checklist Verification 5.1.1.4
L.2	Burns from motor ignition	Ignition while loading motor	Severe Burns, hearing loss	10	3	30	No one may stand in line of motor during loading and transit to pad. No smoking, open flames, or other heat sources are allowed within 25 ft. of the motor.
L.3	Burns from motor ignition	Person too close to launch pad during ignition	Severe Burns, hearing loss	10	2	20	No person may be within 200 ft. of the launch pad while range is active. If rocket misfires, the battery will be disconnected from the launch system and no one will approach the rocket for 60 s after the misfire. Verification: Launch Procedure and Troubleshooting – Checklist Verifications 5.1.9.4 and 5.1.10.4.3
L.3	Uncontrolled detonation of black powder	Heat or flame ignites black powder	Severe burns	8	2	16	Wear metal-free and non-static producing clothes when handling. Release static buildup prior to beginning work. Verification: Ejection Charge Preparation Procedure - Checklist Verification (5.1.4.4);PPE and MSDS located in MAE-C and SDC, and carried to launches.
L.4	Vehicle lands in unsafe area	Vehicle drifts from wind	Injuries from environment during recovery	4	3	12	Monitor wind on launch day and only launch in acceptable wind speeds. Angle the launch rail into the wind.
L.5	Heat	High heat at launch site	Heat exhaustion	7	3	21	Bring water to launch site. Give all team members water and check their well-being throughout the day. Bring pop-up canopy for shade.

Table 32: Launch Hazards Chart

5.3 Failure Mode and Effects Analysis

Failure mode and effects analysis (FMEA) evaluates the impact of component failure on the launch vehicle and its ability to complete the mission. The FMEAs include Structures, Payloads, Avionics and Recovery, and Flight Dynamics. Three ratings are given to each failure mode to quantify the significance of the failure: severity, occurrence, and detection. Severity is rated from 1 to 10 where a rating of 1 means that the failure has no effect while a rating of 10 is a catastrophic failure. Occurrence is rated from 1 to 10 where a rating of 1 means that the failure has little to no chance of occurring while a 10 indicated it is incredibly likely to occur. Detection is rated from 1 to 10 where a 1 is a failure that has a high likelihood of detection while a 10 is a failure that has an extremely low likelihood of detection. A risk priority number (RPN) is calculated as the product of the ratings and will be used to inform the team where mitigation strategies are needed.

5.3.1 Structures

Component	Function	Failure Mode	Failure Cause	Failure Effects			S	O	D	RPN	Corrective Actions
				Local Effects	Next Higher Level	System Effects					
Airframe and coupler	Contains the payload and vehicle hardware	Breaks	Manufacturing defect or poor transportation	Fails to contain payload and other internal components	Launch vehicle assembly fails	Launch vehicle is unrecoverable	10	3	3	90	Inspect launch vehicle immediately after manufacturing and before and after each launch (Test 1)
Fin Fillets	Epoxy keeps the fins attached to the aft airframe and motor tube assembly	Epoxy fails	Improper application	Launch vehicle loses stability	Uncontrolled flight	Launch vehicle drifts or moves uncontrollably, posing a hazard	8	2	4	64	Follow proper procedures for applying epoxy to fins
Centering ring	Keeps the motor centered within the airframe	Epoxy fails	Improper application	Launch vehicle loses stability	Uncontrolled flight	Launch vehicle drifts or moves uncontrollably	10	2	5	100	Inspect launch vehicle before and after each launch
Centering ring	Keeps the motor centered within the airframe	Breaks	Manufacturing defects	Launch vehicle loses stability	Uncontrolled flight	Launch vehicle drifts or moves uncontrollably	10	2	3	60	Inspect component for defects immediately after manufacturing
Bulkhead	Seals the ends of the couplers and protects internal components	Epoxy fails	Improper application	Fails to maintain sufficient seal	Ejection charges fail to separate vehicle	Parachutes not deployed properly, or internal components are damaged	8	2	2	32	Inspect component for defects immediately after manufacturing (Test 3)
Bulkhead	Seals the ends of the couplers and protects internal components	Breaks	Manufacturing defects	Fails to maintain sufficient seal	Ejection charges fail to separate vehicle	Parachutes are not deployed properly, or internal components are damaged	8	2	2	32	Inspect launch vehicle before and after each launch
Shear pins	Keeps components connected before	Early shearing	Excessive pressure from other events or excessive	Airframe and couplers separate	Premature parachute deployment	Reduced altitude, failure to complete payload mission	8	3	8	192	Test ejection charges and ensure that design adequately houses internal components, so

	separation events		force from poor packing								shear pins do not break prematurely (Tests 11, 12)
Shear pins	Keeps components connected before separation events	Do not shear	Insufficient ejection charge during separation event	Parachutes do not deploy	Rapid descent of launch vehicle	Launch vehicle impacts ground with high velocity	8	4	8	256	Test ejection charges to find sufficient amount of black powder for separation (Test 11, 12)

Table 33: Structures FMEA

5.3.2 Payloads

5.3.2.1 Payload Mechanical

Component	**Function**	**Failure Mode**	**Failure Cause**	**Failure Effects**			**S**	**O**	**D**	**RPN**	**Corrective Actions**
				Local Effects	Next Higher Level	System Effects					
3D Printed Sled	Protect and hold all electronics on the payload	Fracture	Stresses and vibrations	Cracking/breaking of plastic	Damaged electronics on payload	Loss of payload functionality	7	2	4	56	Extensive vibrations and stress tests to ensure structural integrity (Test 32, 34, 35)
Rail System	Secure payload in rocket	Fracture	Stresses and shearing	Cracking or shearing from payload	Payload comes loose during flight	Extensive damage to payload	8	3	2	48	Test for payload compatibility and flight performance (Test 32, 34, 35)
Latch System	Retain payload sled in rail system	Fracture	Stresses and shearing/fastener stripping	Latch system breaks or strips off payload sled	Damaged payload sled and/or electronics	Loss of payload functionality	7	2	2	28	Perform testing on latch system to determine maximum force it can withstand (Test 32, 34, 35)
Battery Compartment	Secure batteries on payload sled	Fracture	Stresses and shearing/fastener stripping	Battery compartment breaks or strips off payload sled	Batteries lose connection to electronics on payload	Loss of electronics functionality	1	1	2	2	Ensure fastener and plastic can withstand predicted forces during flight and landing (Test 32, 34, 35)
Camera Mount	House the cameras	Fracture	Stresses and vibrations	Camera mount is damaged	Camera cannot obtain accurate photographs	Inaccurate readings of rocket's current location	2	3	5	30	Test the strength of the camera mount and fly test subjects on subscale launch (Test 37)

Table 34: Payload Mechanical FMEA

5.3.2.2 Payload Electronics

Component	Function	Failure Mode	Failure Cause	Failure Effects			S	O	D	RPN	Corrective Actions
				Local Effects	Next Higher Level	System Effects					
Lithium Battery	Provides power to electronic payload components.	Short circuit	Unintended connection between the positive and negative battery terminals.	High current flow within the battery, generating excessive heat.	Fire within the launch vehicle.	Loss of the payload and vehicle.	9	2	2	36	Ensure no loose or exposed metallic objects are present in the payload bay. Ensure power terminals are fully insulated.
Radio Transceiver	Provides communication between the payload and ground station.	Radio interference	Two or more transmitters transmitting on the same frequency simultaneously.	Data received by the ground station is altered.	The ground station is unable to correctly receive the vehicle's landing location.	The ground station is unable to display the vehicle's landing location.	5	1	1	5	Report all radio frequencies used to NASA officials to avoid overlap with other teams. (Test 42)
Payload Computer	Controls payload peripherals and calculates vehicle's grid location.	Momentary power loss	Poor connection between the battery terminals and control board and/or vehicle vibrations.	The payload computer reboots and the program reinitiates.	The payload is momentarily unable to capture or process images.	The payload's positional estimates become less accurate or the payload is unable to produce an estimate.	5	2	6	60	Use power connectors with strong mechanical latches and include software power-loss recovery mechanisms. (Test 33)

Table 35: Payload Electronics FMEA

5.3.2.3 Payload Software

Component	Function	Failure Mode	Failure Cause	Failure Effects			S	O	D	RPN	Corrective Actions
				Local Effects	Next Higher Level	System Effects					
Microprocessor	Controls payload peripherals and calculates vehicle's grid location.	Software debug error	Unaccounted edge case in software, causing system to crash	The microprocessor reboots. Data may be lost/overwritten	Information regarding the vehicle's flight state and position is lost.	The payload is unable to determine its current grid location.	5	2	5	50	Run testcases preflight, by simulating effect at different altitude/terrain (Test 38)

Table 36: Payload Software FMEA

5.3.3 Avionics and Recovery

Component	Function	Failure Mode	Failure Cause	Failure Effects			S	O	D	RPN	Corrective Actions
				Local Effects	Next Higher Level	System Effects					
Altimeter	Track and record the altitude of the rocket in order to accurately set off ejection charges to cause separation and parachute deployment for both main and drogue parachutes.	Instant detonation of ejection charges when powered on	Polarity of battery reversed due to improper installation.	Ejection charges detonating on the launch pad	Hot gases and heavy rocket components moving near team member responsible for arming altimeter	Unable to launch, potential for burns and other injuries	10	3	1	30	Test wiring of altimeters before placing in rocket and attaching ejection charges. (Test 8 & Avionics and Recovery Preparation Checklist 5.1.1)
Altimeter	Track and record the altitude of the rocket in order to accurately set off ejection charges to cause separation and parachute deployment for both main and drogue parachutes.	Sudden power loss	Disconnection of battery due to inflight motion	Tracking and recording of altitude halts	Ejection charges do not go off, separation does not occur, and parachutes are not deployed.	The launch vehicle goes ballistic and descends uncontrolled	10	1	5	50	Altimeters and their power sources will be secured in the avionics bay. The secondary altimeter will have its own power source. (Test 7)
Altimeter	Track and record the altitude of the rocket in order to accurately set off ejection charges to cause separation and parachute deployment for both main and drogue parachutes.	Reverse wiring of ejection charges, (main ejection plugged into drogue terminal)	Mislabeling of terminals or improper programing of altimeter	Detonation of main parachute ejection charges	Main parachute is deployed at apogee	Launch vehicle drifts out of launch field, potential for launch vehicle to be lost	6	2	4	48	Proper labeling of ejection charges and altimeter terminals. (Ejection Charge Preparation Checklist 5.1.4)
Recovery Harness	The recovery harness tethers the separated sections of the launch vehicle together during descent.	Tearing of recovery harness	Melting of the harness due to ejection charge gases, insufficient strength of recovery harness	The launch vehicle becomes two or more untethered sections	Sections disconnected from the parachutes will descend significantly faster than intended	Partial damage to the launch vehicle	6	1	5	30	Protect the recovery harness from ejection gasses using the parachute protector, ensure the recovery harness is strong enough for the mission during design and testing. (Test 13)
Parachute Protector	Protects the parachute and recovery harness from hot ejection charge gases during separation	Holes or tears in the parachute protector	Excessive use and age	Ejection gases burn the parachute	Holes form or parts of the parachute are melted together	Faster than anticipated descent rate leading to damage to the launch vehicle	7	2	1	14	Inspection of the parachute protector before use. (Tests 11, 12)

Main parachute	Slows the launch vehicle to an acceptable landing velocity	Tangled lines	Improper storage or packing of the parachute	Parachute does not fully inflate on descent	Faster than anticipated descent rate	Minimal to mild damage to the launch vehicle or payload	4	5	1	20	Inspection of parachute pre-packing and safety officer or avionics recovery lead pack the parachute for launch. (Test 21 & Avionics and Recovery Preparation 5.1.1)
Main parachute	Slows the launch vehicle to an acceptable landing velocity	Holes or tears in parachute	Parachute protector failure or exposure to sharp edges	Holes or tears could increase in size and reduce the effectiveness of the parachute	Faster than anticipated descent rate	Damage to the launch vehicle or payload	6	2	1	12	Inspection of parachute before selecting it for use. Perform regular maintenance on parachutes. (Avionics and Recovery Preparation 5.1.1)
Drogue Parachute	Deploys at apogee to slow the initial descent of the launch vehicle	Failure of the drogue parachute to deploy and slow the initial descent	Holes in drogue, failure to deploy due to insufficient ejection charges, failed altimeter, torn recovery harness	Launch vehicle descends much faster initially until deployment of main parachute	Launch vehicle zippers or other components are damaged during main parachute deployment	Damage to the launch vehicle or payload	6	1	4	24	Properly pack the drogue parachute and follow mitigation strategies for other potential causes of failure. (Avionics and Recovery Preparation 5.1.1)

Table 37: Avionics and Recovery FMEA

5.3.4 Flight Dynamics

Component	Function	Failure Mode	Failure Cause	Failure Effects			S	O	D	RPN	Corrective Actions
				Local Effects	Next Higher Level	System Effects					
Propellant	Generate appropriate thrust to propel the rocket.	Propellant Failure	Improper storage of motor.	Improper propellant burnout or incomplete propellant ignition.	Changes the propellant burn distribution creating abrupt changes in thrust.	Overpressure risks, unpredictable trajectory/flight, or rocket does not take off.	9	3	4	108	Ensure the structural integrity of the propellant by visually ensuring defects, or moisture is not present. Motors need to be contained in a Climate Regulated room, and ensure they are handled carefully. (Motor Preparation Checklist 5.1.6 & Safety Officers will inspect motor storage monthly)
Nozzle	Controls the mass flow rate of the propellant	Nozzle Deformation	Structural failure of nozzle.	Nozzle exit area, nozzle exhaust pressure, propellant flow rate change.	Abrupt changes in the thrust vector.	Altered trajectory of the rocket creating potential danger to bystanders.	9	3	5	135	Always handle nozzle carefully, and visually inspect ensuring defects are not present. (Motor Preparation Checklist 5.1.6)
Motor Case (including forward and aft closures)	Enclose solid propellant to protect the body from ignited propellant.	Case Defect	Defect or structural failure of the motor case including the forward and aft enclosures.	Propellant burns through motor case interacting with the rocket body.	Motor assembly gets damaged.	Structural integrity of motor tube and body tube are compromised.	7	2	8	112	Always handle motor case carefully, and visually inspect ensuring defects are not present. Always have a protective cover over the casing until launch. (Motor Preparation Checklist 5.1.6)
Motor Tube	Encloses the motor assembly in the correct position.	Motor Tube Fails or Dislodges	Defect or structural failure of the motor tube	Motor case is not held in correct position.	Improperly aligned thrust vector	Altered flight trajectory and potential damage to other components.	6	3	6	108	Always handle motor tube carefully, and visually inspect ensuring defects are not present. (Motor Preparation Checklist 5.1.6)
Motor Mount	Retains the motor inside the rocket	Motor Mount Fails	Structural failure of mount, screws	Motor case moves forward in the rocket	Damage to forward	Rocket integrity is compromised,	7	4	7	196	Visually inspect ensuring defects are not present

			improperly fastened, or failure of epoxy bonds		rocket components	and function is lost.					and tighten screws. (Test 18)
Thrust Plate	Transfers thrust from centering rings to airframe	Thrust Plate Fails	Structural failure of thrust plate or screws improperly fastened	Structural integrity of centering ring becomes compromised	Improperly aligned thrust vector	Altered flight trajectory and potential damage to other components.	5	4	7	140	Visually inspect ensuring defects are not present and tighten screws. (Test 18)

Table 38: Flight Dynamics FMEA

5.4 Environmental Concerns

Environmental concerns are any hazards that the vehicle poses on the environment, or the environment poses on the vehicle. These concerns are quantified by assigning severity and likelihood values to each hazard (Table 39). This method yields a score from 1-100 in the same manner as personnel hazards (Table 39).

	Severity (S)	**Likelihood (L)**
1	No effect on environment or launch vehicle	Extremely Unlikely
2	Minimal effect on environment or launch vehicle	Unlikely/low probability
3		
4	Moderate but resolvable harm to environment or launch vehicle	
5		Likely
6	Moderate harm to environment or launch vehicle with lasting impact	
7		Highly likely/high probability
8		
9	Serious environmental harm requiring immediate and drastic response/Launch vehicle suffers extensive damage	
10	Catastrophic impact on launch environment, difficult to resolve with lasting damage/Total loss of launch vehicle	Extremely likely/almost certain

Table 39: Environmental Concerns Score Chart

5.4.1 Effect of Vehicle on Environment

The effects of the vehicle on the environment include any hazards posed by the vehicle during testing, launch preparation, and launch (Table 40).

Hazard	Cause	Effect	S	L	Score	Mitigation & Verification
Falling debris	Recovery harness fails	Debris pollutes land around launch site	5	2	10	Properly fold parachute and check recovery harness and motor retainer connections. (Test 13, Avionics and Recovery Preparation 5.1.1)
	Parachute fails to deploy					
	Motor retainer fails					
Environment around vehicle ignites	Sparks from ejection charge testing	Uncontrolled fire	8	2	16	Follow range safety officer instructions on properly conducting ejection charge testing. Only test and launch in approved areas cleared of flammable debris.
	Motor exhaust					
Chemical leaks	Battery leaks	Ground around vehicle is polluted	6	2	12	Check battery for damage before loading it on the vehicle. Isolate battery from components with the potential to pierce the battery casing. (Payload Bay Preparation 5.1.3)
Paint enters water supply	Failure to recover rocket	Potential toxins in water supply for humans and animals	6	1	6	Launch will occur only in high visibility to enable visual tracking of rocket. Rocket will contain tested GPS (Test 19).
	Launch vehicle lands in body of water		5	2	10	Paint will be properly applied and set to ensure minimal release in the case of a water landing.
Fiberglass in ground	Failure to recover rocket, materials degrade over time	Skin irritation hazard for future users of site Ingestion hazard for animals	5	1	5	Launch will occur only in high visibility to enable visual tracking of rocket. Rocket will contain tested GPS (Test 19).
	Ground impact breaks apart launch vehicle		5	2	10	Launch vehicle will be constructed of high-strength fiberglass to prevent damage when landing (Test 2).

Table 40: Effect of Vehicle on Environment Chart

5.4.2 Effect of Environment on Vehicle

The effects of the environment on the vehicle include any hazards present during testing, launch preparation, and launch (Table 41).

Hazard	Cause	Effect	S	L	Score	Mitigation & Verification
Vehicle exposed to moisture	Humidity	Warping of plywood centering rings	3	3	9	Store vehicle in a cool, dry, well-ventilated area. Check for changes in weather while vehicle is exposed to the environment. (Accessible centering rings will be inspected before and after each flight)
	Precipitation soaks vehicle					
	Vehicle lands in water	Electronics are ruined	9	3	27	
Clouds obscure camera	Cloudy skies on launch day	Landmarks for mission objective cannot be identified	7	4	28	Only launch when skies are clear. Monitor weather in launch area as launch day approaches to explore alternatives. (Launch Procedure 5.1.9)
Excessive drift	Wind during vehicle flight	Vehicle lands in unsafe area	8	5	40	Monitor wind and weather conditions at the launch site. Only launch when wind is within acceptable ranges. Angle the launch rail into the direction of the wind. (Launch Procedure 5.1.9)
		Vehicle lands outside of grid	6	6	36	
Vehicle lost in sky	Fog at launch site	Inability to visually track vehicle; potential vehicle loss	7	3	21	Monitor weather conditions at the launch site. Only launch when there is high visibility around the launch site and sky. (Launch Procedure 5.1.9)
	Clouds at flight altitudes					
Overheated electronics	High temperatures at launch site	Unusable electronics, delayed launch, mission failure	7	5	35	Keep electronics and launch vehicle under canopy prior to launch. (Team has pop-up canopy in launch prep storage area)
Weathercocking	High winds at launch site	Unexpected flight path, lower apogee than predicted	7	5	35	Launch will not occur if winds exceed 20mph Stability at launch rod clearance is designed to be 2.2 calibers (Pre-launch analysis will ensure stability acceptable to team and RSO)

Table 41: Effect of Environment on Vehicle Chart

6. Project Plan

6.1 Launch Vehicle Testing

6.1.1 Launch Vehicle – Required Testing Plan

The launch vehicle testing plan is defined (Table 42).

Test Number	Test Name	Objective	Methodology	Variable
1	Airframe Compression Analysis	Measure compressive strength of airframe material	Place material in Instron Universal Testing Machine to simulate compressive forces and record data. Plot and analyze the stress strain response to determine key material properties. Compress airframe both laterally and axially.	Compressive strength
2	Airframe Drop Resistance Demonstration	Measure the drop resistance of airframe material	Drop airframe material from height of at least 20 ft to simulate how launch vehicle would land after launch onto a similar landing terrain of grass. Assess resulting behavior of fiberglass.	Durability of airframe material
3	Bulkhead Resistance Demonstration	Measure the drop resistance of bulkhead material	Drop bulkhead material from height of at least 20 ft to simulate how launch vehicle would land after launch onto a similar landing terrain of grass. Assess resulting behavior of PVC.	Durability of bulkhead material
4	Rotation & Rolling Analysis	Measure potential rotation and rolling effects on rocket during launch	Using the SolidWorks simulation, determine the severity of the rotation and rolling effects during launch and evaluate the results.	Pitch and yaw moment, axial rotation

5	Vehicle Drag Analysis	Determine drag produced by the vehicle at various orientations	Use computational fluid dynamics (CFD) simulation software to find simulated values for drag for multiple angles of attack.	Coefficient of drag
6	Parachute Drag Analysis	Determine which parachutes provide the appropriate drag to slow the launch vehicle during descent	Attach a weight to the parachute and drop from a height of about 80 ft. Record the drop using a video camera. Analyze the time versus height found in the recorded video and use data to calculate coefficient of drag. Repeat for each parachute.	Coefficient of drag
7	Recovery Altimeter Resolution Test	Ensure both the primary and secondary altimeters are detecting the correct altitude	Place the Entacore AIM altimeter at multiple heights and record altitude readings. Repeat for the Stratologger altimeter.	Altitude
8	Barometer Functionality Test	Ensure barometer reads change in pressure	Place plastic straw over barometer, seal the edges, and provide suction on the straw to change pressure.	Pressure
9	Subscale Main Parachute Ejection Demonstration	Determine the amount of Pyrodex required to completely separate the nosecone and forward sections	Prepare Pyrodex ejection charge and assemble the launch vehicle. Place launch vehicle on test stand and ignite charge.	Amount of Pyrodex
10	Subscale Drogue Parachute Ejection Demonstration	Determine the amount of Pyrodex required to completely separate the forward and aft sections	Prepare Pyrodex ejection charge and assemble the launch vehicle. Place launch vehicle on test stand and ignite charge.	Amount of Pyrodex

11	Full scale Main Parachute Ejection Demonstration	Determine the amount of black powder required to completely separate the nosecone and forward sections	Prepare black powder ejection charge and assemble the launch vehicle. Place launch vehicle on test stand and ignite charge.	Amount of black powder
12	Full scale Drogue Parachute Ejection Demonstration	Determine the amount of black powder required to completely separate the forward and aft sections	Prepare black powder ejection charge and assemble the launch vehicle. Place launch vehicle on test stand and ignite charge.	Amount of black powder
13	Recovery Harness Strength Analysis	Measure the strength of the recovery harness	Place material in Instron Universal Testing Machine and apply a tensile force to the harness.	Yield strength of recovery harness
14	Zippering Demonstration	Ensure the launch vehicle structure will not zipper	Apply an instantaneous force that would simulate the deployment of parachutes.	Strength of airframe material
15	Vibrational Resistance Test	Ensure vibrational movement during launch will not damage the launch vehicle	Simulate vibrational forces comparable to those expected during launch on the launch vehicle.	Durability of launch vehicle
16	RocketPoxy Density Inspection	Determine weight per inch of RocketPoxy epoxy	Weigh two pieces of fiberglass. Then, epoxy pieces together with RocketPoxy and weigh once more.	Density of epoxy
17	JB Weld Density Inspection	Determine weight per inch of JB Weld epoxy	Weight two pieces of fiberglass. Then, epoxy pieces together with JB Weld and weigh once more.	Density of epoxy

18	Epoxy Strength Analysis	Determine the operational shear strength of the epoxy utilized in the launch vehicle	Use epoxy to create fillet between two pieces of fiberglass. Load the epoxied fiberglass into the Instron Universal Testing Machine and determine the final load at failure. Observe the failed specimen to determine adhesive area and calculate maximum shear stress.	Maximum shear strength of the epoxy
19	GPS Functionality Demonstration	Ensure GPS can transmit the correct data over 2,500 ft	Power on GPS and determine if it is detecting the correct coordinate location. Increase distance between transmitter and receiver and determine if it is transmitting data properly.	Functionality of GPS and transmission range
20	Parachute Packing Demonstration	Ensure that parachute fits in airframe and will deploy smoothly	Fold parachute in an appropriate manner and simulate deployment. Fold in the same manner and place in the airframe.	How the parachute fits within the airframe and ability to deploy
21	Parachute Opening Demonstration	Ensure that the parachute properly opens	Attach weight to parachute and from a height of about 80 ft.	Ability of parachute to open
22	Center of Gravity Inspection	Determine the launch vehicle's center of gravity	Fully configure the vehicle for launch and balance the vehicle on a team member's hand.	Location of center of gravity
23	Subscale Demonstration Flight	Demonstrate the functionality of all components of the subscale launch vehicle	Design and manufacture a subscale model and conduct a launch.	Performance of subscale model during launch, descent, and landing

24	Vehicle Demonstration Flight	Demonstrate the functionality of all components of the full scale launch vehicle	Design and manufacture a full scale model and conduct a launch.	Performance of full scale model during launch, descent, and landing
25	Launch Rehearsal	Ensure all preparation and assembly of launch vehicle and payload can be completed within two hours.	Fully assemble the launch vehicle (without the motor) and payload in the appropriate amount of time.	Time for full assembly

Table 42: Launch Vehicle Testing Plan

6.1.2 Launch Vehicle Testing – Success Criteria and Justifications

The success criteria and justifications for the launch vehicle testing plan are defined (Table 43).

Test Number	Test Name	Success Criteria	Justification
1	Airframe Compression Analysis	The airframe material does not deform and is recoverable and reusable following landing.	The airframe material must not fail during launch or landing or else the launch vehicle will not be reusable, and the launch is considered unsuccessful.
2	Airframe Drop Resistance Demonstration	The airframe material does not deform and is recoverable and reusable following landing.	The airframe material must not fail during landing or else the launch vehicle will not be reusable, and the launch is considered unsuccessful.
3	Bulkhead Resistance Demonstration	The bulkhead material does not deform and is reusable following landing.	The bulkhead material must not fail during landing, or the internal components may be damaged, and the launch vehicle will not be reusable, and the launch is considered unsuccessful.
4	Rotation & Rolling Analysis	The effects of the pitch and yaw moment, as well as the axial rotation, are not too severe on the rocket and will not greatly affect the launch vehicle's flight.	In order for stable flight, the launch vehicle should not oscillate excessively, affecting control and negatively impacting the launch vehicle's flight.

5	Vehicle Drag Analysis	The vehicle drag is small enough so that it does not negatively impact the flight of the launch vehicle.	The launch vehicle must be designed such that the drag on it is not great enough to negatively impact the launch vehicle’s flight and prevents the vehicle from reaching target altitude.
6	Parachute Drag Analysis	Parachutes adequately slow down the launch vehicle during descent to desired velocity.	Parachutes need to have a sufficient coefficient of drag and must not fail prematurely, otherwise the launch vehicle will sustain significant damage during landing and will not be reusable and the launch is considered unsuccessful.
7	Recovery Altimeter Resolution Test	Both the primary and secondary altimeters measure the correct altitude when placed at different heights with an error of 10 ft.	In order to determine when the parachutes must be deployed, the altimeters must read the correct altitude measurements, or the parachutes may deploy incorrectly, resulting in a failed launch.
8	Barometer Functionality Test	Barometer measures correct changes in pressure.	In order to determine altitude, the barometer must detect pressure changes in the air correctly. If it does not, the parachutes may deploy incorrectly, resulting in a failed launch.
9	Subscale Main Parachute Ejection Demonstration	The subscale launch vehicle separates, and the main parachute successfully deploys.	The subscale launch vehicle must separate so the main parachute can deploy and result in the desired landing velocity. If the launch vehicle does not separate, the parachute will not deploy and the launch vehicle will land at too high a velocity, resulting in severe damage to the vehicle and a failed launch.
10	Subscale	The subscale launch vehicle separates, and the drogue parachute successfully deploys.	The subscale launch vehicle must separate so the drogue parachute can deploy and result in the desired descent velocity. If the

	Drogue Parachute Ejection Demonstration		launch vehicle does not separate, the parachute will not deploy and the launch vehicle will land at too high a velocity, resulting in severe damage to the vehicle and a failed launch.
11	Full scale Main Parachute Ejection Demonstration	The full scale launch vehicle separates, and the main parachute successfully deploys.	The full scale launch vehicle must separate so the main parachute can deploy and result in the desired landing velocity. If the launch vehicle does not separate, the parachute will not deploy and the launch vehicle will land at too high a velocity, resulting in severe damage to the vehicle and a failed launch.
12	Full scale Drogue Parachute Ejection Demonstration	The full scale launch vehicle separates, and the drogue parachute successfully deploys.	The full scale launch vehicle must separate so the drogue parachute can deploy and result in the desired descent velocity. If the launch vehicle does not separate, the parachute will not deploy and the launch vehicle will land at too high a velocity, resulting in severe damage to the vehicle and a failed launch.
13	Recovery Harness Strength Analysis	The recovery harness withstands the forces applied to it and does not fail.	The recovery harness must stay intact when the launch vehicle separates in order to ensure that the launch vehicle remains attached to the parachutes. If the harness fails and the launch vehicle does not remain attached to the parachutes, sections of the vehicle will land at too high of a velocity, resulting in severe damages to the vehicle and a failed launch.
14	Zippering Demonstration	The fiberglass airframe can withstand the simulated parachute deployment force without zippering.	The airframe material must not be damaged during parachute deployment or else the launch vehicle will not be reusable, and

			the launch is considered unsuccessful.
15	Vibrational Resistance Test	The launch vehicle is not damaged due to vibrational forces and is reusable.	The launch vehicle must not be damaged during launch or else it will not be reusable, and the launch is considered unsuccessful.
16	RocketPoxy Density Inspection	The density of RocketPoxy is determined.	The weight of epoxy must be accounted for in the launch vehicle's overall weight in order to simulate realistic results.
17	JB Weld Density Inspection	The density of JB Weld is determined.	The weight of epoxy must be accounted for in the launch vehicle's overall weight in order to simulate realistic results.
18	Epoxy Strength Analysis	The epoxy displays an adhesive shear strength large enough for operational parameters.	The adhesive joints within the airframe must be strong enough to withstand the landing forces the launch experiences, or components may break, and the launch vehicle will not be considered reusable.
19	GPS Functionality Demonstration	The GPS reads the correct coordinates and can transmit data over 2,500 ft.	The GPS must be able to transmit location data over the entire launch field radius so the team can compare the true location data with the grid location determined by the payload. The GPS data will also be used to locate the launch vehicle upon landing, thus if the GPS does not function correctly, the vehicle may not be recoverable.
20	Parachute Packing Demonstration	The parachute fits in the airframe with enough clearance so the parachute can easily slide within the airframe, allowing the parachute to properly deploy during separation.	If the parachute does not fit properly in the airframe, it may not deploy correctly during separation. This would result in the launch vehicle descending at too high of a velocity, possibly damaging the launch vehicle and

			causing the launch to be considered unsuccessful.
21	Parachute Opening Demonstration	The parachute opens properly during deployment.	If the parachute does not fully open, the launch vehicle will land at too high a velocity. This impact may damage the launch vehicle and the launch will be considered unsuccessful.
22	Center of Gravity Inspection	The true center of gravity is located near enough to the calculated point so that the stability margin is at least 2.0.	If the center of gravity location does not provide a stability margin of at least 2.0, the launch vehicle may not fly in the predicted manner and may be unsuccessful.
23	Subscale Demonstration Flight	The subscale launches, separates, and lands properly and all components are recoverable and reusable.	The subscale model must successfully fly in order to verify the design's functionality prior to constructing the full scale model.
24	Vehicle Demonstration Flight	The full scale launches, separates, and lands properly and all components are recoverable and reusable.	The full scale model must successfully fly in order to verify the design's functionality prior to the final launch day.
25	Launch Rehearsal	The time for launch vehicle and payload assembly is within the allowed time.	The team must be prepared to prepare the launch vehicle and payload in the appropriate amount of time, or the flight may be negatively impacted.

Table 43: Launch Vehicle Testing Success Criteria

6.1.3 Launch Vehicle Testing – Resultant Effects

The effects from the results of the launch vehicle testing plan are defined.

1. Airframe Compression Analysis

If the airframe fails and the material is not reusable, a new airframe material will be selected that is strong enough to withstand landing forces.

2. Airframe Drop Resistance Demonstration

If the airframe fails and the material is not reusable, a new airframe material will be selected that is strong enough to withstand landing forces.

3. Bulkhead Resistance Demonstration

If the bulkhead fails and the material is not reusable, a new bulkhead material will be selected that is strong enough to withstand landing forces.

4. Rotation and Rolling Analysis
If the rocket does not adequately handle the rotational and rolling forces, the launch vehicle design must be modified to better withstand them. This modification may include altering the weight distribution with added ballast to change the stability.

5. Vehicle Drag Analysis
If the launch vehicle induces too much drag that it significantly impacts the flight, the vehicle finish will be modified in order to reduce the drag.

6. Parachute Drag Analysis
If the parachute has an insufficient coefficient of drag and fails to slow the weight of the launch vehicle, a larger parachute will be chosen that is able to induce the desired drag effects.

7. Recovery Altimeter Resolution Test
If the altimeters fail to read the correct altitude, they will be replaced with new altimeters.

8. Barometer Functionality Test
If the barometer fails to read the correct change in pressure, it will be replaced with a new barometer.

9. Subscale Main Parachute Ejection Demonstration
If the subscale vehicle does not separate, the launch vehicle will be evaluated to determine if there is leaking air within the launch vehicle, if there is adequate continuity with the remote ignitor, or if the ejection charge did not provide enough separation force. The issue can be resolved by resealing possible locations of air leakage, reconnecting the charge wires, or increasing the amount of Pyrodex in the ejection charge, respectively.

10. Subscale Drogue Parachute Ejection Demonstration
If the subscale vehicle does not separate, the launch vehicle will be evaluated to determine if there is leaking air within the launch vehicle, if there is adequate continuity with the remote ignitor, or if the ejection charge did not provide enough separation force. The issue can be resolved by resealing possible locations of air leakage, reconnecting the charge wires, or increasing the amount of Pyrodex in the ejection charge, respectively.

11. Full scale Main Parachute Ejection Demonstration
If the full scale vehicle does not separate, the launch vehicle will be evaluated to determine if there is leaking air within the launch vehicle, if there is adequate continuity with the remote ignitor, or if the ejection charge did not provide enough separation force. The issue can be resolved by resealing possible locations of air leakage, reconnecting the charge wires, or increasing the amount of black powder in the ejection charge, respectively.

12. Full scale Drogue Parachute Ejection Demonstration
If the full scale vehicle does not separate, the launch vehicle will be evaluated to determine if there is leaking air within the launch vehicle, if there is adequate continuity with the remote ignitor, or if the ejection charge did not provide enough separation force. The issue can be resolved by resealing possible

locations of air leakage, reconnecting the charge wires, or increasing the amount of black powder in the ejection charge, respectively.

13. Recovery Harness Strength Analysis
If the recovery harness does not withstand the forces applied to it, a new harness with a higher yield strength will be used.

14. Zippering Demonstration
If the airframe material experiences zippering under simulated loads, the recovery system will be modified as fiberglass zippering is likely caused by a recovery system issue. These modifications may include utilizing a thicker recovery harness or attaching a tennis ball to the recovery harness where the harness contacts the airframe to reduce the pressure.

15. Vibrational Resistance Test
If the launch vehicle fails and becomes too damaged, the vehicle will be modified so it will be strong enough to withstand vibrational forces. These modifications may include reinforcing the coupler sections with tape to combat bending or reapplying epoxy to sections that require it.

16. RocketPoxy Density Inspection
The epoxy density measured will be the density utilized when measuring the launch vehicle's total weight.

17. JB Weld Density Inspection
The epoxy density measured will be the density utilized when measuring the launch vehicle's total weight.

18. Epoxy Strength Analysis
If the chosen epoxy does not have an acceptable shear strength to maintain structural integrity of the launch vehicle, a new epoxy with a higher strength will be chosen.

19. GPS Functionality Demonstration
If the GPS does not read the correct location data or cannot transmit data over 2,500 ft, a new GPS will be chosen.

20. Parachute Packing Demonstration
If the parachute does not fit comfortably within the airframe, the parachute will be refolded and repacked into the airframe with a different method.

21. Parachute Opening Demonstration
If the parachute does not open properly, the parachute will be refolded and repacked into the airframe in a different manner.

22. Center of Gravity Inspection
If the center of gravity is not located within the allowable range, ballast will be added to the vehicle accordingly.

23. Subscale Demonstration Flight

If the subscale flight is unsuccessful, a thorough investigation will be conducted of the launch vehicle to determine the failures that occurred and what components must be modified in order to resolve the failures and the model will be relaunched.

24. Vehicle Demonstration Flight

If the full scale flight is unsuccessful, a thorough investigation will be conducted of the launch vehicle to determine the failures that occurred and what components must be modified in order to resolve the failures and the model will be relaunched.

25. Launch Rehearsal

If the assembly of the launch vehicle and payload takes more than the allowed time, the team will discuss and determine which components can be prepared more quickly or ahead of time.

6.2 Payload Testing

The payload testing plan is defined (Table 44).

Test Number	Test Name	Objective	Methodology	Variable
26	Drone Camera Landmark Analysis	Determine how many keypoints can be captured during launch time by OV5642 cameras	Place payload camera on a testing drone and fly it to predicted altitude, then fly back to the ground. Allow camera to take photos during ascent and descent. Perform test for both the cameras.	Number of keypoints captured
27	Drone Camera Quality Demonstration	Determine quality of images taken by OV5642 cameras	Place payload camera on a testing drone and fly it to predicted altitude, then fly back to the ground. Allow camera to take photos during ascent and descent. Perform test for both the cameras.	Quality of images captured
28	Field-of-View Inspection	Determine true field-of-view (FOV) of OV5642 cameras	Place payload camera on a testing drone and measure the distance the camera can see. Confirm observations with given field-of-view from manufacturer. Perform	True FOV of cameras

			test for both the cameras.	
29	Battery Life Demonstration	Verify that the battery can maintain the necessary charge for at least 2 hours	Allow the battery to run for a minimum of 2 hours. Perform test for the payload, altimeter, and GPS batteries.	Charge of battery
30	Accelerometer Functionality Test	Verify that the accelerometer reports accurate displacement values	Attach the accelerometer to the recovery harness and spin it to simulate launch movements, then move the spinning accelerometer a straight, measured distance and evaluate displacement readings.	Displacement readings
31	Heat Resistance Demonstration	Ensure the payload will not overheat if left running outside for at least 2 hours	Place payload inside the airframe and allow it to run software while leaving it outside in sunlight for at least 2 hours. Measure the temperature and assess possible resulting damage from heat.	Damage to payload
32	Ejection Resistance Demonstration	Ensure that the payload will not be damaged by the forces created during separation	Perform a separation ejection test with the payload inside the launch vehicle.	Damage to payload
33	Power Loss Test	Ensure that the payload can operate if it loses power	Disconnect power when the launch vehicle is configured for launch. Assess if the system's redundancies allow it to recover and continue operation.	Functionality of software and electrical components
34	Vibrational Resistance Test	Ensure that the payload will not be damaged by	Simulate vibrational forces on the payload	Damage to payload

		vibrations during launch	similar to those expected during launch.	
35	Payload Drop Test	Ensure the payload will not be damaged during landing	Drop payload in the airframe from a height of at least 20 ft.	Damage to payload
36	Strength of Camera Mount Test	Ensure the camera mount will not detach from the launch vehicle during flight	Simulate forces comparable to those expected during launch on the camera mount using CFD simulations.	Attachment of camera mount
37	Static Firing Test	Ensure that the motor firing does not cause the electronic wiring of the payload to overheat	A test stand will be designed and built by the Structures Lead. Configure the payload and motor inside airframe, place on test stand, and fire the motor.	Damage to wires
38	Software Implementation Demonstration	Verify that the software runs as intended	Run the code written for the payload and check for errors.	Functionality of software with hardware
39	Raspberry Pi Functionality Demonstration	Ensure Raspberry Pi operates and responds to software	Power on the Raspberry Pi and confirm it properly responds to code instructions.	Functionality of Raspberry Pi
40	Inertial Measurement Unit (IMU) Functionality Demonstration	Ensure IMU gives the correct measurement of acceleration and orientation	Connect IMU with the Raspberry Pi. Orientate IMU in a controlled manner and compare the data collected with IMU to the known acceleration and orientation.	Functionality of IMU
41	XBee Radio Functionality Demonstration	Ensure XBee radio can send and receive data correctly	Connect XBee radio transmitter to one laptop with X-TCU opened and connect XBee radio receiver to another laptop with X-TCU	Communication between transmitter and receiver

			opened. Send data through the transmitter and use the software to see if the receiver collects the message properly.	
42	Microprocessor Functionality Demonstration	Ensure microprocessor can run program correctly	Plug microprocessor into laptop and upload an example program. Determine if the example program is running properly.	Functionality of microprocessor
43	SD Card Functionality Demonstration	Ensure the SD card can store data	data to the SD card through the Raspberry Pi. Ensure the data can be accessed by reading back data and confirm that it matches the originally written data.	Functionality of SD card
44	Payload Altimeter Functionality Test	Ensure altimeter is detecting the correct altitude	Place the altimeter at multiple heights and record the altitude readings.	Altimeter altitude reading
45	Wire Tube Inspection	Ensure that wire tube is wide enough to protect wires without compromising motor position	Configure wire tube set-up and observe if tube interferes with centering rings and if tube fits within airframe.	Protection of wires
46	Payload Launch Detection Demonstration	Ensure that the payload can detect sudden acceleration changes	Induce a sudden movement on the payload from rest.	Movement detection
47	Payload Data Compilation Test	Ensure that the payload can compile at least 100 images within five minutes	Run the software to completion and determine the amount of time required for the payload to compile the received data.	Time for data compilation

48	Payload Transmission Range Test	Ensure the transmission range of the payload is at least one mile.	Evaluate the transmission capabilities of the Xbee radio over a distance of one mile.	Transmission range
49	IMU Drift Analysis	Ensure the drift of the IMU at rest does not exceed 100 ft over a period of 90 s	Place the IMU at rest and measure the offset error of the IMU while it is stationary. Evaluate the error over 90 s to determine the expected drift during flight.	IMU drift
50	Payload Demonstration Flight	Demonstrate the complete functionality of the payload.	Design and assemble the payload and conduct a full scale launch including the payload.	Performance of payload during launch, descent, and landing.

Table 44: Payload Testing Plan

6.2.1 Payload Testing – Success Criteria and Justifications

The success criteria and justifications for the payload testing plan are defined (Table 45).

Test Number	Test Name	Success Criteria	Justification
26	Drone Camera Landmark Analysis	The camera captures at least 150 keypoints during launch time in order to determine location.	The number of keypoints captured must be sufficient enough for software to determine the final grid location of the launch vehicle, or the launch is considered unsuccessful.
27	Drone Camera Quality Demonstration	The image quality and resolution are sufficient enough for software to determine keypoints.	The camera quality and resolution must be sufficient enough for keypoints to be identified and thus the final grid location of the launch vehicle can be determined. Insufficient camera quality may result in keypoints not being recognized.
28	Field-of-View Inspection	The field-of-view is sufficient enough for the cameras to view	The camera FOV must be sufficient enough for keypoints to

		the entire launch field (5,000 ft by 5,000 ft) at the target altitude while also maintaining a high resolution so that the software can determine keypoints.	be identified and thus the final grid location of the launch vehicle can be determined. Insufficient FOV may result in keypoints not being identified.
29	Battery Life Demonstration	The batteries are able to maintain the charge needed for at least 2 hours. The payload and altimeters battery's voltage will decrease over time but should reach a plateau of about 7.40V. The GPS battery's voltage will decrease over time but should reach a plateau of about 3.7V.	The batteries must be able to maintain the necessary charge for at least 2 hours so the launch vehicle can be launch-ready for at least 2 hours, or the payload or avionics electronics may not have enough power to function during flight.
30	Accelerometer Functionality Test	The displacement reported by the accelerometer matches the measured distance it was moved.	The values measured by the accelerometer must be accurate, so the payload can detect acceleration as the launch vehicle moves so that the payload can begin collecting data and measure the displacement between the image capture location and the landing location.
31	Heat Resistance Demonstration	The payload does not overheat and incur damage.	The payload must be able to run for at least 2 hours when it is outside so that it is launch-ready for at least 2 hours and does not overheat within this time.
32	Ejection Resistance Demonstration	The payload does not incur damage during separation.	The payload must complete its objective and therefore must not be damaged during separation, or else the launch is considered unsuccessful.
33	Power Loss Test	The payload is functional after power is momentarily lost.	If power is lost during launch, the payload must be able to recover and continue functioning to ensure that the launch is successful.
34	Vibrational Resistance Test	Payload does not incur damage from vibrational forces.	The payload must complete its objective and therefore must not

			be damaged during flight, or else the launch is considered unsuccessful.
35	Payload Drop Test	Payload does not incur damage from landing forces.	The payload must complete its objective and therefore must not be damaged during landing, or else the launch is considered unsuccessful.
36	Strength of Camera Mount Test	The camera mount remains attached to the launch vehicle during flight.	The camera mount must be attached to the launch vehicle for the entire flight so the camera can take and process images. If the camera mount fasteners fail and the cameras fall from the launch vehicle, then the keypoints will not be captured and the launch will be considered unsuccessful.
37	Static Firing Test	The payload wiring does not incur damage after the motor has finished firing.	If the wires overheat when the motor fires, the payload will be unable to function properly, and the launch will be considered unsuccessful.
38	Software Implementation Demonstration	The payload code runs as intended without producing any errors.	The software for the payload is responsible for processing images taken by the cameras to determine the location of the rocket, thus its functionality is crucial to the payload's success. If the software has errors and does not run correctly, the data received cannot be compiled and the launch will be considered unsuccessful.
39	Raspberry Pi Functionality Demonstration	The Raspberry Pi responds correctly to the software.	The Raspberry Pi is the basis of the electronics in the payload and its functionality is necessary to complete the mission since it extrapolates the image data and computes the launch vehicle's location. If it does not function as

			intended, the launch will be considered unsuccessful.
40	Inertial Measurement Unit (IMU) Functionality Demonstration	The IMU produces correct acceleration and orientation data.	The IMU must collect the acceleration and orientation data in order for the software to accurately locate keypoints and determine the payload's final grid location.
41	XBee Radio Functionality Demonstration	The XBee radio transmitter sends data and receiver collects data correctly.	The XBee radio must be able to communicate with the ground station in order to transmit the payload data and relay the payload's final grid location.
42	Microprocessor Functionality Demonstration	The microprocessor runs the programs correctly.	The microprocessor must process the images from the camera as well as use IMU data to compute the drift of the launch vehicle in order to determine the payload's final grid location.
43	SD Card Functionality Demonstration	The SD card can store the collected data and the data is able to be used and analyzed.	The images must be stored on the SD card in order for the payload to compile the data and determine its final grid location.
44	Payload Altimeter Functionality Test	Altimeter measures the correct altitude when placed at different heights.	The correct altitude measurement is required for the software to determine the scale of the collected images in order for the payload to determine its final grid location.
45	Wire Tube Inspection	The wire tube adequately protects the wires while not interfering with the position of the motor.	The wires must be protected by the tubing in order to ensure they will not be damaged during launch while also not affecting the motor alignment. If the wires are not adequately protected or the motor is misaligned, then the payload and the flight path will be respectively negatively impacted and the launch may be considered unsuccessful.

46	Payload Launch Detection Demonstration	The payload will detect changes in acceleration due to launch initiation.	The payload must be able to recognize the presence of motion so that it will be able to detect launch initiation and begin collecting data.
47	Payload Data Compilation Test	The payload can compile image data in under 5 minutes.	If the payload can successfully compile image data under 5 minutes, it can successfully execute location processing and the final grid location will be determined. The image data should be compiled within 5 minutes so that the payload's full function can be completed before its battery runs out of charge.
48	Payload Transmission Range Test	The payloads transmission ranges at least one mile.	The payload must be able to send and receive signals to the ground station successfully, even from one mile away. Otherwise, the payload will not transmit data correctly and may not be able to function successfully.
49	IMU Drift Analysis	The expected drift of IMU is within 100 ft over a period of 90 s.	The IMU measurements cannot drift more than 100 ft over 90 s so that the final estimate of location of launch vehicle does not have a significant error.
50	Payload Demonstration Flight	The payload captures images and thus significant keypoints during flight and can compile the collected data to determine its grid location when landed.	The payload must successfully determine its location in order to verify the design's functionality prior to the final launch day.

Table 45: Payload Testing Plan Success Criteria

6.2.2 Payload Testing – Resultant Effects

26. Drone Camera Landmark Analysis

If the camera does not capture enough keypoints during launch time, assess camera functionality and replace it with a camera of faster shutter speed.

27. Drone Camera Quality Demonstration

If camera quality and resolution is not high enough, a new camera will be chosen with a higher image quality.

28. Field-of-View Inspection
If FOV of camera is not large enough, a new camera will be chosen with a larger FOV.

29. Battery Life Demonstration
If the battery cannot maintain the necessary charge, a new battery will be selected with a longer battery life.

30. Accelerometer Functionality Test
If the accelerometer reports inaccurate readings, a new accurate accelerometer will be selected.

31. Heat Resistance Demonstration
If the payload overheats, insulation would be added to prevent overheating from occurring.

32. Ejection Resistance Demonstration
If the payload is damaged during separation, the bulkhead separating the payload bay and the separation point will be analyzed and reinforced to further protect the payload or the payload sled will be modified in such a way that retains the payload more securely within the payload bay.

33. Power Loss Test
If the payload is unable to recover after losing power, the redundancies in its system responsible for power recovery will be evaluated and modified.

34. Vibrational Resistance Test
If the payload is damaged due to vibrations during launch, the payload sled will be modified in such a way that allows it to more adequately resist vibrational motion.

35. Payload Drop Test
If the payload is damaged during landing, the payload sled would be modified in such a way that allows it to more adequately resist dropping motion.

36. Strength of Camera Mount Test
If the camera mount does not remain attached to the launch vehicle during flight, a new attachment method will be implemented.

37. Static Firing Test
If the camera or wiring overheat because of the motor firing, a new design that more adequately insulates the wiring will be implemented.

38. Software Implementation Demonstration
If the software produces errors, the code will be examined and debugged. If the software fails to function properly because of connections to hardware, the design and connectivity of the hardware and software of the payload will be reevaluated.

39. Raspberry Pi Functionality Demonstration
If the Raspberry Pi does not respond to software and does not operate the other electronics, replace the Raspberry Pi with a new computer.

40. Inertial Measurement Unit (IMU) Functionality Demonstration
If the IMU does not measure the correct orientation and acceleration data, a new IMU will be chosen.

41. XBee Radio Functionality Demonstration
If the XBee does not transmit or receive data properly, a new radio will be chosen.

42. Microprocessor Functionality Demonstration
If the microprocessor does not process the data successfully, a new microprocessor will be chosen.

43. SD Card Functionality Demonstration
If the SD card does not correctly store the data or does not have the adequate space to store the data, a new SD card will be chosen.

44. Payload Altimeter Functionality Test
If the altimeter does not read the correct altitude, a new altimeter will be chosen.

45. Wire Tube Inspection
If the wire tubes do not protect the wires sufficiently or interfere with the motor position, the diameter of the tubes may be modified or the positioning of the tubes within the airframe will be adjusted.

46. Payload Launch Detection Demonstration
If the payload is unable to recognize motion, the software will be modified so that the program begins to run when the IMU accelerometer detects acceleration.

47. Payload Data Compilation Test
If the payload is unable to compile image data in under 5 minutes, the software will be modified to ensure it can process data faster by not utilizing the data from all images taken, only those that provide a keypoint match with the pre-uploaded image of the launch field.

48. Payload Transmission Range Test
If the payload is unable to transmit data over one mile, a new radio will be chosen.

49. IMU Drift Analysis
If the measured drift exceeds 100 ft in 90 s, a new IMU that does not exceed the allowed drift will be chosen.

50. Payload Demonstration Flight
If the payload demonstration flight is unsuccessful, a thorough investigation of the payload will be done to determine the failures that occurred and what components must be modified in order to resolve the failures and the model will be relaunched.

6.3 Completed Subscale Testing

6.3.1 Test #7 – Recovery Altimeter Resolution Test

This test was performed prior to the subscale demonstration flight to ensure the functionality of the secondary recovery altimeter.

Independent Variable: altitude of altimeter

Dependent Variable: altimeter altitude reading

Materials Used:

- Secondary Entacore AIM Altimeter
- Entacore AIM software

Procedure:

- Power on altimeter and open altimeter software
- Record initial altimeter altitude reading
- Raise altimeter a measured distance
- Record altimeter altitude reading and compare to actual height change

The secondary altimeter was powered on and initially read an altitude of 51.1 m, which matched the calculations of the current altitude above sea level. The altimeter was then raised 8.5 ft and read 53.3 m, a change of 2.2 m or 7.2 ft. The altimeter's reading had about 1 ft of error, which is not large enough to result in a drastic misreading. Therefore, the test was deemed successful, and the secondary altimeter was able to be used (Figure 71).

Figure 71: Recovery Altimeter Resolution Test

6.3.2 Test #8 – Barometer Functionality Test

This test was performed prior to the subscale demonstration flight to ensure the functionality of the recovery barometer.

Independent Variable: pressure on barometer

Dependent Variable: barometer pressure reading

Materials Used:

- Barometer on Primary Stratologger Altimeter
- Barometer on Secondary Entacore AIM Altimeter
- Stratologger software
- Entacore AIM software
- Plastic straw

Procedure:

- Power on barometer and open barometer software
- Wait for barometer to emit beeping sounds, indicating the barometer is collecting pressure data
- Place plastic straw over barometer and provide suction force
- Wait for beeping sounds to cease, indicating barometer has sensed pressure change

The barometer was powered on and began to emit beeping sounds. The beeping sounds are expected to stop when the barometer senses a pressure change. A plastic straw was placed over the barometer and a suction force was induced to simulate a pressure change and the beeping ceased. A smooth curve was also produced on the barometer's software, indicating a pressure change. Therefore, the test was deemed successful, and barometer was able to be used (ref picture).

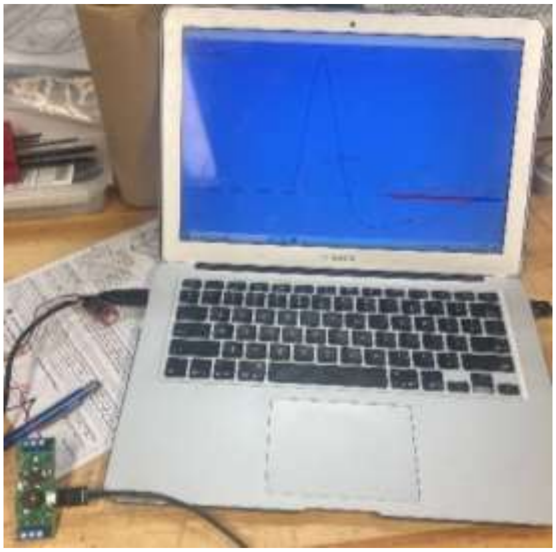


Figure 72: Barometer Functionality Test

6.3.3 Test #9 – Subscale Main Parachute Ejection Demonstration

This test was performed prior to the subscale demonstration flight.

Variable: amount of Pyrodex

Materials Used:

- Pyrodex
- E-match
- Copper wire
- 9V battery

- Test stand
- Launch vehicle

Procedure:

- Create ejection charge and record amount of Pyrodex used
- Fold main parachute
- Assemble the forward and nosecone sections of the launch vehicle with floating ejection charge wired to altimeter terminals and main parachute inside
- Attach copper wires to altimeter terminals
- Place launch vehicle on test stand
- Ignite ejection charge by touching copper wires to 9V battery

The team chose to utilize Pyrodex for the ejection charges in the subscale model due to the team's short supply of black powder. The ejection charge design implemented was floating charges and the nosecone and forward sections were assembled to complete this test. The first test attempted utilized 2 grams of Pyrodex but was unsuccessful due to leaking through the holes in the bulkhead. This issue was remedied by sealing all holes on the bulkhead with clay. The second test attempted utilized 2.25 grams of Pyrodex but was again unsuccessful due to leaking through the sides of the bulkhead. The bulkhead was then remanufactured to ensure that it would fit perfectly within the airframe. The third test attempted utilized 2.5 grams of Pyrodex but was again not successful because of leaking through the nosecone coupler. The coupler was covered with one strip of electrical tape to seal the gap between the nosecone and forward sections. With all the leaks identified and accounted for, the fourth attempt was successful. This attempt utilized 2.5 grams of Pyrodex to completely separate the nosecone and forward sections and to fully deploy the main parachute (Figure 73 and Figure 74). The test was deemed successful, thus 2.5 grams of Pyrodex were utilized for the primary main charge. Additionally, a 3.125 gram backup charge was also tested.

Figure 73: Subscale Main Ejection Demonstration Setup

Figure 74: Subscale Main Ejection Demonstration Success

6.3.4 Test #10 – Subscale Drogue Parachute Ejection Demonstration

This test was performed prior to the subscale demonstration flight.

Variable: amount of Pyrodex

Materials Used:

- Pyrodex
- E-match
- Copper wire
- Remote igniter
- 9V battery
- Test stand
- Launch vehicle

Procedure:

- Create ejection charge and record amount of Pyrodex used
- Fold drogue parachute
- Assemble all sections of the launch vehicle with floating ejection charge wired to altimeter terminals and drogue parachute inside
- Attach copper wires to altimeter terminals
- Place launch vehicle on test stand
- Ignite ejection charge by touching copper wires to 9V battery

The team chose to utilize Pyrodex for the ejection charges in the subscale model. The ejection charge design implemented was floating charges and the full launch vehicle was assembled to complete this test. The first test attempted was unsuccessful due to the fact that the ejection charge used was 1 gram and was therefore too small to provide enough force. The second test attempted was successful when the charge was increased to 2 grams. This test resulted in complete separation of the forward and aft sections and the drogue parachute fully deployed (Figure 75 and Figure 76). The test was deemed complete, thus 2 grams of Pyrodex were utilized for the primary drogue charge. 2.5 grams of Pyrodex were successfully tested for the backup charge as well.

Figure 75: Subscale Drogue Ejection Demonstration Setup

Figure 76: Subscale Drogue Ejection Demonstration Success

6.3.5 Test #16 – RocketPoxy Density Inspection

This test was conducted prior to the subscale demonstration flight to determine the total weight of RocketPoxy epoxy implemented in the design.

Variable: density of RocketPoxy

Materials Used:

- 5-in fiberglass piece
- 6-in fiberglass piece
- RocketPoxy resin and hardener
- Wooden popsicle stick

Procedure:

- Weigh the two pieces of fiberglass
- Epoxy pieces together with RocketPoxy using a fillet technique: mix the epoxy with equal parts resin and hardener; create fillet by applying epoxy to the corner where the two fiberglass pieces meet; smooth out the epoxy with a 1-in wooden popsicle stick.
- Weigh the epoxied fiberglass pieces
- Determine the epoxy weight through calculation

The calculation performed to determine the total weight of RocketPoxy required for the rocket is as follows:

5-in fiberglass piece = 1 oz

6-in fiberglass piece = 3.2 oz

Epoxied pieces = 4.6 oz, thus Total Epoxy = 0.4 oz, thus Epoxy = 0.08 oz per in

RocketPoxy is utilized for external epoxy fillets. The fins implemented in the launch vehicle design are 10 in long, and therefore required 0.8 oz of epoxy per side of each fin. The fins are epoxied on both sides to the outside of the airframe so therefore, this weight was multiplied by 2 to account for both sides of the fin. There are 4 fins implemented on the launch vehicle, so the total weight of the external epoxy required for the fins is 6.4 oz (Figure 77).

Figure 77: RocketPoxy Inspection

6.3.6 Test #17 – JB Weld Density Inspection

This test was conducted prior to the subscale demonstration flight to determine the total weight of JB Weld epoxy implemented in the design.

Variable: density of JB Weld

Materials Used:

- 5-in fiberglass piece
- 6-in fiberglass piece
- JB Weld resin and hardener
- Wooden popsicle stick

Procedure:

- Weigh the two pieces of fiberglass
- Epoxy pieces together with JB Weld using a fillet technique: mix the epoxy with equal parts resin and hardener; create fillet by applying epoxy to the corner where the two fiberglass pieces meet; smooth out the epoxy with a 1-in wooden popsicle stick.
- Weigh the epoxied fiberglass pieces
- Determine the epoxy weight through calculation

The calculation performed to determine the total weight of JB Weld required for the rocket is as follows:

5-in fiberglass piece = 1 oz

6-in fiberglass piece = 3.2 oz

Epoxied pieces = 4.4 oz, thus Total Epoxy = 0.2 oz, thus Epoxy = 0.04 oz per in

JB Weld is utilized for epoxying the centering rings. The centering rings implemented in the launch vehicle design are 3 in in diameter, and therefore required about 0.12 oz of epoxy per side of each ring. The centering rings are epoxied on both sides so therefore, this weight was multiplied by 2 to account for both sides of the ring. The weight was multiplied by 3 the account for the epoxy required to account for all three centering rings implemented in the launch vehicle. The total weight of the internal epoxy required for the fins is 0.72 oz (Figure 78).

Figure 78: JB Weld Inspection

6.3.7 Test #20 – Parachute Packing Demonstration

This test was performed prior to the subscale demonstration flight to ensure the parachutes were packed correctly so that they will deploy and open properly during separation.

Independent Variable: Manner of folding

Dependent Variable: Ability to deploy

Materials Used:
- Main parachute

Procedure:
- Fold parachutes in the appropriate manner
- Have two team members hold onto each end of the recovery harness and a third team member support the parachute in the middle
- Have two team members pull on the recovery harness simultaneously

The parachute was folded, and three team members participated in the test. The two team members pulled on the recovery harness simultaneously and the parachute opened successfully (Figure 79 and Figure 80). The test was deemed successful, and the parachute was refolded in the same manner.

Figure 79: Parachute Packing Demonstration Setup

Figure 80: Parachute Packing Demonstration Success

6.3.8 Test #22 – Center of Gravity Inspection

This test was performed on the day of the subscale demonstration flight once all components of the launch vehicle were fully assembled.

Variable: Center of gravity

Materials Used:

- Launch vehicle

Procedure:

- Place the launch vehicle on a team member's hand
- Shift hand location under the launch vehicle until the launch vehicle could perfectly balance
- Mark the balance point as the center of gravity

A team member balanced the launch vehicle on their hand and the balance point was marked as the center of gravity (Figure 81). The test was deemed successful because the center of gravity found allowed the launch vehicle to have a stability margin of 2.3 calibers.

Figure 81: Center of Gravity Inspection

6.3.9 Test #23 – Subscale Demonstration Flight

The subscale demonstration flight was performed in Labelle, FL on December 4th, 2021.

Variable: Performance of subscale model during launch, descent, and landing

Materials Used:

- Subscale launch vehicle assembled in full
- Launch rail
- Remote igniter

Procedure:

- Fully assemble subscale launch vehicle for flight
- Place launch vehicle on launch rail
- Launch using remote igniter

The team chose not to use the data from the payload due to issues with the performance of the cameras but included the full payload assembly, including the sled and electronics, within the airframe to account for its weight. The camera mounts were attached to the launch vehicle to account for the drag that the mounts induced to the team could analyze the resultant effects from the drag. The payload did, however, collect IMU data during the flight in order for the team to analyze the displacement of the launch vehicle. The payload and launch vehicle were assembled in full, and the motor was loaded into the motor casing. The vehicle was launched and successfully separated, allowing the parachutes to deploy properly (Figure 82). The forward and aft sections separated at apogee, enabling the drogue parachute to correctly deploy and open. The main parachute also successfully deployed and open, although the forward and nosecone sections may have separated when the secondary ejection charges were ignited and not the primary charges.

Figure 82: Subscale Demonstration Flight

No damage was incurred on the launch vehicle during the flight or landing, resulting in a successful demonstration flight on the first attempt, as the launch vehicle is recoverable and reusable (Figure 83 and Figure 84).

Figure 83: Subscale Recovery Site View 1

Figure 84: Subscale Recovery Site View 2

Two small holes were burned into the main parachute (circled in blue) from the ejection charges but did not affect descent (Figure 85). These holes can be fixed; thus, the parachute is still reusable. The drogue parachute did not incur any damage (Figure 86). This issue will be remedied for the full scale model by packing the main parachute in a different manner so that the parachute protector will protect it more adequately.

Figure 85: Parachute Burn Holes

Figure 86: Drogue Parachute Post-Launch

6.3.10 Test #29 – Battery Life Demonstration

This test was performed prior to the subscale demonstration flight to verify the battery life of the payload battery.

Variable: battery lifetime

Materials Used:

- Payload battery
- Full payload electronic configuration
- Voltage meter

Procedure:

- Record initial battery voltage using voltage meter
- Connect battery to payload electronics
- Let electronics run for 2 hrs, recording the battery voltage every 20 mins
- Record the final battery voltage after 2 hrs and determine if it maintained enough charge

The battery utilized for the payload was connected to the payload electronics. The starting voltage of the battery was 8.23V and the electronics were left running for 2 hrs. The voltage of the battery was checked every 20 mins. The battery lost about 0.3V of charge every 20 mins for the first hour, but then lost about 0.2V of charge every 20 mins for the second hour, indicating a plateau in voltage loss. This plateau was expected. The final voltage of the battery after running for 2 hrs was 8.10V. This test was deemed successful for the payload battery since the lowest allowable charge the battery can be is 7.40V, which is significantly less than the final measured voltage (Figure 87).

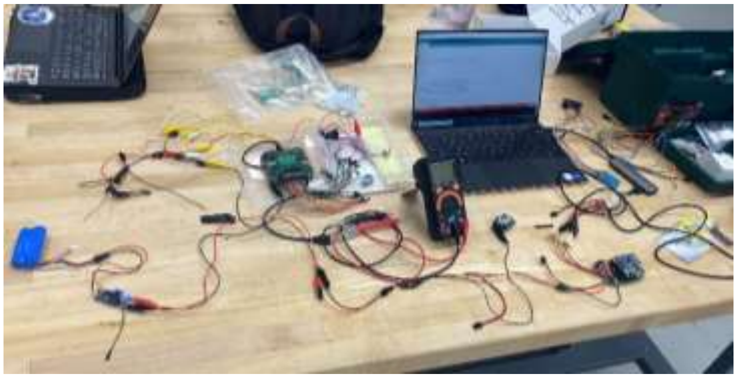


Figure 87: Battery Life Demonstration

This test is not fully completed, however. The lifetimes of the batteries for the avionics electronics must still be demonstrated.

6.4 Requirements Compliance

6.4.1 Competition Requirements

6.4.1.1 General Requirements

The general competition requirements are defined (Table 46).

Requirement	Implementation Plan	Method of Verification	Status
1.1. Students on the team will do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Teams will submit new work. Excessive use of past work will merit penalties.	The entirety of the launch vehicle and payload will be designed, manufactured, and prepared by the students on the team. All reports will be written by the students and the work will not be plagiarized or recycled.	Inspection	Partial Verification: all work so far has been completed by students on the team.
1.2. The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	The team will create an outline that includes project milestones, a budget, community support, checklists, personnel assignments, STEM engagement events, risks, and mitigations. This document will be updated when new reports are generated.	Inspection	Verified: the project plan is included in this report.

1.3. Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during Launch Week due to security restrictions. In addition, FN's may be separated from their team during certain activities on site at Marshall Space Flight Center.	Due to security restrictions, FN team members must be identified by the subteam leaders. A compiled list of all FN members will be submitted prior to PDR and may or may not have access to certain activities or be separated from their team during Launch Week at Marshall Space Flight Center.	Inspection	Verified: any FN team members were self-identified in the team's Gateway.
1.4. The team must identify all team members who plan to attend Launch Week activities by the Critical Design Review (CDR). Team members will include: 1.4.1. Students actively engaged in the project throughout the entire year. 1.4.2. One mentor (see requirement 1.13). 1.4.3. No more than two adult educators	Team members who will attend Launch Week activities will be members with consistent engagement, a selected mentor, and a limit of 2 adult educators. A list of these active members that plan to attend will be compiled prior to CDR.	Inspection	Verified: the list of attending members has been compiled.
1.5. The team will engage a minimum of 250 participants in direct educational, hands-on science, technology, engineering, and mathematics (STEM) activities. These activities can be conducted in-person or virtually. To satisfy this requirement, all events must occur between project acceptance and the FRR due date. A template of the STEM Engagement Activity Report can be found on pages 40-43.	At least 250 participants will engage in direct educational STEM activities offered by the team in-person or online during the time between project acceptance and the FRR due date. This requirement will be satisfied through the partnership with Alachua County Public Schools to engage with elementary and middle school students.	Inspection	Unverified: the team has engaged with 12 out of 250 participants thus far. The team plans to engage with over 1000 students at a Career Fair event in Starke, FL on February 3, 2022.
1.6. The team will establish and maintain a social media presence to inform the public about team activities.	An active and engaging social media presence has been established and will be maintained to publicize team activities on Instagram (@SwampLaunch), Twitter (@SwampLaunch), and Fac	Inspection	Verified: the team has active and engaging social media platforms. The team's Instagram account has

	ebook (@Swamp Launch Rocket Team).		684 followers, the team’s Twitter account has 31 followers, and the team’s Facebook account has 175 followers.
1.7. Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient. Late submissions of milestone documents will be accepted up to 72 hours after the submission deadline. Late submissions will incur an overall penalty. No milestone documents will be accepted beyond the 72-hour window. Teams that fail to submit milestone documents will be eliminated from the project.	All email deliverable materials will be sent by the team’s project manager by the deadline specified in the handbook. In the event that materials are sent in late, the team will only be allowed 72 hours after the specified deadline to send the deliverables with a penalty. There are no acceptations beyond this deadline.	Inspection	Verified: the Project Manager, Megan Wnek, has sent and will send all deliverables via email.
1.8. All deliverables must be in PDF format.	All email deliverable materials will be in PDF format.	Inspection	Partial Verification: the deliverables for PDR were in PDF format and all future deliverables will be as well.
1.9. In every report, teams will provide a table of contents including major sections and their respective sub-sections.	All reports will include a table of contents outlining important sections and their sub-sections.	Inspection	Partial Verification: the PDR report included a table of contents with major sections and sub-sections. All future reports will include a

			table of contents with major sections and sub-sections as well.
1.10. In every report, the team will include the page number at the bottom of the page.	All reports will include page numbers at the bottom of each page.	Inspection	Partial Verification: the PDR report included page numbers at the bottom of each page. All future reports will include page numbers at the bottom of each page as well.
1.11. The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.	In the event of a teleconference with the review panel, all video teleconference equipment (camera, microphone, computer, Internet connection) will be provided by the team.	Inspection	Partial Verification: the team provided all video equipment for the PDR teleconference and will continue to do so for future teleconferences.
1.12. All teams attending Launch Week will be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted at the NASA Launch Complex. At launch, 8-foot 1010 rails and 12-foot 1515 rails will be provided. The launch rails will be canted 5 to 10 degrees away from the crowd on Launch Day. The exact cant will depend on Launch Day wind conditions.	At Launch Week, the team will utilize the 8-foot 1010 rails, or the 12-foot 1515 rails canted 5 to 10 degrees away from the crowd provided by the launch services provider. These are the only launch pads the team will utilize.	Inspection and demonstration	Unverified: the launch has not yet been performed; however, the team plans to utilize the 12-ft 1515 rails canted 5 deg away from the crowd.
1.13. Each team must identify a "mentor." A mentor is defined as an adult who is included as a team	The team's mentor is Jimmy Yawn, a level 3 certified NAR member. The	Inspection	Verified: the team maintains consistent

member, who will be supporting the team (or multiple teams) throughout the project year and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to Launch Week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attend Launch Week in April.	team's mentor is in good standing with the NAR and has launched the required number of flights. Mr. Yawn is the designated owner of the rocket and will be traveling with the team.		contact with Mr. Yawn, and he attended the subscale demonstration flight.
1.14 Teams will track and report the number of hours spent working on each milestone.	All progress will be recorded and reported with specifications on hours spent and goals met. Each subteam will record their progress once per week.	Inspection	Verified: the hours spent working are included in this report.

Table 46: General Requirements Compliance

6.4.1.2 Vehicle Requirements

The competition requirements for the vehicle are defined (Table 47).

Requirements	Implementation Plan	Method of Verification	Status
2.1. The vehicle will deliver the payload to an apogee altitude between 4,000 and 6,000 feet above ground level (AGL). Teams flying below 4,000 feet or above 6,000 feet on their competition launch will receive zero altitude points towards their overall project	An altitude between 4,000 and 6,000 feet AGL must be met for the team's vehicle to be considered for the Altitude Award or to obtain altitude points towards overall project score. The	Demonstration	Unverified: the apogee will be verified during the full scale demonstration flight.

score and will not be eligible for the Altitude Award.	team’s current altitude estimate is 4,578 ft.		
2.2. Teams shall identify their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team’s altitude score.	A target altitude goal will be decided at the PDR milestone through which will be used to determine the team's altitude score.	Analysis	Verified: the target altitude is 4,578 ft and was determined through OpenRocket simulations.
2.3. The vehicle will carry, at a minimum, two commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events (see Requirement 3.4). An altimeter will be marked as the official scoring altitude used in determining the Altitude Award winner. The Altitude Award winner will be given to the team with the smallest difference between the measured apogee and their official target altitude for their competition launch.	In order to measure the altitude, the team's vehicle will carry at least 2 barometric altimeters specially for rocketry recovery. This measured altitude from the barometric altimeter will be utilized to determine the team's altitude points and consideration for the Altitude Award.	Inspection	Verified: the launch vehicle carries 2 barometric altimeters: a Stratologger altimeter and an Entacore AIM altimeter.
2.4. The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	The team’s launch vehicle will be designed with a recovery system that allows it to be able to launch again without significant modifications within the same day.	Analysis and demonstration	Partial Verification: the Subscale Demonstration Flight (Test #23) was successful. OpenRocket simulations reveal that the launch vehicle will land at appropriate speeds. The Vehicle Demonstration Flight has not yet been performed.
2.5. The launch vehicle will have a maximum of four (4) independent sections. An independent section is	The team’s launch vehicle will have 3 sections, including the	Analysis	Verified: the team’s design has 3 sections,

defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute. 2.5.1. Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length. 2.5.2. Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.	nosecone section, the forward section, and the aft section. In-flight separation points will have coupler shoulders that will be at least 4 in. in length and nosecone shoulders that will be 4 in. length.		determined through analysis to decide where the separation points should be.
2.6. The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	The team's launch vehicle will be made ready for flight within 2 hours as outlined by Test #25.	Testing	Unverified
2.7. The launch vehicle and payload will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged.	Without losing any vital functionality or components, the launch vehicle will be able to withstand a launch ready position for at least 2 hours. This will be verified by Test #29.	Testing	Verified: Test #29 was deemed successful.
2.8. The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.	The team's launch vehicle will utilize a motor that is compatible with a 12-volt direct current firing system offered by NASA launch services.	Analysis	Verified: the team's design utilizes a compatible motor, an AeroTech L1090W motor, confirmed by OpenRocket simulations.
2.9. The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).	The team's chosen motor will be capable of initiating launch without external circuitry or specific ground support.	Inspection	Verified: the team has chosen components that do not require external circuitry.

2.10. The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR). 2.10.1. Final motor choices will be declared by the Critical Design Review (CDR) milestone. 2.10.2. Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment will not be approved. A penalty against the team's overall score will be incurred when a motor change is made after the CDR milestone, regardless of the reason.	The team's launch vehicle will use an NAR, TRA, or CAR certified APCP motor propulsion system. Additionally, the choice of motor will be finalized before the CDR deadline. The chosen motor is an AeroTech L1090W, which satisfies the motor requirements. If changing motors is necessary after the CDR deadline, the team will be sure to attain approval from the NASA Range Safety Officer. It is understood that a penalty will be given to the team if a motor change is necessary.	Inspection and analysis	Verified: the motor, an AeroTech L1090W, was chosen using OpenRocket simulations and adheres to the certification requirements.
2.11. The launch vehicle will be limited to a single stage.	The team will utilize one motor.	Analysis	Verified: the team's OpenRocket simulations were designed using one motor
2.12. The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).	The team's chosen motor will not exceed L-class. The chosen motor is an AeroTech L1090W (L-class).	Inspection	Verified: the chosen motor is an L-class motor and thus adheres to the class requirements.
2.13. Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria: 2.13.1. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.	The team will not utilize pressure vessels in the launch vehicle.	Inspection	Verified: there are no pressure vessels implemented in the design.

2.13.2. Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank. 2.13.3. The full pedigree of the tank will be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.			
2.14. The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	The team’s launch vehicle will have a static stability margin of at least 2.0. This will be ensured through OpenRocket simulations to determine the stability margin.	Analysis	Verified: the OpenRocket simulations ensure a stability margin of 2.2 calibers at rail exit.
2.15. The launch vehicle will have a minimum thrust to weight ratio of 5.0:1.0.	A minimum thrust ratio of 5.0:1.0 will be enforced on the launch vehicle.	Analysis	Verified: the OpenRocket simulations ensure a thrust-to-weight ratio of 9.6:1.0.
2.16. Any structural protuberance on the rocket will be located aft of the burnout center of gravity. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket’s stability.	The rocket will include external camera mounts that will not provide substantial aerodynamic effect.	Analysis	Verified: CFD simulations ensure that the external camera housings will not negatively impact flight.
2.17. The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	The team’s launch vehicle will reach 88.6 ft/s at the rail exit. This will be ensured through OpenRocket simulations to determine the velocity.	Analysis	Verified: the OpenRocket simulations ensure an appropriate rail exit velocity and the vehicle will reach 88.6

			ft/s at the rail exit.
2.18. All teams will successfully launch and recover a subscale model of their rocket prior to CDR. The subscale flight may be conducted at any time between proposal award and the CDR submission deadline. Subscale flight data will be reported at the CDR milestone. Subscales are required to use a minimum motor impulse class of E (Mid Power motor).	The teams will launch and recover a subscale model of the rocket after the Proposal and prior to the CDR submission deadline. Section 6.1 outlines the planned schedule including this launch.	Demonstration	Verified: Test #23 was deemed successful.
2.18.1. The subscale model should resemble and perform as similarly as possible to the full-scale model; however, the full-scale will not be used as the subscale model.	The team's subscale model will be of utmost similarity to the full-scale model in order to obtain data for the full-scale model. The team will not use the full-scale model as the subscale model since the subscale model is smaller than the full scale model.	Analysis	Verified: the subscale model is geometrically similar to the full scale and is 75% of the size of the full scale model.
2.18.2. The subscale model will carry an altimeter capable of recording the model's apogee altitude.	The team's subscale model will carry a Stratologger and an Entacore AIM altimeter to record the model's apogee altitude.	Inspection	Verified: the launch vehicle will carry the 2 altimeters.
2.18.3. The subscale rocket shall be a newly constructed rocket, designed and built specifically for this year's project.	The team's subscale rocket will be designed and built for this year's project.	Inspection	Verified: the subscale rocket was newly designed and built on November 21-29, 2021.
2.18.4. Proof of a successful flight shall be supplied in the CDR report. Altimeter flight profile graph(s) OR a quality video showing successful launch and recovery events as deemed by the NASA management panel are acceptable methods of proof.	The team will provide successful flight data in the CDR report from altimeter flight profile graphs or a sufficient video showing all parts of launch and recovery.	Analysis and demonstration	Verified: Test #23 was deemed successful, and the required data is included in section 3.4.1 of this report.
2.18.5. The subscale rocket shall not exceed 75% of the dimensions	The team's subscale model will not be larger than 75%	Analysis	Verified: the subscale model

(length and diameter) of your designed full-scale rocket. For example, if your full-scale rocket is a 4" diameter 100" length rocket your subscale shall not exceed 3" diameter and 75" in length.	of the full-scale model's dimensions.		is 75% of the size of the full scale model. The length of the subscale is 86 in.
2.19. All teams will complete demonstration flights as outlined below.	See the guidelines specified below.	See below	See below
2.19.1. Vehicle Demonstration Flight - All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown shall be the same rocket to be flown for their competition launch. The purpose of the Vehicle Demonstration Flight is to validate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). The following criteria shall be met during the full-scale demonstration flight:	The teams rocket will demonstrate a successful flight and recovery prior to FRR with the same rocket intended for the competition. The rocket's success will be defined by its stability, minimal changes in structure, proper recovery systems, proper preparation, and functionality of hardware.	Demonstration	Unverified
2.19.1.1. The vehicle and recovery system will have functioned as designed.	During the full-scale flight demonstration, the team's rocket will function as intended through either the primary or redundant systems.	Demonstration	Unverified
2.19.1.2. The full-scale rocket shall be a newly constructed rocket, designed and built specifically for this year's project.	The team's rocket will be designed and built specifically for this year's project.	Inspection	Unverified
2.19.1.3. The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply:	The following requirements apply during the full-scale Vehicle Demonstration Flight:	See below	See below

2.19.1.3.1. If the payload is not flown, mass simulators will be used to simulate the payload mass.	If the payload is not flown, the mass of the payload will be simulated by mass simulators.	Demonstration	Unverified
2.19.1.3.2. The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.	The mass simulators will be placed in the aft section, approximately the same location as the payload.	Inspection	Unverified
2.19.1.4. If the payload changes the external surfaces of the rocket (such as camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale Vehicle Demonstration Flight.	Since external camera housings are intended for the design, these features will be included in the Vehicle Demonstration Flight.	Inspection	Unverified
2.19.1.5. Teams shall fly the competition launch motor for the Vehicle Demonstration Flight. The team may request a waiver for the use of an alternative motor in advance if the home launch field cannot support the full impulse of the competition launch motor or in other extenuating circumstances.	Teams must use the chosen competition launch motor, an AeroTech L1090W, or the Vehicle Demonstration Flight since the team's home launch field is capable of supporting its motor.	Inspection	Unverified
2.19.1.6. The vehicle shall be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the maximum amount of ballast that will be flown during the competition launch flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.	At the full-scale test flight, the team's rocket will be prepared in a fully ballasted configuration to test how the flight will be on Launch Day.	Inspection and analysis	Unverified
2.19.1.7. After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).	The launch vehicle or its components will not be changed without the agreement of the NASA Range Safety Officer after a successful full-scale demonstration flight.	Inspection	Unverified
2.19.1.8. Proof of a successful flight shall be supplied in the FRR report. Altimeter flight profile data output with accompanying altitude and	The FRR report will contain proof of a successful flight. This will include altimeter flight profile data output with accompanying altitude	Inspection	Unverified

velocity versus time plots is required to meet this requirement.	and velocity versus time plots.		
2.19.1.9. Vehicle Demonstration flights shall be completed by the FRR submission deadline. No exceptions will be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. THIS EXTENSION IS ONLY VALID FOR RE-FLIGHTS, NOT FIRST TIME FLIGHTS. Teams completing a required re-flight shall submit an FRR Addendum by the FRR Addendum deadline. 11 General and Proposal Requirements	Vehicle Demonstration flights must be made by the FRR submission deadline. An extension may be allowed if a Vehicle Demonstration Re-flight is necessary as determined by the Student Launch office. Teams completing a required re-flight must submit an FRR Addendum by the FRR Addendum deadline (April 4, 2021).	Inspection	Unverified
2.19.2. Payload Demonstration Flight - All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown shall be the same rocket to be flown as their competition launch. The purpose of the Payload Demonstration Flight is to prove the launch vehicle’s ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. The following criteria shall be met during the Payload Demonstration Flight:	The team must launch their full-scale rocket, including the payload, successfully by the Payload Demonstration Flight deadline. The payload will be launched in the rocket intended for competition. The payload will be fully retained, and the rocket will experience a stable ascent.	Demonstration	Unverified
2.19.2.1. The payload shall be fully retained until the intended point of deployment (if applicable), all retention mechanisms shall function as designed, and the retention mechanism shall not sustain damage requiring repair.	The team’s design outlines that payload will not jettison and will be retained properly within the launch vehicle.	Analysis	Verified: the payload will not jettison.

2.19.2.2. The payload flown shall be the final, active version.	The payload will be completed and flown in its final version.	Inspection	Unverified
2.19.2.3. If the above criteria are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required.	If the payload is successfully flown at the Vehicle Demonstration Flight, the Payload Demonstration Flight is not required and will not be performed.	Demonstration	Unverified
2.19.2.4. Payload Demonstration Flights shall be completed by the FRR Addendum deadline. NO EXTENSIONS WILL BE GRANTED.	The Payload Demonstration Flight must be completed by the submission deadline of the FRR Addendum of April 4, 2021, with no exceptions.	Demonstration	Unverified
2.20. An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA-required Vehicle Demonstration Re-flight after the submission of the FRR Report.	If the Payload Demonstration Flight or Vehicle Demonstration Flight is completed after the submission of the FRR report, an FRR Addendum must be completed by the team by the FRR Addendum deadline of April 4, 2021.	Inspection	Unverified
2.20.1. Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline will not be permitted to fly a final competition launch.	If the team requires a Vehicle Demonstration Re-flight, the team will submit the FRR Addendum or will be banned from the final launch.	Inspection	Unverified
2.20.2. Teams who successfully complete a Vehicle Demonstration Flight but fail to qualify the payload by satisfactorily completing the Payload Demonstration Flight requirement will not be permitted to fly a final competition launch.	The team will have a successful launch for both the Vehicle Demonstration Flight and the Payload Demonstration Flight.	Demonstration	Unverified
2.20.3. Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload at launch week. Permission will not be granted if the RSO or the Review Panel have any safety concerns.	If the Payload Demonstration Flight is not successful, the team may request to fly the payload during launch week, only with permission from the NASA RSO.	Demonstration	Unverified

2.21. The team's name and Launch Day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.	The team will include their name and contact information on each section of the launch vehicle that is not tethered to the main airframe.	Inspection	Unverified
2.22. All Lithium Polymer batteries will be sufficiently protected from impact with the ground and will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.	Lithium Polymer batteries will be appropriately protected and marked using orange tape.	Inspection	Verified: safety precautions will be taken as outlined in the safety section, section 5.
2.23. Vehicle Prohibitions:	See Vehicle Prohibitions below.	See below	See below
2.23.1. The launch vehicle will not utilize forward firing motors.	The launch vehicle will use rear-firing motors.	Inspection	Verified: the chosen motor, an AeroTech L1090W, is a rear-firing motor.
2.23.2. The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	The launch vehicle will use an AeroTech K1090W-PS motor that does not release titanium sponges.	Inspection	Verified: the chosen motor, an AeroTech L1090W, does not release titanium sponges.
2.23.3. The launch vehicle will not utilize hybrid motors.	The motor chosen for the launch vehicle is not a hybrid motor.	Inspection	Verified: the chosen motor, an AeroTech L1090W, is not a hybrid motor.
2.23.4. The launch vehicle will not utilize a cluster of motors.	A single motor is chosen for the launch vehicle.	Inspection	Verified: the team's design includes one motor, an AeroTech L1090W.
2.23.5. The launch vehicle will not utilize friction fitting for motors.	The chosen motor will use centering rings and a thrust plate for motor retention.	Inspection	Verified: the motor has the appropriate

			retention system, discussed in section 3.1.1.5.3, involving centering rings for motor alignment and a motor retainer to keep the motor in place.
2.23.6. The launch vehicle will not exceed Mach 1 at any point during flight.	The rocket will not exceed Mach 1 during flight, ensured through utilizing OpenRocket simulations to determine the launch vehicle's velocity.	Analysis	Verified: the OpenRocket simulations ensure that the launch vehicle will not exceed Mach 1. The vehicle is expected to reach a Mach number of 0.59.
2.23.7. Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad (i.e. a rocket with an unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast)	Any vehicle ballast utilized will not weigh more than 10% of the rocket's total unballasted weight.	Analysis	Unverified
2.23.8. Transmissions from onboard transmitters, which are active at any point prior to landing, will not exceed 250 mW of power (per transmitter).	Each transmitter will not exceed 250 mW of power.	Inspection	Verified: the onboard GPS utilizes 250 mW of power.
2.23.9. Transmitters will not create excessive interference. Teams will utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams.	Each transmitter will be equipped appropriately to minimize interference; the bulkhead that the GPS is mounted on will be covered with aluminum foil.	Analysis	Unverified
2.23.10. Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of	The team's design will only include minimal lightweight	Inspection	Verified: the team's design does not use

lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	metal primarily in the tip of the nosecone.		excessive metal.

Table 47: Vehicle Requirements Compliance

6.4.1.3 Recovery System Requirements

The competition requirements for the recovery system are defined (Table 48).

Requirement	Implementation Plan	Method of Verification	Status
3.1. The full-scale launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee, and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue stage descent is reasonable, as deemed by the RSO.	The full-scale launch vehicle will use a dual deploy system. A Sky Angle 24-in C3 drogue parachute will be deployed at apogee, and a Fruity Chutes 72-in Iris Ultra main parachute will deploy at 600 feet.	Analysis	Verified: Deployment time was calculated using OpenRocket and spreadsheet simulations.
3.1.1. The main parachute shall be deployed no lower than 500 feet.	The main parachute will be deployed at 600 feet.	Analysis	Verified: Deployment time was calculated using OpenRocket and spreadsheet simulations.
3.1.2. The apogee event may contain a delay of no more than 2 seconds.	The primary charge for the drogue deployment will not have a delay for drogue deployment.	Analysis	Verified: Deployment time was calculated using OpenRocket and spreadsheet simulations.
3.1.3. Motor ejection is not a permissible form of primary or secondary deployment.	Motor ejection will not be used as a form of parachute deployment.	Inspection	Verified: the team's design does not utilize motor ejection.
3.2. Each team will perform a successful ground ejection test	The testing lead and safety officers will perform ejection	Demonstration	Partial verification:

for all electronically initiated recovery events prior to the initial flights of the subscale and full-scale vehicles.	tests for all electronic recovery events for both the subscale and full-scale launch vehicles prior to their first flights.		Tests #9 and #10 were deemed successful, but Tests #11 and #12 were not yet performed.
3.3. Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing.	It will be ensured that no section of the launch vehicle has a kinetic energy that equals or exceeds 75 ft-lbf at landing. This will be done using OpenRocket simulations, and the current maximum kinetic energy is estimated to be 70.0 ft-lbf.	Analysis	Verified: OpenRocket simulations ensure the appropriate kinetic energy.
3.4. The recovery system will contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.	The design will include a redundant Entacore AIM altimeter.	Inspection	Verified: a secondary altimeter is implemented in the design.
3.5. Each altimeter will have a dedicated power supply, and all recovery electronics will be powered by commercially available batteries.	Each altimeter implemented will have an independent fully charged 9-volt battery power source.	Inspection	Verified: the avionics design includes an independent battery.
3.6. Each altimeter will be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	The altimeters will have the ability to be armed through a key switch on the switch band of the avionics bay.	Inspection	Verified: the avionics design includes a key switch located on the switch band.
3.7. Each arming switch will be capable of being locked in the ON position for launch (i.e., cannot be disarmed due to flight forces).	The arming switches will be locked in the “on” position before launch by the level 2 NAR certified team member.	Inspection	Verified: the key switch has the ability to be locked in the “on” position.
3.8. The recovery system electrical circuits will be completely independent of any payload electrical circuits.	The electronics included in the payload and the recovery system will be separate and will be located in separate sections of the launch	Inspection	Verified: the team’s design involves the avionics system being

	vehicle. The payload electronics will be contained within the payload bay and the recovery system electronics will be contained in the avionics bay.		housed in a separate coupler than the payload.
3.9. Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	The launch vehicle will be secured together through the use of shear pins at any section that will separate and rivets at any section that does not separate.	Inspection	Verified: the team's design utilizes shear pins and rivets in the appropriate locations.
3.10. The recovery area will be limited to a 2,500 ft. radius from the launch pads.	The rocket will not drift farther than 2,500 ft from the launch pad when landing. The current estimated maximum recovery area is 2427 ft. This value will be re-estimated throughout the project process.	Analysis	Verified: OpenRocket and spreadsheet simulations ensure the expected drift is not too great. The current estimated maximum recovery area is 2427 ft.
3.11. Descent time of the launch vehicle will be limited to 90 seconds (apogee to touch down).	The time from apogee to touch down will not exceed 90 seconds. The current estimated landing time is 82.5 sec.	Analysis	Verified: OpenRocket and spreadsheet simulations ensure the expected descent time is within parameters.
3.12. An electronic GPS tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	A GPS will be placed in the nosecone of the launch vehicle and will have the ability to communicate with the ground station.	Inspection	Verified: the team's design implements a GPS.
3.12.1. Any rocket section or payload component, which lands untethered to the launch	There will not be any untethered sections of the launch vehicle or payload.	Inspection	Verified: the team's design involves a fully-

vehicle, will contain an active electronic GPS tracking device.			tethered vehicle.
3.12.2. The electronic GPS tracking device(s) will be fully functional during the official competition launch.	The Testing Lead will be responsible for ensuring the proper functionality of the GPS devices prior to launch through completing Test #19.	Demonstration	Unverified: Test #19 will be performed to verify the functionality of the GPS.
3.13. The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	Any electronic devices involved in the launch vehicle will not interfere with the recovery system electronic capabilities.	Testing	Unverified
3.13.1. The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.	The recovery system altimeters will be located in the avionics bay, away from the devices implemented in the payload that will be located in the aft section.	Inspection	Verified: the recovery and payload electronics are housed in separate couplers.
3.13.2. The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.	The recovery system electronics will be shielded using aluminum foil from interference with any other transmitting devices.	Inspection	Verified: the recovery system design includes shielding.
3.13.3. The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	The recovery system electronics will be shielded using aluminum foil from magnetic waves with any other transmitting devices.	Inspection	Verified: the recovery system design includes shielding.
3.13.4. The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	The recovery system electronics will be shielded using aluminum foil from other devices that may negatively affect the recovery system by being placed in the avionics bay.	Inspection	Verified: the recovery system design includes shielding.

Table 48: Recovery System Requirements Compliance

6.4.1.4 Payload Experiment Requirements

The competition requirements for the payload are defined (Table 49).

Requirement	Implementation Plan	Method of Verification	Status
4. All payload designs shall be approved by NASA. NASA reserves the authority to require a team to modify or change a payload, as deemed necessary by the Review Panel, even after a proposal has been awarded.	The team's payload design must be approved by NASA and may be changed by NASA if necessary.	Inspection	Verified: the team's payload design was approved by NASA after submission of the proposal.
4.1. College/University Division – Teams shall design a payload capable of autonomously locating the launch vehicle upon landing by identifying the launch vehicle's grid position on an aerial image of the launch site without the use of a global positioning system (GPS). The method(s)/design(s) utilized to complete the payload mission will be at the teams' discretion and will be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge. An additional experiment (limit of 1) is allowed, and may be flown, but will not contribute to scoring. If the team chooses to fly an additional experiment, they will provide the appropriate documentation in all design reports so the experiment may be reviewed for flight safety.	The team's payload design will implement cameras placed on the exterior of the airframe and will be utilized to capture images and identify reference points found on the ground during flight in order to locate the grid position of the launch vehicle upon landing.	Analysis	Verified: the team's payload design adheres to the requirements.
4.2.1. The dimensions of the gridded launch field shall not extend beyond 2,500 feet in any direction; i.e., the dimensions of your gridded launch field shall not exceed 5,000 feet by 5,000 feet.	The gridded launch field dimensions are 5,000 ft by 5,000 ft.	Inspection	Verified: the team's gridded launch field adheres to the requirements.
4.2.1.1. Your launch vehicle and any jettisoned components must land within the external borders of the launch field.	The entirety of the launch vehicle and its components will land within the 2,500 ft radius since the estimated maximum drift range is 2427 ft.	Analysis	Verified: OpenRocket and spreadsheet simulations ensure that the launch

			vehicle will not drift outside the field borders.
4.2.2. A legible gridded image with a scale shall be provided to the NASA management panel for approval at the CDR milestone. 4.2.2.1. The dimensions of each grid box shall not exceed 250 feet by 250 feet. 4.2.2.2. The entire launch field, not to exceed 5,000 feet by 5,000 feet, shall be gridded. 4.2.2.3. Each grid box shall be square in shape. 4.2.2.4. Each grid box shall be equal in size, it is permissible for grid boxes occurring on the perimeter of your launch field to fall outside the dimensions of the launch field. Do not alter the shape of a grid box to fit the dimension or shape of your launch field. 4.2.2.5. Each grid box shall be numbered 4.2.2.6. The identified launch vehicle's grid box, upon landing, will be transmitted to your team's ground station.	A gridded image of the launch field with an appropriate scale has been created and will be submitted at the CDR deadline. Each square grid is 250 ft by 250 ft and the grid box that the launch vehicle lands in will be communicated to the ground station.	Inspection	Verified: the created gridded launch field adheres to the requirements and is included in this report.
4.2.3. GPS shall not be used to aid in any part of the payload mission. 4.2.3.1. GPS coordinates of the launch vehicles landing location shall be known and used solely for the purpose of verification of payload functionality and mission success. 4.2.3.2. GPS verification data shall be included in your team's PLAR.	A GPS is not included in the payload design. The GPS located in the nosecone will be used only for verification of the payload's results.	Inspection	Verified: the payload's design does not implement a GPS.
4.2.4. The gridded image shall be of high quality, as deemed by the NASA management team, that comes from an aerial photograph or satellite image of your launch day launch field. 4.2.4.1. The location of your launch pad shall be depicted on your image	The gridded image is a high-quality satellite image of the launch field, and the launch pad location will be depicted.	Inspection	Verified: the gridded launch field is of high image quality and the launch pad location is noted.

and confirmed by either the NASA management panel for those flying in Huntsville or your local club's RSO. (GPS coordinates are allowed for determining your launch pad location).			
4.2.5. No external hardware or software is permitted outside the team's prep area or the launch vehicle itself prior to launch.	The hardware and software utilized is implemented only in the launch vehicle or on the ground station.	Inspection	Verified: the team's payload design does not exceed location parameters.
4.3. General Payload Requirements:	See the payload requirements below.	See below	See below
4.3.1. Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics will not be permitted for any surface operations.	Black powder and Pyrodex will be used for ejection charges only.	Inspection	Verified: the payload's design does not implement energetics.
4.3.2. Teams shall abide by all FAA and NAR rules and regulations.	The team will follow rules set forth by the FAA and NAR.	Inspection	Verified: the team is adhering to FAA and NAR guidelines, as outlined in section 5.
4.3.3. Any experiment element that is jettisoned during the recovery phase will receive real-time RSO permission prior to initiating the jettison event, unless exempted from the requirement at the CDR milestone by NASA.	No components will be jettisoned without RSO approval.	Inspection	Verified: the team will not jettison any portion of the payload.
4.3.4. Unmanned aircraft system (UAS) payloads, if designed to be deployed during descent, will be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAS.	The team will not utilize UAS payloads.	Inspection	Verified: the team's payload design does not include a UAS payload.
4.3.5. Teams flying UASs will abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112-95 Section 336; see https://www.faa.gov/uas/faqs).	The team will not utilize UAS payloads.	Inspection	Verified: the team's payload design does not include a UAS payload.

4.3.6. Any UAS weighing more than .55 lbs. will be registered with the FAA and the registration number marked on the vehicle.	The team will not utilize UAS payloads.	Inspection	Verified: the team's payload design does not include a UAS payload.

Table 49: Payload Experiment Requirements Compliance

6.4.1.5 Safety Requirements

The competition requirements for safety are defined (Table 50).

Requirement	Implementation Plan	Method of Verification	Status
5.1. Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations.	The team will create a launch and safety checklist based on the launch requirements that will be included in FRR and utilized during LRR and Launch Day. This checklist will be enforced by the team's safety officers.	Analysis	Unverified
5.2. Each team shall identify a student safety officer who will be responsible for all items in section 5.3.	Jason Rosenblum and Raymond Pace are the team's chosen safety officers and are responsible for the items listed below.	Inspection	Verified: the safety officers were declared in the Proposal.
5.3. The role and responsibilities of the safety officer will include, but are not limited to: 5.3.1. Monitor team activities with an emphasis on safety during: 5.3.1.1. Design of vehicle and payload 5.3.1.2. Construction of vehicle and payload components 5.3.1.3. Assembly of vehicle and payload 5.3.1.4. Ground testing of vehicle and payload 5.3.1.5. Subscale launch test(s) 5.3.1.6. Full-scale launch test(s) 5.3.1.7. Competition Launch 5.3.1.8. Recovery activities 5.3.1.9. STEM Engagement Activities	The safety officers will monitor the design, construction, and assembly of the vehicle and payload. The safety officers will be present during ground testing procedures and will attend both the subscale launch and full-scale launch, enforcing proper safety procedures. The safety officers will oversee recovery and ensure that team members are following safety precautions when completing recovery activities. The safety officers will also monitor any STEM engagement activities that involve safety hazards.	Inspection	Verified: the safety officers follow the guidelines set forth and will continue to do so.
5.3.2. Implement procedures developed by the team for construction, assembly, launch, and recovery activities.	The safety officers will review the team's manufacturing, assembly, launch, and recovery plans and enforce	Analysis	Verified: the safety officers have reviewed previous procedures

	proper safety protocols during these processes.		and will continue to do so.
5.3.3. Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	The team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data is updated by the safety officers and is shared with the remaining team members through a Microsoft Teams account.	Analysis	Verified: the safety officers have included safety procedures in section 5 of this report and share the information with team members.
5.3.4. Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	The safety officers will assist in creating and writing the team's hazard analyses, failure modes analyses, and procedures that will be included in reports.	Inspection	Verified: the safety officers have written the appropriate sections (section 5 of this report).
5.4. During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	The team will abide by rules set forth by the safety officers. The team will communicate appropriately prior to attending NAR/TRA launches.	Inspection	Verified: the team abides by all rules set forth.
5.5. Teams will abide by all rules set forth by the FAA.	The team has reviewed the rules set forth by the FAA and will abide by all regulations. The team's project plan accounts for these regulations.	Inspection	Verified: all plans designed by the team adhere to all regulations.

Table 50: Safety Requirements Compliance

6.4.2 Team-Derived Requirements

The team has created requirements that are specific to the team's design. These team-derived requirements specify components of the design that go beyond the minimum competition requirements and are applied to ensure success of the team's design.

6.4.2.1 Vehicle Requirements

The team-derived requirements for the launch vehicle are defined (Table 51).

Requirement	Justification	Method of Verification	Status
1.1 The launch vehicle must not have a coefficient of drag that exceeds 2.5 due to the external camera mounts.	The external camera mounts must not induce a larger coefficient of drag or the launch vehicle's flight will be negatively impacted, and the vehicle may not reach its target altitude.	Analysis	Verified: The launch vehicle's coefficient of drag is 2.5, determined through OpenRocket analyses.
1.2 The motor centering rings' holes must be aligned sufficiently in order for electronics tubes to fit through the holes properly.	The electronics tubes cannot bend as this may compromise the wiring within and cause the payload to fail.	Inspection	Partial Verification: Marks will be made by the Structures Lead during manufacturing that indicate where the centering rings must align for the subscale launch vehicle. The same procedure will be performed for the full scale launch vehicle.

Table 51: Team Derived Vehicle Requirements

6.4.2.2 Recovery Requirements

The team-derived requirements for recovery are defined (Table 52).

Requirement	Justification	Method of Verification	Status
2.1 The drogue parachute will have a descent rate of 82.5 ft/s.	This descent rate ensures the vehicle is at a slow enough velocity once the main parachute must be deployed.	Testing	Unverified: Test #6, Parachute Drag Analysis, will ensure the drag induced by the parachute is sufficient.
2.2 The main parachute will have a descent rate of 17.6 ft/s.	This descent rate ensures the launch vehicle will not be harmed during landing by landing at an appropriate velocity.	Testing	Unverified: Test #6, Parachute Drag Analysis, will ensure the drag induced by the

			parachute is sufficient.
2.3 Each recovery harness will have a length of 2.5 times the total length of the vehicle.	This length is required to ensure the separate sections of the launch vehicle do not collide during descent. This length also prevents breakage of the recovery harness during separation, as a longer harness provides more slack.	Inspection	Verified: Visual inspection of the length of the recovery harness will be performed by the Avionics and Recovery Lead and the Project Manager.
2.4 There will be a delay of the secondary aft ejection charge of 0.5 seconds after the ejection of the primary charge.	The delay ensures that the launch vehicle does not over-pressurize, a possible occurrence during ejection that may occur if multiple charges ignite at once.	Testing	Verified: Test #8, Barometer Functionality Test, ensures that the barometer functions correctly, and thus ignites the ejection charge at the appropriate time.
2.5 There will be a delay of the secondary forward ejection charge to eject at an altitude of 50 ft below the altitude of primary charge, thus ejecting at an altitude of about 550 ft.	The delay ensures that the launch vehicle does not over-pressurize, a possible occurrence during ejection that may occur if multiple charges ignite at once.	Testing	Verified: Test #8, Barometer Functionality Test, ensures that the barometer functions correctly, and thus ignites the ejection charge at the appropriate time.
2.6 The secondary ejection charges will be 25% larger in black powder or Pyrodex weight than the primary charges.	The secondary charge must be larger than the primary in the event that the primary fails to separate the vehicle and thus the larger secondary charge can provide a greater force and result in successful separation.	Inspection	Partial Verification: The weight of the Pyrodex was verified by the Avionics and Recovery Lead and the Project Manager prior to the subscale demonstration flight.

Table 52: Team Derived Recovery Requirements

6.4.2.3 Payload Requirements

The team-derived requirements for the payload are defined (Table 53).

Requirement	Justification	Method of Verification	Status
3.1 The payload will be able to resume operation after a momentary power loss.	The payload must be able to continue operation without losing previously captured images or data.	Demonstration	Unverified: Test #33, Power Loss Test, ensures that the payload will continue operation correctly in a circumstance of loss of power.
3.2 The payload IMU expected positional drift must not exceed 100 ft over 90 sec.	The payload must be able detect the correct grid space the launch vehicle is located in.	Analysis	Unverified: Test #49, IMU Drift Analysis, determines the expected drift and ensures it does not exceed 100 ft.
3.3 The payload must be able to detect launch.	Launch detection allows the payload to idle in a low-power state while on the launch pad, preserving battery life, but will begin collecting data once launch is detected.	Demonstration	Unverified: Test #46, Payload Launch Detection Demonstration, ensures that the payload can detect the sudden acceleration that will occur during launch.
3.4 The payload transmitter must have a range of at least one mile.	The payload must be able to communicate its results successfully even in the event of maximum drift as well as possible obstructions.	Testing	Unverified: Test #48, Payload Transmission Range Test, ensures that the payload can transmit data over at least one mile.
3.5 The payload must be able to process at least 100 images within five minutes of landing.	The payload must be able to compile the data within five minutes in order to determine its grid location before the battery runs out of charge.	Testing	Unverified: Test #47, Payload Data Compilation Test, ensures that the data can be compiled in the appropriate amount of time.

Table 53: Team Derived Payload Requirements

6.5 Budgeting and Timeline

6.5.1 Funding

6.5.1.1 Funding Plan

This project will be primarily funded by the University of Florida's Student Government during the Fall 2021 semester. The team will also be seeking funding from the University of Florida's Mechanical and Aerospace Engineering Department. The request approval will determine how much funding is allotted to travel and the full-scale rocket build in the Spring 2021 semester. The team sponsor is Aerojet Rocketdyne. The team is actively seeking more corporate sponsorships by having weekly meetings specifically dedicated to reaching out to potential sponsors. The sponsorships range from $250 to $1,000, with additional donations made optional. Funding will first be received by our advisors, Dr. Lind and Dr. Niemi, and will then be allocated to our group. The team has also started an alumni program to stay in touch with dedicated members who have graduated, encouraging them to stay involved and support the future

6.5.1.2 Funding Contingency Plan

Since the team's funding comes primarily out of the University's Student Government, unforeseen budget cuts should be accounted for by a mitigation plan. Although the team was allotted funding with margins for additional purchases in the Fall 2021 term, a contingency plan is important since the campus has returned to in-person activity, and it is suspected that the University has had to make budget cuts as well. Team component purchases have been made in bulk using the Fall 2021 term funding. The purchase included the components needed for the current project, as well as components to increase stock of components to account for required activities. If the team's funding is reduced below what the design has accounted for, the team will adjust their designs as necessary.

6.5.2 Funding

The team's expected budget for the 2021-2022 season is $5,600.00 (Figure 88), (Table 54). This budget is based off a total of all estimated component and travel costs, including components needed for the full-scale rocket design and the subscale rocket build. It also accounts for changes that may occur from any necessary changes and testing or unexpected damages. The components are broken down by rocket subgroup (Table 55) and listed out (Table 56, Table 57, Table 58, Table 59, Table 60). Travel costs are also included in the budget accounting for road travel and hotel stays for the competition and launches.

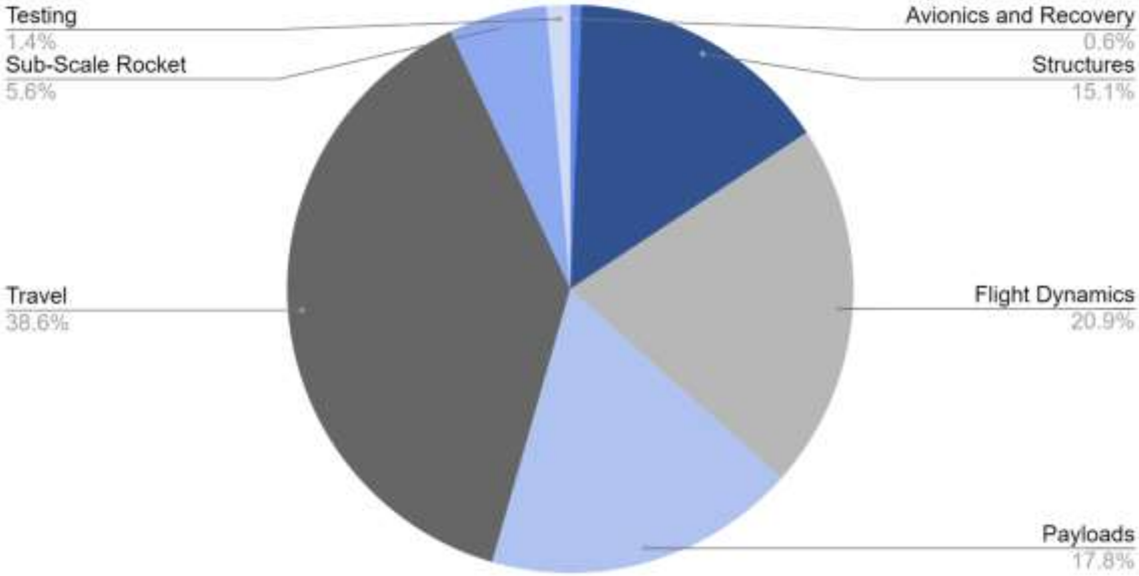


Figure 88: Budget Pie Chart

Category	Total Cost ($)
Full-Scale Rocket	3200.56
Travel	2000.00
Subscale	291.23
Testing	70.00
Total:	5561.79

Table 54: Project Costs by Category

Subgroup	Total Cost ($)
Structures	782.31
Avionics and Recovery	33.13
Flight Dynamics	1082.34
Payloads	900.08
Total:	3200.56

Table 55: Full Scale Rocket Costs by Subteam

Component	Quantity	Unit Cost ($)	Total Cost ($)
4" 5:1 fiberglass Ogive nosecone w/ metal tip	1	79.95	79.95

4" diameter fiberglass airframe (5 ft)	2	116.75	233.50
2.1" fiberglass motor tube (3 ft)	1	43.20	43.20
3/16" thick, 24" x 24" G10 fiberglass sheets (fins)	2	51.30	102.60
1/2" thick, 24" x 24" plywood (bulkheads, centering rings)	2	17.60	35.20
Jewel (10 oz)	4	14.27	57.08
RocketPoxy (2 qt)	2	85.31	170.62
Shear Pins	4	3.52	14.08
Rivets	4	7.41	29.64
Rail buttons	2	8.22	16.44
Sandpaper	N/A	N/A	Inventory
Total:			782.31

Table 56: Structure's Costs by Component

Category	**Quantity**	**Unit Cost ($)**	**Total Cost ($)**
9 V Battery	2	8.00	16.00
Eyebolt	4	4.28	17.12
Main Parachute	1	N/A	Inventory
Drogue Parachute	1	N/A	Inventory
Recovery Harness	2	N/A	Inventory
Swivel	2	N/A	Inventory
Quick Link	6	N/A	Inventory
Altimeter	2	N/A	Inventory
Terminal block	4	N/A	Inventory
Key lock switch	2	N/A	Inventory
Total:			33.13

Table 57: Avionics and Recovery's Costs by Component

Category	**Quantity**	**Unit Cost ($)**	**Total Cost ($)**
Motor Retainer	1	46.66	46.66

Motor Forward Closure	1	77.52	77.52
Motor Aft Closure	1	56.18	56.18
Motor Casing	1	203.92	203.92
Thrust Plate	1	44.87	44.87
Aerotech L1090W	3	230.99	692.97
Total:			1122.12

Table 58: Flight Dynamics' Costs by Component

Category	Quantity	Unit Cost ($)	Total Cost ($)
Raspberry Pi 4 8GB	1	149.99	149.99
OV5640 Camera	3	39.99	119.97
XBee Transceiver	2	54.08	108.16
Lithium-Ion Batteries	4	14.50	58.00
IMU	4	328.9	328.9
Altimeter	1	21.90	21.90
Printed Circuit Board	5	12.00	60.00
Wiring	1	5.99	5.99
JST Connector Kit	1	23.99	23.99
1/4-20 Well Nuts	4	6.00	24.00
1/4-20 Fasteners	8	N/A	Inventory
1/4-20 Hex nuts	4	N/A	Inventory
Total:			900.08

Table 59: Payload's Costs by Component

Category	Quantity	Unit Cost ($)	Total Cost (includes shipping) ($)
3" diameter fiberglass nosecone	1	59.95	59.95
3" diameter fiberglass airframe	2	102.55	205.10
1.5" diameter motor tube (2 ft)	1	26.18	26.18
Total:			291.23

Table 60: Subscale Structural Costs

6.5.3 Timeline and Schedules

6.5.3.1 Milestone Schedule

A schedule containing all deliverables and requirements was developed for the team to follow throughout the entire competition season (Figure 89). Progress was tracked using that schedule and presented in a tabular format (Table 61).

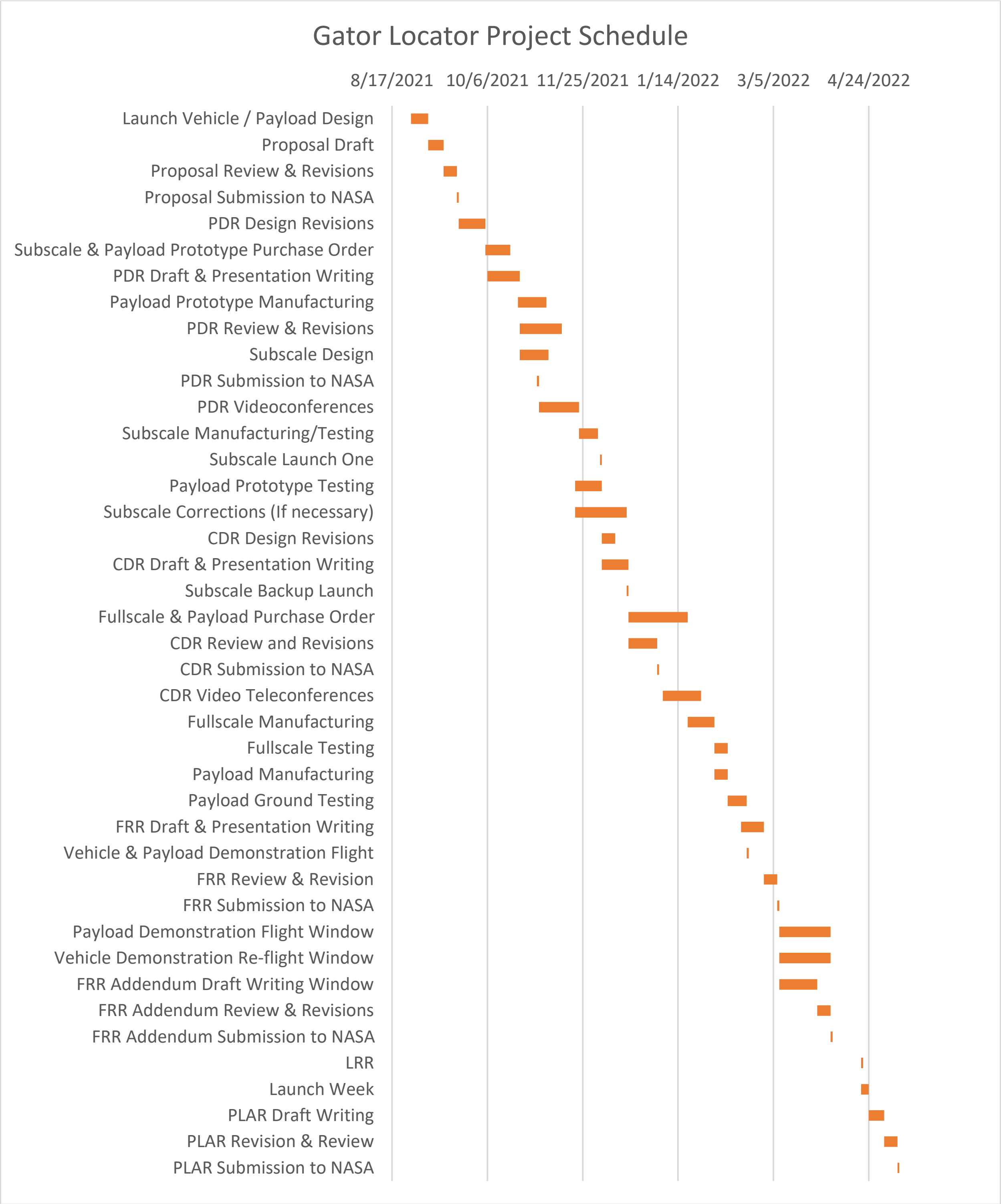


Figure 89: Full Schedule

Task	Start Date	End Date	Duration	Status
Launch Vehicle / Payload Design	8/27/2021	9/5/2021	9	Complete
Proposal Draft	9/5/2021	9/13/2021	8	Complete
Proposal Review & Revisions	9/13/2021	9/20/2021	7	Complete
Proposal Submission to NASA	9/20/2021	9/21/2021	1	Complete
PDR Design Revisions	9/21/2021	10/5/2021	14	Complete
Subscale & Payload Prototype Purchase Order	10/5/2021	10/18/2021	13	Complete
PDR Draft & Presentation Writing	10/6/2021	10/23/2021	17	Complete
Payload Prototype Manufacturing	10/22/2021	11/6/2021	15	Complete
PDR Review & Revisions	10/23/2021	11/14/2021	22	Complete
Subscale Design	10/23/2021	11/7/2021	15	Complete
PDR Submission to NASA	11/1/2021	11/2/2021	1	Complete
PDR Videoconferences	11/2/2021	11/23/2021	21	Complete
Subscale Manufacturing/Testing	11/23/2021	12/3/2021	10	Complete
Subscale Launch One	12/4/2021	12/5/2021	1	Complete
Payload Prototype Testing	11/21/2021	12/5/2021	14	Complete
Subscale Corrections (If necessary)	11/21/2021	12/18/2021	27	Not Required
CDR Design Revisions	12/5/2021	12/12/2021	7	Complete
CDR Draft & Presentation Writing	12/5/2021	12/19/2021	14	Complete
Subscale Backup Launch	12/18/2021	12/19/2021	1	Not Required
Full scale & Payload Purchase Order	12/19/2021	1/19/2022	31	Pending
CDR Review and Revisions	12/19/2021	1/3/2022	15	Complete
CDR Submission to NASA	1/3/2022	1/4/2022	1	Complete
CDR Video Teleconferences	1/6/2022	1/26/2022	20	Pending
Full scale Manufacturing	1/19/2022	2/2/2022	14	Incomplete
Full scale Testing	2/2/2022	2/9/2022	7	Incomplete
Payload Manufacturing	2/2/2022	2/9/2022	7	Incomplete

Payload Ground Testing	2/9/2022	2/19/2022	10	Incomplete
FRR Draft & Presentation Writing	2/16/2022	2/28/2022	12	Incomplete
Vehicle & Payload Demonstration Flight	2/19/2022	2/20/2022	1	Incomplete
FRR Review & Revision	2/28/2022	3/7/2022	7	Incomplete
FRR Submission to NASA	3/7/2022	3/8/2022	1	Incomplete
Payload Demonstration Flight Window	3/8/2022	4/4/2022	27	Incomplete
Vehicle Demonstration Re-flight Window	3/8/2022	4/4/2022	27	Incomplete
FRR Addendum Draft Writing Window	3/8/2022	3/28/2022	20	Incomplete
FRR Addendum Review & Revisions	3/28/2022	4/4/2022	7	Incomplete
FRR Addendum Submission to NASA	4/4/2022	4/5/2022	1	Incomplete
LRR	4/20/2022	4/21/2022	1	Incomplete
Launch Week	4/20/2022	4/24/2022	4	Incomplete
PLAR Draft Writing	4/24/2022	5/2/2022	8	Incomplete
PLAR Revision & Review	5/2/2022	5/9/2022	7	Incomplete
PLAR Submission to NASA	5/9/2022	5/10/2022	1	Incomplete

Table 61: Milestone Status

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6.5.3.2 Flight Dynamics and Simulation Schedule

A schedule was developed for the flight dynamics subteam (Figure 90). Progress was documented in tabular format (Table 62).

Figure 90: Flight Dynamics Subteam Schedule

Task	Start Date	End Date	Duration	Status
Proposed Full Scale Launch Vehicle OpenRocket Design	8/27/2021	9/5/2021	9	Complete
Proposal Draft and Initial Simulations	9/5/2021	9/13/2021	8	Complete
Proposal Review & Revisions	9/13/2021	9/20/2021	7	Complete
Motor Selection and Simulations	9/21/2021	10/5/2021	14	Complete
Subscale Purchase Order	10/5/2021	10/18/2021	13	Complete
Determine Target Altitude	10/6/2021	10/23/2021	17	Complete
PDR Draft and Presentation Writing	10/23/2021	10/30/2021	7	Complete
PDR Review and Revision	10/23/2021	11/14/2021	22	Complete
Subscale Launch Vehicle OpenRocket Design	10/23/2021	11/23/2021	31	Complete
Support Manufacturing and Make Corrections	11/23/2021	12/3/2021	10	Complete
Subscale Launch One	12/4/2021	12/5/2021	1	Complete
Contingency Period (if necessary)	12/4/2021	12/18/2021	14	Not Required
CDR Draft and Presentation Writing	12/5/2021	12/19/2021	14	Complete
Full Scale Purchase Order	12/19/2021	1/19/2022	31	Pending
CDR Review and Revision	12/19/2021	1/3/2022	15	Complete
Support Full Scale Manufacturing and Testing	1/19/2022	2/19/2022	31	Incomplete
FRR Draft and Presentation Writing	2/16/2022	2/28/2022	12	Incomplete
Vehicle and Payload Demonstration Flight	2/19/2022	2/20/2022	1	Incomplete
FRR Review and Revision	2/28/2022	3/7/2022	7	Incomplete
Support Addendum Period (If Necessary)	3/8/2022	4/5/2022	28	Incomplete
LRR	4/20/2022	4/21/2022	1	Incomplete

Launch Week	4/20/2022	4/24/2022	4	Incomplete
PLAR Draft Writing	4/24/2022	5/2/2022	8	Incomplete
PLAR Revision & Review	5/2/2022	5/9/2022	7	Incomplete

Table 62: Flight Dynamics Milestone Status

6.5.3.3 Structures and Manufacturing Schedule

A schedule was developed for the structures and manufacturing subteam (Figure 91). Progress was documented in tabular format (Table 63).

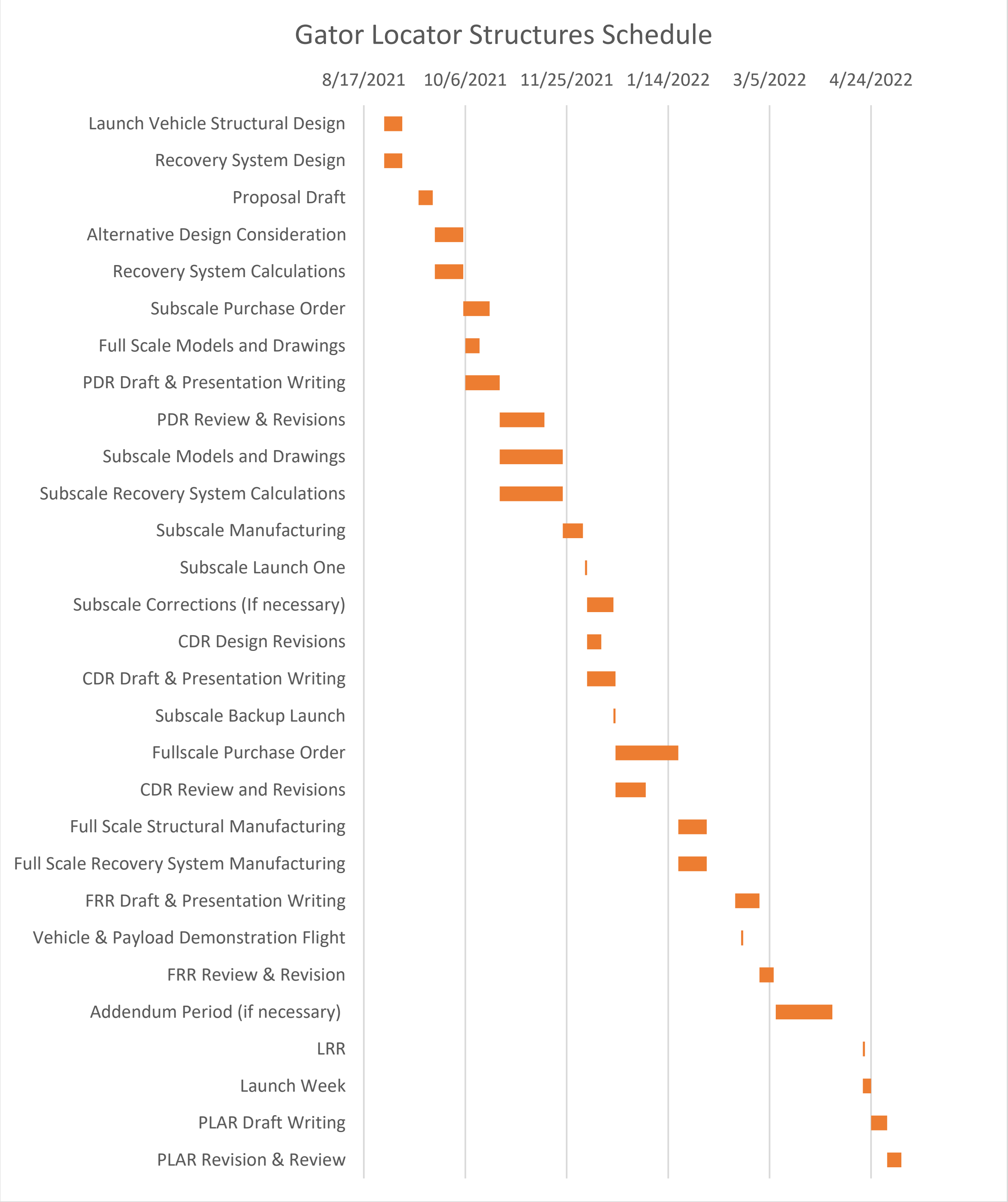

Figure 91: Structures and Manufacturing Schedule

Task	Start Date	End Date	Duration	Status
Launch Vehicle Structural Design	8/27/2021	9/5/2021	9	Complete
Recovery System Design	8/27/2021	9/5/2021	9	Complete
Proposal Draft	9/13/2021	9/20/2021	7	Complete
Alternative Design Consideration	9/21/2021	10/5/2021	14	Complete
Recovery System Calculations	9/21/2021	10/5/2021	14	Complete
Subscale Purchase Order	10/5/2021	10/18/2021	13	Complete
Full Scale Models and Drawings	10/6/2021	10/13/2021	7	Complete
PDR Draft & Presentation Writing	10/6/2021	10/23/2021	17	Complete
PDR Review & Revisions	10/23/2021	11/14/2021	22	Complete
Subscale Models and Drawings	10/23/2021	11/23/2021	31	Complete
Subscale Recovery System Calculations	10/23/2021	11/23/2021	31	Complete
Subscale Manufacturing	11/23/2021	12/3/2021	10	Complete
Subscale Launch One	12/4/2021	12/5/2021	1	Complete
Subscale Corrections (If necessary)	12/5/2021	12/18/2021	13	Complete
CDR Design Revisions	12/5/2021	12/12/2021	7	Complete
CDR Draft & Presentation Writing	12/5/2021	12/19/2021	14	Complete
Subscale Backup Launch	12/18/2021	12/19/2021	1	Not Required
Full scale Purchase Order	12/19/2021	1/19/2022	31	Pending
CDR Review and Revisions	12/19/2021	1/3/2022	15	Complete
Full Scale Structural Manufacturing	1/19/2022	2/2/2022	14	Incomplete
Full Scale Recovery System Manufacturing	1/19/2022	2/2/2022	14	Incomplete
FRR Draft & Presentation Writing	2/16/2022	2/28/2022	12	Incomplete
Vehicle & Payload Demonstration Flight	2/19/2022	2/20/2022	1	Incomplete
FRR Review & Revision	2/28/2022	3/7/2022	7	Incomplete
Addendum Period (if necessary)	3/8/2022	4/5/2022	28	Incomplete

LRR	4/20/2022	4/21/2022	1	Incomplete
Launch Week	4/20/2022	4/24/2022	4	Incomplete
PLAR Draft Writing	4/24/2022	5/2/2022	8	Incomplete
PLAR Revision & Review	5/2/2022	5/9/2022	7	Incomplete

Table 63: Structures and Manufacturing Milestone Status

6.5.3.4 Payload Development and Manufacturing Schedule

A schedule was developed for the Payloads subteams (Figure 92). Progress was documented in tabular format (Table 64).

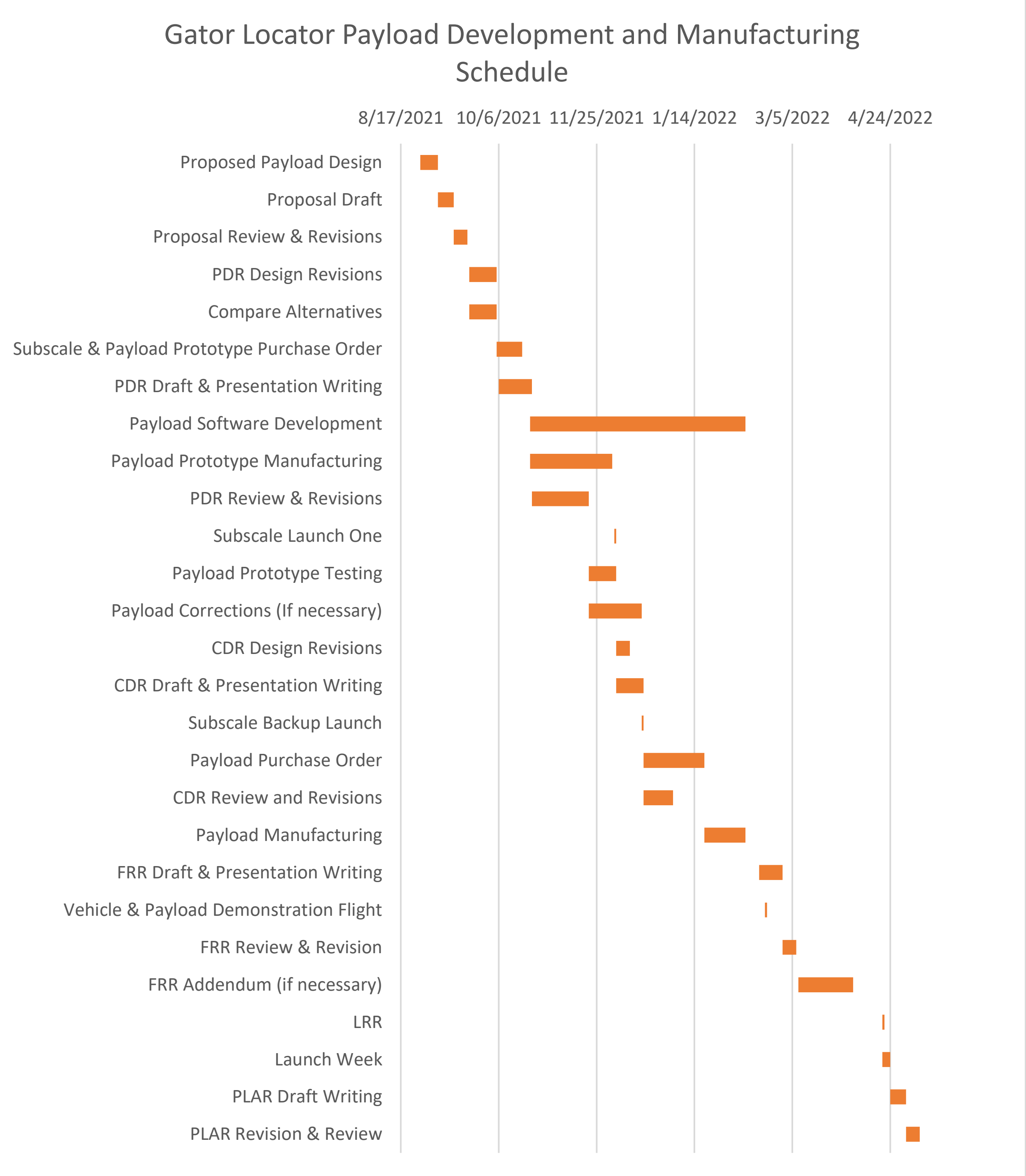

Figure 92: Payloads Schedule

Task	Start Date	End Date	Duration	Status
Proposed Payload Design	8/27/2021	9/5/2021	9	Complete
Proposal Draft	9/5/2021	9/13/2021	8	Complete
Proposal Review & Revisions	9/13/2021	9/20/2021	7	Complete
PDR Design Revisions	9/21/2021	10/5/2021	14	Complete
Compare Alternatives	9/21/2021	10/5/2021	14	Complete
Subscale & Payload Prototype Purchase Order	10/5/2021	10/18/2021	13	Complete
PDR Draft & Presentation Writing	10/6/2021	10/23/2021	17	Complete
Payload Software Development	10/22/2021	2/9/2022	110	Pending
Payload Prototype Manufacturing	10/22/2021	12/3/2021	42	Complete
PDR Review & Revisions	10/23/2021	11/21/2021	29	Complete
Subscale Launch One	12/4/2021	12/5/2021	1	Complete
Payload Prototype Testing	11/21/2021	12/5/2021	14	Complete
Payload Corrections (If necessary)	11/21/2021	12/18/2021	27	Not Required
CDR Design Revisions	12/5/2021	12/12/2021	7	Complete
CDR Draft & Presentation Writing	12/5/2021	12/19/2021	14	Complete
Subscale Backup Launch	12/18/2021	12/19/2021	1	Not Required
Payload Purchase Order	12/19/2021	1/19/2022	31	Pending
CDR Review and Revisions	12/19/2021	1/3/2022	15	Complete
Payload Manufacturing	1/19/2022	2/9/2022	21	Incomplete
FRR Draft & Presentation Writing	2/16/2022	2/28/2022	12	Incomplete
Vehicle & Payload Demonstration Flight	2/19/2022	2/20/2022	1	Incomplete
FRR Review & Revision	2/28/2022	3/7/2022	7	Incomplete
FRR Addendum (if necessary)	3/8/2022	4/5/2022	28	Incomplete
LRR	4/20/2022	4/21/2022	1	Incomplete

Launch Week	4/20/2022	4/24/2022	4	Incomplete
PLAR Draft Writing	4/24/2022	5/2/2022	8	Incomplete
PLAR Revision & Review	5/2/2022	5/9/2022	7	Incomplete

Table 64: Payloads Milestone Status

6.5.3.5 Testing Schedule

A schedule was developed for the testing subteam (Figure 93). Progress was documented in tabular format (Table 65).

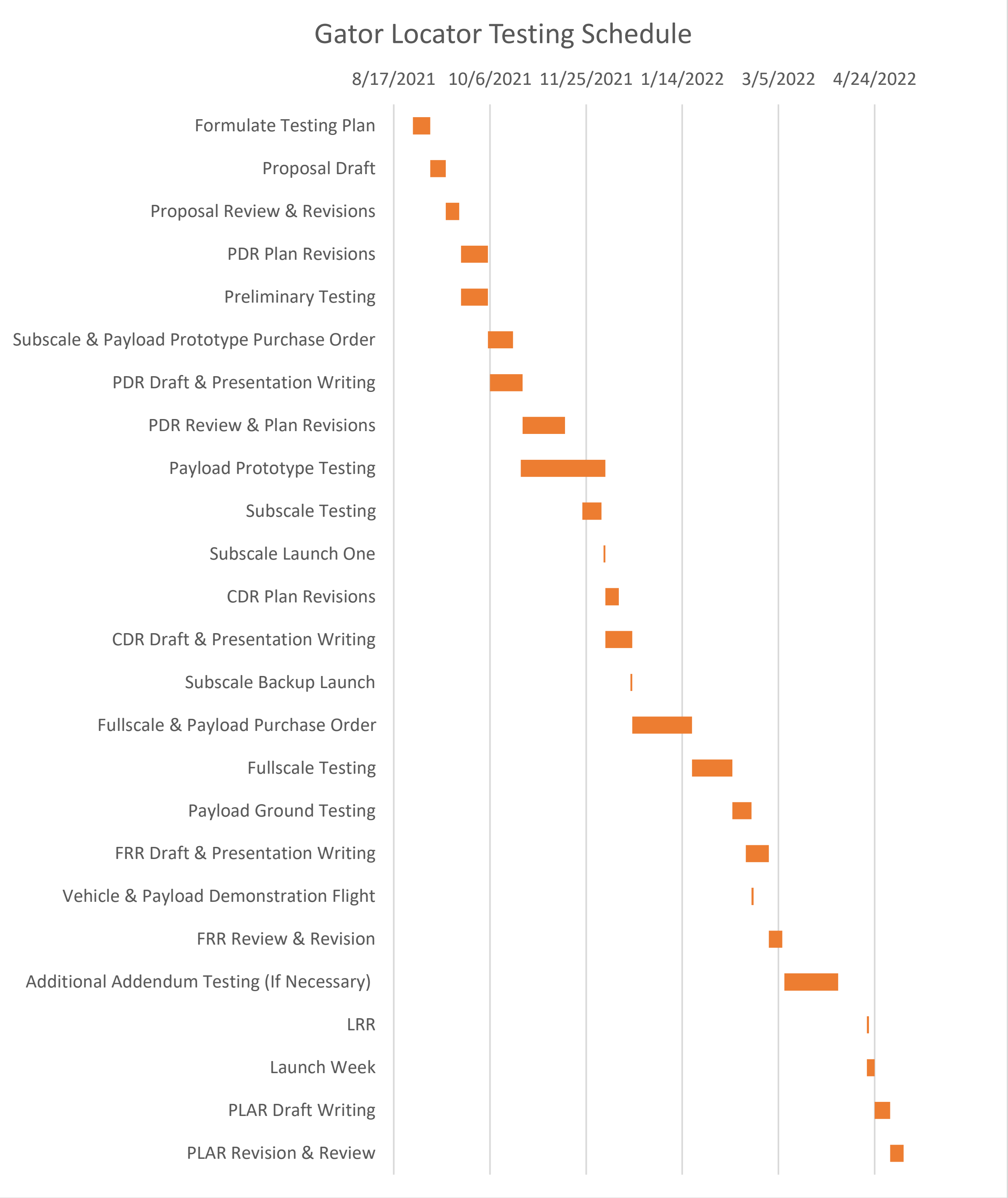

Figure 93: Testing Schedule

Task	Start Date	End Date	Duration	Status
Formulate Testing Plan	8/27/2021	9/5/2021	9	Complete
Proposal Draft	9/5/2021	9/13/2021	8	Complete
Proposal Review & Revisions	9/13/2021	9/20/2021	7	Complete
PDR Plan Revisions	9/21/2021	10/5/2021	14	Complete
Preliminary Testing	9/21/2021	10/5/2021	14	Complete
Subscale & Payload Prototype Purchase Order	10/5/2021	10/18/2021	13	Complete
PDR Draft & Presentation Writing	10/6/2021	10/23/2021	17	Complete
PDR Review & Plan Revisions	10/23/2021	11/14/2021	22	Complete
Payload Prototype Testing	10/22/2021	12/5/2021	44	Complete
Subscale Testing	11/23/2021	12/3/2021	10	Complete
Subscale Launch One	12/4/2021	12/5/2021	1	Complete
CDR Plan Revisions	12/5/2021	12/12/2021	7	Complete
CDR Draft & Presentation Writing	12/5/2021	12/19/2021	14	Complete
Subscale Backup Launch	12/18/2021	12/19/2021	1	Not Required
Full scale & Payload Purchase Order	12/19/2021	1/19/2022	31	Pending
Full scale Testing	1/19/2022	2/9/2022	21	Incomplete
Payload Ground Testing	2/9/2022	2/19/2022	10	Incomplete
FRR Draft & Presentation Writing	2/16/2022	2/28/2022	12	Incomplete
Vehicle & Payload Demonstration Flight	2/19/2022	2/20/2022	1	Incomplete
FRR Review & Revision	2/28/2022	3/7/2022	7	Incomplete
Additional Addendum Testing (If Necessary)	3/8/2022	4/5/2022	28	Incomplete
LRR	4/20/2022	4/21/2022	1	Incomplete
Launch Week	4/20/2022	4/24/2022	4	Incomplete
PLAR Draft Writing	4/24/2022	5/2/2022	8	Incomplete
PLAR Revision & Review	5/2/2022	5/9/2022	7	Incomplete

Table 65: Testing Milestone Status

7. Launch Week Preparation

7.1 Team Members Attending Launch Week

Per Requirement 1.4, a preliminary list of those attending Launch week was accumulated in preparation for the upcoming competition currently planned to take place in Huntsville, AL on April 20-24, 2022 (Table 66).

Leadership:	Project Manager	Megan Wnek
	President	Joel Perez
	External Vice President	Mikaela De Gracia
	L2 certified member	Bilal Hassan
	Safety Officer	Raymond Pace
	Safety Officer	Jason Rosenblum
Mentor:		Jimmy Yawn
Structures subteam:	Lead	Erik Dearmin
	Team member	Maggie Wielatz
Avionics and Recovery subteam:	Lead	Collin Larke
Payloads Mechanical Subteam	Lead	Joseph Pinkston
Payloads Electrical Subteam	Lead	Dylan Ogrodowski
	Team member	London Torres
Payloads Software Subteam	Lead	Abishanka Saha
Flight Dynamics Subteam	Lead	Krusha Patel
Testing Subteam	Lead	Brida Gibbons
Educational Engagement	Lead	Gabriella Peburn

Table 66: Preliminary Launch Week Roster