NC STATE UNIVERSITY

Tacho Lycos
2019 NASA Student Launch
Flight Readiness Review Report

High-Powered Rocketry Club at NC State University
911 Oval Drive
Raleigh, NC 27695

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Common Abbreviations & Nomenclature

AGL	=	above ground level
APCP	=	ammonium perchlorate composite propellant
ARRD	=	advanced retention and release device
AV	=	avionics
BP	=	black powder
CDR	=	Critical Design Review
CG	=	center of gravity
CP	=	center of pressure
EIT	=	electronics and information technology
FAA	=	Federal Aviation Administration
FMECA	=	failure mode, effects, and criticality analysis
FN	=	foreign national
FRR	=	Flight Readiness Review
GPS	=	Global Positioning System
HEO	=	Human Exploration and Operations
HPR	=	High Power Rocketry
HPRC	=	High-Powered Rocketry Club
L3CC	=	Level 3 Certification Committee (NAR)
LCO	=	Launch Control Officer
LRR	=	Launch Readiness Review
MAE	=	Mechanical & Aerospace Engineering Department
MSDS	=	Material Safety Data Sheet
MSFC	=	Marshall Space Flight Center
NAR	=	National Association of Rocketry
NCSU	=	North Carolina State University
NFPA	=	National Fire Protection Association
PDR	=	Preliminary Design Review
PLAR	=	Post-Launch Assessment Review
PPE	=	personal protective equipment
RF	=	Radio Frequency
RFP	=	Request for Proposal
RSO	=	Range Safety Officer
SL	=	Student Launch
SLS	=	Space Launch System
SME	=	subject matter expert
SNB	=	Simulated Navigational Beacon
SOW	=	statement of work
STEM	=	Science, Technology, Engineering, and Mathematics
TAP	=	Technical Advisory Panel (TRA)
TRA	=	Tripoli Rocketry Association
UART	=	Universal Asynchronous Receiver/Transmitter
VTX	=	Video Transmitter

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1.1 Team Summary

1.1.1 Team Name and Mailing Address

Team Name: High-Powered Rocketry Club at NC State
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1.1.2 Mentor Information

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1.2 Launch Vehicle Summary

1.2.1 Size and Mass

The launch vehicle as built is 98 inches long with a diameter of 5.5 inches. The takeoff weight of the launch vehicle is 39.2 pounds.

1.2.2 Final motor choice.

The launch vehicle shall utilize an Aerotech L1150R motor.

1.2.3 Official Target Altitude

The team is declaring a target altitude of 4090 feet.

1.2.4 Recovery System

The team shall utilize an 18-inch drogue parachute that deploys at apogee and a 108-inch main parachute that deploys at 500 feet which are both controlled by a redundant altimeter system.

1.2.5 Rail Size

The launch vehicle shall launch from a 12 foot long 1515 rail.

1.2.6 Milestone Review Flysheet

This document has been submitted separately.

1.3 Payload Experiment Summary – "The Eagle and the Egg"

The team aims for the payload to successfully eject from the launch vehicle, arm the motors, and safely fly to and deliver the simulated navigational beacon. To accomplish the mission, the team will utilize a payload pod, designated the "Egg," which will house the UAV, the "Eagle," while the launch vehicle is in flight. The purpose of the Egg is to protect the UAV, provide the UAV a means to self-right, and to act as a place to take off from once the launch vehicle has landed. A receiver will be placed forward of the payload bay on a removable bulkhead that will receive a signal from the hand-held radio transmitter. This receiver will activate a preprogrammed controller that will control all the electronics involved in deploying the payload.

2. Changes Made Since CDR

2.1 Changes Made to Vehicle Criteria

Change	Reason for Change
Fin tab shape and dimensions were adjusted.	The slots cut in the fin can to locate the fins were not placed as expected causing interference between the fin tabs and the motor block. See Section 3.1.1.1 for more details.
Nose cone ballast was included.	Upon arrival, each of the airframe components, particularly the nose cone, were lighter than expected. Nose cone ballast was needed to achieve an acceptable stability margin. See Section 3.1.4.6 for more details.
Six shear pins will be used to connect the payload bay to the main parachute bay.	During the attempted launch on February 9, the main parachute was deployed prematurely and is believed to be a result of insufficient shear pin strength. See Section 3.1.1.3 for more details.

2.2 Changes Made to Payload Criteria

Change	Reason for Change
Lead Screw pitch change and addition of gears	Gears were added to the stepper motor system to increase the torque.
Pod Flap Shape Change	The pod flaps are now open at the top to allow the UAV space to takeoff in more situations.
Vertical pins added to payload pod	The pins will allow the drone to take off smoothly and in a vertical direction and keep the drone from sliding during flight.
Electrical Relay added to latch circuit	An electrical relay was added to amplify the voltage going to the retention latch.
Quick Disconnects changed to more effective model	New quick disconnects were purchased because others kept breaking.
AA Battery packs have been moved	The AA Battery packs have been moved to the inside of the Nosecone.
Addition of Electronics Cover	A cover has been added to protect the Arduino and wiring from in-flight forces.
Addition of latch terminal block	A terminal block has been added for easy access to the payload latch system.
Increased motor speed	The speed of the motor has been increased to deploy the pod faster.
Battery protection sled streamlined	The battery protection sleds were streamlined along the longest axis of the pod.
Folding arm hinge slot increased	The hinge slots on the arm of the drone increased in angle by three (3) degrees to fold the arms in further.
Hinge slot radius increased	The hinge slot radius was increased to reduce friction between the metal rod and the hinge.

Electronic Switch added for Solenoid	The electronic switch was added to have a mechanism to activate the solenoid when necessary.
VTX changed to lower power output	A different VTX is being implemented that will operate at a lower power output.

2.3 Changes Made to Project Plan

Change	Reason for Change
Addition of Shear Pin Failure Test	The recovery failure during the vehicle demonstration flight caused the team to re-evaluate the shear strength of the #4-40 nylon shear pins used at separation points. This test was executed to allow the team to choose a more accurate number of shear pins at the main separation point.
Changed TDR 6.24 and the Adverse Conditions UAV Flight Test	The team found that the UAV was capable of flying for over 20 minutes at a time and found requirement 6.24 which called for over 1.5 miles of flight distance to be excessive. This number was reduced to 0.5 miles.
All test results added	All results of tests have been added to Section 6.1
Budget updated to reflect Spring Student Government Appropriations	Prior to mid-February the team did not know how much funding would be given by Student Government at NC State. Funds have now been allocated and the current document reflects this.
Re-Formatting of Requirement Verification Matrices	These tables were re-formatted to better reflect the verification process.

3. Vehicle Criteria

3.1 Design and Construction of Vehicle

3.1.1 Changes to Launch Vehicle

3.1.1.1 Fin Tabs

The original design of the launch vehicle included a 6inch long fin tab which would be attached to the interior of the launch vehicle. Due to errors in the fin slot locations as discussed in Section 3.1.4.7, the fin tab sizes had to be adjusted. First, the total length of the fin slots are 6.125 inches rather than 6 inches. In addition, the motor block now interferes with part of the fin slots and therefore the fin tab had to be reduced. Part of the fin tab is still present to fill the space of the fin slot but does not enter the interior of the fin can to attach to the motor tube. The final dimensions of the fins, including the modified fin tabs, are shown in Figure 3-1.

3.1.1.2 Nose Cone Ballast

In the CDR it was reported that no nose ballast would be utilized. However, upon material arrival, it was discovered that all body tubes and the nose cone were lighter than anticipated. Because of this, ballast was necessary in the tip of the nose cone to maintain an acceptable stability margin. For more details on the added ballast, see Section 3.1.4.6.

3.1.1.3 Shear Pin Increase

It was initially believed that the #4-40 shear pins used had a shear strength of approximately 70 lb. However, during flight on February 9th, the main parachute deployed around the same time that the drogue parachute was deployed and prior to main ejection charges being ignited. The cause of this is believed to be insufficient strength of the shear pins. Based on testing discussed in Section 6.1.2, the shear pins being used have a shear strength of between 35 to 40 lb. Because of this, it has been determined that six shear pins will be used.

3.1.2 Launch and Recovery Features

3.1.2.1 Structural Elements

3.1.2.1(a) Airframe

The launch vehicle airframe is constructed entirely of fiberglass. Fiberglass is one of the strongest commercially available rocket body materials and is also resistant to water damage which will make the rocket as durable as possible. This will enable the launch vehicle to be launched multiple times with no damage as required in requirement 2.7 of the Student Launch Handbook. For more details on the strength of the airframe, see Section 3.3.1.1(a).

3.1.2.1(b) Fins

Each fin was constructed out of two layers of 1/8 inch thick birch plywood. The fin layers were epoxied using West Systems 2 part epoxy to the motor tube within the launch vehicle as well as at overlaps onto the exterior of the body tube. In addition, the fin tabs were epoxy filleted to the interior of the body tube and the exterior of the motor tube. Finally, the fins were epoxy filleted to the exterior of the body tube to create a smooth transition. For more details on the fin construction process, see Section 3.1.4.3 and Section 3.1.4.4.

The dimensions of the cross section of the fins are shown in Figure 3-1.

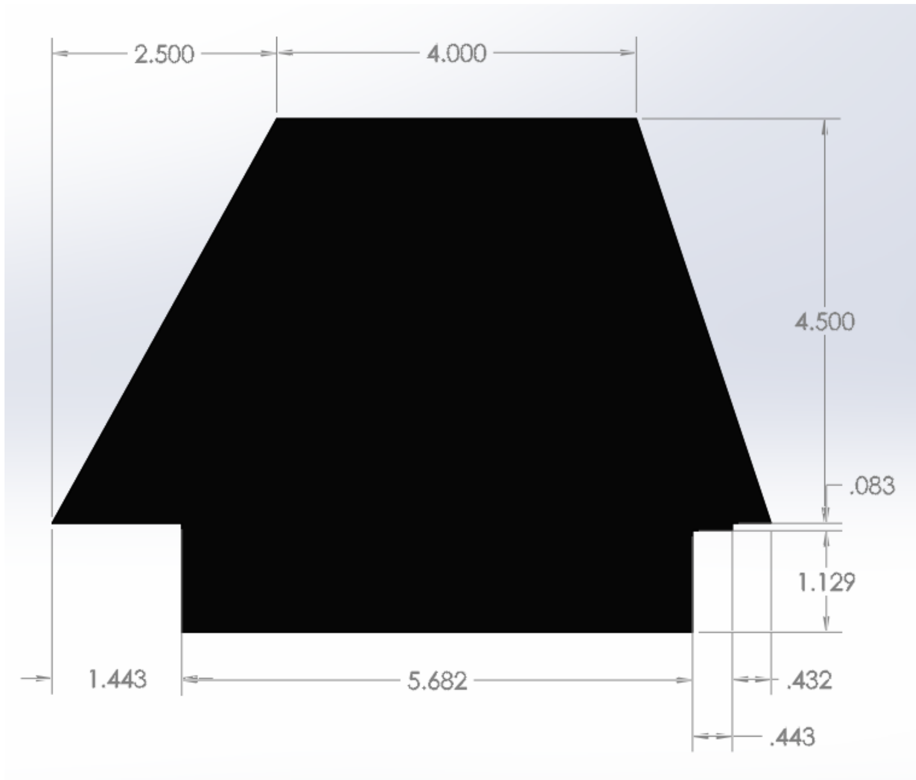


Figure 3-1 Fin Dimensions

3.1.2.1(c) Bulkheads

All bulkheads were laser cut from 1/8 inch thick birch plywood; the layers were then epoxied together using West Systems 2 part epoxy to form the full thickness of each bulkhead. For more details on the construction process of the bulkheads, see Section 3.1.4.3.

The nose cone bulkhead was fabricated out of 6 layers of 1/8 inch plywood for a total nominal thickness of ¾ inch. However, after fabrication, the bulkhead measured 0.72 inch thick, likely due to a slightly less than nominal thickness of the plywood. This bulkhead was fabricated with a diameter of 5.264 inches; this is the measured inner diameter of the nose cone shoulder and was selected so that the bulkhead would be able to fit and be installed but still maintain as much diameter and therefore strength as possible.

The outer edge of the nose cone bulkhead was tapered to match the curvature of the interior of the nose cone. For more details on this process, see Section

3.1.4.6. Holes were drilled in the bulkhead after fabrication for installation of the U-bolt which will ultimately be secured to the main parachute shock cord.

To seal the payload bay from black powder charges at parachute deployment, a plug is being utilized. This plug consists of two layers of bulkhead which are 5.383 inches in diameter and two layers which fill the shape of the end centering ring. This plug has a slot cut to allow the shock cord to pass through and also has a U-bolt attached to secure it after main parachute deployment. The plug is shown in Figure 3-2.

Figure 3-2 Payload Bay Plug

The plug has rubber bands secured around the insert portion to hold it in place during flight. It separates the main parachute bay from the payload bay and provides a seal so that proper pressurization for deployment is reached.

The AV Bay bulkheads were constructed by epoxying three layers of plywood of 5.838 inch diameter, which is the inner diameter of the body tubes, and three layers of 5.183 inch diameter, which is the inner diameter of the coupler, together for a total actual thickness of 0.72 inch. These bulkheads have two holes in each which allow threaded rods to run through the AV bay. These threaded rods support the AV sled as well as secure the bulkheads to the AV bay coupler. In addition, the bulkheads each have a U-bolt attached to connect to either the main parachute shock cord or drogue parachute shock cord. Finally, the bulkheads house the blast caps made of ¾ inch diameter PVC pipe caps which will hold black powder for ejection charges as well as terminal blocks to connect charges to the altimeters. The forward AV Bay bulkhead is shown in Figure 3-3.

Figure 3-3 AV Bay Bulkhead

The fin can bulkhead was constructed of five layers of 1/8 inch birch plywood with diameter of 5.383 inches with one additional layer with a 3.128 inch circular cutout. This cutout matches the outer diameter of the motor tube and acts to support the edge of the motor tube. This bulkhead has a U-bolt installed which is offset so as not to interfere with the motor tube and will be attached to the drogue parachute during flight.

The motor block was constructed of 8 layers of birch plywood epoxied together with West Systems 2 part epoxy for a total actual thickness of 0.96 inch. Each layer has an outer diameter of 5.383 inches with an inner diameter of 3.128 inches. The motor block is intended to withstand the loading from the thrust of the motor.

For details on the strengths of each structural bulkhead, see Section 3.3.1.1(b).

3.1.2.1(d) Attachment Hardware

Each bulkhead which is attached to a length of shock cord has a U-bolt installed to allow for the connection. The nose cone, AV bay, and fin can bulkheads each utilize a 5/16 inch thick U-bolt as these are the bulkheads which will experience the loading from parachute deployment. The payload bay plug also has a U-bolt to attach it to shock cord, however, this U-bolt is only ¼ inch in diameter as this U-bolt will not be experiencing any significant loading during flight. For details on the strength of the structural U-bolts, see Section 3.3.1.1(d).

To connect the shock cords to the U-bolts installed in the bulkheads, 5/16 inch thick quick links are used as shown in Figure 3-4.

Figure 3-4 Quick link

Though no material properties were found for the quick links, it is assumed that because they are the same thickness as the U-bolts, they will be able to withstand similar loading.

3.1.2.2 Electrical Elements

3.1.3 Flight Reliability Confidence

Based on the results of the tests and demonstrations described in Section 6.1 coupled with the results of the first vehicle demonstration flight described in Section 3.4, the team is confident that the launch vehicle will be capable of fulfilling all criteria for mission success as stated in Section 3.1.3.1.

3.1.3.1 Mission Success Criteria

Mission success is defined firstly as compliance with the requirements of the NASA Student Launch Competition as defined in Section 6.2.1 as well as the team derived requirements described in Section 6.2.2. The team has also defined a successful mission as one that achieves the target apogee of 4090 ft., safe landing with drogue parachute deploying at apogee and main parachute deploying at 600 ft AGL, deployment of UAV after landing, and placement of the beacon in the designated target area.

3.1.4 Construction Process

3.1.4.1 Material Inspections

Throughout the build process, a few issues arose with the materials received from vendors. First, upon inspecting the nose cone upon arrival, it was noticed that there were chips on the tip, as shown in Figure 3-5.

Figure 3-5 Chip in Nose Cone

Though this chip in the nose cone could cause unintended drag during flight, due to the team's accelerated build schedule, there was not sufficient time to source a new nose cone and wait for it to be shipped. For this reason, the team continued as planned with this nose cone.

After the attempted launch on February 9th, however, a repair was made to the nose cone to make it the proper shape. For more details on this repair, see Section 3.1.4.6.

In addition to the nose cone damage, upon inspecting the fin slots cut in the fin can by the supplier, it was realized that they were cut in the wrong location. This was in part due to a dimensioning error by the team, however, the fin tabs were adjusted to account for this and no further fixes were required. For more information on the adjusted fin tabs, see Section 3.1.1.1.

Finally, while laser cutting the bulkhead, centering ring, and fin layers, it was noticed that the birch plywood was slightly warped. However, again due to the team's accelerated build schedule, there was not time to order more plywood and wait to receive it. To mitigate the issue as much as possible, the parts of the wood that were the least warped were used first and weights were placed on it while cutting to ensure that the cuts were consistent and not affected by any inconsistencies in the wood. However, despite mitigation efforts, this defect did cause obstacles during the launch vehicle construction, such as causing a fin to be warped as discussed in Section 3.1.4.7.

All other launch vehicle materials were inspected upon arrival and deemed acceptable.

3.1.4.2 Body Tube Construction

The first step in launch vehicle construction was to have the body tubes, couplers, nose cone shoulder, and motor tube cut to proper size once they arrived. Because the team does not possess the proper machinery to be able to cut the pieces accurately, they were measured and marked as shown in Figure 3-6 and given to the departmental machine shop to be cut.

Figure 3-6 Measured Launch Vehicle Components

Once returned, the cuts were inspected and determined to not be level; each cut was off to some degree, the worst being the fin can shown in Figure 3-7.

Figure 3-7 Fin Can Edge

To remedy this, each of the cut edges were sanded using 120 grit sandpaper until level. Once each of the components was satisfactory, each was washed with soap and water to remove any residual mold release or other chemicals from the fabrication process that could affect the adherence of epoxy to the surface, as shown in Figure 3-8.

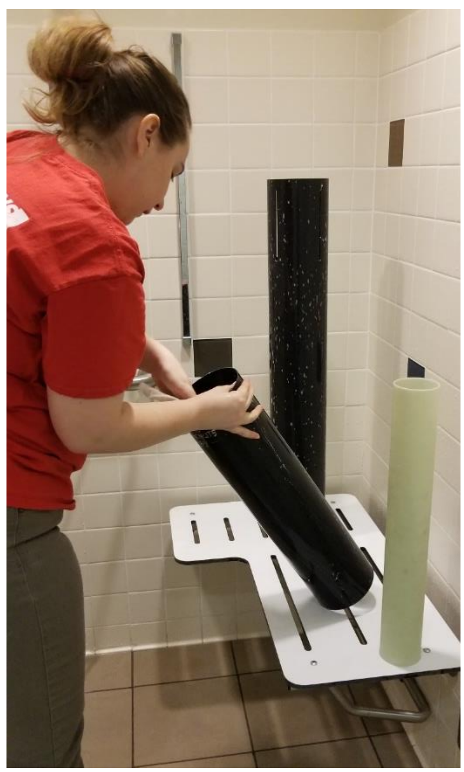


Figure 3-8 Cleaning of All Fiberglass Launch Vehicle Components

The sections of coupler for the payload bay and AV bay were then epoxied together using West Systems 2 part epoxy and allowed to cure for at least 24 hours before being handled. The payload bay and AV bay are shown in Figure 3-9.

Figure 3-9 Payload Bay and AV Bay Coupler Attachments

The payload bay and nose cone as well as the AV bay and main parachute bay are attached permanently during flight using threaded t-nut inserts. These inserts consist of a circular piece of 1/8 inch birch plywood with a t-nut inserted as shown in Figure 3-10.

Figure 3-10 Permanent Threaded Inserts

The thickness of the t-nut which sticks out of the plywood is long enough to fit flush with the edge of the coupler section in which it is seated in. Four of these inserts are used at each attachment point; the holes were spaced evenly apart and drilled with the two sections taped together to ensure that the holes align as shown in Figure 3-11.

Figure 3-11 T-Nut Insert Hole Alignment

The inserts were then epoxied into each of the AV bay coupler section and the nose cone shoulder and allowed to cure for at least 24 hours as shown in Figure 3-12.

Figure 3-12 T-Nut Inserts Attachment

Four evenly spaced 9/32 inch holes were drilled in the AV bay body tube section to act as pressure ports as well as to allow access to the screw switches which control the altimeters and the GPS.

Finally, holes were drilled at the joints between the main parachute bay and the payload bay as well as between the fin can and the AV bay for shear pins. The holes were made to match the shear pin diameter so that they were large enough to easily fit the shear pins while also not being too loose.

3.1.4.3 Bulkhead Fabrication

All bulkhead and fin layers were cut using the VLS 6.60 Laser Table to provide accurate and consistent dimensions. The layers were cut from sheets of 1/8 inch thick birch plywood after measuring actual dimensions of the body tubes to ensure correct sizing. To further ensure correct measurements and avoid wasting material, one layer of the motor tube centering ring was first cut and checked with scraps of the motor tube and body tube as shown in Figure 3-13.

Figure 3-13 Centering Ring Sizing

Because these dimensions fit well, the rest of the bulkhead layers and fins were then cut all at once. It can also be seen in Figure 3-13 that the layers have two small holes cut out of them; these holes were used to insert dowel rods into during the curing process for the bulkheads to ensure that the layers did not slide or rotate in relation to one another and stayed perfectly aligned.

Prior to epoxying the layers of each bulkhead, centering ring, or fin together, the faces which would be adhered to one another were sanded with low grit sand paper and wiped with baby wipes as shown in Figure 3-14. This is to give better adherence between the layers as the surfaces are rougher and free of any dust or other debris that could interfere.

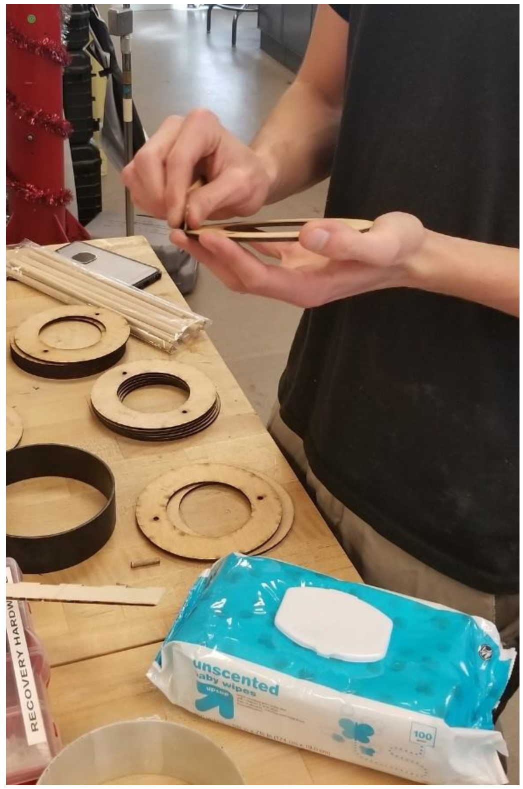


Figure 3-14 Bulkhead Layer Preparation

The bulkhead and fin layers were then adhered together using West Systems 2 part epoxy. Each completed bulkhead and fin were wrapped in peel ply, breather material, and then placed under vacuum and weight for 24 hours as shown in Figure 3-15 and Figure 3-16.

Figure 3-15 Bulkheads and Fins Under Vacuum

Figure 3-16 Bulkheads and Fins with Weight

Once the bulkheads were finished curing, they were removed from the breather and peel ply and the outer edges were sanded. This was done to remove the layer that was charred by the laser cutter and to rough up the surface to allow for better adherence when epoxied into the launch vehicle.

3.1.4.4 Fin Can Construction

Construction of the fin can began with securing the forward fin can bulkhead. The bulkhead was epoxied into the body tube using West Systems 2 part epoxy and was aligned by also inserting the motor tube and motor block into their proper places without epoxy as shown in Figure 3-17.

Figure 3-17 Fin Can Bulkhead Alignment

Because the fin can bulkhead has one layer of motor tube centering ring, the motor tube was able to sit in the bulkhead and ensure that it was placed properly and did not tip or shift. In addition, to keep the bulkhead from moving forward, a mallet was placed against the forward side of the bulkhead as shown in Figure 3-18 to support it.

Figure 3-18 Fin Can Bulkhead Support

The body tube was supported on either side to prevent it from rolling and the epoxy was allowed to cure for at least 24 hours before being handled. Once this epoxy was cured, an epoxy fillet was added to each side of the bulkhead to add strength. The epoxy fillet was done using West Systems 2 part epoxy and West Systems colloidal silica adhesive filler until a peanut butter consistency was reached. This combination was then applied around the outer edge of the bulkhead and onto the body tube to act as a fillet. This is shown in Figure 3-19.

Figure 3-19 Fin Can Bulkhead Epoxy Fillet

While the bulkhead fillet was curing, the motor tube and motor centering ring were also installed. Epoxy was applied to the forward edge of the motor tube to adhere to the bulkhead and was also adhered to the centering ring. The centering ring was epoxied using West Systems 2 part epoxy to the body tube and positioned to sit just forward of the fin slots. Once this epoxy had cured for 24 hours, an epoxy fillet was added to the aft side of the motor centering ring on both the outer edge and the inner edge which is in contact with the motor tube. Since the fin can bulkhead was already installed, it was not possible to fillet the forward side of the centering ring.

The fins were each installed at the same time as the motor centering ring fillet. The fin tabs were epoxied to the motor tube as well as to the centering ring and the bottom surface of the fins were epoxied to the outer surface of the fin can. The fins were then placed in a jig which was laser cut to ensure that the fins remained at exactly 90 degrees to each other while curing, as shown in Figure 3-20.

Figure 3-20 Fin Support While Curing

After 24 hours, epoxy fillets were added to the interior of the fin can both at the outer surface of the motor tube and the inner surface of the body tube. The motor block was then epoxied to both the body tube and the motor tube and positioned against the aft end of the fin tabs. Once this epoxy had cured for 24 hours, an epoxy fillet was added to the aft side of the motor block and left to cure for 24 hours.

Finally, epoxy fillets were added between the fins and the outer surface of the fin can. To do this, painters tape was placed on the fin can and on the fins at the desired location of the edge of the fillet. Then, epoxy mixed with silica powder was spread across the edge of the fin, then a large popsicle stick was used to create the desired radius as well as taper the forward and aft ends of the fillet. Two fillets were done at a time as shown in Figure 3-21 and allowed to cure for a few hours until no longer malleable before rotating the fin can to do the next set. All fillets were cured for 24 hours prior to any loading.

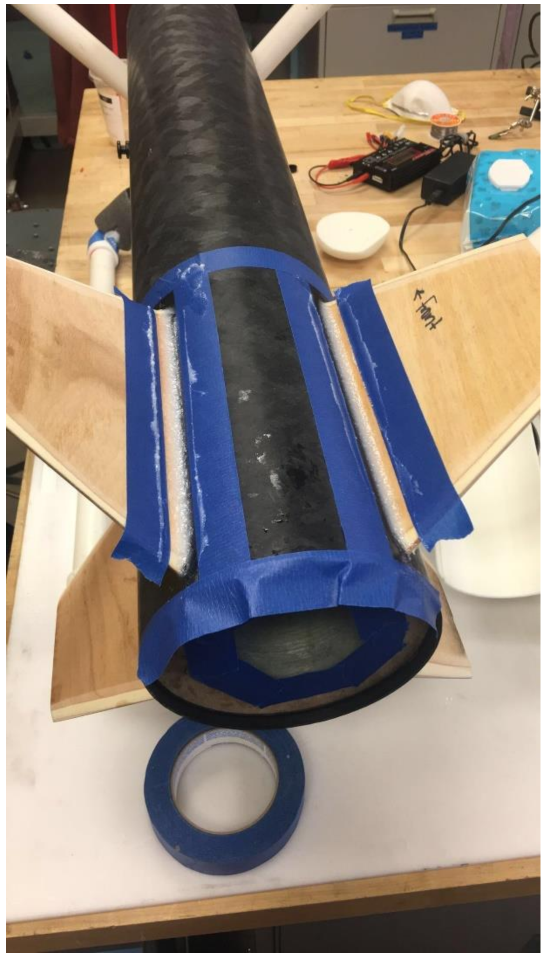


Figure 3-21 Fin Fillet Setup

Prior to installing the motor block, holes were marked and drilled and threaded inserts were installed for the motor retainer to attach to. To ensure the holes align, after the motor tube was installed in the fin can, the motor casing, motor block, and motor retainer were all placed in the fin can in their proper places. The holes were marked through the retainer and drilled accordingly.

3.1.4.5 Payload Bay Construction

To begin constructing the payload bay, the centering ring which is positioned against the coupler section was installed. This centering ring was chosen to be installed first because it is one of the innermost centering rings and its location was easily identified. Next, the centering ring which is two inches from the edge of the coupler section was installed and the payload pod was placed through the two centering rings while curing to ensure that they were properly aligned with each other. Once cured for 24 hours, the next centering ring, which was the centering ring flush with the edge of the coupler, was installed. Again, the pod was placed through all 3 centering rings while curing; however, while curing this time, the payload bay was set upright so that gravity would assist in keeping this centering ring flush with the edge.

Once this centering ring was cured, upon inspecting the payload bay, it was noticed that the shock cord slot did not align with the two previously installed centering rings. It was initially believed that this most recent centering ring had been installed backwards; however, upon further investigation, it was determined that the two interior centering rings were backwards. Initial attempts to Dremel out the shape that the centering ring should have from what was already installed were made, however, this was difficult to execute and too much damage was made to the initial centering rings. As a result, the two incorrectly installed centering rings were removed altogether and were remade.

Due to time constraints, it was necessary to install all three of the remaining centering rings at one time in order for the proper amount of curing time to be allowed prior to launch. In order to be able to accomplish this while still maintaining correct spacing, holes were drilled in each of the centering rings to allow for small threaded rods to be placed through each centering ring. Nuts were placed on the threaded rods and spaced apart to hold the centering rings in their proper places relative to one another. This is shown in Figure 3-22.

Figure 3-22 Payload Bay Centering Rings

Because the centering ring in the middle of these three is designed to sit against the coupler section in the interior of the payload bay, this was used to ensure that all three centering rings were located in the correct spot. All three were epoxied into the body tube simultaneously and, while curing, the pod was placed through all four centering rings to ensure proper alignment.

Finally, the holes on the removable payload bulkhead for the L-brackets were mapped out on the surface as shown in Figure 3-23.

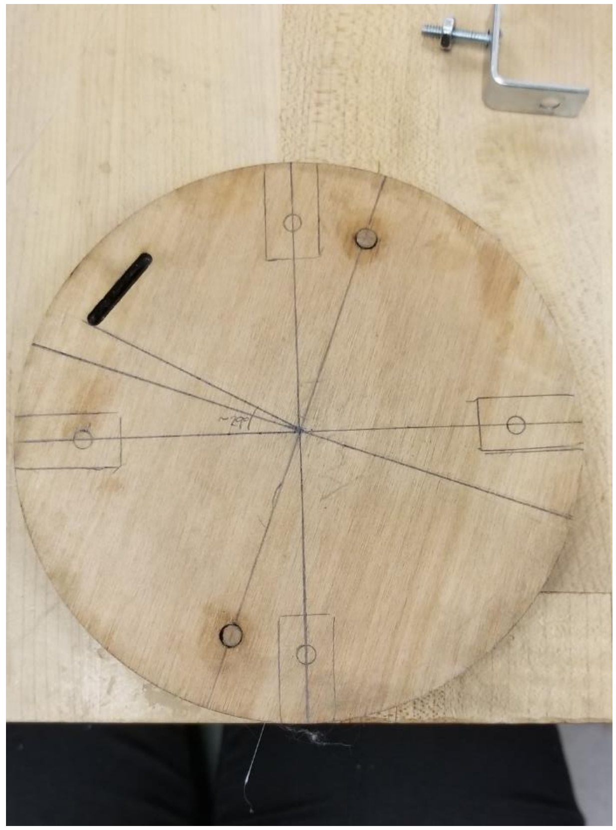


Figure 3-23 Payload Bay Bulkhead L-Bracket Locations

The holes were drilled in these locations and the L-brackets were installed onto the bulkhead. The bulkhead was then positioned in the payload bay so as to align the shock cord slot with the slot in the centering rings and holes were drilled through the body tube to match the L-bracket locations.

3.1.4.6 Nose Cone Construction

Construction of the nose cone began with installing the nose cone ballast. A measured amount of 0.375 lb of lead shot was epoxied into the tip of the nose cone for ballast. Once this epoxy was allowed to cure for 24 hours, the nose cone bulkhead was installed.

The nose cone bulkhead was first sanded using a belt sander at a 6 degree angle to produce a tapered edge. This angle was calculated using the dimensions of the nose cone and the tangent ogive equation and was produced on the bulkhead to allow the bulkhead to seat properly within the nose cone. The tapered bulkhead is shown in Figure 3-24.

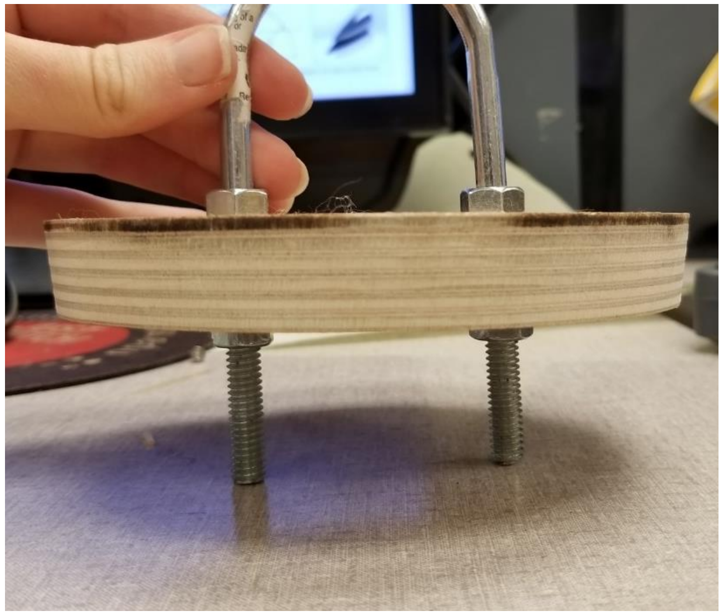


Figure 3-24 Nose Cone Bulkhead

The bulkhead was then epoxied into the nose cone by placing it into the nose cone until a snug fit was reached. This epoxy was allowed to cure for 24 hours and then an epoxy fillet was added around the outer surface of the bulkhead.

After the February 9 attempted launch, some changes were made to the nose cone configuration. As discussed in Section 3.1.4.1, the nose cone was chipped when it arrived from the supplier. However, with additional time, this was remedied by reshaping the tip of the nose cone using Bondo Epoxy Clay as shown in Figure 3-25.

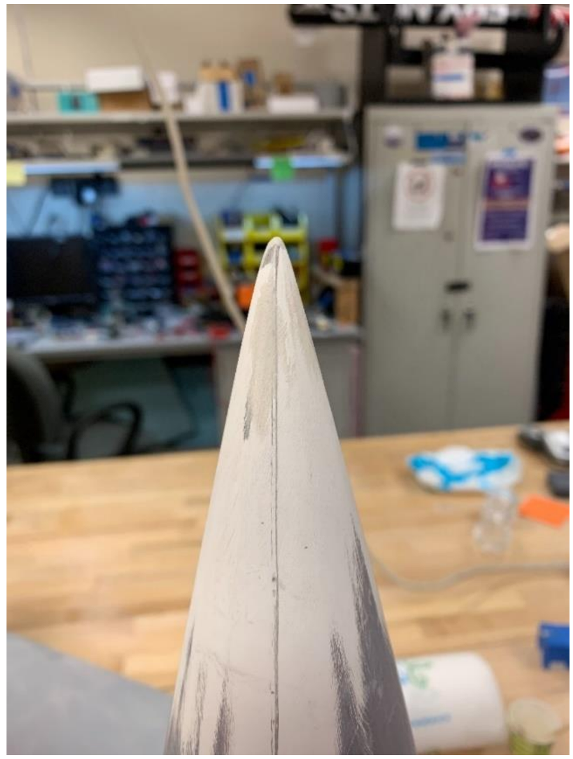


Figure 3-25 Fixed Nose Cone Tip

Finally, 3D printed inserts were installed into the nose cone to provide a mounting surface for the payload deployment battery packs. These inserts are seen in Figure 3-26.

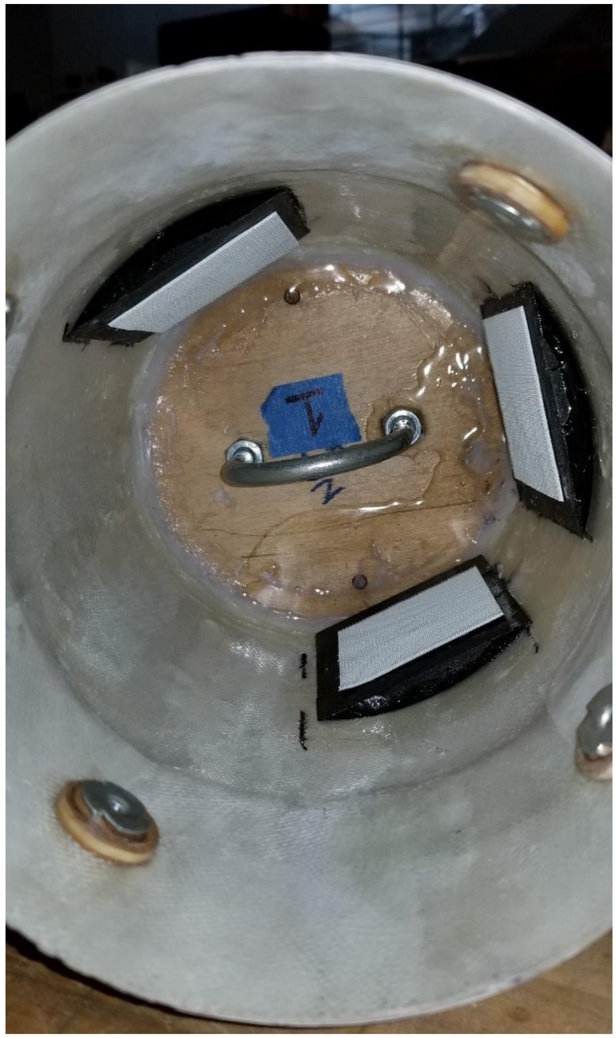


Figure 3-26 Nose Cone Battery Attachment Inserts

As can be seen, these inserts attach to the curved surface of the nose cone but provide a flat surface for the batteries to attach to. Velcro is attached to the inserts which will secure the battery packs during flight. An attached battery pack is shown in Figure 3-27.

Figure 3-27 Attached Battery Pack

By using the Velcro, the battery packs are removable during preparation for flight but will be secure during flight.

3.1.4.7 Obstacles During Construction

Some obstacles were experienced during the construction of the launch vehicle. First, as a result of the warped plywood discussed in Section 3.1.4.1, one of the fins that was fabricated initially was found to be noticeably warped. Though attempts were made to straighten the original fin, the warping was too significant and was deemed unacceptable; a new fin was fabricated and used in its place.

In addition, while installing the threaded inserts into the motor block for the motor retainer, one screw became jammed in the insert and broke. This insert then had to be drilled out as shown in Figure 3-28.

Figure 3-28 Damaged Threaded Insert

Once the damaged insert was drilled out, a spare was set into the motor block using epoxy. Though this is not as strong as if the threaded insert was in the bulkhead itself, based on advice from team mentors and because it was only one of the twelve total inserts, the team deemed this repair sufficient.

It was also realized during construction that due to dimensioning errors, the stepper motor which deploys the payload pod would block the nose cone shoulder from inserting fully. Because of this, a slot was required to be cut out of the nose cone shoulder as shown in Figure 3-29. Because the nose cone is permanently attached to the payload bay by threaded inserts during flight, this did not affect any launch vehicle requirements.

Figure 3-29 Slot Cut in Nose Cone Shoulder

Finally, while installing the payload bay centering rings, it was discovered that two of the centering rings had been installed backwards. Initial attempts were made to modify the installed centering rings to still use them, however, during this attempted repair, the centering rings were damaged too much and were ultimately removed altogether. New centering rings were fabricated and installed as described in Section 3.1.4.5.

While these obstacles were not ideal, the team was still able to complete the launch vehicle build process with only a slight delay; because a buffer period was built into the schedule, this did not affect the launch of the vehicle.

3.1.5 Schematics of Fully Constructed Vehicle

The final dimensions of the constructed launch vehicle are presented in Figure 3-30.

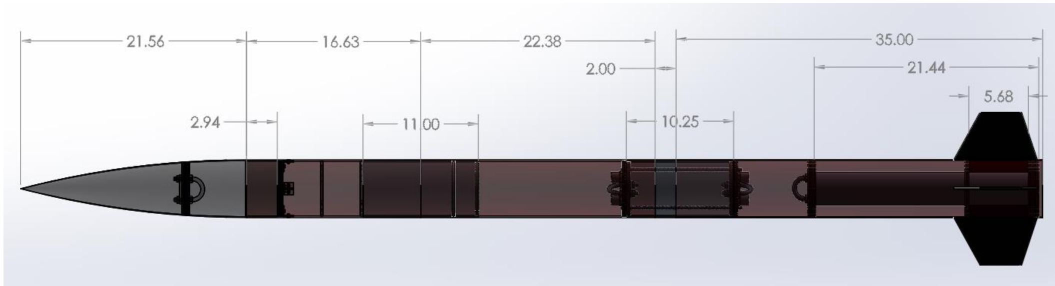


Figure 3-30 Dimensions Fully Constructed Launch Vehicle

While some dimensions vary slightly, the overall dimensions are very close to the intended design. The total length of the rocket without including the motor retainer is 97.57 inches.

3.1.5.1 Nose Cone

The nosecone shape is a 4:1 ogive design. This shape has a larger interior space in which the payload deployment electronics can be stored aft of the bulkhead. These payload deployment electronics and their placement is discussed in Section 5.3.

The nosecone is 21.56 inches long with a 2.94 inch long shoulder. A permanent ballast of 0.375 lb was installed into the tip of the nosecone to increase stability. The nosecone bulkhead is secured 5.44 inches forward from the end of the shoulder, as this is the location where the maximum diameter of the tapered bulkhead fits against the inside wall of the nosecone. Three 3D printed inserts are installed along the inner shoulder of the nosecone to provide a mounting surface for the payload deployment battery packs, as shown in Figure 3-26 and Figure 3-27. The total mass of the nosecone assembly, including the added ballast, 3D printed inserts, and payload battery, is 3.1 lb.

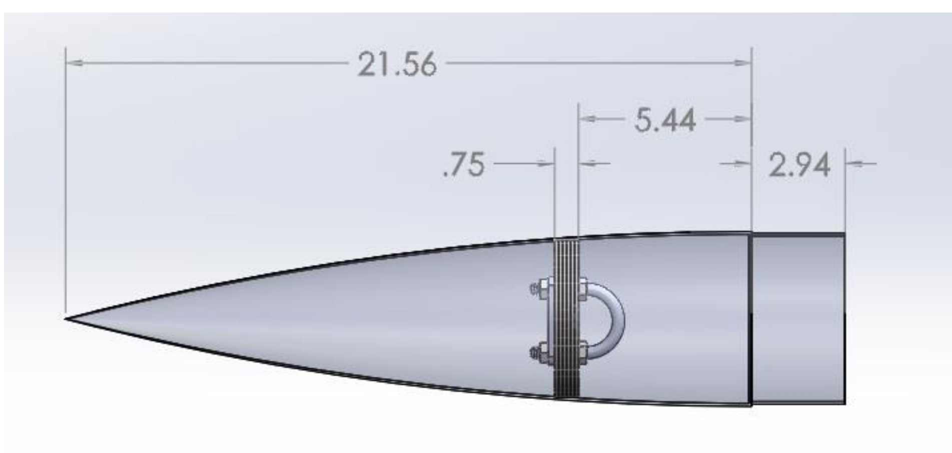


Figure 3-31 Dimensions of Nose Cone Assembly

3.1.5.2 Payload Bay

The payload bay is 22.12 inches long, with four centering rings spaced as shown in Figure 3-32. The payload bulkhead is mounted on 4 L-brackets and therefore removable and is located 3 inches from the forward end of the payload bay. Including the payload, the payload bay assembly has a weight of 8.2 lb.

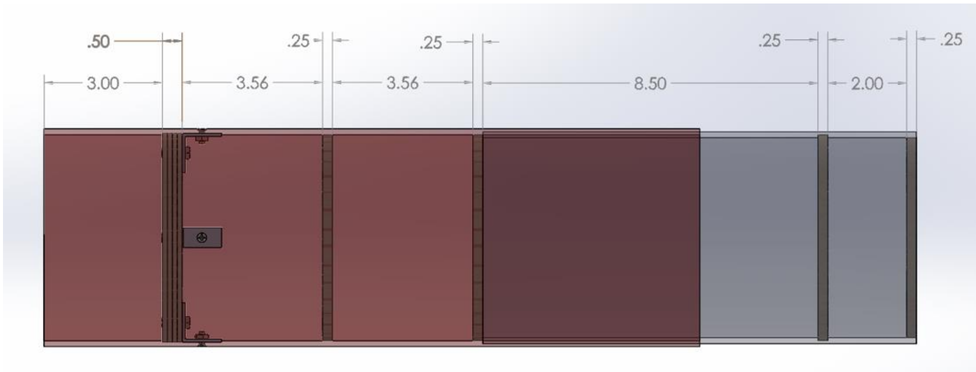


Figure 3-32 Dimensions of Payload Bay Assembly

3.1.5.3 Main Parachute Bay

The main parachute bay is 22.38 inches long as shown in Figure 3-33. It is positioned between the payload bay and the AV bay, and will house the main parachute and shock chord. With the main parachute and shock chord, the weight of this section is 2.2 lb.

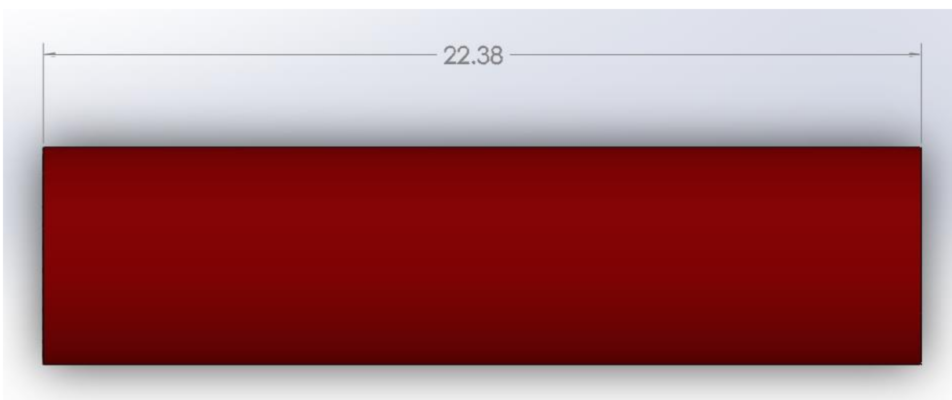


Figure 3-33 Dimensions of Main Parachute Bay

3.1.5.4 AV Bay

The coupler section of the AV bay is 10.25 inches long, with a body tube section of 2 inches as shown in Figure 3-34. 2.75 inches of the coupler connects to the main parachute bay, and 5.50 inches of the coupler connects to the fin can. The weight of the AV bay with the AV sled and electronic components is 4.1 lb.

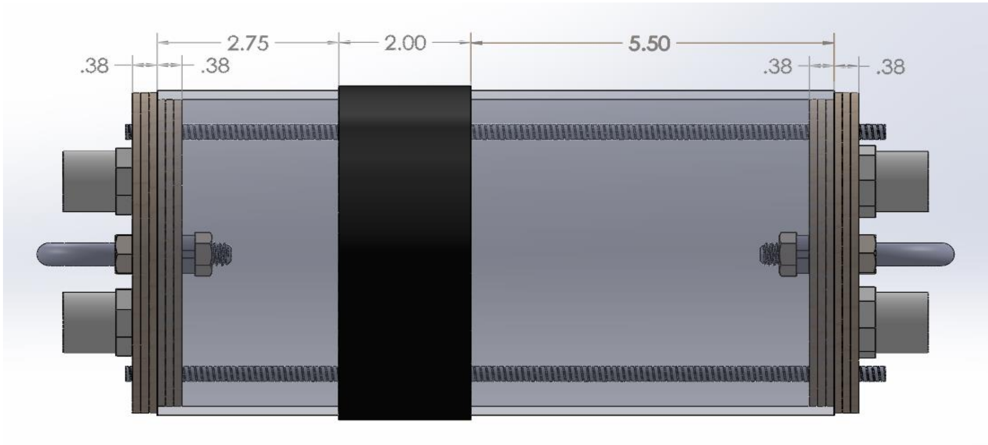


Figure 3-34 Dimensions of AV Bay Assembly

3.1.5.5 Fin Can

The total length of the fin can is 35.001 inches. Forward of the fin can bulkhead, there is a 12.563-inch-long section to house the drogue parachute and shock chord. The motor tube sits flush with the aft end of the motor block and has a total length of 21.3125 in. The fin can bulkhead sits at the forward end of the motor tube and there is a centering ring located at the forward end of the fin tabs. The fin can assembly is shown in Figure 3-35 and has a weight of 9.8 lb including the motor casing.

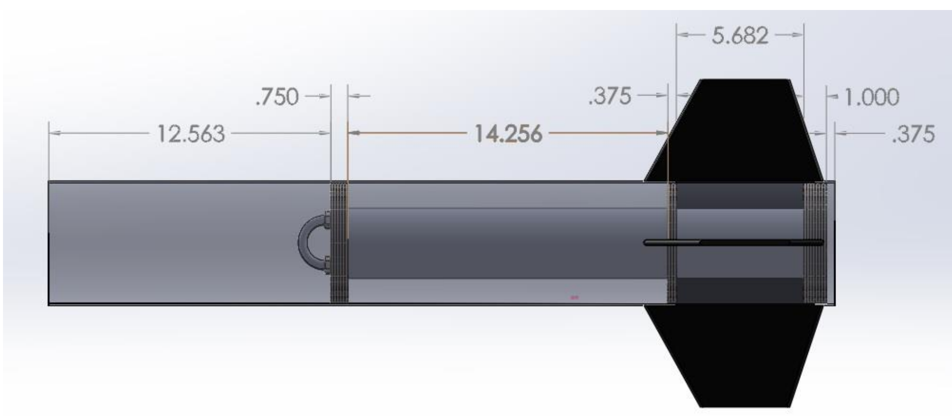


Figure 3-35 Dimensions of Fin Can Assembly

3.1.6 Difference from Earlier Models

The current launch vehicle differs from previous designs as discussed in Section 2.1 and Section 3.1.1.

3.2 Recovery Subsystem

Successful recovery system performance begins in the avionics bay. For the recovery system, the avionics bay houses two altimeters, the main altimeter and the redundant altimeter. For the full-scale, at apogee, a signal is sent from the main altimeter to the terminal block in the drogue compartment, aft of the avionics bay and forward of the fin can/motor Section. The terminal block relays the signal through an E-match to a small PVC cap housing enough black powder to complete the first separation, covered by 3M electrical tape to secure the electronic match within the cap. The calculations for the exact black powder charge sizes are described in Section 3.3.10 and will be tested in ground ejection tests prior to launch. The transmitted signal will cause the first separation to occur, and the drogue parachute will release. One second after apogee, a second, redundant altimeter will send a signal through the terminal block in the drogue compartment to an E-match inserted into a second, black powder charge containing 0.5 gram additional black powder in an identical PVC setup, releasing the drogue parachute should there be an interruption or failure in the first, main system charge. At this point, the first separation of the recovery system is complete.

The second step of the recovery system is a successful, second separation and release of the main parachute. For the full-scale launch vehicle, the second separation will occur at 600 ft AGL. At 600 ft AGL, the main altimeter, housed in the avionics bay, will send an electrical signal to the terminal block in the compartment housing the main parachute. The signal will transmit from the terminal block through an E-match connected to a PVC cap filled with an appropriately sized black powder charge, secured with 3M electrical tape. This charge will pressurize the main cavity and forcefully separate the nosecone from the midsection of the launch vehicle, releasing the main parachute deployment bag. This will allow for more time during the unfurling of shroud lines and parachute opening, decreasing the force from the parachute opening on the separated body sections. At an altitude of 550 ft AGL, a terminal block to a second E-match connected to a second, separate PVC cap containing a 0.5 gram greater black powder charge, also sealed by painters' tape to contain the charge. The calculations for charge sizes are included in Section 3.3.10 and will also be tested with ground ejection tests prior to launch. At this point, the second, main separation of the recovery system is complete.

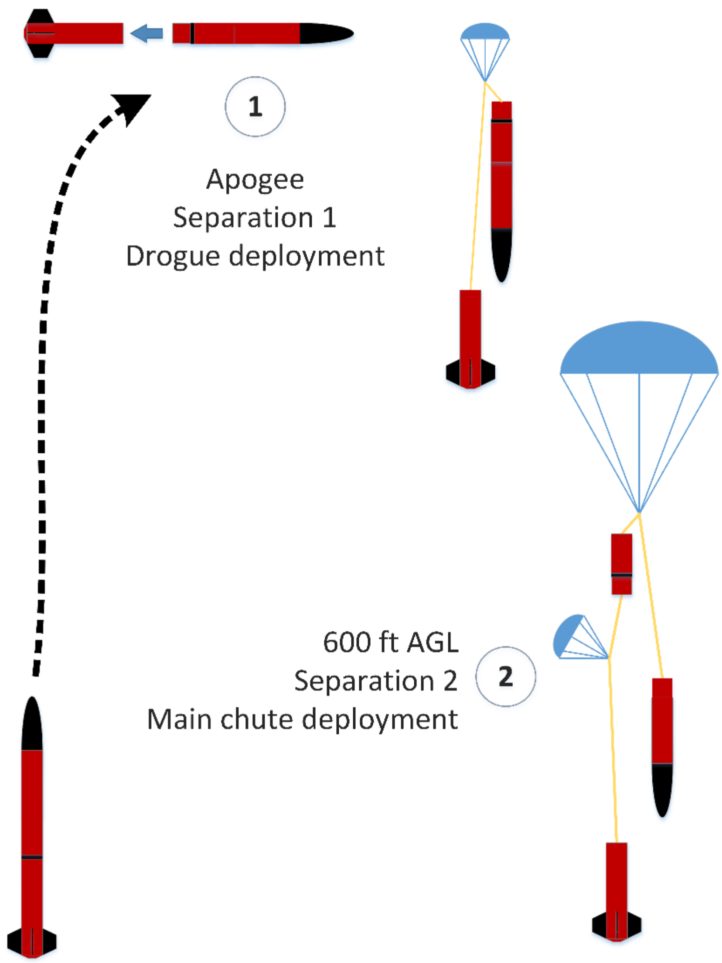


Figure 3-36 Recovery Events Overview

At each joint between separable sections, nylon shear pins were used to ensure no premature separations of sections occur during flight. Two shear pins were used between the midsection and fincan. Six shear pins were used to join the midsection and forward section. Previously, only two shear pins were used to join the midsection and forward section. During the first Vehicle Demonstration Flight attempt, only two shear pins was found to be insufficient to hold the forward section to the midsection during drogue deployment. This resulted in the premature deployment of the main parachute. Following additional testing of the failure properties of the shear pins, the quantity of shear pins securing the forward section to the midsection was increased to six.

Following the competition rules, the team will always conduct ground tests of black powder ejection events as described in the Requirements Verification and Testing Section to confirm to confidently separate launch vehicle sections without damaging any components before each flight. See Section 6.1.11 for more information.

3.2.1 Description of As-built Recovery System

3.2.1.1 Structural Elements

3.2.1.1(a) Avionics Sled

The AV sled was constructed from aircraft-grade birch plywood. The sled was assembled from sections of plywood sheeting, laser-cut to shape. These joints will be sanded for surface preparation before being bonded using wood glue. Each StratoLoggerCF altimeter is affixed to the AV sled by four nylon M4 machine screws. Each of the two commercially-available 9 V batteries powering each altimeter rest snugly within a compartment in the AV sled. A lid on the battery compartment which is affixed with four #4-40 machine screws secures the batteries within the compartments and ensure the power connectors remain attached to the batteries' terminals.

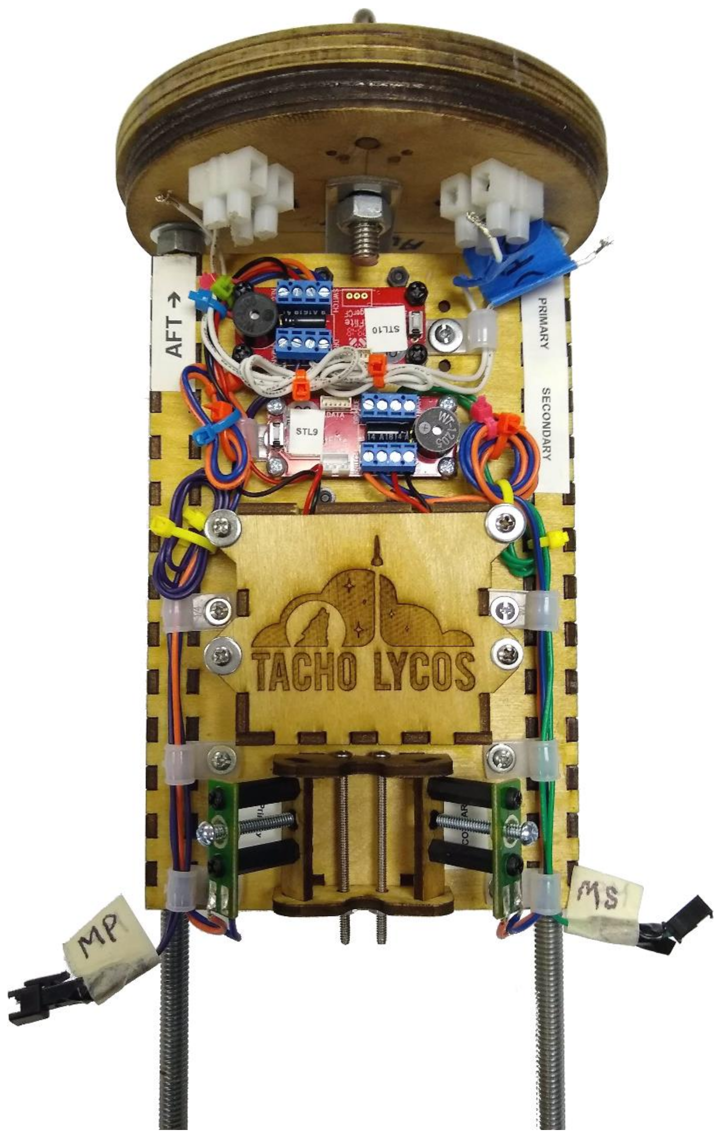


Figure 3-37 Assembled Avionics Sled with Battery Compartment Cover in Place

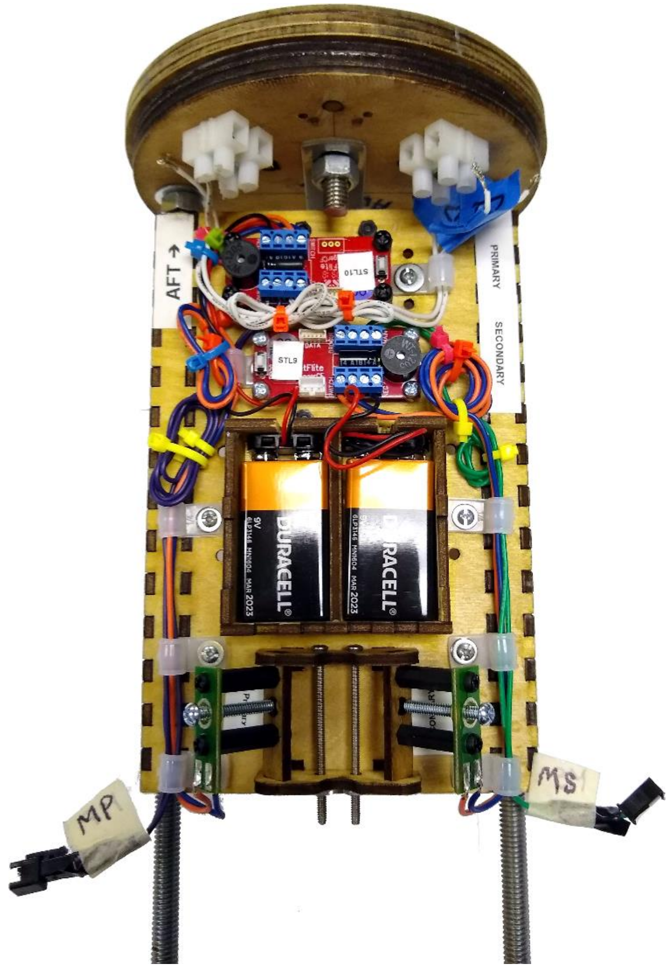


Figure 3-38 Assembled Avionics Sled Without Battery Compartment Cover

3.2.1.1(b) Quick links

Quick Links will be used to connect the parachutes, deployment bags, and nomex cloths to the recovery harness shock cord. Additionally, quick links will secure the shock cord to the U-bolts attached to the launch vehicle bulkheads. The quick links used in the recovery harness are discussed in Section 3.1.2.1(d).

3.2.1.1(c) Pressure Sampling Holes

To mitigate risk of pressure anomalies within the AV bay during flight, openings must be drilled in the walls of the AV bay. Four static ports will be spaced evenly around the circumference of the avionics bay. The use of four static ports will reduce the risk of pressure fluctuations from wind or flight at any angle of attack. The diameter of the static ports is determined using the following equation, from the manufacturer’s manual for the StratoLoggerCF altimeter:[3]

$$H = D^2 * L * 0.0008 \text{ in}^{-2} \quad (5)$$

Where *H* is the diameter of the static ports, *D* is the internal diameter of the avionics bay, and *L* is the internal length of the avionics bay. The pressure sampling holes in the avionics bay have a diameter of 9/32 inch.

3.2.1.1(d) Shock Cord

All shock cord used in the recovery system will be 5/8 inch tubular Kevlar, which is rated to 2000 lbf, making it capable of withstanding the decoupling forces. The team has used this type of shock cord successfully in the past for launch vehicles of similar size and weight to the vehicle, thus the team expects it to perform safely.

The length of shock cord to be used between each tethered section is 360 inches. This length is sufficient to allow the safe separation of the sections during descent. Figure 334 shows the shock cord sizing with respect to the separated sections of the leading alternative design.

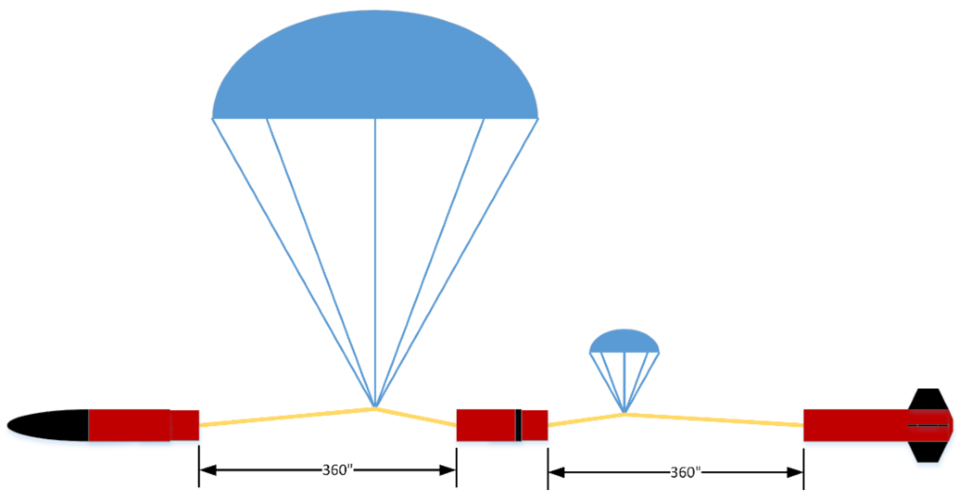


Figure 3-39 Shock Cord Sizing Diagram

3.2.1.2 Electrical Elements

3.2.1.2(a) Altimeters

Two PerfectFlite StratoLoggerCF altimeters will control the events of the recovery system. One altimeter will be designated the "Primary" altimeter, and the other will be designated the "Redundant" altimeter.

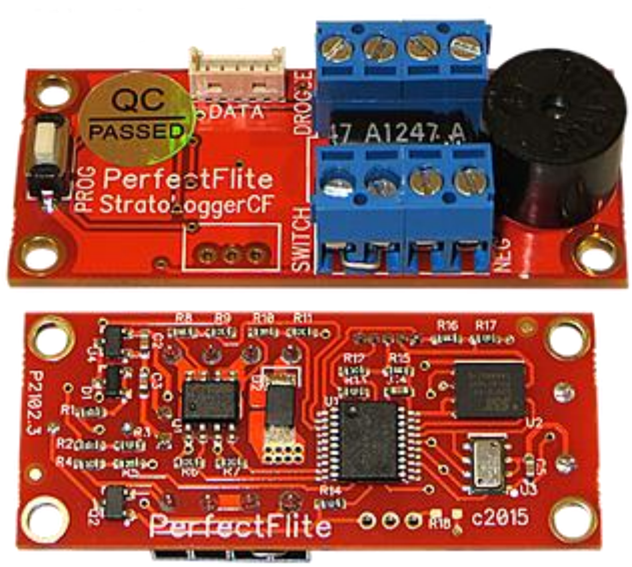


Figure 3-40 PerfectFlite StratoLogger CF Altimeter

The StratoLoggerCF measures altitude with a resolution of one foot at altitudes less than 38,000 ft MSL. This was deemed accurate enough to achieve reliability of the recovery system and record accurate telemetry data of the flight. The StratoLoggerCF requires the launch vehicle to reach an apogee of at least 100 ft AGL to function correctly. This is well below the target apogee for the launch vehicle. In addition to altitude, the StratoLoggerCF records data detailing the ambient temperature and battery voltage. The StratoLoggerCF is capable of up to 18 minutes of recording per flight which is sufficient for the expected duration of the mission.

Each altimeter onboard the launch vehicle will be independently powered by its own power source, controlled by its own power switch, and connected to its own black powder charge for each event. This ensures the complete independence of each altimeter for full dual-redundancy of the system. The batteries powering each altimeter will be commercially-available, Duracell brand 9 Volt alkaline batteries. These batteries have a service life in excess of 300 hours before decreasing to the minimum voltage required to operate the StratoLoggerCF altimeters. The screw switch controlling each altimeter's power supply allows the altimeter to be turned off until the launch vehicle is on the pad undergoing its final launch preparations.

To ensure that the altimeters are working correctly, both altimeters will be tested as described in the Requirements Verification and Testing section, see Section 6.1.11

3.2.1.2(b) Switches

Two screw switches are mounted on the avionics sled within the avionics bay airframe to allow the altimeters to be powered on using a screwdriver. Other types of switches considered include rotary key switches, which require a specific key to operate, and sliding two-position switches. The two-position sliding switches were not selected because their design risks possible unintended movement of the switch if the switch were to be subjected to high g-forces or aerodynamic forces in the direction of the switch sliding motion. Screw switches and rotary key switches do not suffer that same vulnerability. The rotary key switches were not selected because the requirement for use of a key to operate the switch presents a safety hazard. The key would need to be kept with personnel closest to the vehicle at all times in order to allow the altimeters and their connected energetics to be disarmed safely without unnecessary delay. Furthermore, in the event of the launch vehicle landing with un-detonated black-powder charges still contained within the vehicle, it is hazardous to remain near the vehicle until all altimeters controlling the charges have been powered off. Any recovery personnel not possessing the required key would be unable to complete this urgent task. This ability to actuate the altimeter power switches using only a screwdriver, edge of a blade, or fingernail enhances the safety of the launch vehicle and mitigates risks associated with the recovery system. For these reasons, the team selected the non-key-activated screw switches to control power to the altimeters.

3.2.1.2(c) Batteries

To ensure uninterrupted power for the recovery avionics systems, batteries for altimeters are only used for a single flight. Prior to flight, the batteries are tested to ensure their voltage is sufficient for flight.

The avionics system will be contained within the midsection of the launch vehicle. This will allow the avionics to be prepared separately from the rest of the vehicle assembly process. Because the avionics assembly process includes the loading of energetics, this will enhance safety while also allowing the team to prepare the launch vehicle for flight quickly to meet the requirement that the vehicle must be ready for flight within two hours of the opening of the FAA waiver at the launch site.

3.2.1.2(d) Electrical Schematic of Recovery System

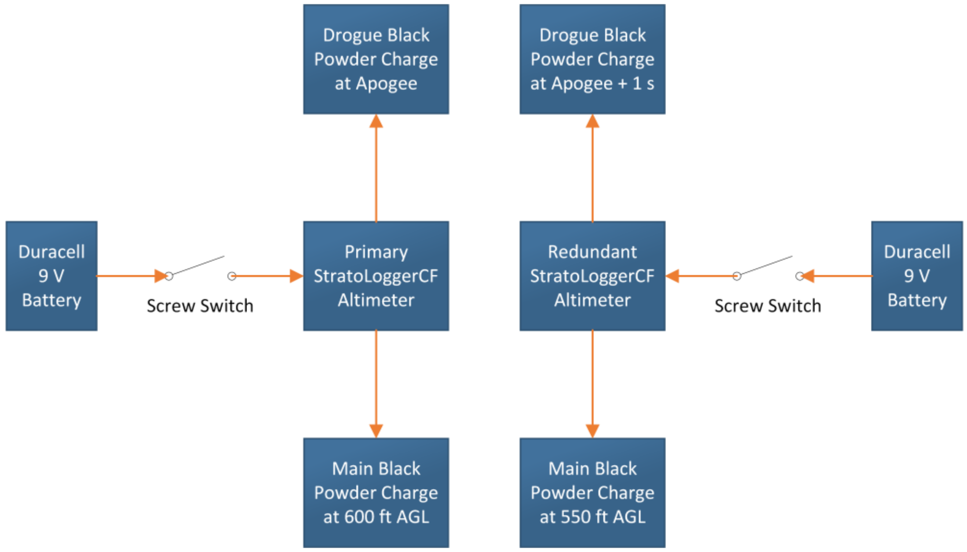


Figure 3-41 Electrical Schematic of Recovery System

This schematic demonstrates the full independence and dual redundancy inherent to the system design and compliance with competition handbook requirements 3.6. This schematic also demonstrates the design's compliance with competition handbook requirement 3.4, which states that the recovery system electrical circuits will be completely independent of any payload electrical circuits. The altimeters will each be independently powered by a commercially-available Duracell 9 V battery, in adherence to competition handbook requirement 3.5.

3.2.1.3 Redundancy Features

The recovery electronics system features two (2) StratoLoggerCF altimeters for redundancy. The two altimeters are powered by two independent 9V batteries as seen in Figure 3-41 above. The primary altimeter transmits a signal at apogee to ignite the drogue ejection charge. One second later the redundant altimeter sends a signal to ignite the redundant ejection charge. At 600 ft, the primary altimeter transmits a signal to ignite the main ejection charge. At 550 ft, the redundant altimeter sends a signal to ignite the redundant ejection charge. This redundancy is implemented to reduce the chance of a recovery failure due to faulty electronics.

3.2.1.4 As-Built Parachute Sizes and Descent Rates

To calculate the descent velocity of the vehicle under parachute, the following equation is used:

$$v = \sqrt{\frac{W}{2\rho C_D \pi \left(\frac{D}{2}\right)^2}} \tag{8}$$

Where *v* is the descent velocity, *W* is the weight of the vehicle (after motor burnout), ρ is the density of air, C_D is the drag coefficient of the parachute with reference to the nominal area of the parachute, and *D* is the nominal diameter of the parachute.

3.2.1.4(a) Main Parachute

Due to budgetary constraints, a team-derived requirement was established stating the team shall use a main parachute already in the team's inventory. The Fruity Chutes 84 inch Iris UltraCompact is the only acceptable main parachute alternative to meet the competition recovery system requirements and this team derived requirement. Thus, it was determined that the Fruity Chutes 84 inch Iris UltraCompact parachute was selected for use as the launch vehicle's main parachute. The parachute has a drag coefficient for 2.13. This results in a main parachute descent rate of 17 ft/s.

The main parachute deployment altitude was selected to be 600 ft AGL to minimize wind drift and descent time while also allowing sufficient time for parachute deployment. The selected main parachute deployment altitude meets the competition handbook requirement 3.1.1, which states that the main parachute shall be deployed no lower than 500 ft.

3.2.1.4(b) Drogue Parachute

The Fruity Chutes 24 inch Classic Elliptical parachute is the launch vehicle's drogue parachute. It will be deployed at apogee by the separation of the midsection and fin can, as described previously. The Fruity Chutes 24 inch Classic Elliptical parachute has a drag coefficient of 1.47. This results in a drogue parachute descent rate of 71.5 ft/s. The drag produced by the parachute will reduce the descent velocity of the launch vehicle to allow for a safe and controlled deployment of the main parachute.

3.2.1.5 Drawings and Schematics of the As-Built Electrical and Structural Assemblies

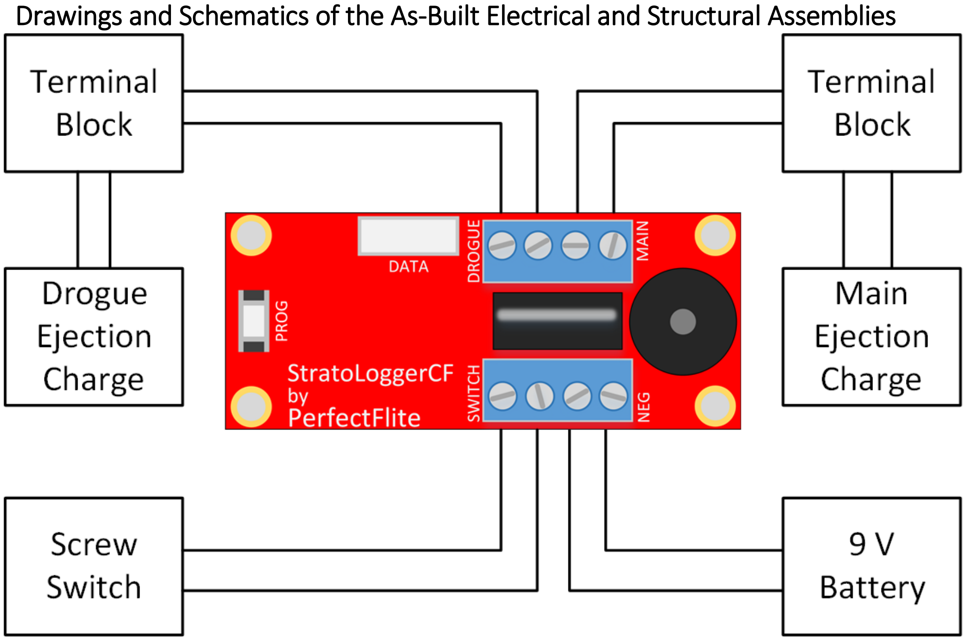


Figure 3-42 StratoLoggerCF Wiring Schematic

Figure 3-42 shows the wiring method for the PerfectFlite StratoLoggerCF altimeter.

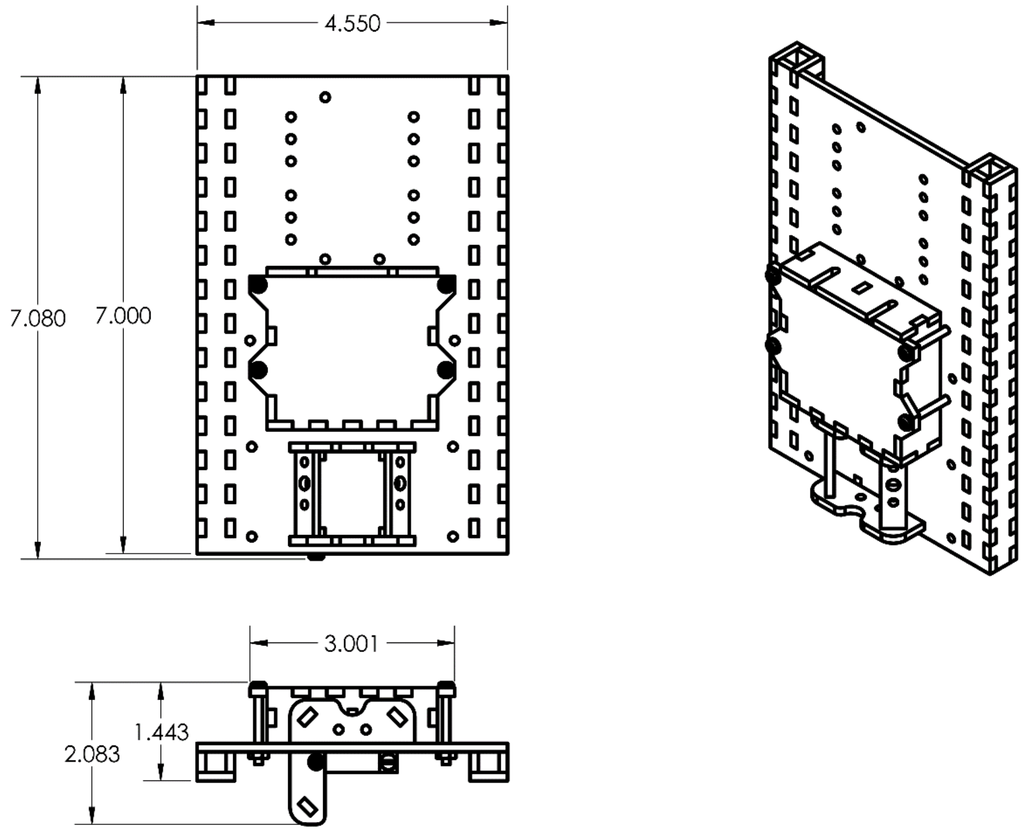


Figure 3-43 Avionics Sled Dimension Drawing

Figure 3-43 shows the assembled avionics sled as constructed with key dimensions marked in inches. The sled is depicted without any electrical components affixed.

3.2.1.6 Rocket Locating Transmitters

The launch vehicle will be equipped with a BigRedbee 900 GPS tracker which will transmit the launch vehicle's GPS location on the 900 MHz band.[1] This will be received by a ground station connected by USB cable to a laptop operated by a team member. The laptop will display graphically in three dimensions in the mapping software Google Earth the latitude, longitude, and altitude received from the GPS tracker. This data can be viewed in real-time to track the launch vehicle. The location data is also logged for post-flight analysis and review. In addition, the receiver ground station displays the tracker status and received latitude and longitude coordinates on an LCD on the receiver device without needing to be connected to

[1] **Invalid source specified.**

the laptop computer. This provides a redundant method of tracking the launch vehicle in case the laptop malfunctions or is otherwise inoperable.

The GPS tracker within the launch vehicle will be powered by a 3.7 V, 1000 mAh, Lithium Polymer (LiPo) battery. This battery will solely be powering the GPS tracker. This meets the required 2-hour pad, flight, and post-flight time needed to locate and recover the launch vehicle. The device will be powered on during preflight preparations on the launch pad.

There is no second tracking device in the vehicle because failure of the tracking device would not result in any safety risks or failure to meet the mission success criteria. Thus, it is not considered a flight-critical or mission-critical component. The tracking device itself is considered a redundant solution to the primary means of locating the launch vehicle during and after flight: visually tracking the launch vehicle during its flight and descent. The tracking device serves as a backup to this method if any abnormal flight events render this method unsuccessful.

3.2.1.7 Sensitivity to Transmitters

The altimeters, due to their design, are not sensitive to RF radiation, so there will be no interference from the GPS tracker location transmitter, and no risk from placing the GPS tracker transmitter device in the same bay as the altimeters.

3.3 Mission Performance Predictions

3.3.1 Flight Profile Simulations

Having completed the construction of the full-scale launch vehicle, the team was able to refine the current RockSim model to better predict flight performance. A simulation was performed using weight and CG values gathered during the vehicle demonstration flight. Values for altitude, velocity and acceleration as a function of time for this simulation can be found in Figure 3-44 below.

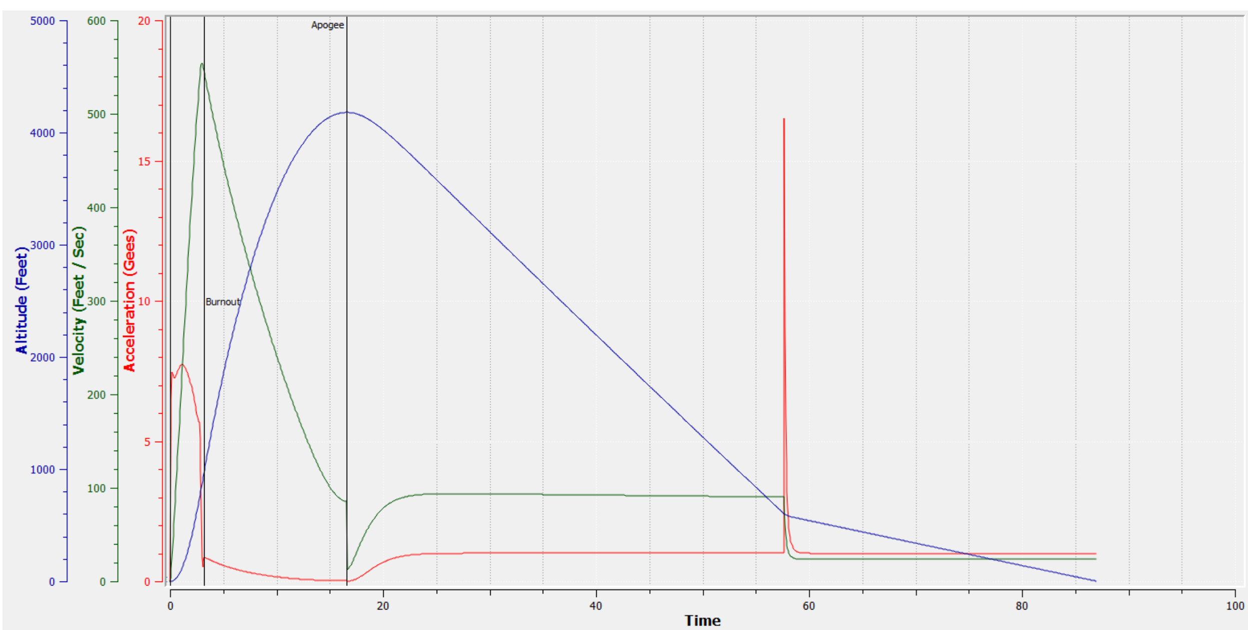


Figure 3-44 RockSim Simulation of As-Built Launch Vehicle in Nominal Conditions

The simulated thrust curve of the Aerotech L1150R that was used for all simulations can be found in Figure 3-45 below.

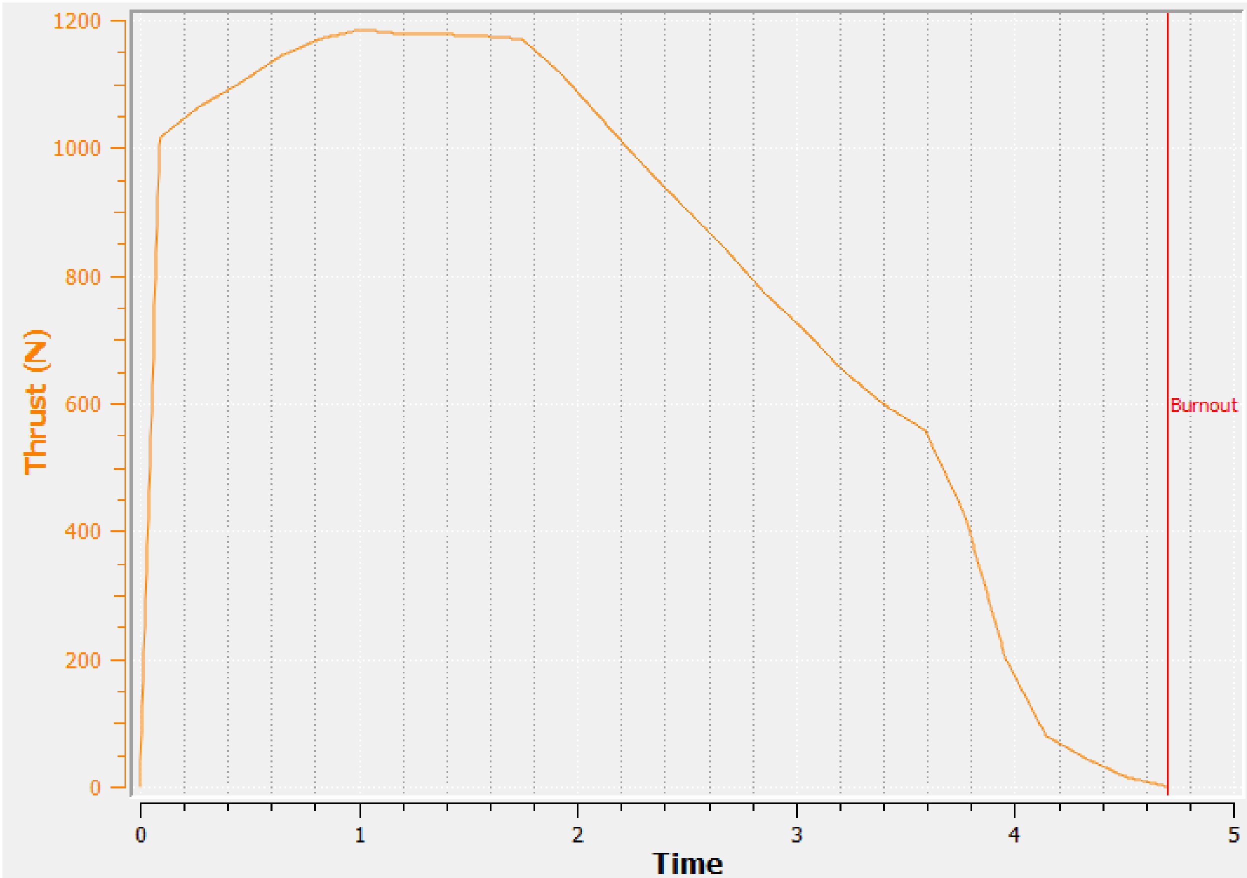


Figure 3-45 RockSim Simulation of Aerotech L1150R Thrust Curve

This simulation predicted an Apogee of 4173 ft., Rail exit velocity of 69.45 fps and maximum velocity of 553.7 fps or .47 Mach. These values confirm the launch vehicle's compliance with team derived requirements 6.8 and 6.7, and NASA requirement 2.18, respectively.

3.3.1.1 Verification of Vehicle robustness

3.3.1.1(a) Airframe

The body of the launch vehicle is responsible for housing all the necessary rocket components such as the motor, parachutes, avionics, and payload. Each of these components are in some way attached to the rocket body, whether it be directly or through a bulkhead that is then attached to the body. Because of this, it was imperative to ensure that the airframe material would be able to withstand the loads it would experience during flight. To determine the strength necessary for the fiberglass body material, the compressive force on the rocket was calculated as follows:

$$F_C = F_D + F_I \quad (1)$$

Where F_D is the drag force on the airframe and F_I is the inertial force. The drag force on the launch vehicle is calculated below:

$$F_D = C_D * \frac{\rho V^2}{2} A \quad (2)$$

Where C_D is the coefficient of drag, ρ is the density of air, V is the velocity of the launch vehicle, and the reference area, A. Air density is assumed constant at a value of 0.0749 lbm/ft^3 and the area is 23.97 in^2. The coefficient of drag for airframe is 0.55 based on simulations performed in RockSim and the maximum velocity is 557.02 ft/s. This gives a drag force of F_D = 33.046 lbf. The inertial force is calculated as follows:

$$F_I = ma \quad (3)$$

Where m is the mass of the rocket and a is the peak acceleration. The final weight of the launch vehicle with all components installed is m = 39.2 lbm and the peak acceleration using the current leading motor selection is 220.409 ft/s^2. Using these values, the inertial force on the rocket is calculated to be 268.324 lbf; this means that the total force on the airframe is 301.37 lbf.

Fiberglass is the strongest commercially available material used in hobby rocketry and with an expected load of only 301.37 lbf, the team was confident that fiberglass would be able to withstand any normal flight loads and still be reusable. In addition, fiberglass is impervious to moisture and would not require filling or sealing to prevent potential water damage. Because of this, the launch vehicle is expected to be as durable as possible and be able to withstand multiple launches.

3.3.1.1(b) Bulkheads

Finite element analysis was re-performed on critical bulkheads for the as-built dimensions and expected loading.

The as-built nose cone and payload bay configuration has a total weight of 11.3 lb. At main parachute deployment, the system experiences a maximum acceleration of 20.722 gees. Using these two values, the load on the nose cone bulkhead at main parachute deployment is calculated to be 234.16 lb. The results of the finite element analysis for this bulkhead are shown in Figure 3-46 and Figure 3-47.

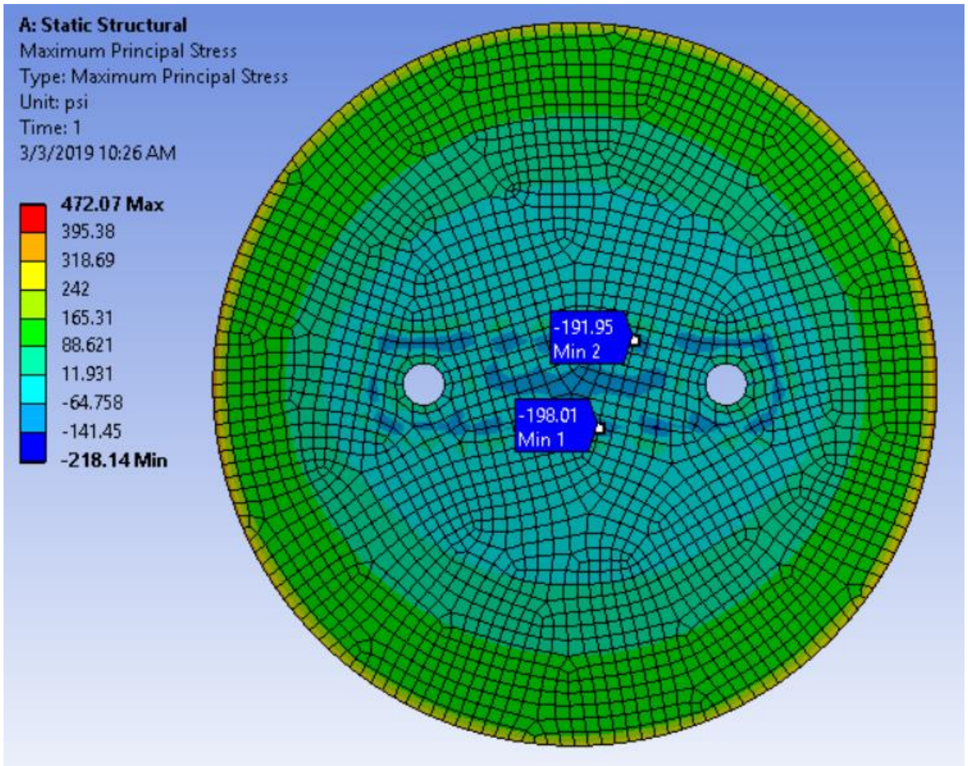


Figure 3-46 Nose Cone Bulkhead Compressive Stress

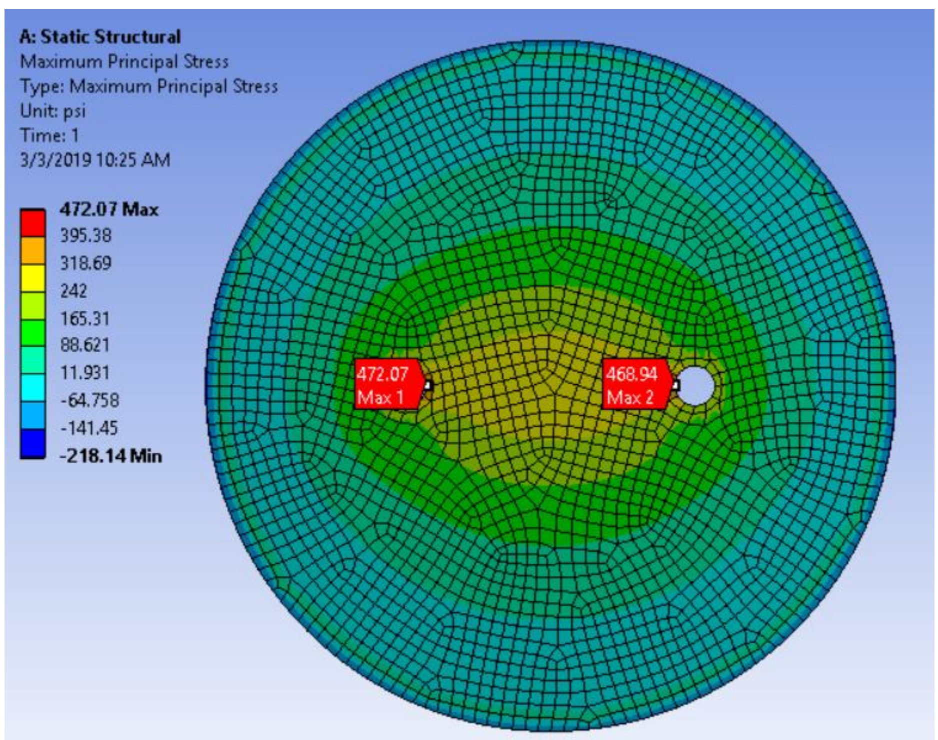


Figure 3-47 Nose Cone Bulkhead Tensile Stress

The bulkhead experiences a maximum tensile stress of 472.07 psi at the edge of the U-bolt hole and a maximum compressive stress of 198.01 psi where the U-bolt plate is located. Using a tensile strength of 1000 psi and a compressive strength of 1570 psi[2] as presented in the CDR, this bulkhead has a factor of safety of 2.12, which is sufficiently strong to withstand in flight loads and meets team derived requirement 6.12.

The AV bay bulkheads also experience high stress at parachute deployment. The forward AV bay bulkhead at main parachute deployment is considered the most critical; at main deployment, the AV bay and main parachute bay have a combined weight of 6.3 lb. This results in a maximum load of 130.54 lb. The finite element results for this bulkhead are shown in Figure 3-48.

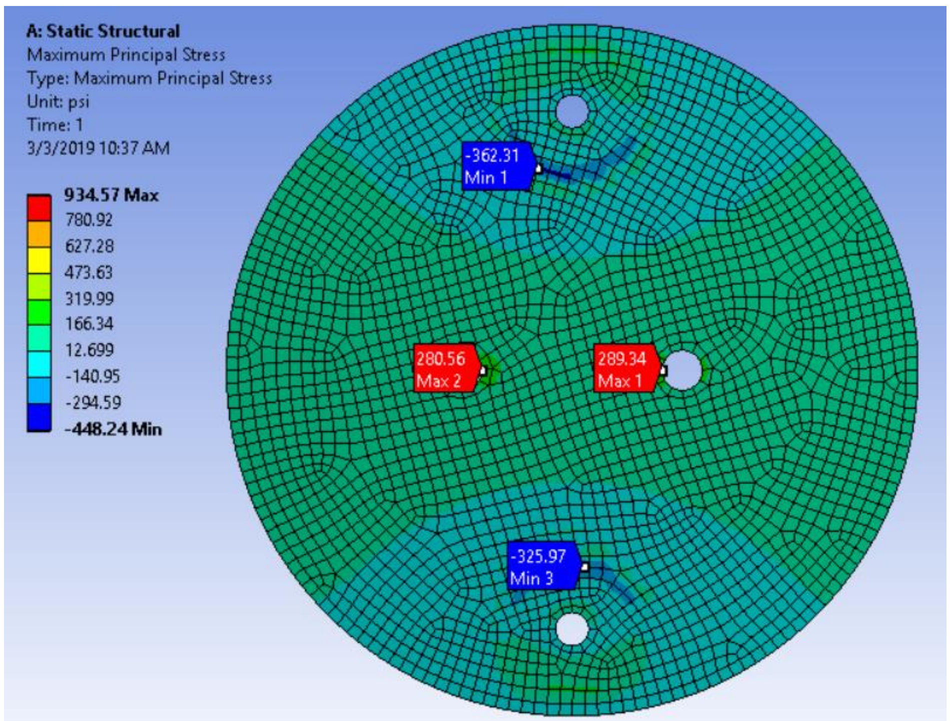


Figure 3-48 AV Bay Bulkhead Stresses

The AV bay bulkhead experiences a maximum tensile stress of 289.34 psi and a maximum compressive stress of 362.31 psi. Based on the aforementioned material properties of birch plywood, this bulkhead has a factor of safety of 3.46. Therefore, this bulkhead will be sufficiently strong and will not experience damage during flight as it meets team derived requirement 6.12.

Finally, the payload bay bulkhead is secured by four evenly spaced L-brackets and supports all of the payload system during flight. The weight of the payload components which will be secured by this bulkhead is 4.6 lb, giving a load of 95.32

[2] (European Birch Wood n.d.)

lb at main parachute deployment. The finite element results for this bulkhead are given in Figure 3-49.

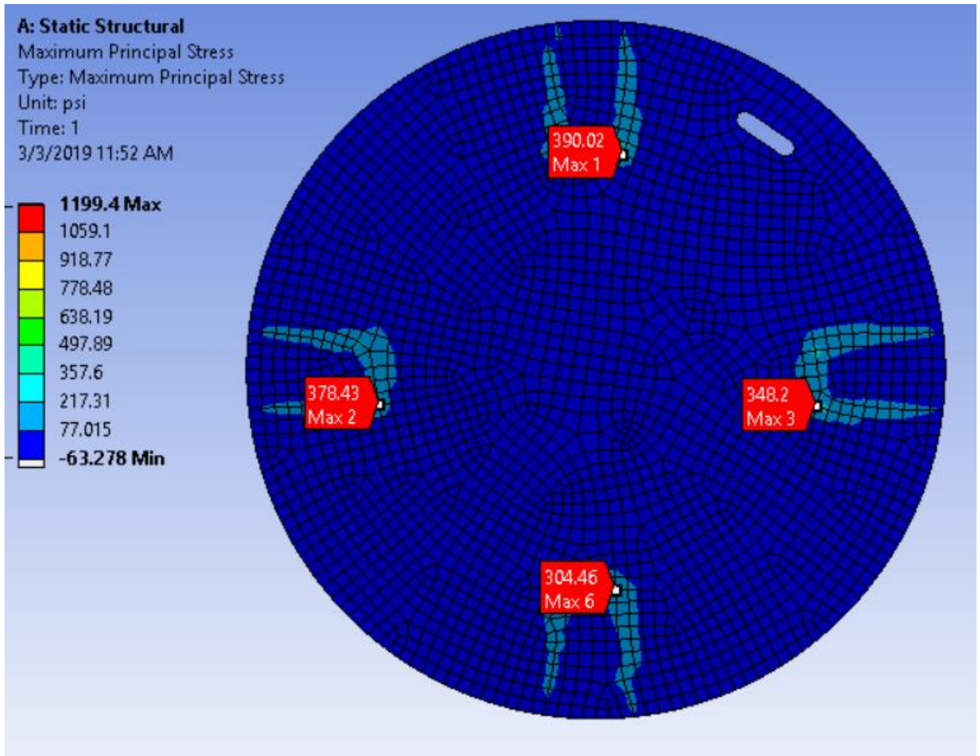


Figure 3-49 Payload Bay Bulkhead Stresses

The maximum tensile stress on this bulkhead at main parachute deployment is 390.02 psi. Using a strength of 1000 psi, this bulkhead has a factor of safety of 2.56. This factor of safety indicates that this bulkhead is sufficiently strong and will be able to withstand multiple flights with no damage.

3.3.1.1(c) Screws

The payload bay bulkhead will be secured to the body tube with four #6-32 stainless steel machine screws. Due to the 95.32 lbf load the payload bulkhead will experience, the screws will also experience significant stresses. This joint is a simple single shear joint, so the shear stress in the screws can be calculated as follows.

$$\tau = \frac{F}{A} \tag{4}$$

Where F is the load applied and A is the cross-sectional area of the screw. The diameter of #6 machine screws is 0.138 inches. The load value is divided by four because the four screws will each support this load evenly; using these values, the shear stress in each of the screws is 1593.22 psi. Though the exact grade of the stainless steel is unknown, the lowest listed shear strength in the material property data website MatWeb[3] is 33000 psi. Using this value, the screws have a factor of safety of 20.71, meaning that they will be sufficiently strong enough to withstand normal flight loads. The launch vehicle sections which are attached permanently during flight are secured by the same stainless-steel screws which secure the payload bay bulkhead. The loading on these screws is less than the load on the payload bay bulkhead and therefore will also be sufficiently strong to withstand flight.

3.3.1.1(d) U-bolts

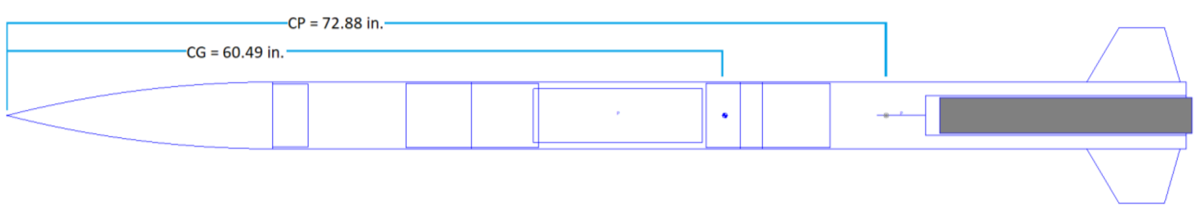
The U-bolts used to withstand the loading of parachute deployments are all 5/16 inch thick. Based on data from McMaster-Carr[4], U-bolts of 5/16 inch have a capacity of 600 lb. The highest expected load on a bulkhead during flight has been calculated to be 211.42 lb; with a factor of safety of two, this load is 422.234 lb. This is below the given strength of the U-bolts being used, which indicates that the U-bolts will be able to withstand the loading they will experience in flight.

3.3.1.1(e) Velcro

Each battery pack weighs 0.29 lb and has a 2 inch by 2 inch section of Velcro hook and loop attached. Velcro reports that their hook and loop has a shear strength of 14 psi[5]; this gives the Velcro strips being used a strength of 56 lb. At main parachute deployment, the acceleration change is 18.71 gees; this gives a shear force of 5.43 lb. Based on these values, the Velcro attachments have a factor of safety of 10.32 and will withstand in flight loading.

3.3.2 Stability Margin

The center of pressure was updated to reflect the final dimensions of the as-built launch vehicle that are described in Section 3.1.5. The center of pressure changed from 73.8 in. to 72.9 in. from the nose according to RockSim after updating all dimensions. The center of gravity of the launch vehicle was also updated after the vehicle demonstration flight. The CG changed from 58.8 in. to 59.20 in. These changes resulted in an increase in stability margin to 2.49 caliber. This stability margin is noncompliant with team derived requirement 6.9 in Table 6-6 . In the weeks following the vehicle demonstration flight, the team has added ballast aft of the CG to reduce the stability margin to 2.25 caliber. The final CG and CP locations are shown in Figure 3-50 below.



[3] (Overview of Materials for Stainless Steel n.d.)
[4] (McMaster-Carr n.d.)
[5] (Hook and Loop n.d.)

Figure 3-50 CG and CP Locations for As-Built Launch Vehicle

3.3.3 Kinetic Energy at Landing

The team shall design a recovery system such that no independent section of the vehicle lands with greater than 75 ft-lb of kinetic energy. The kinetic energy of each section at landing can be calculated using the following equation:[5]

$$KE = \frac{1}{2} m\, v^2 \qquad (5)$$

Where *m* is the mass of the section and *v* is the descent rate of the vehicle under main parachute. Given the current leading alternative design for the recovery system uses a dual-deployment recovery system in which all independent sections remain tethered and make their final descent beneath a single main parachute. This means the vehicle's descent rate under the main parachute is constrained by the velocity required to meet this kinetic energy requirement. Thus, Equation (6), can be re-arranged to calculate the maximum allowable descent rate for each independent section of the vehicle using the following equation:

$$v_{max} = \sqrt{2\, KE\, m} \qquad (6)$$

Where v_{max} is the maximum allowable descent velocity of the section, *KE* is the maximum allowable kinetic energy of the section, 75 ft-lb, and *m* is the mass of the section. The results of Equation (6) were plotted in Figure 3-51, below, to demonstrate how the mass of the section affects the maximum allowable descent rate of that section.

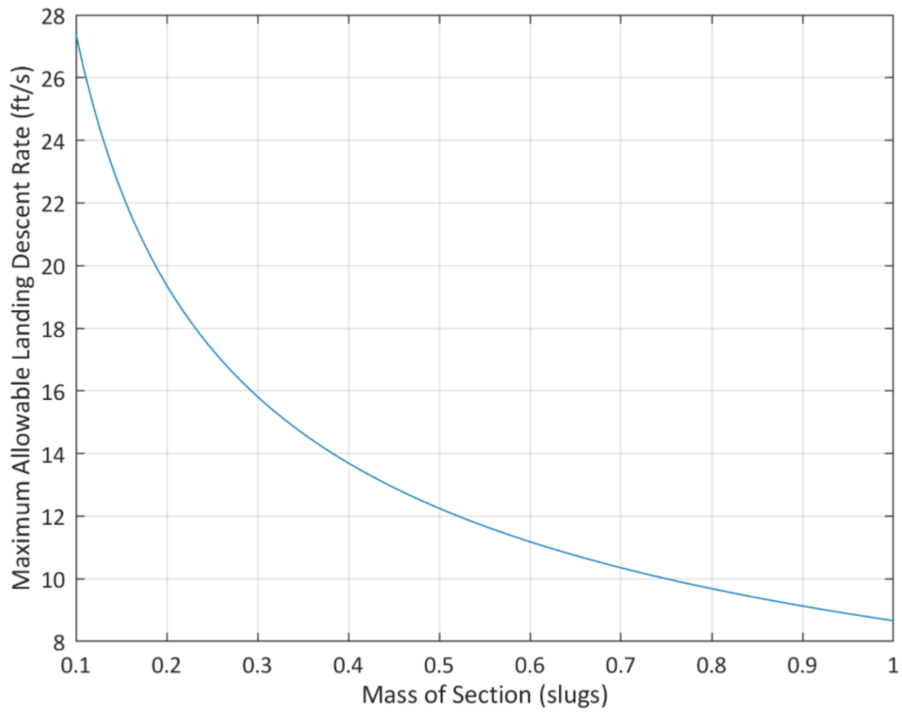


Figure 3-51 Plot of Maximum Landing Descent Rate vs. Section Mass

Equation (6) as used to calculate the maximum allowable descent velocity for each independent section of the leading vehicle design alternative for use in the development and selection of the design alternatives for the recovery system. The results of those calculations for the leading vehicle design alternative are shown below in Table 3-1.

Table 3-1 Maximum Descent Rate to Achieve Landing Kinetic Energy Requirement for Each Independent Section

Section	Mass	Maximum Descent Velocity
Nosecone	.3744 slugs	20.0 ft/s
Midsection	.2685 slugs	23.6 ft/s
Fin can	.4267 slugs	18.7 ft/s

Because all three independent sections of the leading design alternative will be tethered and descending together under the same main parachute in the leading recovery system design alternative, the descent rate of the vehicle under main parachute must not exceed any of the maximum descent velocities listed in Table 3-1 above, if the system is to meet the landing kinetic energy requirement.

Table 3-2, below, lists the masses and landing kinetic energy of each section, calculated using Equation (6) and the calculated descent rate of the launch vehicle as constructed under main parachute detailed in 3.2.1.4(a). The results of these calculations demonstrate the as-built design meets the required performance to achieve the required landing kinetic energy.

Table 3-2 Kinetic Energy of Independent Sections at Landing

Section	Mass	Kinetic Energy at Landing
Nosecone	.3512 slugs	50.6 ft-lb
Midsection	.2191 slugs	31.6 ft-lb
Fin can	.3046 slugs	43.9 ft-lb

Table 3-3 Kinetic Energy of Independent Sections While Descending Under Drogue

Section	Mass	Kinetic Energy under Drogue
Nosecone	.3512 slugs	898.7 ft-lb
Midsection	.2191 slugs	560.7 ft-lb
Fin can	.3046 slugs	779.4 ft-lb

3.3.4 Descent Time and Wind Drift Calculations

Wind drift was calculated assuming apogee over the launch pad. The results in Table 3-4, assume constant drogue and main parachute descent rates with deployment at apogee and 600 ft AGL, respectively. In all cases, the descent times are below the 90 second maximum allowable descent time. Additionally, all drift distances are within the maximum allowable distance of 2500 ft.

Table 3-4 Hand-Calculations of Wind Drift and Descent Time

Wind Speed	Apogee	Descent Time	Drift Distance
0 mph	4272 ft AGL	87 s	0 ft
5 mph	4220 ft AGL	86 s	630 ft
10 mph	4143 ft AGL	85 s	1245 ft
15 mph	4043 ft AGL	83 s	1836 ft
20 mph	3922 ft AGL	82 s	2399 ft

Additionally, RockSim was used to calculate wind drift at the aforementioned wind speeds. It is not possible to introduce wind effects partway through a simulation so creating simulations with apogee directly over the pad is not possible. However, RockSim is capable of generating detailed reports for each simulation. Included in these reports are the downrange location of the launch vehicle at various in-flight events. Taking the difference between the distance at apogee and the distance at touchdown yields the total wind drift distance as if apogee had occurred over the pad. Table 3-5 shows the wind drift values that were obtained through this method. All wind drift values in this table are below 2500ft, therefore the launch vehicle is compliant with requirement 3.9 in Table 6-5 .

Table 3-5 RockSim Estimations of Wind Drift Distance of Full-Scale Launch Vehicle

Wind Speed	Apogee (ft)	Drift Distance (ft)
0	4272	0
5	4220	525
10	4143	948
15	4043	1554
20	3922	2044

3.4 Vehicle Demonstration Flight

3.4.1 Launch Day Conditions and Simulation

On February 9, 2019, the team executed the first flight of the full-scale launch vehicle, No Promises, in Bayboro, NC. The launch field in Bayboro is a corn field used for launching high-powered rockets in the off-season with a total area of 6.5 square miles as shown in Figure 3-52 below.

Figure 3-52 Satellite Image of Bayboro Launch Field

The launch field is divided into many different sections, each separated with an irrigation ditch. These ditches are hazardous to both the launch vehicle and personnel, described in Section 4.1. The fields have rows of dead corn stalks that make traversing the terrain difficult and slow and could potentially harm the launch vehicle. The team launched from approximately the middle of the field pictured above. Figure 10-2, shows the field conditions the morning of the launch. The ground was dry and the cloud cover dispersed throughout the day. Visibility was suitable by the time of launch. There was a high temperature of 51 ˚F and a low temperature of 31 ˚F with a sea level pressure of 30.72 inHg. This equates to a density altitude of –1787 ft. The maximum wind speed in

Bayboro on launch day was 18 mph, but the team observed 8-12 mph steady with gusts above these values.

Using the launch day conditions, a RockSim simulation was created to estimate the Apogee. Figure 3-53 shows the Predicted flight profile of the full-scale launch vehicle.

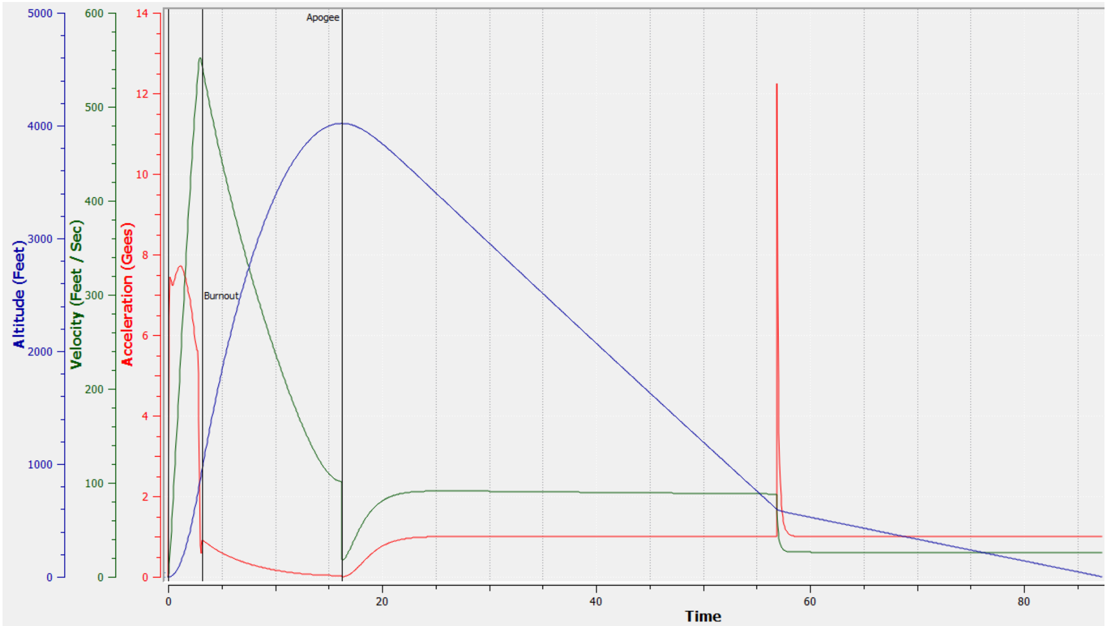


Figure 3-53 RockSim Simulation Using Launch Day Conditions

This simulation predicted an apogee of 4334 ft. Section 3.4.2 describes the difference between this simulation and the actual results

3.4.2 Analysis of Flight

Upon rail exit the rocket experienced extreme weathercocking. It traveled in a pronounced arc for the duration of the flight. This resulted in a measured apogee of 3560ft. Figure 10-9 shows the launch vehicle shortly after takeoff. The smoke trail was used to approximate the angle that launch vehicle deviated from vertical after rail exit. This angle was estimated to be 15 degrees from vertical.

Due to errors in shear pin calculations the flight was further compromised by the deployment of the main parachute at apogee. Post-flight testing indicated that shear pins thought to be rated for 70-75 lbf only supported 30-35 lbf. The force of drogue deployment was likely enough to shear through the main parachute bay shear pins and cause premature deployment. During recovery, the main parachute black powder charges were both discovered to have detonated during the descent phase of the flight. These detonations combined with a thorough check of the altimeter and recovery system wiring harness served to rule out altimeter or powder charge failure. This initial conclusion was later backed by testing of shear pins from the same batch as those used during the demonstration flight that indicated an insufficient number of shear pins were used during the demonstration flight.

3.4.2.1 Comparison of simulation and demonstration flight

Apogee was approximately 800 ft below the simulated apogee for prevailing conditions of the field and launch vehicle. Figure 3-54 shows the altimeter data from the primary altimeter used on launch day.

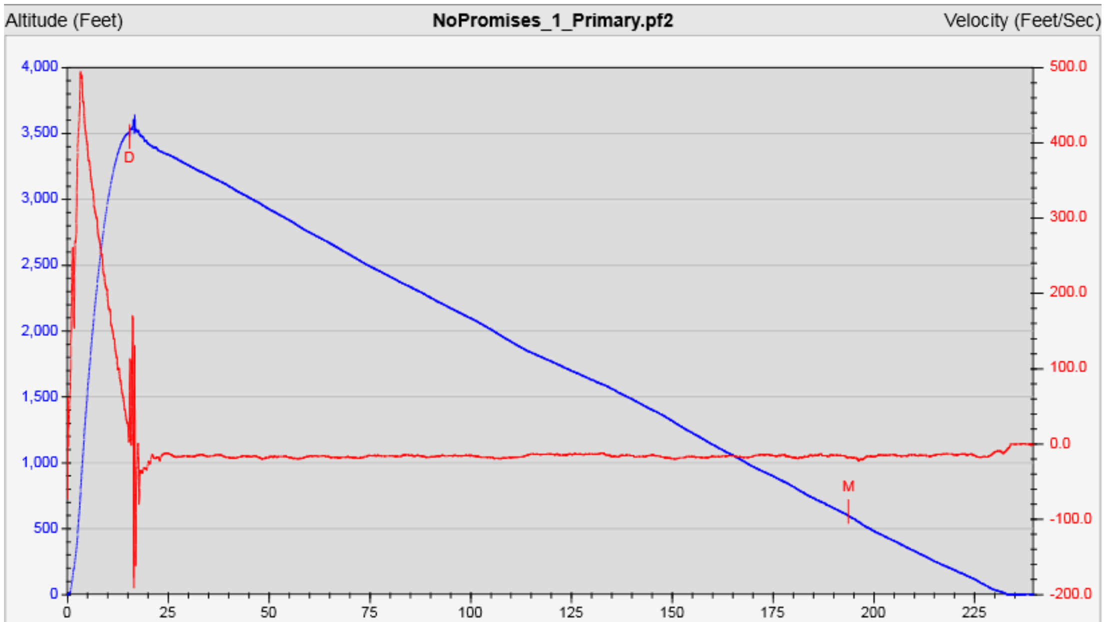


Figure 3-54 Flight Data from Primary Altimeter

Adjusting the launch rail angle to 15 degrees in Rocksim produced the flight profile in Figure 3-55.

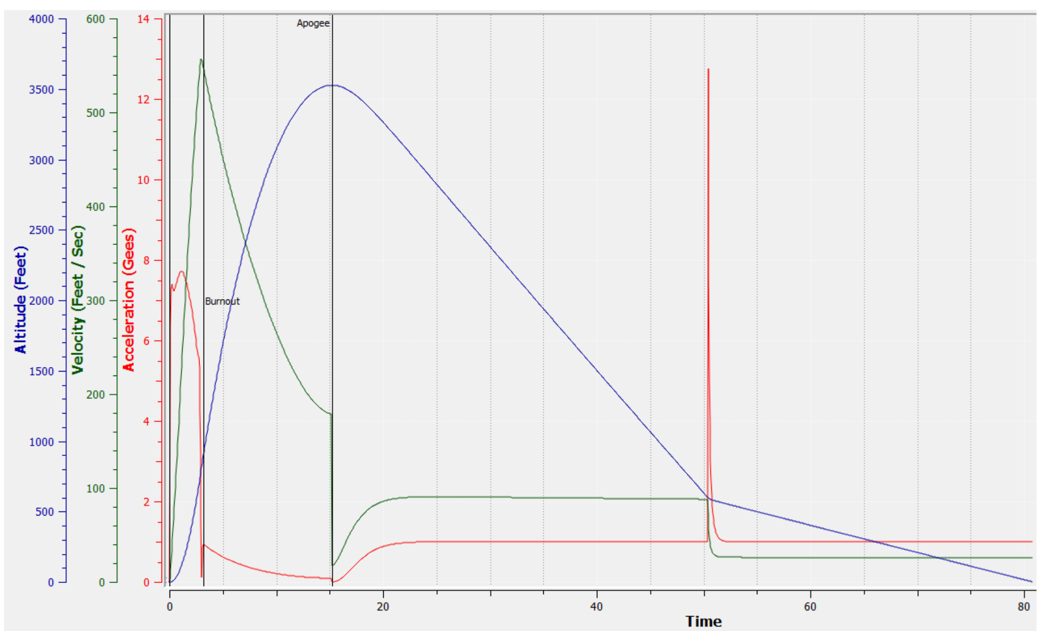


Figure 3-55 RockSim Simulation using Launch Day Conditions and Rail Angle of 15 degrees

3.4.2.2 Sources of Error

The RSO noted that he had released his hand from the launch control for several seconds before motor ignition. While not conclusive, this does lend itself to concerns that a slow motor start exasperated the already weathercocked flight profile. Additionally, the ignitor was not inserted into the motor using a dowel. With larger motors, a dowel ensures that the ignitor head is located at the forwardmost end of the grains. The ignitor wire was measured and marked with the length of the motor as a means of confirming its proper placement. However, it is possible that the wire did not hold its shape resulting in the ignitor head being installed improperly.

Several spectators reported that the launch pad was swaying slightly due to gusts of wind. The team mentors describe this phenomenon as “pad whip” and suggested that it may have hindered the launch vehicle in the initial seconds after ignition. Based on these observations, the team has elected to make several procedural changes. All of these changes seek to reduce the launch vehicles vulnerability to weathercocking in the moments immediately after rail exit.

In the future, the team plans to use a dowel rod to confirm proper ignitor installation. Furthermore, the local Tripoli prefecture has permitted the team to use a larger, more stable launch pad for future launches. In addition to this stronger launch pad, the team will be using a 10 ft launch rail for all future demonstration flights as opposed to the 8 ft rail used in previous flights. Additional time on the rail will allow the launch vehicle to reach a higher velocity before rail exit. This will reduce the angle of apparent wind that the rocket experiences at rail exit.

3.4.2.3 Estimated Drag Coefficient

After concluding that weathercocking was the most significant factor that affected the launch vehicle’s apogee the drag coefficient of the rocket could then be estimated. Using RockSim, and the launch conditions described in Section 3.4.1, the CD was manually overridden until the apogee values matched those of the vehicle demonstration flight. This resulted in an estimated drag coefficient of 0.55. Figure 3-56shows the flight profile of the full-scale rocket in nominal wind conditions.

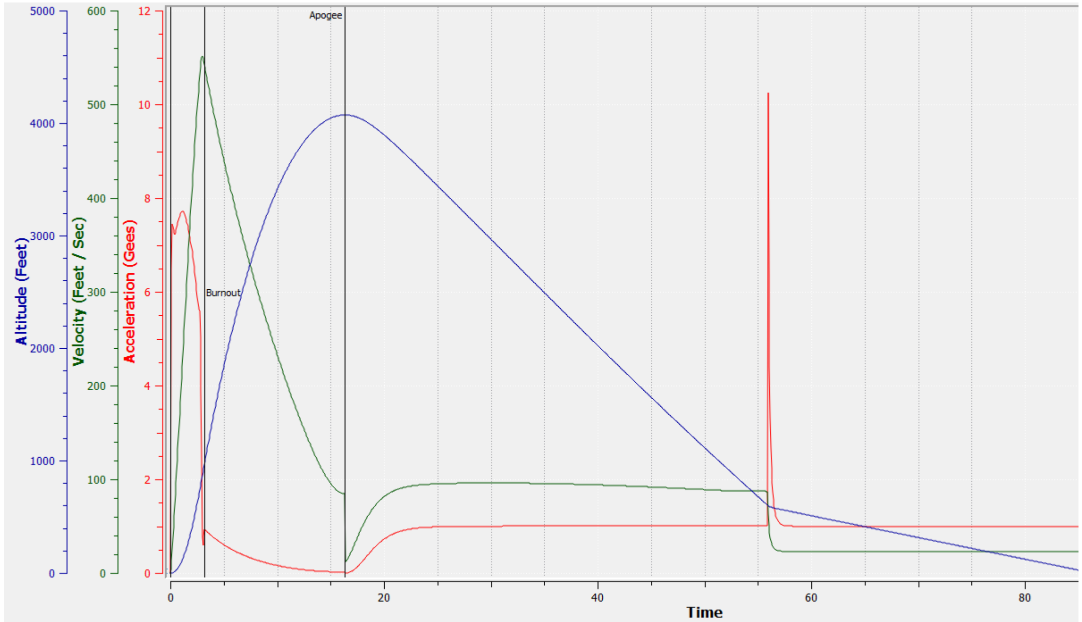


Figure 3-56Flight Profile of Full-Scale Launch Vehicle with adjusted Drag Coefficient

3.4.2.4 Comparison of Full-Scale and Subscale

In both cases, the launch vehicles exhibited severe weathercocking upon leaving the launch rail. This caused the apogee of both vehicles to be lower than what was predicted by RockSim. The subscale made use of 4 shear pins at each connection point, requiring a large amount of black powder for the small size of the vehicle. Conversely, the full-scale launch vehicle made use of two shear pins at each connection point. This was insufficient to hold the main parachute bay in place during drogue deployment and resulted in premature deployment of the main parachute. Following the shear pin tensile test described in Section 6.1.2, this number was increased to six shear pins. Both launch vehicles had soft landings and suffered minimal damage due to ground impacts and dragging. All onboard electronics were protected from water damage, but the payload electronics on the full-scale launch vehicle suffered damage due to inertial forces. Changes were made to better protect the electronics from damage, these changes are described in Section 5.1.2.2.

4. Safety and Procedures

4.1 Safety and Environment

4.1.1 Updated Personnel Hazards Analysis

The updated Personnel Hazards Analysis tables are in Appendix A of this document.

4.1.2 Updated Failure Modes and Effects Analysis

See Appendix A for FMEA Tables relevant to this project. Clarifications for the mission success spectrum, severity levels, and likelihood levels are given in the following tables

Table 4-1 Clarification on the Spectrum of Mission Failure to Mission Success

Level	Aspects	
	Project	Human
Complete Failure	Unrecoverable launch vehicle Unrecoverable UAV	Severe crew and/or spectator injuries due to operational and non-operational activities
Partial Failure	Launch vehicle repairable Successful takeoff and unsuccessful descent of launch vehicle UAV repairable Successful primary takeoff, unsuccessful beacon release, and unsuccessful secondary takeoff of UAV	Minor crew and/or spectator injuries due to operational and non-operational activities
Partial Success	Launch vehicle repairable Successful takeoff and descent of launch vehicle UAV repairable Successful primary takeoff, beacon release, and secondary takeoff of UAV	Near miss incidents involving crew and/or spectators related to operational and non-operational activities
Complete Success	Recoverable launch vehicle Nominal launch vehicle takeoff and descent Recoverable UAV Nominal UAV primary takeoff, beacon release, and secondary takeoff Launch operations can be repeated same day	No crew and/or spectator injuries related to operational and non-operational activities

Table 4-2 Clarifications of Severity

Level	Description
4	Human safety and project safety at minimum risk due to active safety measures.
3	Human safety and project safety at lesser risk due to active safety measures.
2	Human safety and project safety at greater risk despite active safety measures.

1	Human safety and project safety at maximum risk despite active safety measures.

Table 4-3 Clarifications of Likelihood

Level	Description
4	Minimum frequency of failure possible due to active safety measures.
3	Lesser frequency of failure possible due to active safety measures.
2	Greater frequency of failure possible despite active safety measures.
1	Maximum frequency of failure possible despite active safety measures.

4.1.3 Updated Environmental Hazards Analysis

The updated Environmental Hazards Analysis tables are in Appendix A.

4.2 Launch Operations Procedures

All launch operations are detailed in Appendix B of this document.

5. Payload Criteria

5.1 Payload Design and Testing

5.1.1 Changes since CDR

Change	Reason for Change
Lead Screw Pitch Change	A three times shallower pitch lead screw was used to increase the robustness of the deployment system.
Addition of Gearing System	Two (2) gears were added to the motor configuration to increase the torque on the lead screw.
Pod Flap Shape Change	Seen in Section __, the shape of the pod flaps has changed to accommodate the UAV arms after deployment.
Pins added to payload pod	Pins were added to the floor of the payload pod in order to improve the takeoff characteristics of the UAV.
Electrical Relay added to latch circuit	An electrical relay was added to amplify the voltage going to the retention latch.
Quick Disconnects changed to more effective model	New quick disconnects were purchased because others kept breaking.
AA Battery packs have been moved	The AA Battery packs have been moved to the inside of the Nosecone.

Addition of Electronics Cover	A cover has been added to protect the Arduino and wiring from in-flight forces.
Addition of latch terminal block	A terminal block has been added for easy access to the payload latch system.
Increased motor speed	The speed of the motor has been increased to deploy the pod faster.
Battery protection sled streamlined	The battery protection sleds were streamlined along the longest axis of the pod.
Folding arm hinge slot increased	The hinge slots on the arm of the drone increased in angle by three (3) degrees to fold the arms in further.
Hinge slot radius increased	The hinge slot radius was increased to reduce friction between the metal rod and the hinge.
Electronic Switch added for Solenoid	The electronic switch was added to have a mechanism to activate the solenoid when necessary.

5.1.2 Payload Features

In order to best complete the competition, many components, both custom and off-the-shelf, have been added to this UAV. The details of these systems are as follows:

5.1.2.1 Structural Elements

The Payload pod is designed to hold the UAV during flight, be rotated and deployed with the UAV, and act as a launch pad for UAV takeoff. By threading the carbon fiber rod through the center of both the pod and UAV, they are both able to rotate heavy side down upon exiting the body tube.

The removable bulkhead allows for better assembly and design of the payload bay electronics, motors, and payload latch. Because the entire bulkhead can be removed, each item on the bulkhead can be fastened more securely.

The pusher assembly is what drives the payload pod and UAV from the body tube. The pusher rides along a lead screw, pushing the payload pod and eventually supporting it on the cantilevered rod. The Pusher is prevented from rotating by an auxiliary rod forcing it to slide axially within the payload bay instead of rotating until it hits the wall. The auxiliary rod also prevents the pusher from tipping forward under the weight of the pod.

The Arduino, shield, and radio receiver are stacked in that order, one on top of the other, and secured in place with solder and friction-fit metal pins, respectively. The electronics cover is then placed on top, with all wires from the Arduino and the radio antenna exiting the cover via small slots for just such purposes. The entire subassembly is next firmly secured to the payload bay bulkhead via 2-inch-long 4-40 screws. The electrical relay is inserted into its aforementioned box atop the electronics cover and a small zip-tie is secured through a pair of holes in the side of the relay box, securing the relay in place during flight. All wires directly connected to the relay are secured with hot melt adhesive to ensure a constant and high-quality connection with the small integrated pins of the relay. The wires of the latch circuit are secured into the appropriate holes such that the lead from the relay connects to the voltage supply and signal receptacles of the latch while the ground wires are connected to each other. A model of the assembly is shown in Section 5.1.4.

The constructed UAV was based on a generic QAV-R 220 carbon fiber racing quadcopter frame. This has the obvious disadvantage of not fitting easily into the 5.5 inch launch vehicle body tube. To circumvent this problem, custom hinges were designed and fitted onto each arm of the UAV. Two hinges are applied to each of the four arms, for a total of eight hinges. The two hinges on each arm allow for maximum transfer of loading from the motors to the UAV body and are bolted to the frame in three places. The fourth hole in the hinge is a slot through which a bar that is fitted into the carbon fiber arm slides. The slots curve through a 60 degree angle, allowing the arms of the UAV to fold slightly past parallel to the payload containment pod. A dimensioned drawing of the final hinge is presented below in PLACEFIGURENUMBERHERE. The hinge width is the same as the arm of the quadcopter, and a double radius fillet has been applied to slim the profile of the folded configuration. The bolt holes were printed as 0.13 inch in diameter which allows a #4-40 bolt to thread itself through the ABS printed plastic.

In compliance with requirement 4.4.10, a battery sled system has been designed and attached to the UAV to protect the battery from ground impacts. In flight, the battery is mounted to the UAV underneath the main body and held by two hook and loop straps, one in front and one behind for ease of removal. The sled acts as a set of legs that extends past the battery, meaning any ground loading is transferred through the legs. The legs are 3D printed and attached via the same #4-40 bolts that hold the hinges. A dimensioned drawing of one of the legs is shown below in Section 5.1.5.

Due to the payload deployment system design, the cantilever rod that is responsible for pushing the pod out of the launch vehicle must pass through the pod during deployment. Because of this, the FPV camera mount on the drone needed to be adjusted to leave space for the rod to pass through. The FPV camera mount on the UAV was previously made of steel but was determined to be too short to allow adequate space for the cantilever rod. The mount design was made taller to increase the open space between the bottom of the camera and the UAV frame. The new design 3D printed, using PLA filament and installed on the UAV using existing mounting hardware.

Additionally, the quadcopter will utilize two-blade propellers that will also stay parallel with the body tube while in storage during flight.

5.1.2.2 Electrical Elements

In order to provide sufficient electrical power to the latch for successful operation, an electrical relay was implemented between the latch power supply's positive terminal and the remainder of the latch circuit, with an updated schematic shown below in Figure 5-1.

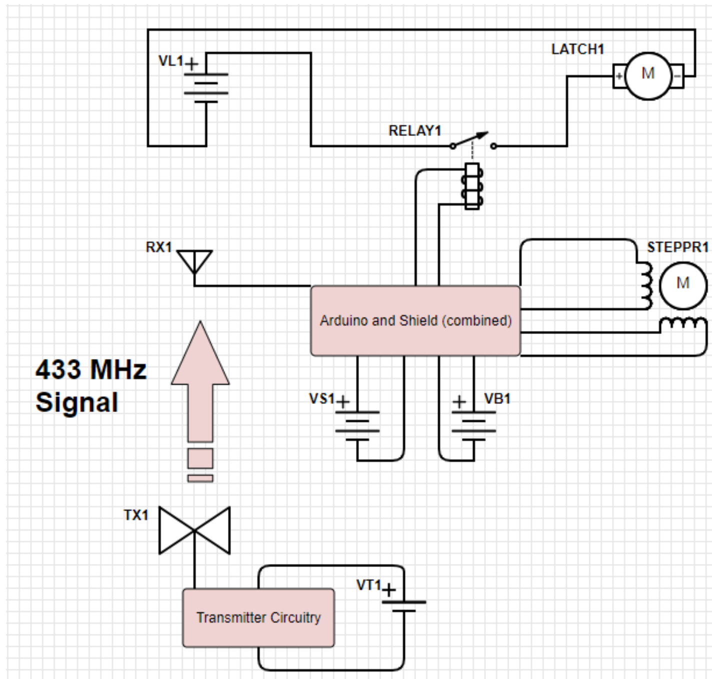


Figure 5-1 Payload Deployment Electronics Schematic

The deployment process has not drastically altered due to this change, but an up-to-date process flowchart is provided in Figure 5-2.

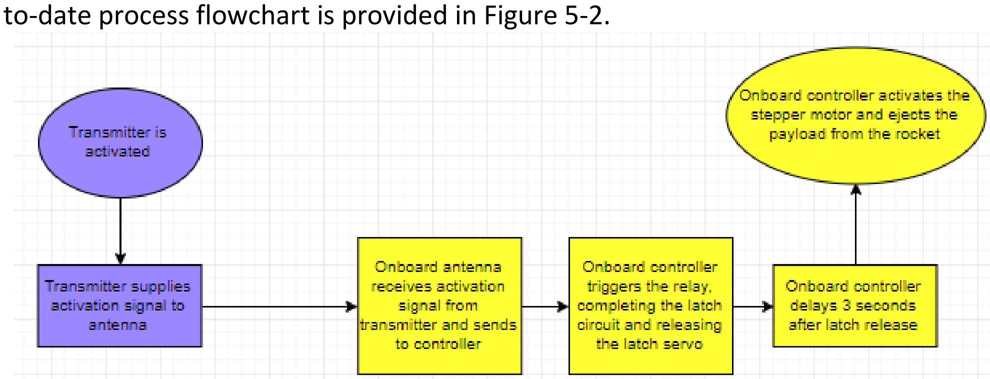


Figure 5-2 Payload Deployment Electronics Flow Chart

The UAV utilizes a solenoid-based system to deploy the Simulated Navigational Beacon (SNB). Originally, it was believed that the flight controller would be able to directly control the solenoid actuation, but there was no method to program the universal asynchronous receiver-transmitter (UART) pads on the flight controller to simply turn on or off. To mitigate this issue, a secondary device was introduced into the system. The secondary device is a RealPit VTX Power Switch, sold by TinysLEDs. While the name suggests its use as a VTX switch, the device is simply a controller that takes SmartDevice input from the RX UART pads on the flight controller as a means to open and close circuits from the radio transmitter. The solenoid is wired to this switch via a 5V source, of which a compatible connection is included on the flight controller. A 3D printed casing is adhered to the solenoid, and the final system is glued to the roof of the UAV. It has a throw of about 1/3 inch and is utilized a as a puller, which, upon activation, will pull a pin from the farthest section of the casing, dropping the SNB.

Table 5-1 Quadcopter Electronic Components List

Component	Product	Notes
Motors	EMAX RS2205 2300KV	
Flight Controller	Airbot OmniNXT 7	
ESC	Airbot Typhoon32	35A 4-in-1
Power Cell	GOLDBAT 3S LiPo	11.1V, 3000mAh, 30C
Camera	Crazypony RunCam	
Propellers	Lumineer 5x3.5x2	
Frame	QAV-R 220	
Antennae	Pagoda 5.8GHz	(x2) circular polarized
Video Transmitter (VTX)	WolfWhoop T86	0/25/200/600mW switchable
Radio Receiver	FrSky XM+ SBUS Mini	
Video Receiver	DX800 DVR 5.8GHz	
Radio Transmitter	FrSky Tarannis X-Lite	
Solenoid	Sparkfun Solenoid 5V	
Solenoid Switch	RealPit VTX Power Switch	Not wired to the VTX

5.1.3 Flight Reliability Confidence

In order to improve payload flight reliability, the payload pod must be successfully retained and deployed. The connection between the removable bulkhead, the latch, the eye-ring, and the pod were all tested under expected flight loads with an additional factor of safety. The results from this test as well as a description of the steps taken can be found in Section 6.1**.** The torque of the deployment motor was also increased using a low-pitch lead screw and a 2.5 to 1 gearing ratio. If debris from the ground were to interact with the deploying payload pod, this additional torque would assist in successful deployment.

Based on the results of the tests and demonstrations described in Section 6.1 coupled with the results of the first payload demonstration flight described in Section 5.1.7 , the team is confident that the launch vehicle will be capable of fulfilling all criteria for mission success.

5.1.4 Construction Process of the Payload

In order to construct the Payload Bay, A SOLIDWORKS model was created for all internal systems. Many of the parts for the payload bay are either 3-D Printed or laser cut. By ensuring that all of the parts worked together within the model, the team was able to focus on manufacturing and installing the parts. Using the files created for the model, the pusher, payload pod, motor cover, and Arduino cover were 3-D Printed. The centering rings were also made from SOLIDWORKS files and were manufactured using a laser cutter and epoxy layup.

The removable bulkhead, created with the same method as other body tube bulkheads, was specially modified to act as the payload bulkhead. Using precise locations from the SOLIDWORKS model, holes were drilled in the bulkhead for the latch, lead screw bearing, motor axle, motor screws, body tube L-Brackets, and Arduino screws. Each of these parts was secured to the bulkhead with the appropriate fasteners.

The electronics cover and relay box were both designed using SolidWorks and converted into a format usable by a 3-D Printer, as the precise dimensions required were too fine to confidently achieve via hand manufacturing. After printing, the relay box was permanently attached to the top of the cover using cyanoacrylate, as seen below in Figure 5-3.

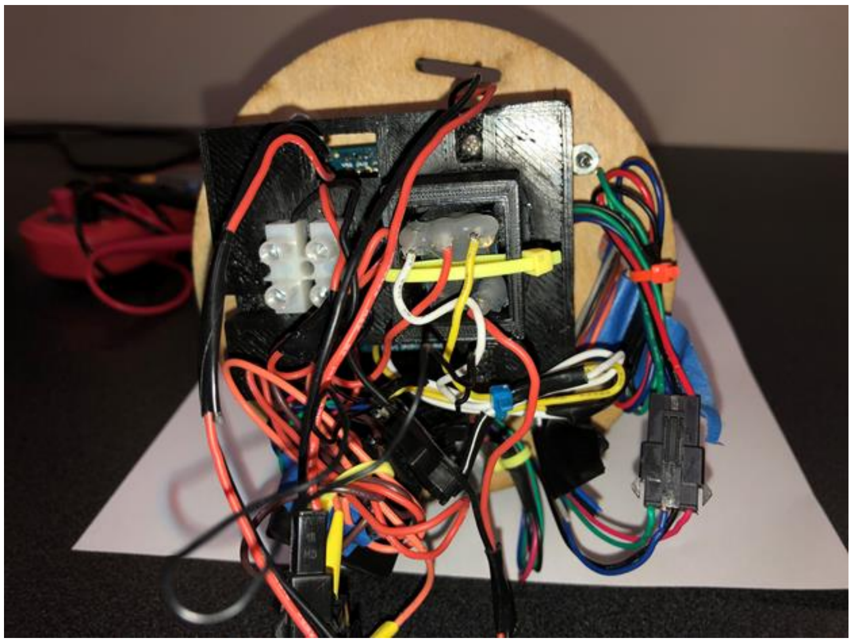


Figure 5-3 Payload Electronics Mount

For most electrical connections, soldering was utilized in order to ensure a strong, permanent bond. However, for connections that need to be temporary, such as connections between the power supply and Arduino, a different approach was taken. Shorter, permanent wires were soldered into connections that would be made permanently and the other end was trimmed and soldered into a locking quick disconnect, with an example of the finished locking disconnect presented in Figure 5-4.

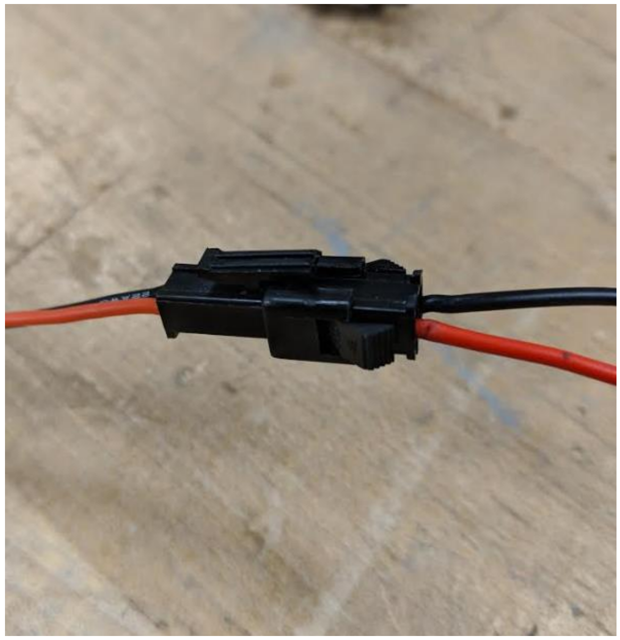


Figure 5-4 Quick Disconnect

The UAV construction process began with the installation of the hinges. In the Figure 5-5, the metal pins are not yet present.

Figure 5-5 UAV with Folding Hinges in Place

Once the pins were added, rubber bands were stretched between adjacent pins to hold the arms open. The 4-in-1 ESC was mounted using M3 nylon standoffs. At this stage the arms were also labelled with the numbers designated to them by Betaflight, the software used to program the flight controller.

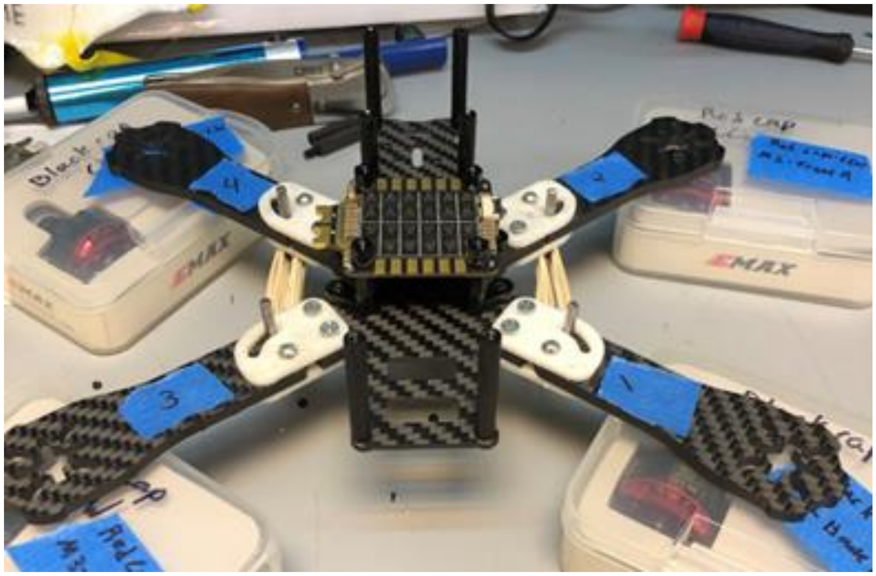


Figure 5-6 UAV with Rubber Bands Holding the Arms Open

For the standoffs to fit onto the 4-in-1 ESC, the edges had to be sanded down using a handheld rotary tool, as shown in Figure 5-7.

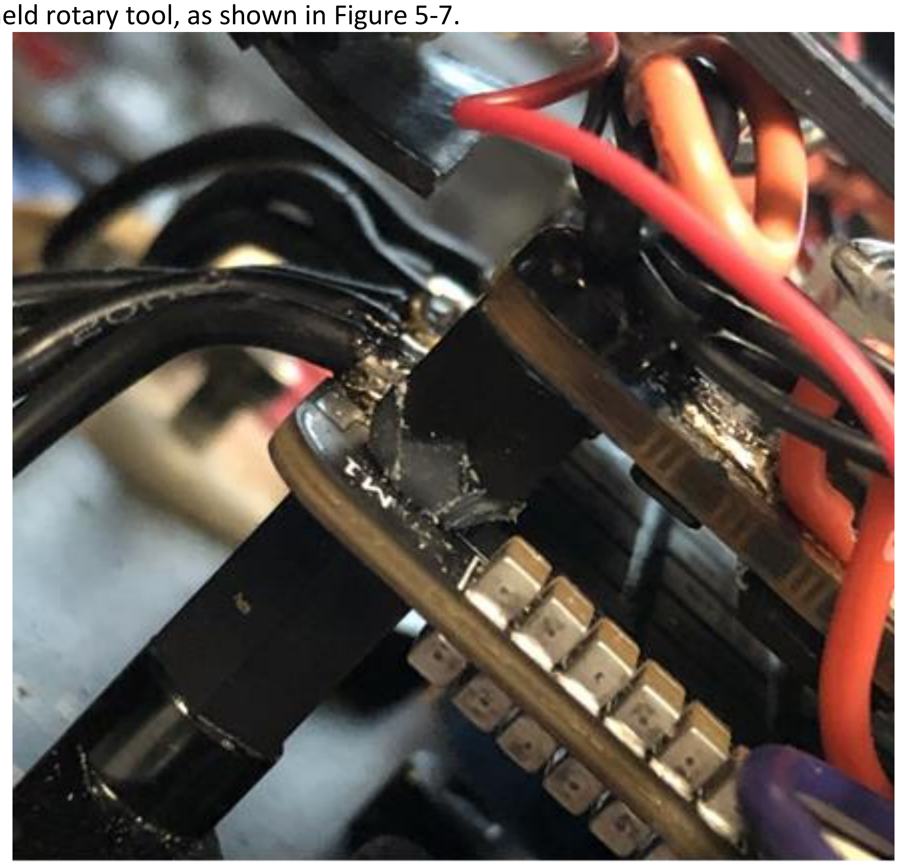


Figure 5-7 UAV Flight Computer Stand Offs

The motors were wired to the 4-in-1 ESC and the flight controller was mounted to the stack. Figure 5-8 also shows the radio receiver in a potential location to be mounted.

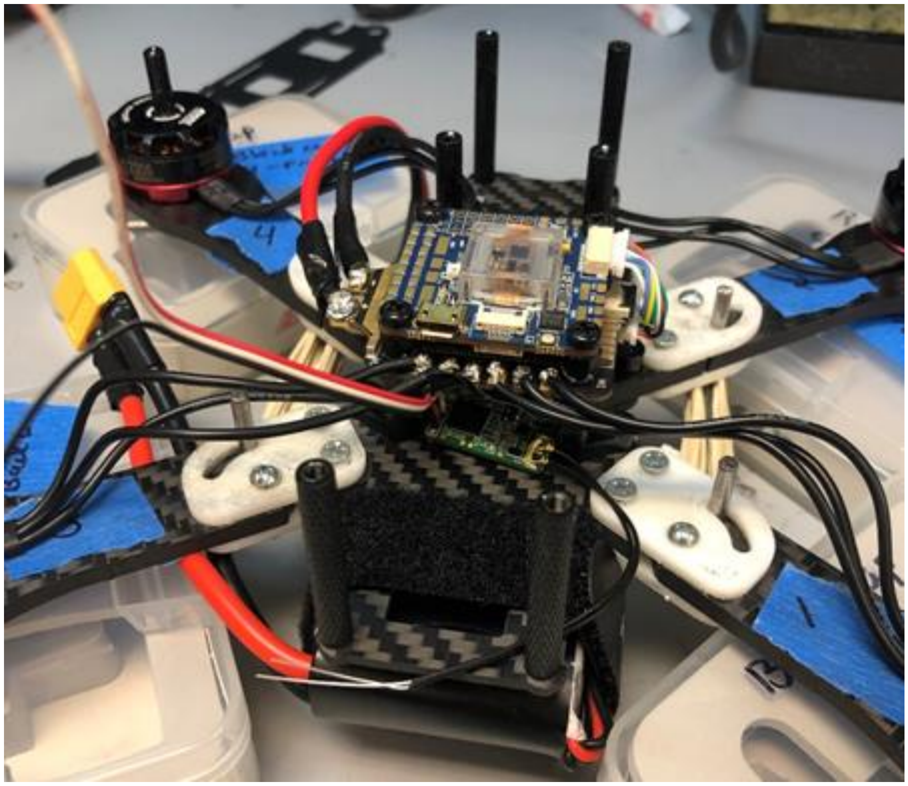


Figure 5-8 UAV Motors Wired to Flight Controller

Figure 5-9 is the first demonstration of the video transmitter (VTX) wired to the camera and transmitting video to the video receiver (VRX).

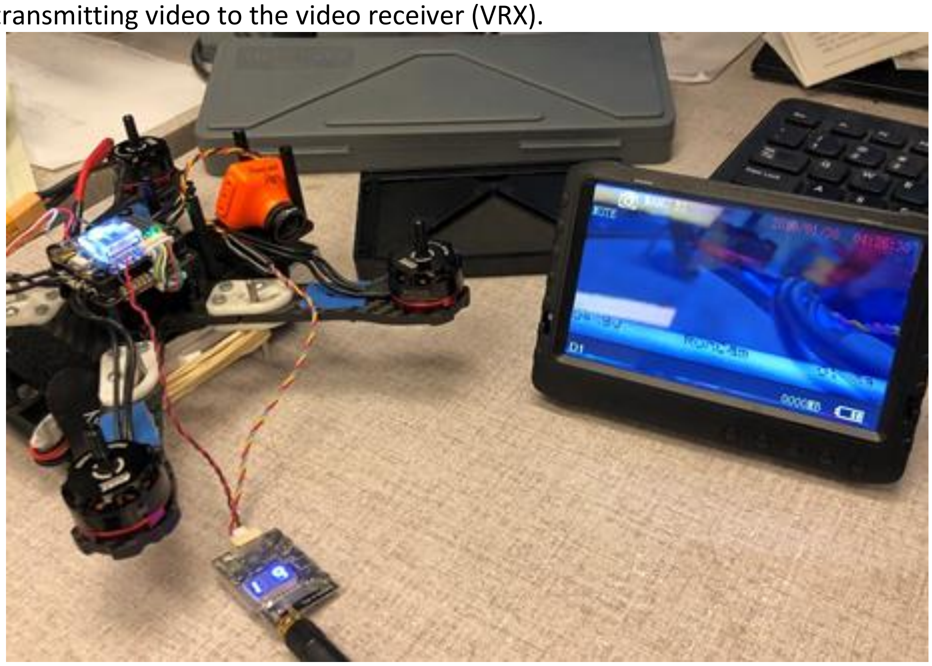


Figure 5-9 VTX Camera Demonstration

The battery protection sled legs were mounted to the bottom of the UAV using longer #4-40 screws than the other hinge mounting holes.

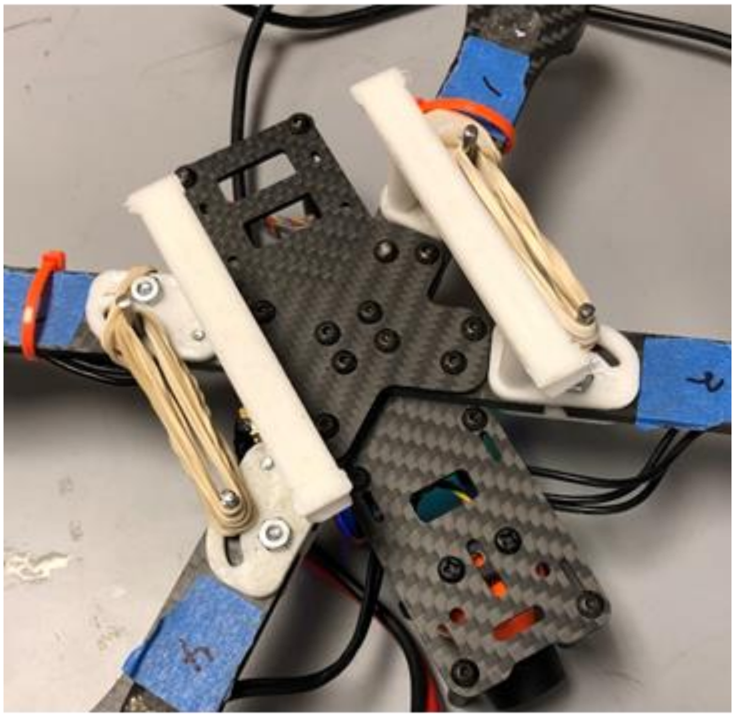


Figure 5-10 UAV Battery Protection Sled Legs

Figure 5-11 shows the UAV in flight-ready configuration for testing prior to final components being added which have negligible impact to flight performance. During these tests, it was discovered the wiring for the motors resulted in all four motors spinning clockwise, therefore producing zero net lift. The two propellers with the red lock nuts are designed to spin counterclockwise and the two propellers with black lock nuts are designed to spin clockwise. This issue was remedied by downloading and flashing the ESC with BL_Heli32 firmware and changing the spin direction of the propellers with the red lock nuts.

Figure 5-11 UAV Configured for Flight Testing

Once the flight issues were fixed, work began on preparing the UAV for integration with the pod and deployment system. Since that includes running a carbon fiber rod through the UAV, space had to be made for that to occur. This had already been taken into account with the electronics stack by using taller standoffs, but the camera proved to be an obstacle. The decision was made to recreate the camera stand that shipped with the camera but modify it to be taller. Since the camera was now too tall to fit into the main chassis, a slot was cut from the body as shown in Figure 5-12.

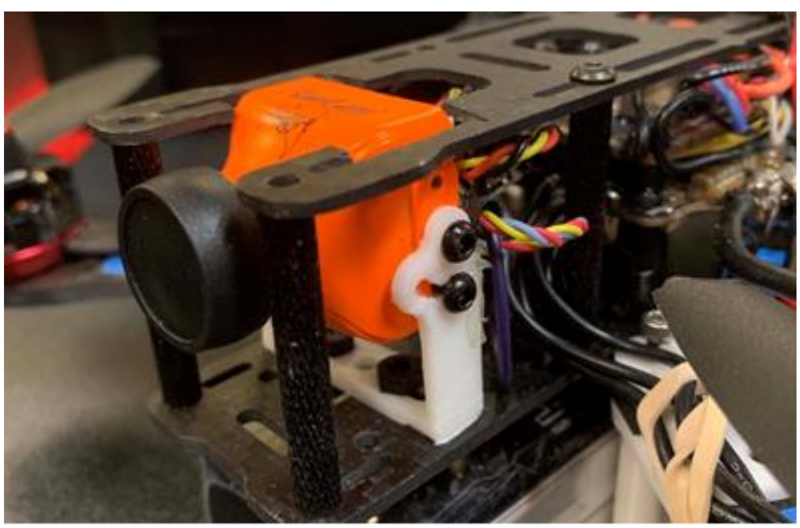


Figure 5-12 New camera mount installed on the UAV

With all components ready to add to the UAV, all wiring is done following the schematic found in Section 5.1.5. The solenoid switch and solenoid are attached and the solenoid and its casing are glued on to the roof of the UAV

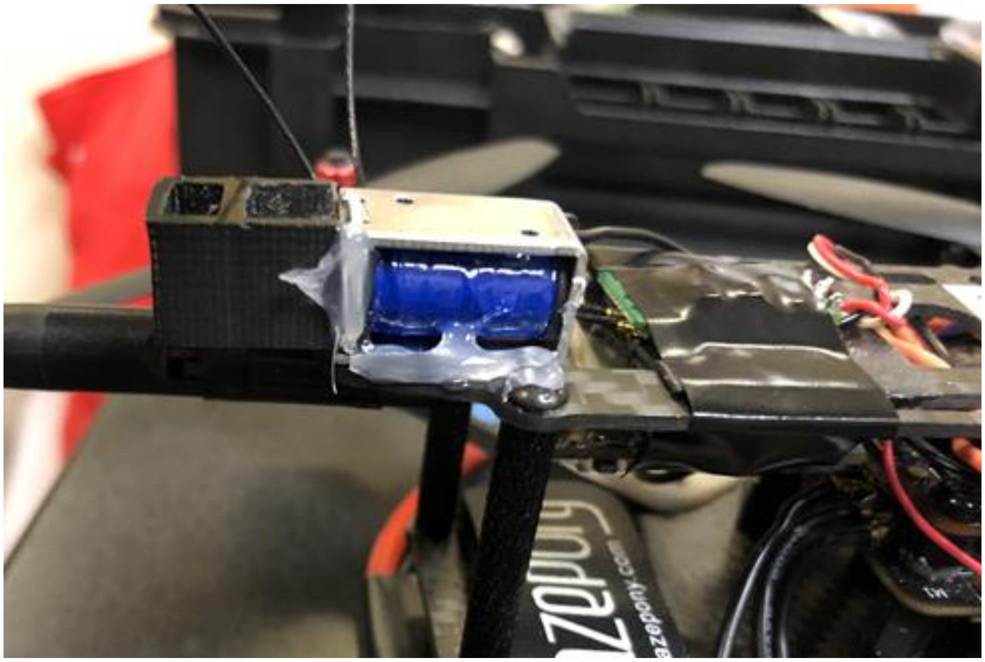


Figure 5-13 Solenoid mount for the SNB

Figure 5-14 UAV Mounting Holes

The above picture, Figure 5-14, shows the UAV mounting holes where the UAV interfaces with the payload pod. These holes are mounted on two (2) guide rods intended to guide the UAV to vertical flight and constrain it during the launch.

5.1.5 Schematics of As-Built Payload

The below figures show dimensioned drawings of the payload pod assembly consisting of the pod base, pod flaps, and pod pusher.

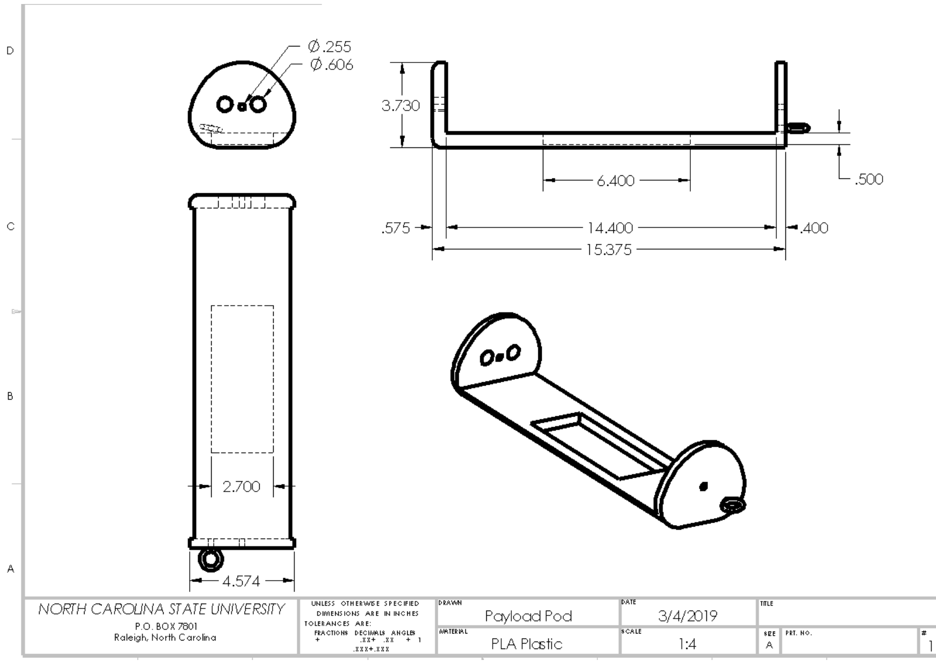


Figure 5-15 Payload Pod Dimensioned Drawing

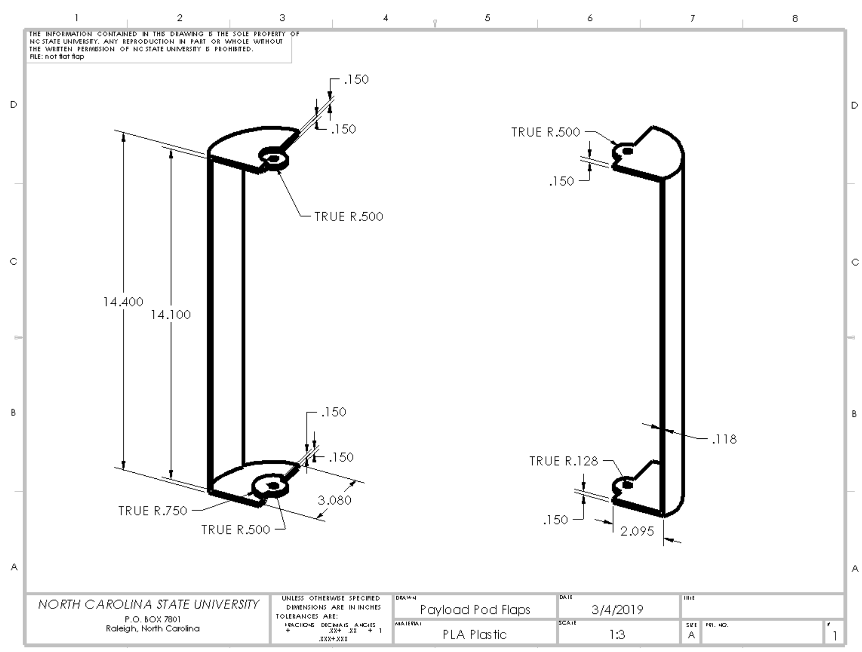


Figure 5-16 Dimensioned Drawing of Both Payload Pod Flaps

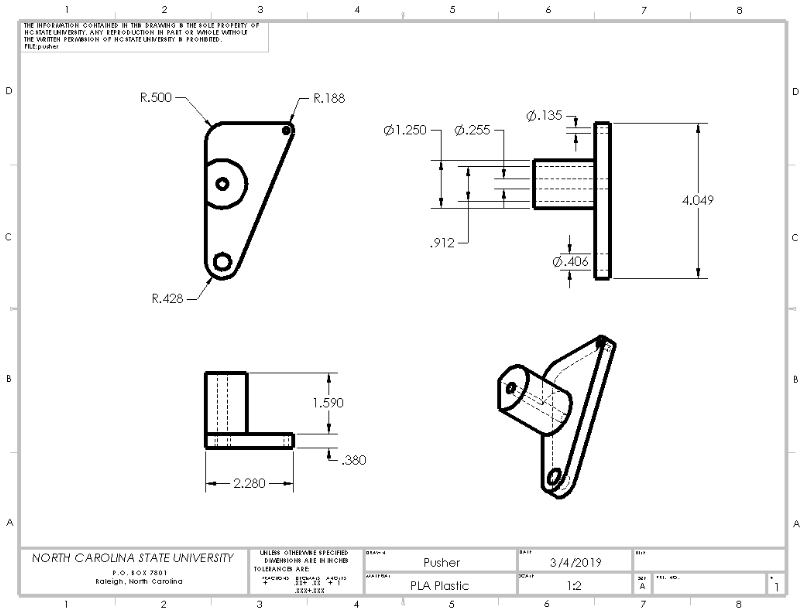


Figure 5-17 Dimensioned Drawing of the Pusher

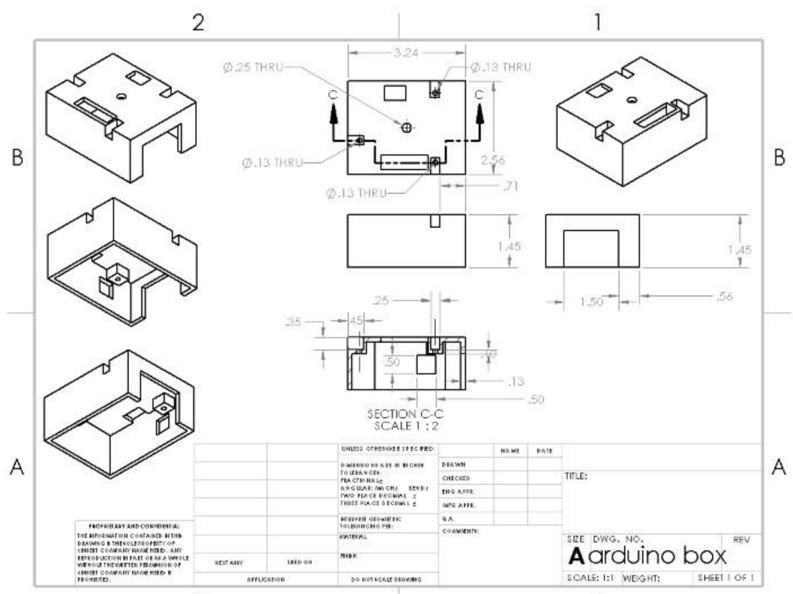


Figure 5-18 Payload Electronics Cover

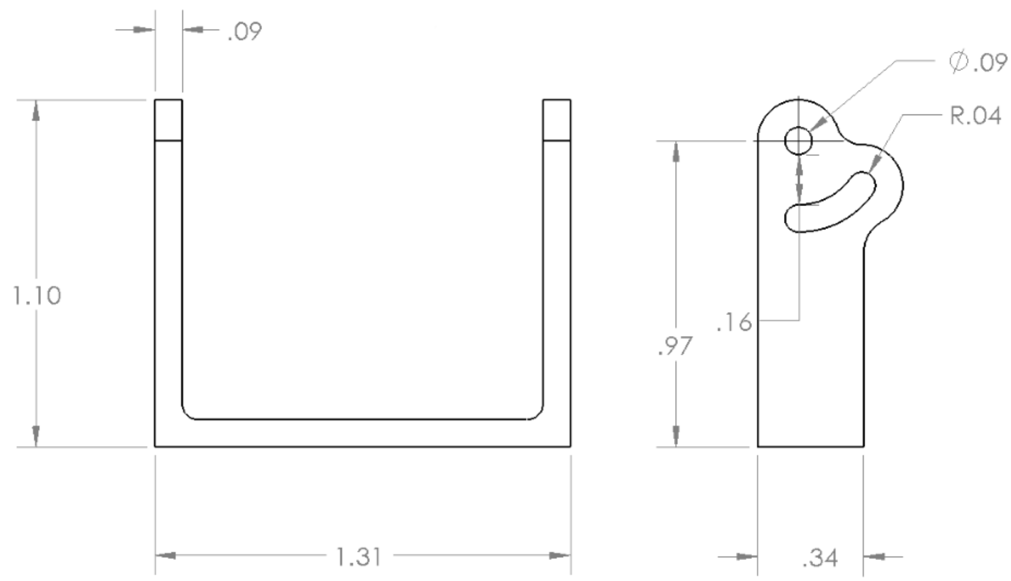


Figure 5-19 UAV Camera Mount

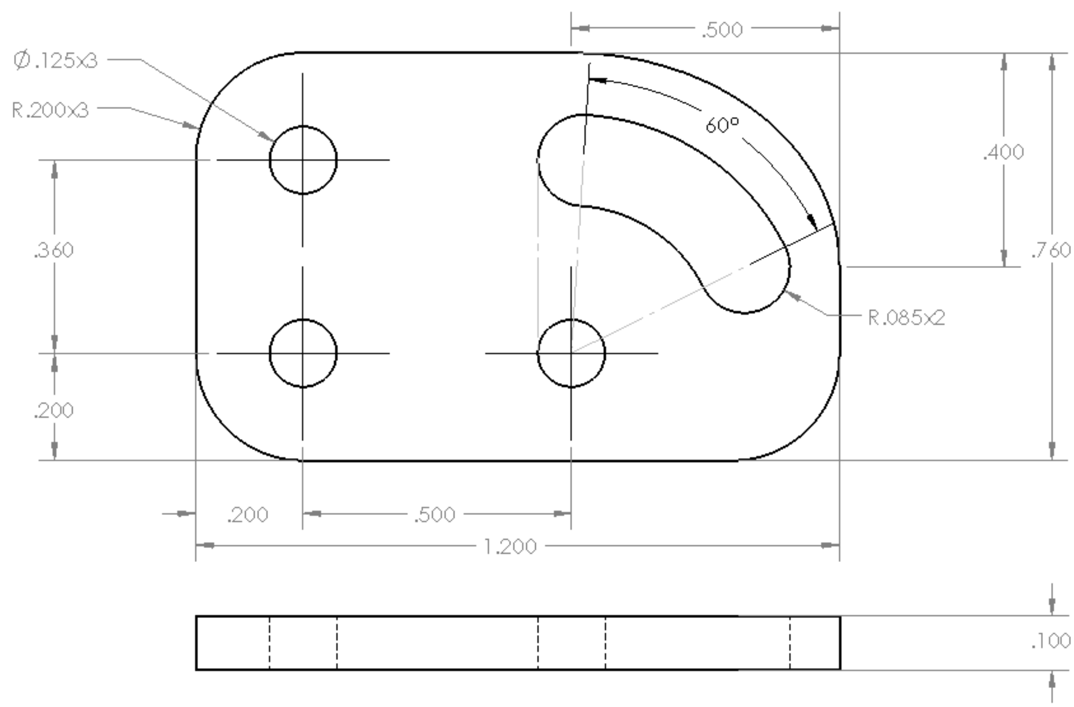


Figure 5-20 UAV Hinges

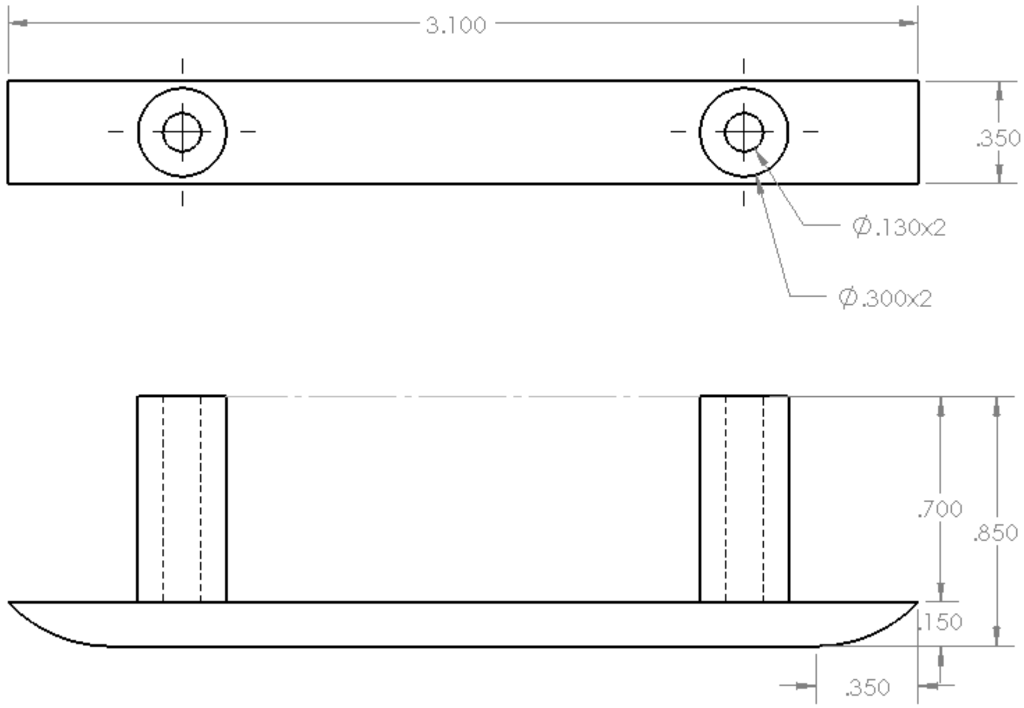


Figure 5-21 UAV landing Sleds

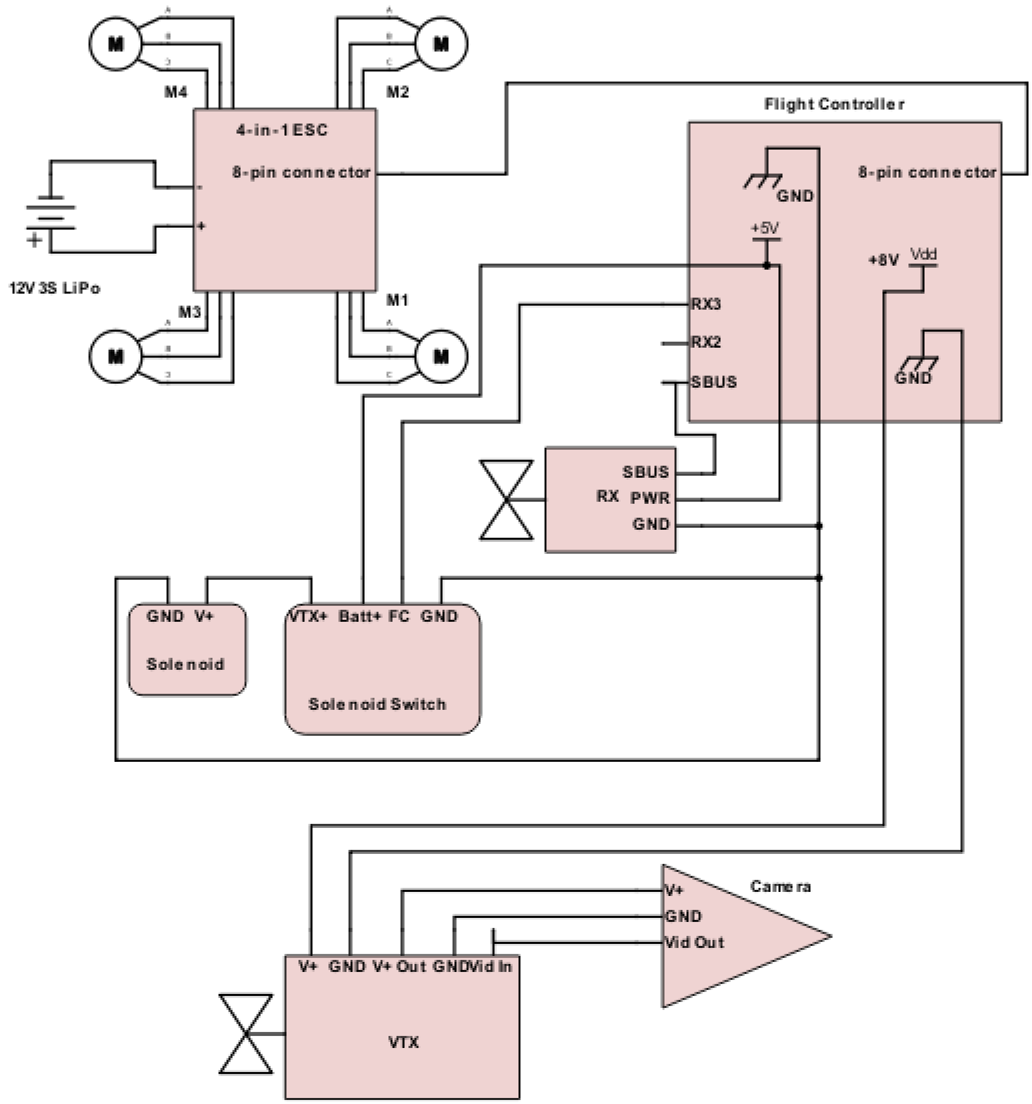


Figure 5-22 Wiring Diagram for the UAV

5.1.6 Differences from Earlier Models

For Payload Deployment, the pitch of the lead screw was reduced to three times shallower, and gears were added, because the motor would stop running in the presence of too much friction. In order to increase robustness to friction and unexpected sources of resistance to deployment, the torque output of the motor needed to be increased through the addition of a gearing system with a 2.5 to 1 gearing ratio. This resulted in 7.5 times the torque output from the system. The speed of the motor has also been adjusted to eject the payload pod faster.

The pod flaps are now open at the top to allow the UAV space to takeoff in more situations. If there is debris on the ground, the flaps may not be able to open fully, which would have interfered with the blades of the UAV. Now, once the rod retracts and the flaps are pushed open, there is a greater chance of successful opening of the pod.

The UAV needs to be secured in 5 degrees of freedom when the flaps are open, and 6 degrees of freedom when the flaps are held shut. Previously, the UAV would be held by a channel cut into the bottom of the pod. Upon takeoff the UAV would be prone to tipping to one side due to friction from the sides of the channel. The new design has vertical pins protruding from the floor of the pod. The drone has matching holes in the sleds which hold the battery. While the flaps and pod floor hold the UAV vertically during flight, the pins now hold it in the other 5 degrees of freedom. When the flaps open, the pins will allow the drone to take off smoothly and in a pure vertical direction.

An electrical relay has been added to the latch circuit to amplify the voltage being sent to the latch. Additionally, a terminal block has been added to the latch circuit to increase ease of access and manipulation of the latch system. Because of weak connections via plastic quick disconnects, new, more robust quick disconnects have been purchased and implemented. To protect the delicate wiring on the Arduino and shield assembly, an electronics cover has been fabricated to go over the Arduino sub-assembly and screw into the removable payload bulkhead.

The three battery packs used to power the latch, Arduino, and Arduino shield have been removed from the removable payload bulkhead and are now housed in the nosecone. These packs are attached to the inside of the nosecone via Velcro strips.

Issues with the planned VTX switch on the original video transmitter meant that the 600mW transmitter could not be used as per NASA requirement 2.24.9. To follow this requirement, the team has opted to forego using a switch on the video transmitter and instead using a new video transmitter that can switch transmission power.

5.1.7 Payload Demonstration Flight

5.1.7.1 Date of Flight

The team attempted a payload demonstration flight on February 9th, 2019 in conjunction with the vehicle demonstration flight described in Section 3.4. An additional Payload Demonstration Flight is scheduled for March.

5.1.7.2 Success Criteria

A successful payload demonstration flight is defined as compliance with handbook requirements 2.20.2.1-2.20.2.4 in Section 6.2. Specifically, the payload shall be retained throughout the duration of the flight and function as designed and the payload shall be in its final active version.

The team has also defined a successful flight as meeting the following criteria:

The pod and UAV are retained through launch, all recovery events, and landing.

The payload pod is successful in deploying from the rocket, orienting itself, and releasing from the carbon fiber rod.

The UAV arms are successful in pushing open the pod doors, fully extending the UAV arms, and allowing for the propellers to freely spin.

The UAV is able to take off vertically and fly to an FEA within 2,500 feet of the rocket landing site.

The UAV is able to successfully and completely release the SNB from the solenoid deployment system.

5.1.7.3 Results of Flight

As discussed in Section 3.4.2, the main parachute deployed at apogee. Because of this, the payload retention system was not subjected to the highest amount of acceleration that it will experience during a normal flight. While the payload pod and retention latch are oriented such that the latch will experience a compressive load at main deployment, this flight cannot be considered to be a comprehensive test of the payload retention system.

As discussed in Section 5.1.2.2, the flight controller requires a switch to properly operate the solenoid. This switch was not present on the drone at the time of launch, making it non-compliant with requirement 2.20.2.2. The switch was since been added and at the time of writing all UAV components have been implemented.

5.1.7.4 Analysis of Payload Retention System Performance

The SouthCo Latch successfully retained the payload throughout the flight. As state previously, this was not a comprehensive demonstration of the payload retention system. However, the results of the payload retention test described in section6.1 suggest that the latch is capable of withstanding the inertial forces that will act on it during flight.

After landing, the deployment sequence was triggered remotely, but the latch failed to disengage. Inspection of the payload electronic found that a wire had broken during flight, locking the latching in the closed position. Additionally, the stepper motor was not able to provide sufficient torque to drive the payload pod out of the payload bay body tube. Changes related to these issues are described in Section 5.1.1.

6. Project Plan

6.1 Testing

6.1.1 Bulkhead Failure Test

6.1.1.1 Test Description

The purpose of this test was to validate the strength of the adherence between the bulkheads in the launch vehicle and the body tube. The bulkheads are attached to the body tube using West Systems 2-part epoxy and cured for at least 24 hours. However, the performance of epoxy is difficult to accurately calculate or predict and therefore required testing to ensure that it would perform as needed. The nose cone bulkhead was of particular interest as it will experience the highest load of the epoxied bulkheads and also is the most difficult to properly install due to the contours of the nose cone. Because of this, this test was designed specifically to validate this bulkhead.

For this test, a 5.5-inch length of 5-inch diameter fiberglass body tube was used. A 5-inch diameter bulkhead was be constructed out of 6 layers of 1/8 inch aircraft grade birch plywood for a total thickness of 0.75 inch. A U-bolt was attached to this bulkhead via two drilled holes and fastened using hex nuts and a metal plate. The bulkhead was installed into the section of body tube using West Systems 2-part epoxy and allowed to cure for more 24 hours as was also done with actual construction of the launch vehicle. While this configuration very closely simulates the nose cone bulkhead design, it will be installed into a body tube section rather than a nose cone due to constraints based on the available testing machinery. A 5-inch diameter, 0.5-inch-thick aluminum bulkhead was machined and secured to the opposite end of the body tube section from the plywood bulkhead. This bulkhead is simply meant as an attachment point to the tensile rig and to reduce any additional points of failure that could be added to the system by using another plywood bulkhead for this purpose.

6.1.1.2 Test Setup

The procedure for this test can be found in Appendix D

6.1.1.3 Safety Notes

During fabrication of the test specimen, safety glasses, masks, gloves, or other PPE was worn by all personnel nearby when appropriate. Safety goggles and a machine cover were also utilized when operating the test machine and all personnel will remain a safe distance away while testing is in progress.

6.1.1.4 Pass/Fail Criteria

At the time of testing, the nose cone bulkhead was expected to experience a maximum load of 234.44 lbf during flight. A successful test would indicate a factor of safety of 2; this means the bulkhead will withstand a load of 468.88 lbf with no signs of damage.

6.1.1.5 Results

This test was run a total of three times. The first iteration allowed the team to identify several parts of the procedure which needed to be adjusted to obtain usable data. Prior to this test, it was discovered that the gripping arm of the universal testing machine was not able to sufficiently grip the U-bolt used in the bulkhead alone. The remedy to this issue the first run of the test was to use a second U-bolt that was offset in order to apply a centered load as shown in Figure 51.

Figure 6-1 Bulkhead Failure Testing Setup – Run 1

In addition, during this test, only four of the six evenly distributed bolts were able to be used to secure the body tube to the aluminum bulkhead. One missing bolt can be seen in Figure 6-1. Finally, it was noted prior to testing that this bulkhead had cured slightly crooked within the body tube. The bulkhead was tested nonetheless and indicated an unacceptable strength of only 252.88 lbf. The data from this test is presented in Figure 6-2.

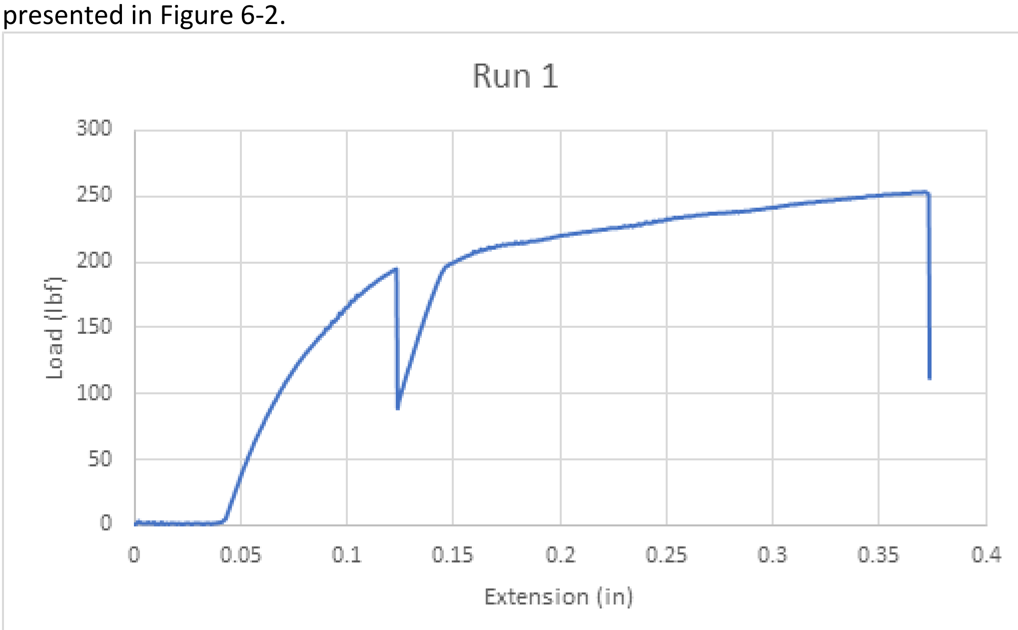


Figure 6-2 Bulkhead Failure Testing Data – Run 1

The data shows two locations where the load decreased sharply. However, the team believes only one to be failure of the bulkhead; the sharp decrease at approximately

190 lbf is thought to be a result of the two U-bolts shifting in place relative to each other rather than failure of the bulkhead as after this occurred during the test, no damage was visible in the bulkhead. At the second drop, the bulkhead had visibly been removed from the body tube.

Though this data indicates that this bulkhead configuration is not sufficient, the team believes this particular run to have several errors which cause it to be an invalid test. These errors include the fact that the bulkhead was not installed properly as well as the method of attachment to the test machine. After testing, the U-bolt which was clamped by the machine was inspected and was visibly deformed as a result of the test.

On the next two runs of this test, measures were taken to mitigate these errors. Rather than using a U-bolt, a quick link was used to attach to the UTM. In addition, measures were taken to ensure that the bulkhead remained positioned correctly while curing of the epoxy. The below graph, Figure 6-3, displays the data collected from the two final iterations of the Bulkhead Failure Test.

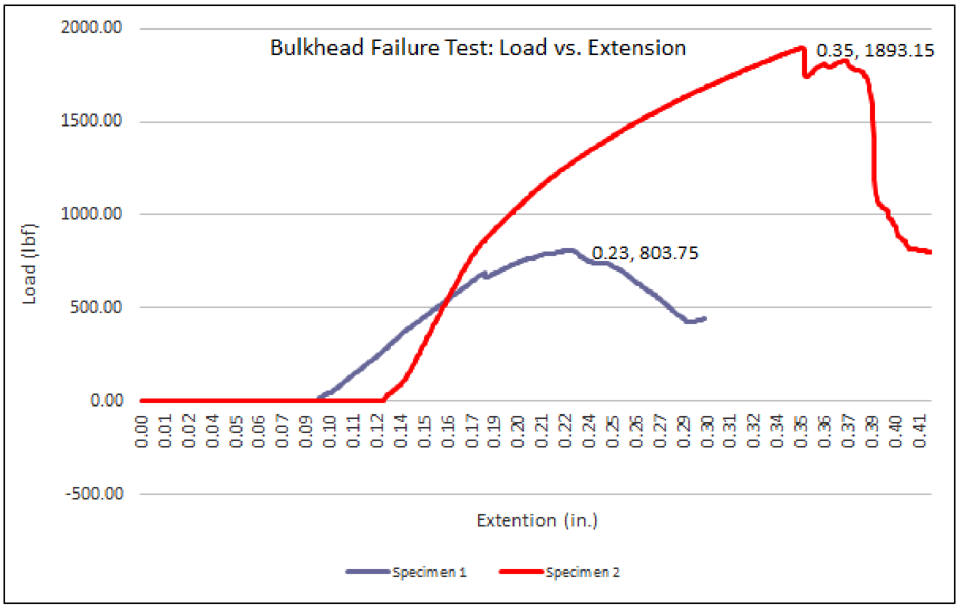


Figure 6-3 Bulkhead Failure Test Load plotted against Extension

The graph displays the axial load applied to the bulkhead plotted against the extension of the bulkhead assembly. In both runs of this test the fiberglass body tube failed before the bulkhead was pulled from inside the tube, as shown in Figure 6-4 below.

Figure 6-4 Bulkhead Failure Test Setup and Fiberglass Failure

The first specimen failed at a load of 803.75 lbf, 1.7 times greater than the load required to pass this test. This gives the epoxied bulkheads a factor of safety of 3.43, much greater than the factor of safety of 2 that the team required. The second specimen failed at a load of 1895.15 lbf, which is even greater than the previous run. The discrepancies in these results can be explained by differences in the thickness of the fiberglass below the bolts as well as how many bolts were inserted. Alignment errors occurred during each run which allowed only some of the six bolts which were intended to attach the body tube to the aluminum bulkhead to be installed. However, both times, based on advice from university professors, attachment with a minimum of four of the six bolts was deemed acceptable and testing was executed.

Though the final failure loads from each of these tests differ greatly, each failure point was significantly above the success criteria without causing the bulkhead to ever fail. Because of this, the results of this test have increased the team's confidence in the security of epoxied bulkheads. No changes will be made to the method of attachment to the body tube.

6.1.2 Shear Pin Failure Test

6.1.2.1 Test Description

The goal of this test was to determine the actual shear strength of the #4-40 nylon shear pins that are used during flight. Based on previous research it was believed that each shear pin could withstand approximately 70 lb; however, after the premature main parachute deployment during the launch on February 9th, more information was required to ensure that the proper number of shear pins would be used in the future.

6.1.2.2 Test Setup

The procedure for this test can be found in Appendix D

6.1.2.3 Safety Notes

All members were required to wear safety glasses and stand a safe distance away from the testing machine during operation. The machine was brought back to resting position after each run before any pieces of the setup were retrieved to avoid any physical injury from the machine.

6.1.2.4 Pass/Fail Criteria

A successful test will indicate that the shear pins fail at approximately 70 lb as expected by the team's research.

6.1.2.5 Results

The results of the shear pin testing are shown in Figure 6-5

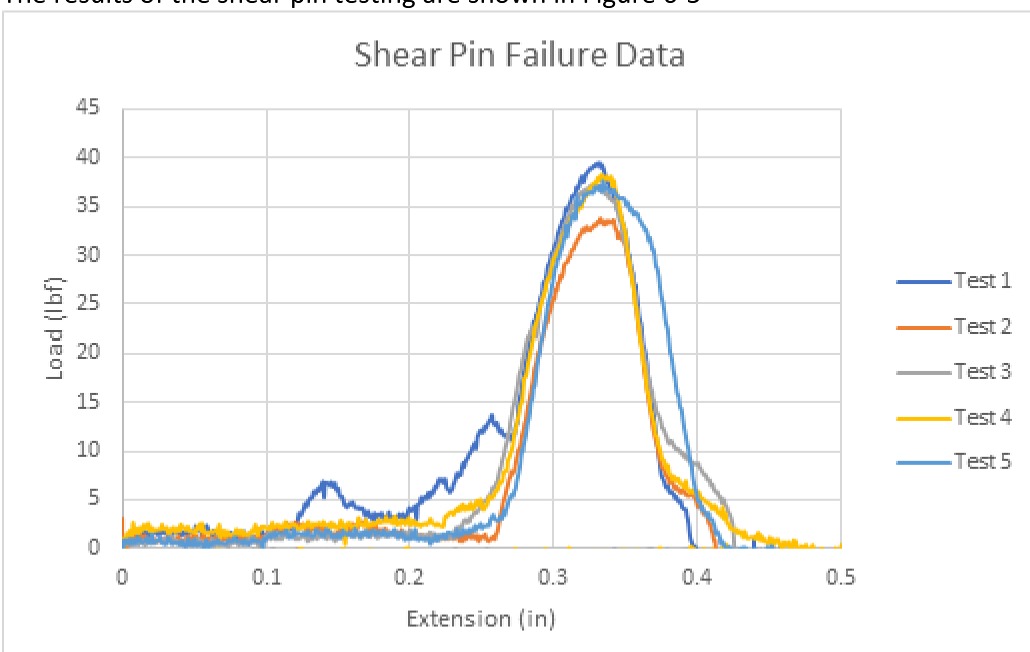


Figure 6-5 Load Plotted Against Deformation for Shear Pin Test

It can be seen that each of the five tested shear pins failed between 30 and 40 pounds; the minimum failure load was 33.8 lb and the maximum was 39.6 lb. The data was fairly consistent and, for this reason, only 5 shear pins were used.

This data clearly indicates that the strength of the shear pins being used is significantly lower than previously believed. Because of this, additional shear pins will be used between the main parachute bay and the payload bay during flight as discussed in Section 3.4.

6.1.3 Payload Deployment Demonstration

6.1.3.1 Test Description

The goal of this test is to demonstrate that the payload will successfully deploy from the rocket from any orientation. This test will be performed both on a prototype of the payload bay and the full-scale payload bay that will be used for qualification.

6.1.3.2 Test Setup

The procedure for this test can be found in Appendix D

6.1.3.3 Success Criteria

Success is defined as the pod leaving the body tube, orienting heavy side down, dropping to the ground and opening fully, revealing the UAV. The UAV should also be left with enough clearance to activate the motors and fly if the correct commands were sent.

6.1.3.4 Safety Notes

There are no specific concerns about the performance of the test besides normal considerations taken when using electronics and working in a testing environment.

6.1.3.5 Results

The current overall result of the payload deployment test is a failure, though modifications have and are currently being made to ensure success before the payload demonstration flight. The payload deployment is not suitably robust to friction and misalignment. The Payload has successfully deployed in a controlled environment, but the success is not consistent between tests. In order to increase robustness to friction, the lead screw pitch was decreased, and gear were added. A more in-depth description of this change can be found in section 5.1.1**.** In addition, graphite lubricant was added in locations where binding is occurring. The changes currently being made are to increase the robustness of the system to misalignment. The weight of the payload pod, while not binding the system, can shift the position of the pusher and prevent the lead screw from turning. The current avenues of improvements are improving the auxiliary rod to assist with resisting a pitching moment in the pod and improving the connection between the gears.

6.1.4 Payload Maximum Operating Range Test

6.1.4.1 Test Description

The purpose of this test is to determine the maximum operating range of the combination of UAV and deployment system, as it is difficult to foresee all possible interference factors that may inhibit successful operation at the launch site. This test shall provide a numerical operation window within which the launch vehicle needs to land in order to successfully deploy and fly the UAV.

6.1.4.2 Test Setup

The procedure for this test can be found in Appendix D

6.1.4.3 Success Criteria

Success for the overall test is defined as a maximum operating range of 0.6 miles or greater for both the payload deployment system and the UAV.

6.1.4.4 Safety Notes

There are no specific concerns about the performance of the test besides normal considerations taken when operating a UAV as found in public Law 112-95, Section 336.

6.1.4.5 Results

This demonstration was executed to show the functionality of the payload at a range of 0.6 miles. The demonstration passed the above described success criteria. No changes were made to the design based on the results of this demonstration.

6.1.5 Payload Retention Test

6.1.5.1 Test Description

The purpose of this test is to test the latching retention mechanism. The test will be based on the maximum force of tension between the latch and the pod. Because of the payload bay configuration, all loading during parachute deployment can only put compressive forces on the latch. The largest tension force will nominally occur during ascent. Using RockSim, the maximum acceleration of the launch vehicle during ascent is 7.3 times gravitational acceleration. The duration of this max force should be 0.25 second. The payload pod, with the payload inside has not yet been completed; its weight will be referred to as w_{pod}. In order to ensure a factor of safety of 1.5, the tested weight will be at minimum 11 times w_{pod}. The test will also be performed again to test the connection between the eye ring and the payload pod itself.

6.1.5.2 Test Setup

The procedure for this test can be found in Appendix D

6.1.5.3 Success Criteria

Success is defined as the latch or eye ring showing no visual or auditory signs of failure, including unexpected movement or cracking noises.

6.1.5.4 Safety Notes

No body parts will be allowed below hanging weights. To prevent injury, the mechanisms will always be treated as though they will fail.

6.1.5.5 Results

The retention system could withstand the flight loads simulated by the weights applied during this test. Neither the Southco latch nor the payload pod eyebolt showed signs of deformation or failure. The success of this test resulted in no additional changes to the payload retention system.

6.1.6 Payload Pad Endurance Test

6.1.6.1 Test Description

The goal of this test is to determine the maximum pad stay time of the payload electronics. As described in NASA requirement 2.11, the onboard electronics must maintain functionality for at least 2 hours after being turned on, and if this condition is not met then the power supply subsystem will require adjustment.

6.1.6.2 Test Setup

The procedure for this test can be found in Appendix D

6.1.6.3 Success Criteria

Success is defined as both the payload deployment system and the UAV exhibiting a pad stay time of 120 minutes or greater.

6.1.6.4 Safety Notes

There are no specific concerns about the performance of the test besides generic considerations taken when working with electronics.

6.1.6.5 Results

The drone was armed inside the rocket for approximately 242 minutes. After the flight, the battery voltage was measured to be 8.01V which was determined to be adequate for stable flight.

The success of this test has confirmed the robustness of the team's current UAV design. No changes will be made to the UAV design.

6.1.7 Hover test

6.1.7.1 Test Description

The below test is intended to determine the maximum no-wind hover time for the fully-loaded quadcopter. This allows the team to get an estimate of ideal competition day conditions and UAV performance under ideal conditions.

6.1.7.2 Test Setup

The procedure for this test can be found in Appendix D.

6.1.7.3 Success Criteria

Failure is considered a flight time less than 5 minutes, as this is estimated to be enough time for the quadcopter to take-off, fly to, and land at the FEA.

6.1.7.4 Safety Notes

To ensure safety of all personnel involved in testing, all FAA guidelines for UAVs of this size shall be adhered to. The quadcopter shall not be operated near trees or other obstructions, including cars, people, and buildings. The quadcopter shall not be operated in unsafe environmental conditions including rain, sleet, snow, high winds, or any other adverse weather.

6.1.7.5 Results

During the testing process, the UAV successfully hovered for approximately 20 minutes and had not expended the aforementioned battery capacity. As the team decided the UAV had more than passed the test, the test was concluded at that time.

The success of this test has confirmed the robustness of the team's current UAV design. No changes will be made to the UAV design.

6.1.8 Adverse Conditions UAV Flight Test

6.1.8.1 Test Description

Determine the flight time and range of quadcopter under normal conditions. "Adverse" conditions are intended to simulate windy day conditions as the team anticipates in Huntsville, Alabama on competition day. This allows the team to get a more accurate estimate of performance under competition conditions, ideally giving a lower bound.

6.1.8.2 Procedure

The procedure for this test can be found in Appendix D

6.1.8.3 Success Criteria

Failure is considered a flight time less than 5 minutes, as this is estimated to be sufficient time for the quadcopter to take-off, fly to, and land at the FEA.

6.1.8.4 Safety Notes

To ensure safety of all personnel involved in testing, all FAA guidelines for UAVs of this size shall be adhered to. The quadcopter shall not be operated near trees or other obstructions, including cars, people, and buildings. The quadcopter shall not be operated in unsafe environmental conditions including rain, sleet, snow, high winds, or any other adverse weather. This test, as stated earlier, requires specific atmospheric conditions, therefore care must be taken to ensure the conditions for the test are met without endangering the testing personnel.

6.1.8.5 Results

The UAV maintained stable flight for the complete duration of a 10-minute flight in sustained winds exceeding 10 mph. Upon completion of the flight, the UAV was able to successfully perform a controlled landing within the target area.

The success of this test has confirmed the robustness of the team's current UAV design. No changes will be made to the UAV design.

6.1.9 GPS Functionality Demonstration

6.1.9.1 Test Description

As described in NASA requirement 3.11, the launch vehicle shall contain an onboard tracking device to transmit the location of the vehicle upon touchdown. The BigRedBee 900 GPS onboard the launch vehicle must function properly to fulfill this requirement.

6.1.9.2 Test Setup

The procedure for this test can be found in Appendix D

6.1.9.3 Success Criteria

The GPS must acquire at least four satellites within five minutes of beginning the demonstration. The data retrieved from the GPS following the conclusion of the demonstration must reflect an accurate depiction of the path tracked.

6.1.9.4 Results

The GPS unit was taken on the Wolfline bus #3 at NC State. This was done so that the route tracked by the GPS could be compared to the Wolfline bus route provided by the university. Figure 6-6, below is an image of the GPS route.

Figure 6-6 BigRedBee GPS route

To verify the functionality of the GPS, this route was compared to the Wolfline #3 bus route in Figure 6-7, below.

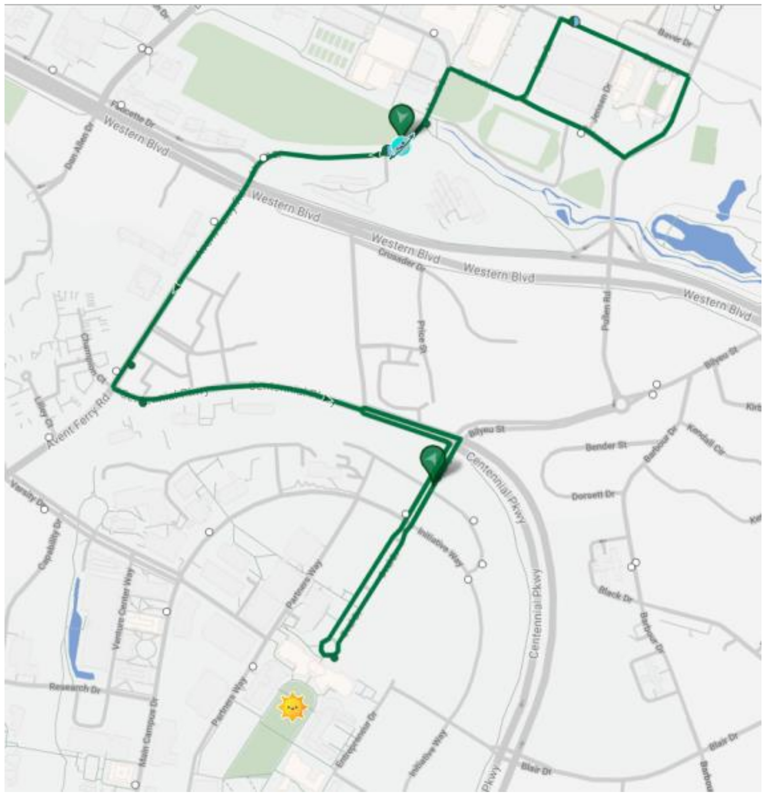


Figure 6-7 Wolfline Bus Route

The team finds the differences between the two routes negligible and have verified the functionality of the BigRedBee GPS.

6.1.10 Recovery Electronics Pad Endurance Test

6.1.10.1 Test Description

The goal of this test is to determine the maximum pad stay time of the recovery electronics. As described in NASA requirement 2.11, the onboard electronics must maintain functionality for at least 2 hours after being turned on. This test will determine how long all recovery electronics will be able to remain on. The recovery electronics are two PerfectFlite StratoLoggerCF altimeters and one BigRedBee GPS.

6.1.10.2 Test Setup

The procedure for this test can be found in Appendix D

6.1.10.3 Success Criteria

Success is defined as both the PerfectFlite StratoLoggerCF altimeters and the BigRedBee GPS have a pad stay time of 120 minutes or greater while maintaining a voltage over 9.0V

6.1.10.4 Safety Notes

There are no specific concerns about the performance of the test besides normal considerations taken when working with electronics.

6.1.10.5 Results

The below tables display the data collected during three rounds of the Recovery electronics Pad Endurance Test. The maximum drop in voltage within a 2-hour time period was 0.2 V.

Prior to each launch, the team checks all the flight-ready batteries for a voltage greater than 9.0 V. These are the batteries that are deemed acceptable by the team. The results of this test have led the team to change the minimum voltage requirement of a 9V battery from 9.0V to at least 9.2V. This is because the maximum drop in voltage observed was 0.2V. Raising the minimum voltage to at least 9.2V would guarantee the battery's voltage is over 9.0V for the duration of the flight.

Table 6-1 Recovery Electronics Pad Endurance Test 1

Time	Primary Voltage (V)	Secondary Voltage (V)
12:15	9.41	9.54
3:22	9.30	9.37

Table 6-2 Recovery Electronics Pad Endurance Test 2

Time	Primary Voltage (V)	Secondary Voltage (V)
3:25	9.62	9.50
5:30	9.45	9.30

Table 6-3 Recovery Electronics pad Endurance Test 3

Time	Primary Voltage (V)	Secondary Voltage (V)
5:35	9.24	9.34
7:40	9.13	9.26

6.1.11 Altimeter Demonstration

6.1.11.1 Demonstration Description

The purpose of this demonstration is to verify the functionality of the flight altimeters and ensure an electrical signal is carried to both the drogue and primary chutes lines.

6.1.11.2 Demonstration Setup

The procedure for this test can be found in Appendix D

6.1.11.3 Safety Notes

Appropriate PPE will also be utilized when operating the vacuum chamber and all personnel will remain a safe distance away while testing is in progress.

6.1.11.4 Pass/Fail Criteria

A successful demonstration of the altimeters will consist of the altimeters triggering the LED's at the appropriate phase of the simulated flight, I.e. drogue chute at simulated apogee and main chute at 500 feet. Failure would be considered if one or both LED's fail to trigger based upon conditions in the simulated flight.

6.1.11.5 Results

The two flight altimeters as well two additional back up altimeters were tested and met the requirements of the Pass/Fail Criteria described above.

The success of this test has led to no changes to the current avionics management system.

6.1.12 Black Powder Ejection Demonstration

6.1.12.1 Demonstration Description

The purpose of this demonstration is to verify the functionality of the black powder charges prior to launch. This will also allow the team to choose more precise black powder charge sizes.

6.1.12.2 Demonstration Setup

The procedure for this test can be found in Appendix D

6.1.12.3 Safety Notes

Appropriate PPE will also be utilized when handling all black powder and when setting off the black powder charges

6.1.12.4 Pass/Fail Criteria

A successful demonstration of the black powder ejection system is defined by full separation between the avionics bay and fin can for drogue and main parachute bay and payload bay for main.

6.1.12.5 Results

Prior to the launch on February 9, an ejection demonstration was executed to prove the black powder charges were sufficient to separate the rocket. This demonstration was successful with two shear pins at each separation point and 2.0g of black powder at the drogue separation point and 3.0g of black powder at the main separation point. Full separation was observed during the procedure but the team's advisor suggested increasing the drogue black powder charge by 0.1g for robustness.

After the failure of the main separation point shear pins during drogue deployment on launch day, the number of shear pins at the main separation point was increased from two to six shear pins. The ejection demonstration was re-executed with 2.1g of black powder at the drogue separation point and 3.8g of black powder at the main separation point. Full separation was observed during the procedure.

6.2 Requirements Compliance

Table 6-4, below, contains the definitions of each heading on the verification plan and execution for the NASA Student Launch Requirements and Team Derived Requirements.

Table 6-4 Definitions of Requirement Verification Subheadings

Heading	Definition
Requirement Number	The Number associated with the requirement
Shall Statement	The requirement statement.
Success Criteria	What defines a successful verification of the requirement?
Verification Method	How the requirement will be verified
Preflight Acceptance	Is this requirement verified before each time the launch vehicle is launched?
Performing Organization	Who is responsible for performing the verification?
Results	Proof that the requirement is verified.

6.2.1 Verification Plan

Table 6-5, below, contains the verification plan and execution for the NASA Student Launch Requirements.

Table 6-5 NASA Requirement Verification Matrix

Requirement Number	Shall Statement	Success Criteria	Verification Method	Preflight Acceptance	Performing Organization	Results
1.1	Team members shall complete 100% of the project, including design, construction, written reports, presentations, and flight preparation.	Outside resources do not contribute to the design, writing, fabrication, testing, or launch of the team's NASA SL launch vehicle.	Demonstration	No	Team Lead	The student led team has completed all parts of the NASA SL project without direct assistance from outside resources.
1.1	Team members shall work alongside L3 mentors in handling motors and black powder charges.	The team's L3 Mentors, Charles Hall, Alan Whitmore, and Jim Livingston	Demonstration	Yes	Team Lead	The team's launch day checklists, in Appendix B, call for the assistance of the

		help the team assemble the launch vehicle's motor and guide the team through black powder charge installation.				team's L3 mentors when assembling the motor. The L3 mentors brief members on the proper installation of black powder charges before launch day.
1.2	Executive board members shall provide and maintain a project plan including the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risk and mitigation.	A complete project plan is found in the FRR milestone document.	Inspection	No	Team Lead	Section 6 contains the complete project plan. Checklists are included in Appendix D. Risk and mitigation strategies are included in Section 6.2.3.
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.	Foreign Nationals are reported to NASA SL officials by the PDR Milestone document.	Inspection	No	Team Lead	The PDR Milestone document has been submitted. The team is not bringing any Foreign Nationals to the NASA SL competition.
1.4	The team shall identify all team members attending launch week activities by the Critical Design Review (CDR).	A list of attendees is reported to NASA SL officials by the CDR Milestone document.	Inspection	No	Team Lead	The CDR Milestone document has been submitted. All attendees have been reported to NASA SL officials.
1.5	The team shall engage a minimum of 200 participants in educational, hands-on STEM activities, as defined in the STEM Engagement Activity Report, by FRR.	The team engages 200 K-12 students in hands-on STEM activities by the FRR Milestone Document.	Inspection	No	Outreach Lead	The Outreach Lead has kept track of all K-12, hands-on STEM events. As of March 4, 2019, the team has engaged 3,850 students.
1.6	The team will establish a social media presence to inform the public about team activities.	The team updates the social media accounts to inform the public regularly.	Inspection	No	Social Media Lead and Webmaster	The team's social media and website are updated on a regular

						basis to inform the public on our activities.
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.	The team sends a link to the club website where all NASA SL documentation is posted for each milestone report.	Inspection	No	Team Lead and Webmaster	The team lead emails a link to each document to NASA SL officials when the milestone report is due.
1.8	All deliverables must be in PDF format.	The team converts all submitted documents to PDF format before posting on the website.	Inspection	No	Team Lead	Every milestone document is in PDF format when submitted.
1.9	In every report, teams will provide a table of contents including major sections and their respective sub-sections.	The table of contents is updated and includes all sub-sections.	Inspection	No	Team Lead	In this report and all previous, the table of contents can be found at the start of the document.
1.10	In every report, the team will include the page number at the bottom of the page	The page number is at the bottom of each page in every milestone document.	Inspection	No	Team Lead	In this report and all previous, the page number is included at the bottom of each page.
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.	The team is prepared for each milestone teleconference with competition officials.	Inspection	No	Team Lead	The team presents each milestone document with all proper equipment.
1.12	All teams will be required to use the launch pads provided by Student Launch's launch services provider. No	The team is prepared to use the competition-	Demonstration	No	Team Lead	Simulations using RockSim have been executed to simulate

	custom pads will be permitted on the launch field. Eight 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.	provided launch rails on launch day.				competition launch conditions.
1.13	Each team must identify a “mentor.” A mentor is defined as an adult who is included as a team 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.	The team selects one of the two mentors, Alan Whitmore or Jim Livingston, to receive the NASA mentor stipend at competition.	Inspection	No	Team Lead	Jim Livingston will be receiving the NASA mentor stipend.
2.1	The vehicle will deliver the payload to an apogee altitude between 4,000 and 5,500 feet above ground level (AGL). Teams flying below 3,500 feet or above 6,000 feet on Launch Day will be	The team’s launch vehicle reaches an apogee between the NASA SL required	Demonstrati on and Analysis	No	Aerodynamic Simulations	The team’s competition launch vehicle is designed to reach an apogee of 4,090 feet as declared

	disqualified and receive zero altitude points towards their overall project score.	4,000 feet and 5,500 feet.				in the PDR Milestone report. The results of the first demonstration flight are described in Section 3.3.4.
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 during Launch Week.	The PDR Milestone report includes a sub-section detailing on the team's altitude predictions.	Inspection	No	Aerodynamic Simulations	The PDR Milestone report declares a competition apogee of 4,090 feet.
2.3	The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the Altitude Award winner. The Altitude Award will be given to the team with the smallest difference between their measured apogee and their official target altitude on launch day.	The team declares which of the two redundant altimeters will be used for scoring the altitude challenge.	Inspection	No	Recovery and Avionics	The primary altimeter is a StratoLogger CF altimeter labeled "PRIMARY" on the Avionics Sled as described in Section 3.2.1.2(a).
2.4	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 team integrates a mechanical arming switch for each altimeter.	Inspection	Yes	Recovery and Avionics	The team uses mechanical screw switches, described in Section 3.2.1.2(b).
2.5	Each altimeter will have a dedicated power supply.	The two altimeters have different power supplies.	Inspection	Yes	Recovery and Avionics	The team has integrated a battery compartment on the AV Sled, intended to hold two 9V batteries for the altimeters as described in Section 3.2.1.2(c).
2.6	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 screw switches cannot be disarmed due to flight forces.	Analysis	Yes	Recovery and Avionics	The threads on the arming switches require a torque on the screw in order to disarm. The individual

						screws will not feel these types of effects during flight.
2.7	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 launch vehicle is reusable on the same day without repairs or modifications.	Demonstrati on	Yes	Structures	The launch vehicle body is robust enough to withstand all flight forces as described in Section 3.1.2.1(a).
2.8	The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	The launch vehicle has no more than four (4) independent sections.	Demonstrati on	No	Structures	The launch vehicle consists of only one (1) section as described in Section 3.1.2.1.
2.8.1	Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length.	All airframe separation points have at least 1 body diameter in length of coupler.	Demonstrati on	No	Structures	The launch vehicle has two (2) separation points. At each of these points 5.5 in of coupler is used as described in Section 3.1.2.1.
2.8.2	Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.	Nosecone shoulders at in-flight separation points have at least ½ body diameter in length.	Demonstrati on	No	Structures	The launch vehicle does not have a separation point at the nosecone.
2.9	The launch vehicle will be limited to a single stage.	The launch vehicle only has one stage.	Demonstrati on	No	Aerodynamic Simulations	The team shall be using one (1) L1150-R motor.
2.10	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 launch vehicle takes less than 2 hours to assemble.	Demonstrati on	No	Team Lead	Appendix B contains the completed checklists used for the launch on February 9. The assembly took approximately 3.5 hours when executed

						linearly. With checklist edits and executing some checklists in parallel, the team expects the time to be under 2 hours.
2.11	The launch vehicle 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.	All launch critical components are capable of remaining in the ON position for over 2 hours.	Test	No	Team Lead	Section 6.1 includes two (2) pad endurance tests that were executed to monitor the endurance of on-board electronics. Both tests were a success.
2.12	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 launch vehicle is designed to be launched by a 12-volt direct current firing system.	Demonstration	Yes	Team Lead	All demonstration flights are executed using a 12-volt direct current firing system.
2.13	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 launch vehicle is self-contained and only requires the aforementioned 12-volt firing circuit to launch.	Demonstration	Yes	Team Lead	All demonstration flights use only the 12-volt firing circuit as ground support equipment.
2.14	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).	The launch vehicle uses a commercially available solid motor.	Demonstration	No	Aerodynamic Simulations	The team is using an Aerotech L1150-R motor in the full-scale launch vehicle.
2.14.1	Final motor choices will be declared by the Critical Design Review (CDR) milestone.	The final motor selection was declared in the CDR Milestone document.	Inspection	No	Team Lead	The CDR Milestone Document includes a section dedicated to motor choice.

2.14.2	Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO) and will only be approved if the change is for the sole purpose of increasing the safety margin. 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 has any motor change after CDR approved by the NASA team.	Demonstration	No	Team Lead	There has been no change in motor choice.
2.15	Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria:	N/A	N/A	N/A	N/A	N/A
2.15.1	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 meets all criteria regarding pressure vessels on-board the launch vehicle.	Inspection	No	Team Lead	There are no pressure vessels on-board the team's launch vehicle.
2.15.2	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.	The team meets all criteria regarding pressure vessels on-board the launch vehicle.	Inspection	No	Team Lead	There are no pressure vessels on-board the team's launch vehicle.
2.15.3	Full pedigree of the tank will be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.	The team meets all criteria regarding pressure vessels on-board the launch vehicle.	Inspection	No	Team Lead	There are no pressure vessels on-board the team's launch vehicle.
2.16	The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class). The total impulse provided by a High School or Middle School launch vehicle will not exceed 2,560 Newton-seconds (K-class).	The team uses a motor with a total impulse less than 5,120 Newton-Seconds.	Demonstration	No	Aerodynamic Simulations	The team is using a L-Class, L1150-R, motor.
2.17	The launch vehicle will have a minimum static stability margin of 2.0	The team's launch vehicle has a static	Analysis	No	Aerodynamic Simulations	Described in Section 3.3.2, the RockSim

	at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.	stability margin greater than 2.0 at the point of rail exit.				analysis of the team's launch vehicle provides a static stability margin of 2.25.
2.18	The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	The team's launch vehicle has a rail exit velocity of at least 52 fps.	Analysis	No	Aerodynamic Simulations	Described in Section 3.3.1, the RockSim analysis of the team's launch vehicle provides a rail exit velocity of 69.45 fps.
2.19	All teams will successfully launch and recover a subscale model of their rocket prior to CDR. Subscales are not required to be high power rockets.	The team launches a subscale model of the competition launch vehicle before the CDR Milestone document.	Demonstrati on	No	Team Lead	The subscale launch was documented and analyzed in the CDR Milestone document.
2.19.1	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 launches a subscale model of the competition launch vehicle before the CDR Milestone document.	Demonstrati on	No	Team Lead	The subscale launch was documented and analyzed in the CDR Milestone document.
2.19.2	The subscale model will carry an altimeter capable of recording the model's apogee altitude.	The team launches a subscale model of the competition launch vehicle before the CDR Milestone document.	Demonstrati on	No	Team Lead	The subscale launch was documented and analyzed in the CDR Milestone document.
2.19.3	The subscale rocket must be a newly constructed rocket, designed and built specifically for this year's project.	The team launches a subscale model of the competition launch vehicle before the CDR	Demonstrati on	No	Team Lead	The subscale launch was documented and analyzed in the CDR Milestone document.

		Milestone document.				
2.19.4	Proof of a successful flight shall be supplied in the CDR report. Altimeter data output may be used to meet this requirement.	The team launches a subscale model of the competition launch vehicle before the CDR Milestone document.	Demonstrati on	No	Team Lead	The subscale launch was documented and analyzed in the CDR Milestone document.
2.20	All teams will complete demonstration flights as outlined below	N/A	N/A	N/A	N/A	N/A
2.20.1	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 must be the same rocket to be flown on launch day. 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 must be met during the full-scale demonstration flight:	N/A	N/A	N/A	N/A	N/A
2.20.1.1	The vehicle and recovery system will have functioned as designed.	The launch vehicle's recovery system functions as designed during the vehicle demonstration flight.	Demonstrati on	No	Recovery and Avionics	Described in Section 3.3.4, the recovery sub-system did not perform as expected.

2.20.1.2	The full-scale rocket must be a newly constructed rocket, designed and built specifically for this year's project.	The launch vehicle is constructed for the 2018-2019 NASA SL competition	Demonstration	No	Structures	Described in Section 3.1.4, the fabrication process for the full-scale rocket took place over several weeks after the CDR Milestone report.
2.20.1.3	The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply:	N/A	N/A	N/A	N/A	N/A
2.20.1.3.1	If the payload is not flown, mass simulators will be used to simulate the payload mass.	Mass simulators are used in place of a payload if necessary.	Demonstration	No	Team Lead	The team has launched the full payload rather than mass simulators.
2.20.1.3.2	The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.	Mass simulators are placed in the correct locations.	Demonstration	No	Team Lead	The team has launched the full payload rather than mass simulators.
2.20.1.4	If the payload changes the external surfaces of the rocket (such as with 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	The payload dependent parts of the launch vehicle are launched as part of the vehicle demonstration flight.	Demonstration	No	Team Lead	There are no payload dependent parts of the launch vehicle.
2.20.1.5	Teams shall fly the launch day motor for the Vehicle Demonstration Flight. The RSO may approve use of an alternative motor if the home launch field cannot support the full impulse of the launch day motor or in other extenuating circumstances.	The L1150-R is used for the vehicle demonstration flight.	Demonstration	No	Team Lead	The team used an L1150-R motor in the vehicle demonstration flight.
2.20.1.6	The vehicle must be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the launch day flight. Additional ballast may not be added	The fully ballasted configuration is flown for the vehicle demonstration flight.	Demonstration	No	Aerodynamic Simulations	The team flew the fully ballasted configuration during the vehicle demonstration flight.

	without a re-flight of the full-scale launch vehicle.					
2.20.1.7	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 final modifications to the full-scale launch vehicle are made before the vehicle demonstration flight.	Demonstrati on	No	Team Lead	The team flew the final design of the full-scale launch vehicle during the vehicle demonstration flight.
2.20.1.8	Proof of a successful flight shall be supplied in the FRR report. Altimeter data output is required to meet this requirement.	Altimeter data from the vehicle demonstration flight is provided in the FRR Milestone document.	Inspection	No	Recovery and Avionics	Section 3.4.2.1 includes the altimeter data from the vehicle demonstration flight.
2.20.1.9	Vehicle Demonstration flights must be completed by the FRR submission deadline. 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 must submit an FRR Addendum by the FRR Addendum deadline.	The vehicle demonstration flight is completed by March 4, 2019.	Demonstrati on	No	Team Lead	The vehicle demonstration flight was completed on February 9, 2019.
2.20.2	N/A	N/A	N/A	N/A	N/A	N/A
2.20.2.1	The payload must be fully retained throughout the entirety of the flight, all retention mechanisms must function as designed, and the retention mechanism must not sustain damage requiring repair.	The payload is retained during flight and functions as designed.	Demonstrati on	No	Payload Integration	Described in Section 5.1.7 the payload retention system succeeded in retaining the payload during the payload demonstration flight. The payload was not deployed as intended.
2.20.2.2	The payload flown must be the final, active version.	The payload is complete for the	Demonstrati on	No	Payload Integration,	The final design of the payload was flown in

		payload demonstration flight.			Payload Structures, Payload Communicatio n	the payload demonstration flight.
2.20.2.3	N/A	N/A	N/A	N/A	N/A	N/A
2.20.2.4	Payload Demonstration Flights must be completed by the FRR Addendum deadline. No extensions will be granted.	The payload demonstration flight is complete before the FRR Addendum deadline.	Demonstrati on	No	Payload Integration, Payload Structures, Payload Communicatio n	The payload demonstration flight was completed on February 9, 2019.
2.21	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.	The team completes an FRR Addendum if necessary.	Inspection	No	Team Lead	If the vehicle and payload demonstration flight is rejected, the team shall complete an FRR Addendum.
2.21.1	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 the vehicle at launch week.	The FRR Addendum is completed on time.	Inspection	No	Team Lead	The FRR Addendum shall be complete by the NASA declared deadline.
2.21.2	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 the payload at launch week.	A non-functioning payload is not launched at competition.	Inspection	No	Payload Integration, Payload Structures, Payload Communicatio n	The payload team shall have a functioning payload and complete payload demonstration flight prior to the FRR Addendum deadline.
2.21.3	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	The team petitions the NASA RSO for permission to fly a payload that was not completely	Demonstrati on	No	Payload Integration, Payload Structures, Payload	The payload team shall have a functioning payload and complete payload demonstration

	granted if the RSO or the Review Panel have any safety concerns.	functional during the payload demonstration flight.			Communicatio n	flight prior to the FRR Addendum deadline.
2.22	Any structural protuberance on the rocket will be located aft of the burnout center of gravity.	The team integrates all structural protuberances aft of the burnout center of gravity.	Demonstrati on	No	Aerodynamic Simulations	The launch vehicle has no structural protuberances forward of the burnout center of gravity.
2.23	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.	Each section of the launch vehicle has contact information for the team.	Inspection	Yes	Team Lead	The launch vehicle shall have a label inside the AV Bay with team contact information.
2.24	N/A	N/A	N/	N/A	N/A	N/A
2.24.1	The launch vehicle will not utilize forward canards. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket's stability.	Apart from cameras, there are no forward canards on the launch vehicle.	Inspection	No	Structures	There are no forward canards on the launch vehicle.
2.24.2	The launch vehicle will not utilize forward firing motors.	There are no forward firing motors on the launch vehicle.	Inspection	No	Aerodynamic Simulations	The one (1) L1150-R motor fires aft of the launch vehicle.
2.24.3	The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	The launch vehicle uses a NASA approved motor.	Inspection	No	Aerodynamic Simulations	The Aerotech L1150-R motor is approved by the NASA team.
2.24.4	The launch vehicle will not utilize hybrid motors.	The launch vehicle uses one (1) solid motor.	Inspection	No	Aerodynamic Simulations	The team is using an L1150-R motor.

2.24.5	The launch vehicle will not utilize a cluster of motors.	The launch vehicle uses one (1) solid motor.	Inspection	No	Aerodynamic Simulations	The team is using an L1150-R motor.
2.24.8	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 and unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast).	The launch vehicle ballast is less than 10% of the unballasted weight.	Inspection	No	Aerodynamic Simulation	The team's current design uses 3% ballast.
2.24.9	Transmissions from onboard transmitters will not exceed 250 mW of power.	On-board transmitters do not exceed 250 mW of power.	Inspection	No	Team Lead	No on-board transmitters exceed the stated limit.
2.24.10	Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	There are no excessive metal components on the launch vehicle.	Inspection	No	Team Lead	There are no excessively large or dense metal components of the launch vehicle.
3.1	The 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 launch vehicle uses dual deployment with a drogue parachute at apogee and a subsequent main parachute.	Demonstrati on	No	Recovery and Avionics	The launch vehicle uses dual deployment with a drogue parachute at apogee and a main parachute at 600 feet. There is no apogee delay on the drogue parachute.
3.1.1	The main parachute shall be deployed no lower than 500 feet.	The main parachute deploys above 500 feet.	Demonstrati on	No	Recovery and Avionics	The main parachute deploys at 600 feet.
3.1.2	The apogee event may contain a delay of no more than 2 seconds.	The apogee event occurs less than 2 seconds after apogee.	Demonstrati on	No	Recovery and Avionics	There is no apogee delay.

3.2	Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full-scale launches.	A ground ejection test is executed prior to launch.	Demonstration	Yes	Recovery and Avionics	The ejection demonstration is described in Section 6.1.12 with the procedure in Appendix D. The ejection demonstration was successful.
3.3	At landing, each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.	The kinetic energy at landing for each section does not exceed 75 ft-lbf.	Analysis	No	Recovery and Avionics	Section 3.3.3 includes the kinetic energy calculations for each section at landing.
3.4	The recovery system electrical circuits will be completely independent of any payload electrical circuits.	The recovery system electronics are independent of payload system electronics.	Demonstration	No	Recovery and Avionics	All recovery electronics are contained within the AV Bay, shown in Section 3.2.1.2.
3.5	All recovery electronics will be powered by commercially available batteries.	The recovery electronics are powered by commercially available batteries.	Demonstration	No	Recovery and Avionics	Recovery electronics are powered by 9V batteries as described in Section 3.2.1.2(c).
3.6	The recovery system will contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.	The altimeters are commercially available.	Demonstration	No	Recovery and Avionics	The recovery electronics system uses two (2) StratoLogger CF altimeters.
3.7	Motor ejection is not a permissible form of primary or secondary deployment.	Motor ejection is not used.	Demonstration	No	Recovery and Avionics	The recovery system does not use motor ejection.
3.8	Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Shear pins are used at each separation point.	Demonstration	No	Recovery and Avionics	Two (2) 4-40 nylon shear pins are used at the drogue separation point. Six (6) 4-40 nylon shear pins are used at the main separation point.

3.9	Recovery area will be limited to a 2,500 ft. radius from the launch pads.	The launch vehicle does not drift over 2,500 ft under parachute.	Analysis	No	Recovery and Avionics	Wind drift calculations are included in Section 3.3.4.
3.10	Descent time will be limited to 90 seconds (apogee to touch down).	The launch vehicle descends under parachute in under 90 seconds.	Analysis	No	Recovery and Avionics	Descent time calculations are included in Section 3.3.4.
3.11	An electronic 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.	The launch vehicle integrates an on-board GPS for tracking position.	Demonstrati on	No	Recovery and Avionics	The team uses a BigRedBee GPS unit attached to the AV Sled.
3.11.1	Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic tracking device.	The launch vehicle uses one (1) GPS for each separate section of the rocket.	Demonstrati on	No	Recovery and Avionics	The team uses one (1) BigRedBee GPS.
3.11.2	The electronic tracking device(s) will be fully functional during the official flight on launch day	The GPS is functional on launch day.	Demonstrati on	No	Recovery and Avionics	The GPS Functionality Demonstration is described in Section 6.1.9 with the procedure in Appendix D.
3.12	The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	The recovery system electronics are not affected by any other on-board electronics.	Demonstrati on	No	Recovery and Avionics	The functionality of the recovery electronics was verified during the vehicle demonstration flight.
3.12.1	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 electronics are housed in a separate compartment in the launch vehicle.	Demonstrati on	No	Recovery and Avionics	Described in Section 3.2.1.2, the recovery electronics are housed in the AV Bay.
3.12.2	The recovery system electronics will be shielded from all onboard transmitting	The recovery electronics are not	Demonstrati on	No	Recovery and Avionics	The functionality of the recovery electronics

	devices to avoid inadvertent excitation of the recovery system electronics.	affected by other on-board electronics.				was verified during the vehicle demonstration flight.
3.12.3	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 electronics are not affected by other on-board electronics.	Demonstration	No	Recovery and Avionics	The functionality of the recovery electronics was verified during the vehicle demonstration flight.
3.12.4	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 electronics are not affected by other on-board electronics.	Demonstration	No	Recovery and Avionics	The functionality of the recovery electronics was verified during the vehicle demonstration flight.
4.1	N/A	N/A	N/A	N/A	N/A	N/A
4.2	N/A	N/A	N/A	N/A	N/A	N/A
4.2.1	N/A	N/A	N/A	N/A	N/A	N/A
4.2.2	N/A	N/A	N/A	N/A	N/A	N/A
4.3	N/A	N/A	N/A	N/A	N/A	N/A
4.4	Deployable Unmanned Aerial Vehicle (UAV) / Beacon Delivery Requirements	N/A	N/A	N/A	N/A	N/A
4.4.1	Teams will design a custom UAV that will deploy from the internal structure of the launch vehicle.	The UAV deploys from the body tube of the launch vehicle.	Demonstration	No	Payload Integration	The payload deployment system is described in Section 5.1.2
4.4.2	The UAV will be powered off until the rocket has safely landed on the ground and is capable of being powered on remotely after landing.	The UAV is powered off until after the payload is deployed.	Test	No	Payload Communication	The payload deployment system is described in Section 5.1.2.
4.4.3	The UAV will be retained within the vehicle utilizing a fail-safe active retention system. The retention system will be robust enough to retain the UAV if atypical flight forces are experienced.	The UAV is retained by a failsafe retention system.	Test	No	Payload Integration	The payload retention system is described in Section 5.1.2. The payload retention test is described in Section 6.1.5 with the

						procedure in Appendix D.
4.4.4	At landing, and under the supervision of the Remote Deployment Officer, the team will remotely activate a trigger to deploy the UAV from the rocket.	The UAV deployment system is remotely activated.	Test	No	Payload Communication	The deployment system is tested in Section 6.1.3 with the procedures in Appendix D.
4.4.5	After deployment and from a position on the ground, the UAV will take off and fly to a NASA specified location, called the Future Excursion Area (FEA). Both autonomous and piloted flight are permissible but all reorientation or unpacking maneuvers must be autonomous.	The UAV flies to the FEA after deployment.	Test	No	Payload Structures	The UAV flight is tested in Section 6.1 with the procedure in Appendix D.
4.4.6	The FEA will be approximately 10 ft. x 10 ft. and constructed of a color which stands out against the ground.	N/A	N/A	N/A	N/A	No action is required from the team.
4.4.7	One or more FEA's will be located in the recovery area of the launch field. FEA samples will be provided to teams upon acceptance and prior to PDR.	N/A	N/A	N/A	N/A	No action is required from the team.
4.4.8	Once the UAV has reached the FEA, it will place or drop a simulated navigational beacon on the target area.	The UAV drops a navigational beacon at the FEA.	Test	No	Payload Structures	The navigational beacon system is described in Section 5.1.2.2. The UAV flight test are in Section 6.1 with procedures in Appendix D.
4.4.9	The simulated navigational beacon will be designed and built by each team and will be a minimum of 1 in W x 1 in H x 1 in D. The school name must be located on the external surface of the beacon.	The navigational beacon is a 1 in cube with the team name.	Inspection	No	Payload Structures	The navigational beacon has been made.

4.4.10	Teams will ensure the UAV's batteries are sufficiently protected from impact with the ground.	The UAV's batteries are protected from impacts.	Inspection	No	Payload Structures	The UAV's battery retention system is described in Section 5.1.2.1.
4.4.11	The batteries powering the UAV will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other UAV parts.	The UAV's batteries are well marked.	Inspection	No	Payload Structures	The UAV's batteries are marked as LiPo batteries.
4.4.12	The team 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 UAV meets the FAA standards.	Inspection	No	Payload Structures	The designated licensed drone pilot, Joseph Taylor, is flying the UAV.
4.4.13	Any UAV weighing more than .55 lbs. will be registered with the FAA and the registration number marked on the vehicle.	The UAV is registered with the FAA.	Inspection	No	Payload Structures	The UAV is registered with the FAA, proper paperwork will be brought to competition.
4.5	N/A	N/A	N/A	N/A	N/A	N/A
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 launch day checklist is complete.	Inspection	Yes	Safety Officer	The checklist used for the vehicle demonstration flight is included in Appendix B.
5.2	Each team must identify a student safety officer who will be responsible for all items in section 5.3	The safety officer is designated.	Inspection	Yes	Safety Officer	The team's designated Safety Officer is Evan Waldron
5.3	The role and responsibilities of each safety officer will include, but are not limited to: Monitor team activities with an emphasis on Safety during: Design of vehicle and payload, Construction of vehicle and payload, Assembly of vehicle and payload, Ground testing of vehicle and payload, Subscale launch test(s), Full-scale launch test(s), Launch	The safety officer is responsible for the mentioned tasks.	Inspection	No	Safety Officer	The team's Safety Officer participated in all of the listed tasks.

	day, Recovery activities, STEM Engagement Activities Implement procedures developed by the team for construction, assembly, launch, and recovery activities. Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data. Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.					
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 abides by all rules provided to them by the local rocketry club's RSO	Inspection	Yes	Team Lead	The local club's RSO informs the team if any part of the design is not up to standard.
5.5	Teams will abide by all rules set forth by the FAA.	The team abides by all FAA guidelines.	Inspection	Yes	Team Lead	The team follows all guidelines provided to them.

6.2.2 Team Derived Requirements

Table 6-6, below, contains the verification plan and execution for the NASA Student Launch Team Derived Requirements.

Table 6-6 Team Derived Requirement Verification matrix

Requirement Number	Shall Statement	Success Criteria	Verification Method	Preflight Acceptance	Performing Organization	Results

6.1	The project shall be divided into six different subsystems: Aerodynamic Simulations, Structures, Avionics and Recovery, Payload Integration, Payload Communications, and Payload Structures.	The team maintains this configuration over the course of the project.	Demonstration	No	Team Lead	The team has six subsystem leads for: Aerodynamic Simulations, Structures, Avionics and Recovery, Payload Integration, Payload Communications, and Payload Structures.
6.2	The team shall meet weekly to discuss project goals and progress.	The team continues to meet weekly on Thursdays over the course of the project.	Demonstration	No	Team Lead	The team has met every academic week since August.
6.3	The payload shall cost no more than $1,000.	The final payload costs less than $1,000.	Demonstration	No	Treasurer	Section 6.3.1 details the team's budget.
6.4	The full-scale launch vehicle shall cost no more than $2,500.	The final full-scale launch vehicle costs less than $2,500.	Demonstration	No	Treasurer	Section 6.3.1 details the team's budget.
6.5	The team shall engage over 750 K-12 students before the FRR milestone report.	The team engages more than 750 K-12 students before Monday, March 4, 2019.	Demonstration	No	Outreach Lead	The team has engaged 3,750 K-12 students before March 4, 2019.
6.6	The launch vehicle shall utilize a motor compatible with a motor casing already in the team's possession.	The final design calls for a motor that utilizes a motor casing owned by the team.	Demonstration	No	Aerodynamic Simulations	The team is using an L1150-R in the full-scale launch vehicle. This fits into the Aerotech 75/3840 motor casing owned by the team.
6.7	The launch vehicle shall not exceed a velocity of Mach 0.7.	Altimeter data from the Vehicle Demonstration Flight indicates a maximum Mach Number of less than 0.7.	Analysis	No	Recovery and Avionics	Section 3.3.1 contains the calculations for maximum Mach Number for the Vehicle Demonstration Flight.

6.8	The launch vehicle shall reach an apogee between 3850ft and 4180ft.	Altimeter data from the Vehicle Demonstration Flight indicates an apogee between 3850ft and 4180ft	Analysis	No	Recovery and Avionics	Section 3.4.2.1 contains the altimeter data from the first flight on February 9, 2019. This requirement has not been verified.
6.9	The launch vehicle shall have a static stability margin between 2.0 and 2.3 upon rail exit.	The static margin as calculated in the Launch Day Checklists in Appendix ___ is between 2.0 and 2.3.	Analysis	Yes	Aerodynamic Simulations	Section 3.3.2 contains the preflight static margin calculated for the launch on February 9, 2019. This requirement has not been verified.
6.10	The launch vehicle's blast caps shall be located at the ends of body tubes.	The launch vehicle's blast caps are easily accessible and exposed.	Demonstration	No	Structures	Section 3.2.1.5 contains the Avionics Bay design and layout.
6.11	The full-scale launch vehicle shall be constructed of fiberglass body tube.	The launch vehicle airframe uses fiberglass tubing.	Demonstration	No	Structures	Section 3.1.5 contains the full-scale launch vehicle design
6.12	All critical components of the launch vehicle shall be designed with a minimum factor of safety of 2.	Bulkheads, body tube, fins, U-bolts, payload latch, and recovery harnesses have a factor of safety of at least 2.	Test	No	Structures, Payload Integration, Recovery and Avionics	Section 6.1 describes the failure analysis of the structural, payload retention, and recovery harnessing components of the launch vehicle, respectively.
6.13	The nose cone bulkhead shall be designed to withstand a load of at least 468.88 lbf.	The sample bulkhead remains completely attached to the body tube at a minimum load of 468.8 lbf.	Test	No	Structures	The Bulkhead Failure Test was executed and the sample bulkhead failed at 803.75 lbf. This was a loading failure on the fiberglass tubing, not the epoxied bulkhead.
6.14	The launch vehicle shall use two StratoLogger CF altimeters to record flight data and trigger ejection charges.	The full-scale launch vehicle is launched using two StratoLogger CF altimeters.	Demonstration	Yes	Recovery and Avionics	The launch on February 9, 2019 used two StratoLogger CF altimeters. The collected data can be found in Section 6.1.1.

6.15	The altimeters shall use one 9V battery each.	The full-scale launch vehicle avionics are powered with 9V batteries.	Demonstration	Yes	Recovery and Avionics	The launch on February 9, 2019 used altimeters powered by 9V batteries.
6.16	Drogue descent velocity shall be less than 100 fps.	The calculated drogue descent velocity is less than 100 fps	Analysis	No	Recovery and Avionics	Section 3.2.1.4 contains the calculations for descent velocity under drogue. The drogue descent velocity is 71.5 fps.
6.17	The launch vehicle shall use recovery devices that the team owns.	The team does not purchase any recovery devices.	Demonstration	No	Recovery and Avionics	Section 3.2.1.4 contains the recovery harness system with all recovery devices listed. The team owns all of these.
6.18	The black powder ejection charges shall produce at least a 15 psi pressure or produce a net force of 234 lbs on the bulkheads at the point of separation.	The launch vehicle separates during the pre-launch ejection demonstration.	Analysis/Demonstration	Yes	Recovery and Avionics	Each charge produces at least 15 psi pressure at the point of separation.
6.19	The launch vehicle shall use U-Bolts for all shock cord attachments	The launch vehicle uses U-Bolts at all shock cord attachments.	Demonstration	No	Structures	Section 3.1.5 contains the lay-out of each bulkhead used for shock cord attachments.
6.20	Video feed shall not be transmitted until the payload has fully exited the rocket.	The video transmitter, mounted on the UAV, remains off for the duration of the launch vehicle flight.	Demonstration	Yes	Payload Structures	Section 5.1.2.2 describes how the video feed is maintained and controlled.
6.21	The UAV and retention system shall fit inside a 5.5” diameter body tube.	The UAV and retention system fit inside the rocket.	Analysis	Yes	Payload Structures, Payload Communication, Payload Integration	Section 5.1.2 describes the design of the UAV and retention system. This system fits inside the 5.5” airframe.
6.22	The UAV and retention system shall weigh less than 5 lb.	When weighed, the complete UAV and	Analysis	Yes	Payload Structures, Payload	Section 5.1.2 describes the design of the UAV and retention system

		retention system weigh less than 5 lb.			Communication, Payload Integration	including weights of all components.
6.23	The UAV deployment mechanism shall use a Southco R4-EM-63-161 latch.	The Southco latch is used in the payload retention system.	Demonstration	No	Payload Integration	Section 5.1.2 describes the design of the UAV retention system and the Southco latch.
6.24	The UAV shall be capable of flying at least 0.5 miles in unfavorable wind conditions.	The UAV flies over 0.5 miles during the Adverse Conditions UAV Flight Test.	Test	No	Payload Structures	Section 6.1.8 includes the Adverse Conditions UAV Flight test. Appendix D includes the procedure for the test. The UAV was capable of flying 10 minutes.
6.25	The UAV shall have a hover flight time of at least 5 minutes.	The UAV hovers for over 5 minutes during the UAV Hover Test.	Test	No	Payload Structures	Section 6.1.7 includes the UAV Hover Test. Appendix D includes the procedure for the test. The UAV was capable of hovering for 20 minutes.
6.26	The payload shall have an operating range of at least 0.6 miles.	The payload is operational at a range of over 0.6 miles.	Test	No	Payload Communication	Section 6.1.4 includes the Payload Maximum Operating Range Test. Appendix D includes the procedure for the test. The payload was capable of functioning at the desired range.
6.27	The payload shall utilize a Taranis X-Lite radio transmitter.	The flight controller is operated by the Taranis X-Lite transmitter.	Demonstration	No	Payload Structures, Payload Communication	Section 5.1.2.2 includes the design of the UAV electronics system. The UAV is controlled by the Taranis X-Lite transmitter.
6.28	The payload deployment system shall utilize an Arduino microcontroller.	The payload retention and deployment system uses the Arduino.	Demonstration	No	Payload Communication	Section 5.1.2 includes the design of the payload retention and deployment system. The Arduino is used to control the Southco latch and run the deployment motor.

6.2.3 Safety Requirement Verification Matrix

The below table covers all safety requirements and how they have been satisfied.

Table 6-7 Safety Requirement Verification Matrix

Causal Factors	Recommendation	Severity	Verification Method	Performing Organization	Preflight Acceptance	Verification Results
High-velocity winds, complete or partial recovery system failure	All team members were instructed prior to and throughout launch day on ongoing launches and measures on steering clear of any potentially dangerous flight paths. At least one club member maintained visual contact with airborne launch vehicles. If an airborne launch vehicle was within close proximity to personnel, visual contact was maintained until the vehicle is static after touchdown. If the RSO's signals of a launch occurring could be heard from the team's work site, the RSO was informed by the club safety officer to accommodate this situation	2	Inspection	Safety Officer	Yes	See Appendix B for launch day procedures regarding safety.

Heavy precipitation	Weather forecasts were used to determine a range of launch dates with favorable conditions. Severe precipitation conditions resulted in cancellation of launch, as human safety is at major risk. In the case of inconsistent to light precipitation conditions, launch would have been carried forward with the RSO's approval. Waterproof materials were brought to shelter the launch vehicle and its components for assembly prior to launch, and recovery after launch. Launch day procedures concerning recovery efforts detail actions and behaviors prioritizing human safety over project safety in unfavorable recovery conditions.	1	Inspection	Safety Officer	Yes	See Appendix C for weather conditions prior to launch.

Cloud cover, high-velocity winds	As NAR Safety Code does not allow for launches into cloudy conditions, low cloud cover would have resulted in cancellation of launch, as human safety is at risk. NAR Safety Code prohibits launching in wind conditions exceeding 20 miles per hour, and windspeed was requested from the RSO prior to launch. If excessively windy conditions prevailed, launch vehicle assembly would have been carried out in whatever shelter provided by the RSO or a team member's vehicle.	2	Inspection	Safety Officer	Yes	See Appendix C for weather conditions prior to launch.

Water features and non-level ground surfaces	Launch day procedures concerning recovery efforts detail actions and behaviors prioritizing human safety over project safety in unfavorable recovery conditions. Additionally, the club safety officer accompanied the recovery sub-team throughout the launch vehicle retrieval process to ensure safety of the crew. All team members were instructed prior to and throughout launch day on steering clear of possible walking hazards on the launch field	2	Demonstration	Safety Officer	Yes	See the Field Recovery Checklist in Appendix B for a list of recovery sub-team personnel.
Severe humidity affecting altimeter calibration	Field Recovery Personnel were equipped with nitrile gloves, leather gloves, safety glasses, and other equipment to handle black powder charges and disarm avionics system prior to handling	1	Demonstration	Safety Officer	Yes	See the Field Recovery Checklist in Appendix B for list of recovery sub-team equipment, recovery sub-team personnel, and field recovery PPE verification.

Improper or no personal protective equipment used	Prior to engaging activities in the lab site, all team members were briefed on how chemicals are used in fabrication, the respective personal protective equipment (gloves, safety glasses, face masks), and their location of these within the lab. Procedures are posted around the lab site as a reminder of safety procedures respective to each material used. The Lab Safety Binder contains MSDS sheets on each material used within the lab, and procedures on reactionary measures for chemical exposure. Additionally, the club safety officer accompanied team members throughout the fabrication process.	1	Demonstration	Safety Officer	No	See Appendix C for lab safety binder.

Improper or no personal protective equipment used, improper storage of energetics	Concerning the motor and black powder, a minimum number of individuals will be allowed contact. The primary handlers of the motor are the safety officer and club advisors. In unforeseen circumstances another club officer may be necessary, but this is unlikely. The team's adherence to manufacturer supplied instructions in the storage, handling, and assembly of the motor shall mitigate any motor failures due to misuse. The motor is stored in the flame and hazard cabinet secured in its original packaging and is not permitted to be assembled in any area not under NAR and/or TRA supervision. Additionally, all energetic materials were stored securely in their original packaging within the flame and hazards cabinet	1	Demonstration	Safety Officer	No	See the Motor Assembly Checklist in Appendix B for motor assembly procedure.

Improper or no personal protective equipment used	Lithium polymer batteries were stored in a cool, dry environment away from other materials that could cause damage to the batteries. When not in use, the batteries were returned to their storage container.	1	Demonstration	Safety Officer	No	See UAV Assembly Checklist in Appendix B for lithium polymer battery handling.
Sustained high-velocity winds	The UAV design specifications have taken into consideration possibly high velocity cross-winds by increasing propeller size, battery capacity, and motor strength, and underwendt testing in similar conditions post-fabrication and prior to launch.	2	Analysis and Test	UAV Lead	No	See section 5.1 for UAV design considerations. See section 6.1 for UAV test results

Non-uniform ground surface conditions including water features	The launch site was inspected for water features and non-uniform surfaces. If the safety officer or RSO deemed that the field conditions posed a severe risk to launch vehicle or payload integrity post-landing, the launch would have been cancelled. The launch vehicle was designed such that it can withstand being dragged across non-uniform terrain and water features.	2	Analysis and Inspection	Safety Officer	Yes	See Section 3.4.1 for field condition overview. See section 3.1.2.1 for launch vehicle structural considerations
Proximity to wooded areas	Wooded areas near the launch site were farther away than the predicted wind drift of the launch vehicle. If the launch vehicle were to be suspended in foliage out of the recovery team's reach, the local fire department would have been called to assist in retrieval – no trees were cut down.	1	Inspection	Safety Officer	Yes	See Section 3.4.1 for field overview with locations of wooded areas marked

Motor exhaust creates a fire or damages the area surrounding the launch rail	The safety officer verified that a blast deflector was in place prior to each launch. If a launch pad fire occured, a fire extinguisher was available to extinguish the fire	2	Inspection	Safety Officer	Yes	See Appendix C for confirmation of blast deflector installation
Loose components during flight or improper handling during assembly punctures a battery	The electronics lead and safety officer verified that only batteries and electronics that have been handled and stored properly are used in the launch vehicle. The safety officer ensured that all electronics and batteries were inspected for leakages prior to their integration into the launch vehicle	2	Inspection	Safety Officer	Yes	See the Launch Day Checklists in Appendix B for battery integrity confirmation
Exposed or faulty wiring creates an electrical short, or electronics overheat and start a fire	The team verified the quality of the wiring and ensured that there are no exposed wires prior to each launch. Only electronics that were determined by the safety officer to be in good physical condition were used in the vehicle.	2	Inspection	Safety Officer	Yes	See AV Bay Assembly Checklist in Appendix B for electronics integrity confirmation

Harmful components may be unintentionally expelled from the launch vehicle due to the forces of launch. Hazardous components in the launch vehicle may also be rendered unrecoverable through a failure of the recovery system. Additionally, the team may unintentionally leave debris at the launch field.	Potentially harmful components were inspected prior to launch to ensure they were securely attached to the launch vehicle. The launch site and the landing zone were inspected for components or debris that had fallen off the launch vehicle. Prior to leaving the launch field, the team ensured to remove any waste left by their activities. Each of these inspections were be verified by the safety officer to ensure all waste had been collected.	2	Inspection	Safety Officer	No	See Field Recovery Checklist in Appendix B for waste removal confirmation

A failure of the recovery system in which the parachutes do not deploy, deploy too late, deploy incorrectly, or are not properly secured to components leading to freefall.	All black power charges were carefully measured and verified by the faculty advisor, Dr. Chuck Hall, and the safety officer, for accuracy. All altimeters were programmed by the recovery lead, and verified by the recovery lead to ensure the black powder chargers were triggered at the proper time. A larger redundant charge was used for each ejection event to ensure that proper and complete ejection occured.	2	Analysis	Recovery Lead	Yes	See section 6.1.12 for black powder ejection testing. See Section 3.2.1.2(a) for altimeter programming description
	The recovery lead inspected all quick link connections to ensure the security of the recovery harnesses	2	Inspection	Recovery Lead	Yes	See Recovery Assembly checklists in Appendix B for quick link security confirmation
	The structures lead conducted a bulkhead tensile test, to verify the security of the connection between the u-bolt and bulk as well as between the bulkhead and body tube	2	Test	Structures Lead	Yes	See Section 6.1.1 for bulkhead test description

The launch vehicle lands in one or several trees near the launch area	The team safety officer inspected the landing site to determine if the rocket could be retrieved without risk to personnel. If the rocket could not have been safely retrieved, the team would have acquired the proper equipment to retrieve the rocket safely at a later date	2	Inspection	Safety Officer	Yes	See Field Recovery Checklist in Appendix B for landing site inspection
CO_2 is released into the atmosphere from club related travel to the launch events and supply store.	The team has carpooled to all launch events. The team uses driving over flying when travelling long distances. When ordering parts, local options were preferred if part quality was deemed to be equal or superior to that of other options	3	Demonstration	Team Lead	No	Carpool confirmation occurs over email with team members

Manufacturing defect, damage during handling within the lab or handling and assembly prior to launch	Visual inspection after shipping and before assembly. Material inspection was documented photographically and stored within the lab safety binder. Manufacturer and distributor would have been contacted for a replacement prior to fabrication process.	2	Inspection	Structures Lead	Yes	See Section 3.1.4.1 for material integrity confirmation

Ground impact due to altimeter failure	Two different altimeters were used for redundancy in mission safety to prevent electronic errors. Ground ejection tests of the calculated black powder charge masses were conducted to verify separation of sections and functionality of altimeter system. Ground altimeter redundancy system tests were periodically completed through simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, the wiring, functionality, and component integrity of the avionics system were confirmed to be in accordance with design specifications by testing continuity and simulated flight	2	Demonstration and Test	Recovery Lead	Yes	See Section 6.1.12 for ground ejection demonstration description. See section 6.1.11 for altimeter testing results

Collision with object in flight path	The safety officer ensured that skies were clear of any foreign objects per NAR regulations prior to launch. Any concerns were reported to the RSO, and the launch would have been halted until uncertainties regarding flight conditions are addressed	2	Inspection	Safety Officer	Yes	See Section 3.4.1 for skies clear verification
Improper storage within the lab and during transportation	Items were not stored on top of nose cone. Prior to departure, the safety officer confirmed this action on the packing checklist. The storage compartment was periodically inspected throughout transport and appropriate adjustments were made.	2	Inspection	Safety Officer	Yes	See Section 3.2.1.1 for appropriate storage confirmation
Collision with other launch vehicle component during descent	The avionics and recovery subteam lead ensured shock cord is long enough to separate nosecone from other components during design, packing, and assembly. The safety officer confirmed this action on the launch day checklist during assembly.	2	Analysis and Inspection	Recovery Lead and Safety Officer	Yes	See Recovery Assembly Checklist in Appendix B for pre-launch confirmation

Improper installation of screws into T-nut fasteners during assembly prior to launch	Design specifications for sizing, inspecting, and installing T-nut fasteners and screws were followed during fabrication and assembly prior to launch. The structures lead coordinated this portion of the assembly process and confirmed these actions on launch day checklist	2	Inspection	Structures Lead	Yes	See Section 3.1.4.6 for T-nut fastener installation description
Epoxy for T-nut fastener blocks underneat coupler not cured or applied properly	Proper procedures for mixing, applying, and curing epoxy were followed. With a flashlight, the connecting layer of epoxy between T-nut block and coupler was inspected for gaps. The structures lead coordinated this portion of the assembly process and confirmed these actions on the launch day checklist.	2	Inspection	Structures Lead	Yes	See Section 3.1.4 for epoxy application description
Loads experienced beyond design specifications	Body tube components were confirmed to hold flight forces in accordance with design specifications. All components were confirmed to maintain a factor of safety of at least 2 during all regimes of flight	1	Analysis	Structures Lead	Yes	See Section 3.1.2.1 for structural analysis details

Fin dimensions are not cut according to design	A laser-cutting instrument was used to cut fins to design specification with manufacturing precision. The fins were measured post-component fabrication to ensure dimensions match design specifications.	2	Inspection	Structures Lead	Yes	See section 3.1.4 for fin fabrication and inspection description
Fins not installed at even increments around fin can	Fin slots were cut by the manufacturer and were measured prior to fabrication to ensure dimensions match design specifications. Manufacturer and distributor would have been contacted for a replacement prior to fabrication process.	2	Inspection	Structures Lead	Yes	See section 3.1.4 for fin slot accuracy verification

Assembled launch vehicle CG is too far forward	The Center of Pressure location was calculated through analytical means to verify the Center of Pressure location given by simulations. The launch vehicle Center of Gravity was measured prior to launch to determine the stability margin. Mass distribution within the launch vehicle was analyzed for stability margins exceeding or under design specification.	2	Analysis	Team Lead	Yes	See section 3.3.2 for Center of Pressure and static stability margin
Loads experienced beyond design specifications	Flight data and ANSYS simulations were analyzed to confirm that factor of safety was at a minimum of 1.5. Any components not meeting this requirement were subject to redesign and/or additional fabrication	1	Analysis	Structures Lead	Yes	See section 3.1.2.1 for component structural integrity analysis
Fin flutter	Launch vehicle did not exceed velocity necessary to induce significant flutter	2	Analysis and Demonstration	Team Lead	Yes	See section 3.3.1 for flight simulations. See section 3.4.2 for logged velocity during flight

Ground impact	The recovery system is designed such that the launch vehicle impacts the ground without sufficient energy to induce fin separation.	2	Analysis	Recovery Lead	Yes	See section 3.3.3 for ground impact energy calculations
Igniter not installed correctly	The launch pad checklist and mentor/RSO supervision were used to ensure correct igniter installation. The safety officer confirmed this action on the launch pad checklist.	4	Inspection	Safety Officer	Yes	See Launch Pad Checklist in Appendix B for igniter installation confirmation
Faulty igniter used	A batch of igniters were tested prior to launch day to ensure quality and functionality.	4	Demonstration	Safety Officer	Yes	Ignitors are purchased from approved vendors
Motor assembled incorrectly	The safety officer followed the motor assembly checklist and used mentor/RSO supervision to ensure correct assembly of the motor. The safety officer confirmed this action on the launch day checklist.	4	Inspection	Safety Officer	Yes	See Motor Assembly Checklist in Appendix B for motor assembly procedure

Motor damaged during handling within the lab or handling and assembly prior to launch	The motor was carefully inspected for cracks, chips, or other damage during assembly, and documented through photography. The safety officer and propulsion lead confirmed this on the packing and launch day checklist.	1	Inspection	Safety Officer	Yes	See Motor Assembly Checklist in Appendix B for motor inspection
Motor assembled incorrectly	The safety officer followed the motor assembly checklist and used mentor/RSO supervision to ensure correct assembly of the motor. The safety officer confirmed this action on the launch day checklist.	1	Inspection	Safety Officer	Yes	See Motor Assembly Checklist in Appendix B for motor assembly procedure
Motor casing dislodged during motor burn	All connection points between motor tube, centering rings, and fins were confirmed to be joined properly using epoxy. Careful inspection of joints prior to launch was performed. The safety officer confirmed the actions above on the launch day checklist.	1	Inspection	Safety Officer	Yes	See Motor Assembly Checklist in Appendix B for motor tube security confirmation

Over-oxidized reaction, reduced fuel efficency	Motors were ordered from a reputable source. Motor fuel was stored and maintained properly and in isolation from other materials in the flame and hazards storage cabinet	2	Demonstration	Safety Officer	Yes	Motors are kept in the team's flame cabinet
Loads experienced beyond design specifications	Structural analysis was performed to ensure bulkhead composite can hold flight forces in accordance with design specifications. All components were confirmed to be able to maintain a factor of safety of at least 2 during all regimes of flight	1	Analysis	Structures Lead	Yes	See Section 6.1.1 for bulkhead load testing
Damaged during handling within the lab, or handling and assembly prior to launch	Each bulkhead was inspected for cracks, warping, chips, or other damage during assembly. Any damaged bulkheads were replaced	1	Inspection	Structures Lead	Yes	See Section 3.1.4 for bulkhead inspection
Epoxy not cured properly	Proper procedures for mixing, applying, and curing epoxy were followed	1	Inspection	Structures Lead	Yes	See Section for epoxy application description

Loads experienced beyond design specifications	U-bolt fasteners and bulkhead composites were designed to handle near-instantaneous loading from parachute and shock cord deployment by simulating shearing force through application of sudden force equivalent to drogue and main deployment. Testing was analyzed to ensure that all components maintained a factor of safety of at least 1.5 during all regimes of flight.	1	Test	Structures Lead	Yes	See Section 6.1.1 for assembled bulkhead failure analysis
Rail buttons separate from launch vehicle	Rail buttons are epoxied into body tube to reduce risk of separation.	1	Inspection	Structures Lead	Yes	See Section 3.1.4 for epoxy application description
Damaged during handling within the lab, or handling and assembly prior to launch	Each rail button and connection was inspected for cracks, warping, chips, or other damage during assembly. Any damaged rail buttons were replaced.	1	Inspection	Structures Lead	Yes	See Appendix C for rail button inspection
Launch rail breaks	The rail was confirmed to be assembled correctly prior to launch. Ground crew and spectators were located away from the launch pad as instructed by the RSO, NAR regulation, and the club safety officer	3	Inspection	Safety Officer	Yes	See Appendix C for launch rail inspection

Rail buttons become stuck in launch rail	Prior to launch, the RSO was contacted to verify that rail buttons match size of launch rail slot. The launch rail and rail buttons were lubricated. The vehicle was visually confirmed to move smoothly on the launch rail during assembly and launch rail erection	2	Inspection	Safety Officer	Yes	See Appendix C for launch rail inspection
Damaged during handling within the lab, or handling and assembly prior to launch	Each shear pin and connection was inspected for cracks, warping, chips, or other damage during assembly. Any damaged shear pins were replaced prior to launch	2	Inspection	Recovery Lead	Yes	See Section 6.1.2 for shear pin testing
Pins fall out of respective holes	The size of holes drilled in body tube was confirmed to match the diameter of shear pins. Additionally, the Recovery and Avionics Sub-team lead inspected the vehicle prior to launch to verify that all shear pins were secure. Loose pins were secured by electrical tape	2	Inspection	Recovery Lead	Yes	See Recovery Assembly Checklists in Appendix B for shear pin security confirmation
Loads beyond design specifications	Pins were confirmed to hold flight forces in accordance with design specifications	2	Test	Recovery Lead	Yes	See Section 6.1.2 for shear pin test results

Pins too tight in body tube holes	The size of holes drilled in body tube was confirmed to match the diameter of shear pins	1	Inspection	Recovery Lead	Yes	See the Recovery Assembly Checklists in Appendix B for mitigations on the shear pin hole sizing
Poor design	Calculations were used to ensure that pins break from forces of detonation. Prior to launch, shear pin in-flight separation was simulated through ground ejection testing with the calculated black powder masses.	1	Demonstration	Recovery Lead	Yes	See Section 6.1.12 for ground ejection demonstration description and results
Snags, tears, or rips during ejection	Shock cord was inspected for damage prior to launch. High-strength shock cord was used with a maximum loading greater than 1,500 lb. Shock cord was confirmed to be folded and stowed properly in the launch vehicle. Sharp edges on the launch vehicle were reduced or eliminated to reduce risk of snagging shock cord and parachutes	1	Analysis and Inspection	Recovery Lead and Safety Officer	Yes	See Recovery Assembly Checklists in Appendix B for shock cord installation procedure
Shock cord disconnects from airframe or parachute	Quick link connects between the shock cord, airframe, and parachutes are confirmed to be tight and secure	1	Inspection	Recovery Lead and Safety Officer	Yes	See Recovery Assembly Checklists in Appendix B for quick link security confirmation

Shock cord stuck within launch vehicle airframe	Shock cord was confirmed to be folded and stowed properly in the launch vehicle. Sharp edges on the launch vehicle were reduced or eliminated to reduce risk of blocking shock cord and parachutes	1	Analysis and Inspection	Recovery Lead and Safety Officer	Yes	See Recovery Assembly Checklists in Appendix B for shock cord installation procedure
Shock cords become tangled	Prior to launch, shock cord and parachute systems were assembled to confirm that accordion-style folding of the shock cords do not tangle.	2	Inspection	Recovery Lead	Yes	See Recovery Assembly Checklists in Appendix B for shock cord inspection
Shock cord and U-bolt connections become loose	Prior to launch, shock cord and parachute systems were assembled to confirm that the quick link connection points between the shock cord and U-bolts were fastened	2	Inspection	Recovery Lead	Yes	See Recovery Assembly Checklists Appendix B for quick link inspection
Parachute bag does not fully open	Prior to launch, the parachute bag was confirmed to be assembled correctly such that nothing could snag the bags within the body tube	2	Inspection	Recovery Lead	Yes	See Recovery Assembly Checklists in Appendix B for deployment bag assembly

Failed black powder charge detonation	Two different altimeters were used for redundancy in mission safety to prevent electronic errors. Ground ejection tests of the calculated black powder charge masses were conducted to verify separation of sections and functionality of altimeter system. Ground altimeter redundancy system tests were periodically completed through simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, the wiring, functionality, and component integrity of the avionics system were confirmed to be in accordance with design specifications by testing continuity and simulated flight	1	Demonstration	Recovery Lead	Yes	See Section 6.1.12 for ground ejection demonstration. See section 6.1.11 for altimeter test results

Black powder charge is too large	Charges were confirmed to be sealed properly, and the correct amount of black powder was used with pre-flight checklist. Ground ejection tests were conducted with the calculated black powder charge masses to verify separation of sections, functionality of altimeter system, and minimal damage to separated launch vehicle components.	2	Demonstration and Inspection	Recovery Lead and Safety Officer	Yes	See section 6.1.12 for ground ejection demonstration. See Recovery Assembly Checklists in Appendix B for black powder installation procedure
Black powder charge is too small	Charges were confirmed to be sealed properly, and the correct amount of black powder was used with pre-flight checklist. Ground ejection tests were conducted with the calculated black powder charge masses to verify complete separation of sections.	1	Demonstration and Inspection	Recovery Lead and Safety Officer	Yes	See section 6.1.12 for ground ejection demonstration. See Recovery Assembly Checklist in Appendix B for black powder installation procedure
Uncharged or insufficiently charged batteries	New and unopened batteries were installed at launch. All batteries were confirmed to have sufficient voltage using a multimeter	1	Inspection	Recovery Lead	Yes	See AV Bay Assembly Checklists in Appendix B for battery charge confirmation

Battery becomes disconnected from altimeter	Altimeters were confirmed to be properly connected and all wires secured prior to launch. Beeps were listened to when altimeters were powered on at the launch pad	1	Inspection	Recovery Lead	Yes	See AV Bay Assembly Checklists in Appendix B for altimeter power confirmation
Wiring short	All wire was confirmed to be properly insulated and wires were securely contained in their respective terminals	1	Inspection	Recovery Lead	Yes	See AV Bay Checklists and Payload Deployment Checklists in Appendix B for wiring confirmation

Manufacturing defect	Ground ejection tests of the calculated black powder charge masses were conducted to verify separation of sections, and functionality of altimeter system. Ground altimeter redundancy system tests were conducted through simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, the wiring, functionality, and component integrity of the avionics system were confirmed to be in accordance with design specifications by testing continuity, and simulated flight. Fault codes were listened for at the launch site.	1	Demonstration	Recovery Lead	Yes	See section 6.1.12 for ground ejection demonstrations. See section 6.1.11 for altimeter test results. See Launch Pad Procedure Checklists in Appendix B for launch pad altimeter procedures
Incorrect altimeter readings	Pressure ports were confirmed to be sized correctly. Fault codes were listened for at the launch site	2	Inspection	Recovery Lead	Yes	See AV Bay Checklists in Appendix B for pressure port inspection

Incorrect altimeter readings or improper programming	Pressure ports were confirmed to be sized correctly. Fault codes were listened for at the launch site. Altimeter chirps during power-on were confirmed to indicate the proper deployment altitude of 500ft AGL	2	Inspection	Recovery Lead	Yes	See section 3.2.1.2(a) for altimeter programming procedure. See Launch Pad Procedure Checklists in Appendix B for chirp code confirmation
Loss of power to ground receiver or laptop	The receiver and laptop are confirmed to be fully charged at least 6 hours prior to flight	3	Inspection	Recovery Lead	No	See AV Bay Checklists in Appendix B for battery charge confirmation
Environment or launch vehicle materials block signal	Range tests were performed to ensure reliability of the system at simulated altitudes and ground distances	3	Test	Recovery Lead	No	See section 6.1.9 for GPS test results
Multiple radio devices on the same local frequency and channel	All transmitting devices were confirmed to be on separate channels. Confirmation with other teams and launch officials was made that no frequency conflict exists	3	Inspection	Recovery Lead	No	See Section 6.1.9 for GPS test results

Flight forces cause GPS to disconnect from power supply	All GPS units are confirmed to be fully charged and simulated load tests were conducted to determine necessary procedures to secure the units	3	Test and Inspection	Recovery Lead	No	See AV Bay Checklists in Appendix B for GPS installation procedure. See AV Bay Checklists in Appendix B for battery charge confirmation
RF radiation	Tests were conducted to ensure other onboard electronics caused no interference with the altimeters	3	Demonstration	Recovery Lead	Yes	See section 6.1.9 for interference testing results
Loads beyond design specifications	Simulated load tests were performed and a sufficient factor of safety was added when designing the avionics sled	1	Analysis	Recovery Lead	Yes	See section 3.1.5.4 for avionics bay design
Damaged during handling within the lab, or handling and assembly prior to launch	Team members involved with avionics bay assembly have been instructed on proper handling and installation procedure	1	Inspection	Recovery Lead	Yes	See AV Bay Checklists in Appendix B for avionics assembly personnel
Improper maintenance	Pre- and post-launch thorough inspections of the avionics sled have been performed	1	Inspection	Recovery Lead	Yes	See AV Bay Checklists in Appendix B for avionics bay inspection
Shock cords become tangled or loose	Shock cords are confirmed to be securely attached and folded correctly	3	Inspection	Recovery Lead	Yes	See Recovery Assembly Checklists in Appendix B for shock cord inspection

Stepper motor failure	The motor has been tested before installation for current, voltage, and output parameters. The motor has undergone an integrated test with the screw-drive deployment system. Finally, the motor was simulated for compressive stress undergone during initial takeoff and separation stages.	4	Test	Payload Electronics Lead	No	See section 6.1.3 for payload deployment demonstration results
Failure of electronically activated latch release	Electronically activated latches were tested prior to installation for mechanical and electrical operational success. Electronically activated latches have completed integration testing to prove that they release the Containment Pod under vertical and horizontal orientations	4	Test	Payload Electronics Lead	No	See section 6.1.3 for payload deployment test results

Buckling of threaded rod	The threaded rod was tested for an ultimate stress, with a factor of safety of 1.5 from the reported maximum compressive stress provided in the material documentation of the part. Additionally, the threaded rod was secured by a journal bearing on the open deployment direction to reduce compressive loading conditions.	4	Analysis and Test	Payload Electronics Lead	No	See section 6.1.3 for payload deployment test results
Centering ring misalignment	The proper procedures have been followed for mixing, applying, and curing epoxy for the adhesion of the centering rings to the inner payload body tube.	4	Inspection	Structures Lead	No	See section 3.1.4.5 for payload centering ring construction

Shock cord entanglement	Shock cord has been routed inline through channels positioned at the outer edges of the bulkheads to prevent excess shock cord from disturbing the exit cavity. Additionally, the convex design of the containment pod's front end shifts any obstruction in the exit cavity out of its path	4	Analysis	Payload Integration Lead	No	See section 5.1.2 for payload integration system design
Shearing at pusher plate and threaded rod joint, cantilevered rod joint, or support rod joint	Pusher plate material was made of a 3D printed PLA which was done for ease of manufacture and more accurate and precise construction. Additionally, a threaded collar was inserted into the pusher plate to transfer loading from the thread rod joint to the area around the joint, effectively distributing the force over a larger area.	4	Analysis	Payload Integration Lead	No	See section 5.1.2 for payload integration system design

Elastic surgical tubing detachment	The Containment Pod was designed and has been tested to exit the payload body tube in multiple orientations on the cantilevered beam. The egg-shaped cross section design and the off-center center of gravity location prevents the Containment Pod from deploying in an "unfavorable orientation" as the mass of the UAV rights the pod.	4	Analysis and Test	Payload Integration Lead	No	See section 5.1.2 for payload integration system design. See section 6.1.3 for payload deployment test results
Avionics package to motor wiring failure	The avionics package to motor wiring has been give slack to account for the tensile stress experienced due to UAV arm extension	4	Analysis	UAV Lead	No	See section 5.1.5 for UAV wiring design
Improper installation of hinges	Hinges have been tested prior to launch under various angular acceleration conditions, as well as the rigidity of the arms in the fully extended position	4	Test	UAV Lead	No	See section 5.1.5 for hinge design

Motor failure	UAV motors were tested before installation for current, voltage, and output parameters. The motors have completed an integrated test with the screw-drive deployment system. Finally, the motors were simulated for compressive stress undergone during initial takeoff and separation stages.	4	Test	UAV Lead	No	See section 6.1.8 for UAV flight test results
Damage during launch vehicle flight	The Containment Pod shelters the UAV with an outer shell and an internal layer of padding foam to reduce loads experience on the UAV body structure. Additionally, a pair of pegs restricts the motion of UAV in five out of six degrees.	4	Analysis	Payload Integration Lead	No	See section 5.1.2.1 for containment pod design
Manufacturing defect	Visual inspection was performed after shipping and before assembly. Manufacturer and distributor would have been contacted for a replacement prior to fabrication process.	4	Inspection	UAV Lead	No	See section 5.1.2.1 for UAV structural design

Damage during handling, launch vehicle flight, or UAV operation	Structural integrity of wiring connections has been tested under simulated flight loads. UAV assembly team members have been briefed on proper handling of the UAV	4	Test	UAV Lead	No	See UAV Assembly Checklists in Appendix B for UAV assembly team members
Foreign objects stuck in UAV motors	UAV liftoff demos have been conducted in areas similar to predicted landing sites to confirm proper operation	4	Demonstration	UAV Lead	No	See section 6.1.8 for UAV flight test results
Signal is not sent properly	Demos have been performed on the UAV transceiver to ensure reliable control signals exist between the UAV and transceiver	4	Demonstration	UAV Lead	No	See section 6.1.8 for UAV flight test results
Programming error	Demos have been performed on the UAV in multiple flight regimes to confirm desired operation	4	Demonstration	UAV Lead	No	See section 6.1.8 for UAV flight test results
Uncharged or insufficiently charged batteries	Batteries were confirmed to be fully charged the night before the launch, and had their voltage checked on launch day prior to integration with the UAV	4	Inspection	UAV Lead	No	See UAV Assembly Checklists and Payload Bay Assembly Checklists in Appendix B for battery charge confirmation

Battery fire	Battery quality has been monitored prior to arrival at the launch field. Damaged batteries have been replaced.	3	Inspection	UAV Lead	No	See UAV Assembly Checklists and Payload Bay Assembly Checklists in Appendix B for battery integrity confirmation

6.3 Budgeting and Timeline

6.3.1 Budget

Table 6-8details the year-long budget for the 2018-2019 competition year.

Table 6-8 Project Budget 2018-2019

	Item	Quantity	Price per Unit	Item Total
Subscale Structure	Aerotech I435T-14A	2	$56.00	$112.00
	Aero Pack 38mm Retainer	1	$27.00	$27.00
	Motor Casing	1	$340.00	$340.00
	38mm G12 Airframe, Motor Tube	1	$64.00	$64.00
	4" Phenolic Airframe, 3 Slots	1	$33.50	$33.50
	4" Phenolic Airframe	2	$26.00	$52.00
	4" Phenolic Coupler	4	$21.00	$84.00
	Plastic 4" 4:1 Ogive Nosecone	1	$23.00	$23.00
	Domestic Birch Plywood 1/8"x2x2	6	$12.68	$76.08
	3/4" L Brackets	4	$1.97	$7.88
	Rail Buttons	4	$2.50	$10.00
	U-Bolts	4	$1.00	$4.00
	Blast Caps	4	$2.50	$10.00
	Terminal Blocks	3	$7.00	$21.00
	Paint	1	$100.00	$100.00
	Key Switches	2	$12.00	$24.00
	Subtotal:			**$988.46**
Full-Scale Structure	Aerotech L1150R-PS	3	$200.00	$600.00
	5.5" G12 Airframe, Half Length (30"), 3 Slots	1	$130.00	$130.00
	5.5" G12 Airframe, Full Length (60")	1	$188.00	$188.00
	3" G12 Airframe, Half Length (30"), Motor Tube	1	$100.00	$100.00
	5.5" G12 Coupler 12" Length	3	$55.00	$165.00
	5.5" Fiberglass 4:1 Ogive Nosecone	1	$84.95	$84.95
	Domestic Birch Plywood 1/8"x2x2	8	$12.68	$101.44
	Aerotech 75/3840 Motor Case	1	$360.00	$360.00
	Motor Retainer	1	$44.00	$44.00
	3/4" L Brackets	4	$1.97	$7.88
	Rail Buttons	4	$2.50	$10.00
	U-Bolts	4	$1.00	$4.00
	Aerotech 75mm Forward Seal Disk	1	$37.50	$37.50
	Blast Caps	4	$2.50	$10.00

	Terminal Blocks	3	$7.00	$21.00
	Paint	1	$150.00	$150.00
	Key Switches	2	$12.00	$24.00
	Poster Printing (feet)	4	$10.00	$40.00
	Subtotal:			**$2,077.77**
Payload	Crazepony EMAX Brushless Motor	1	$56.99	$56.99
	OmniNXT F7 Flight Controller	1	$59.99	$59.99
	Electronic Speed Controller	1	$59.99	$59.99
	11.1V Lipo Battery	1	$21.99	$21.99
	FPV Camera	1	$19.99	$19.99
	Circular Antenna	1	$6.69	$6.69
	Lumenier 5x3.5 2 Blade Propeller	2	$1.79	$3.58
	Readytosky FPV Racing Drone Frame	2	$22.99	$45.98
	Lumenier circular polarized antenna	2	$10.19	$20.38
	AKK K31 Transmitter with Race Band	1	$11.99	$11.99
	FrSky XM+ SBUS Mini Receiver FPC Drone	1	$17.49	$17.49
	Lumenier DX800 DVR w/ 5.8GHz 32CH Receiver	1	$149.99	$149.99
	FRrSky X-Lite Radio Controller	1	$139.99	$139.99
	Arduino Uno	1	$24.95	$24.95
	Arduino USB Cable	1	$6.99	$6.99
	Arduino Servo Shield	1	$19.95	$19.95
	2KM Long Range RF Link Kit	1	$18.00	$18.00
	Breadboard	2	$9.95	$19.90
	LEDs	1	$6.99	$6.99
	Button	1	$5.85	$5.85
	Batteries	1	$15.20	$15.20
	Battery Clips	1	$5.66	$5.66
	Southco R4-EM Latch	1	$68.36	$68.36
	1.1”x1.1” stepper motor	1	$17.90	$17.90
	Hinges	4	$1.97	$7.88
	Aluminum rod	2	$2.21	$4.42
	Carbon Fiber Rod	2	$9.25	$18.50
	Surgical Tubing	2	$2.82	$5.64
	Nema 8 Bipolar Smallest Stepper Motor	1	$24.95	$24.95
	Subtotal:			**$886.18**

Recovery and Avionics	Iris Ultra 84" Compact Parachute	1	$504.00	$504.00
	24" Compact Elliptical Parachute	1	$53.00	$53.00
	Quick Links	8	$1.25	$10.00
	Kevlar Shock Cord (yard)	20	$4.34	$86.80
	Black Powder	1	$30.00	$30.00
	E-Matches	2	$29.00	$58.00
	Shear Pins	3	$3.00	$9.00
	StratoLogger CF Altimeter	4	$60.00	$240.00
	6" Deployment Bag	1	$43.00	$43.00
	18" Nomex Cloth	1	$24.00	$24.00
	BRB 900 Transmitter	1	$200.00	$200.00
	4" Deployment Bag	1	$39.00	$39.00
	13" Nomex Cloth	1	$13.00	$13.00
	Iris Ultra 60" Compact Parachute	1	$225.00	$225.00
	18" Compact Elliptical Parachute	1	$60.00	$60.00
	Kevlar Shock Cord (yard)	13.33	$2.55	$33.99
	Subtotal:			**$1,628.79**
Miscellaneous	Epoxy Resin	2	$86.71	$173.42
	Epoxy Hardener	2	$45.91	$91.82
	Nuts (box)	4	$5.50	$22.00
	Screws (box)	4	$5.00	$20.00
	Washers	4	$5.00	$20.00
	Wire	3	$13.00	$39.00
	Zip Ties	2	$11.00	$22.00
	3M Electrical Tape	4	$8.00	$32.00
	9V Batteries	2	$14.00	$28.00
	Wood Glue	2	$3.00	$6.00
	Rubber Bands	1	$5.00	$5.00
	Paper Towels	2	$25.00	$50.00
	Battery Connectors	3	$5.00	$15.00
	3-D Printer Filament	1	$19.99	$19.99
	Shipping			$1,200.00
	Incidentals (replacement tools, hardware, safety equipment)			$1,200.00
	Subtotal:			**$2,944.23**
Travel	Student Hotel Rooms (# rooms)	4	$791.70	$3,166.80
	Mentor Hotel Rooms (# rooms)	3	$1,178.10	$3,534.30

	Van Rentals (# cars)	2	$198.00	$396.00
	Gas (Miles)	1144	$0.60	$686.40
	Subtotal:			**$7,783.50**
Outreach	Bottle Rocket Launcher	1	$30.00	$30.00
	Paper	4	$10.00	$40.00
	Printing	500	$0.10	$50.00
	Subtotal:			**$120.00**
Promotional	T-Shirts	40	$14.00	$560.00
	Polos	30	$20.00	$600.00
	Stickers	1000	$0.30	$300.00
	Banner	1	$200.00	$200.00
	Subtotal:			**$1,660.00**
Total Expenses:				**$18,088.93**

6.3.2 Funding Plan

HPRC gets all its funding from multiple NC State University organizations, North Carolina Space Grant (NCSG), as well as a sponsorship from Rockwell Collins.

The Engineering Technology Fee at NC State is a funding source for senior design projects within the Mechanical and Aerospace Engineering department. Through the team's advisor and senior design professor, the team shall have access to $1,500 to put towards materials and construction costs.

The NC State University Student Government Association's Appropriations Committee is responsible for distributing university funds to campus organizations. The SGA allocates funds through an application process with a proposal, presentation, and an in-person interview. For the Fall session, the team has received $640 and a request for $2,000 was submitted in the spring semester, assuming the Appropriations Committee budget will remain the same. The team received $1,520 in the spring appropriations session.

Student and faculty advisor travel costs will be covered by NC State's College of Engineering Enhancement Funds. These funds come from a pool of money dedicated to supporting engineering extracurriculars at NC State. The total travel cost for University affiliated attendees comes to $6,000.

In addition to funding through NC State organizations, the North Carolina Space Grant will provide a large amount of monetary support to the club. NCSG accepts funding proposals during the fall semester and teams can request up to $5,000 for participation in NASA competitions. NCSG will review the proposal and inform the club on the amount awarded, which will likely be the full amount requested. These funds will be available for use starting November 2018.

Our sponsor, Rockwell Collins, has given $5,000 to be put toward the construction and launch of our competition rockets.

These totals are listed in Table 6-9, which compares the projected costs and incoming grants for the 2018-19 school year.

Table 6-9 Projected Costs for 2018-2019 Competition Year

Organization	Fall Semester Amount	Spring Semester Amount	School Year Total
SGA Appropriations	$640.00	$1,520.00	$2,160.00
Engineering Technology Fee	-	-	$1,500.00
NC Space Grant	-	-	$5,000.00
Rockwell Collins	-	-	$5,000.00
College of Engineering	-	-	$5,500.00
Total Funding:			**$19,160.00**
Total Expenses:			**$18,088.93**
Difference:			**$1,071.07**

6.3.1 Timeline

The below table is a comprehensive timeline of team activities over the course of the competition schedule. Gannt charts illustrating this timeline can be found in Appendix C: Project Timeline Gantt Charts.

Table 6-10 Timeline for 2018-2019 Competition Year

Task Name	Duration	Start	Finish
Proposal	**21 days**	**Wed 8/22/18**	**Wed 9/19/18**
General	1 day	Mon 9/3/18	Mon 9/3/18
Vehicle Criteria	8 days	Tue 9/4/18	Thu 9/13/18
Payload Criteria	8 days	Tue 9/4/18	Thu 9/13/18
Safety	9 days	Thu 9/6/18	Tue 9/18/18
Project Plan	2 days	Mon 9/10/18	Tue 9/11/18
Proposal Complete	0 days	Wed 9/19/18	Wed 9/19/18
PDR Milestone Report	**22 days**	**Thu 10/4/18**	**Fri 11/2/18**
General	1 day	Tue 10/9/18	Tue 10/9/18
Vehicle Criteria	10 days	Thu 10/11/18	Wed 10/24/18
Payload Criteria	10 days	Thu 10/11/18	Wed 10/24/18
Safety	10 days	Thu 10/18/18	Wed 10/31/18

Project Plan	3 days	Mon 10/29/18	Wed 10/31/18
Changes Since Proposal	1 day	Wed 10/31/18	Wed 10/31/18
PDR Milestone Report Complete	0 days	Fri 11/2/18	Fri 11/2/18
Subscale Construction	**14 days**	**Wed 10/31/18**	**Sat 11/17/18**
Lasercut Bulkheads and Fins	2 days	Wed 10/31/18	Thu 11/1/18
Cut Airframe Tubes	3 days	Wed 10/31/18	Fri 11/2/18
Altimeter Testing	1 day	Thu 11/1/18	Thu 11/1/18
Bulkhead Fabrication	4 days	Fri 11/2/18	Wed 11/7/18
Payload Bay Bulkhead Installation	1 day	Mon 11/5/18	Mon 11/5/18
Nosecone Bulkhead Installation	1 day	Mon 11/5/18	Mon 11/5/18
AV Bay Bulkhead Installation	1 day	Tue 11/6/18	Tue 11/6/18
Fin Can Bulkhead/Centering Ring Installation	5 days	Tue 11/6/18	Mon 11/12/18
Drill Pressure Ports and Switch Holes in AV Bay	0.5 days	Tue 11/6/18	Tue 11/6/18
Lasercut AV Sled	1 day	Tue 11/6/18	Tue 11/6/18
Install Motor Tube	1 day	Tue 11/6/18	Tue 11/6/18
Checklist Writing	7 days	Tue 11/6/18	Wed 11/14/18
AV Sled Fabrication	3 days	Wed 11/7/18	Fri 11/9/18
Install Fwd Rail Button	1 day	Wed 11/7/18	Wed 11/7/18
Install Fins	3 days	Thu 11/8/18	Mon 11/12/18
AV Wiring	3 days	Mon 11/12/18	Wed 11/14/18

Install Aft Rail Button	1 day	Mon 11/12/18	Mon 11/12/18
Install Motor Retainer	1 day	Mon 11/12/18	Mon 11/12/18
Install AV Sled	2 days	Thu 11/15/18	Fri 11/16/18
Paint	1 day	Thu 11/15/18	Thu 11/15/18
Black Powder Demonstration	1 day	Fri 11/16/18	Fri 11/16/18
Subscale Launch	0 days	Sat 11/17/18	Sat 11/17/18
CDR Milestone Report	**40 days**	**Mon 11/19/18**	**Fri 1/11/19**
Changes Since PDR	7 days	Mon 11/19/18	Tue 11/27/18
Vehicle Criteria	31 days	Mon 11/26/18	Mon 1/7/19
Safety	32 days	Wed 11/28/18	Thu 1/10/19
Payload Criteria	27 days	Sat 12/1/18	Mon 1/7/19
Project Plan	7 days	Tue 1/1/19	Wed 1/9/19
Summary	2 days	Tue 1/8/19	Wed 1/9/19
CDR Milestone Report Complete	0 days	Fri 1/11/19	Fri 1/11/19
Testing	**36 days**	**Fri 1/11/19**	**Fri 3/1/19**
Bulkhead Failure Testing	3 days	Fri 1/11/19	Tue 1/15/19
Real Conditions Endurance Testing	2 days	Fri 1/18/19	Sun 1/20/19
Payload Pad Endurance Testing	3 days	Mon 1/21/19	Wed 1/23/19
Payload Deployment Demonstration	2 days	Mon 1/21/19	Tue 1/22/19
Payload Retention Testing	2 days	Thu 1/24/19	Fri 1/25/19
Recovery Electronics Endurance Testing	3 days	Tue 1/29/19	Thu 1/31/19

Hover Endurance Testing	2 days	Fri 2/1/19	Sun 2/3/19
Altimeter Demonstration	1 day	Fri 2/1/19	Fri 2/1/19
Black Powder Ejection Demonstration	1 day	Thu 2/7/19	Thu 2/7/19
GPS Testing	2 days	Thu 2/14/19	Fri 2/15/19
Payload Operation Range Testing	2 days	Fri 2/15/19	Mon 2/18/19
Full-scale Construction	**21 days**	**Mon 1/14/19**	**Sat 2/9/19**
Lasercut Bulkheads and Fins	2 days	Mon 1/14/19	Tue 1/15/19
Altimeter Testing	1 day	Mon 1/14/19	Mon 1/14/19
Bulkhead Fabrication	4 days	Tue 1/15/19	Fri 1/18/19
Cut Airframe Tubes	3 days	Wed 1/16/19	Fri 1/18/19
Fin Can Bulkhead/Centering Ring Installation	6 days	Thu 1/17/19	Thu 1/24/19
Lasercut AV Sled	1 day	Thu 1/17/19	Thu 1/17/19
Install Motor Tube	1 day	Thu 1/17/19	Thu 1/17/19
AV Sled Fabrication	3 days	Fri 1/18/19	Tue 1/22/19
Install Fwd Rail Button	1 day	Fri 1/18/19	Fri 1/18/19
AV Bay Bulkhead Installation	1 day	Mon 1/21/19	Mon 1/21/19
Nosecone Bulkhead Installation	1 day	Mon 1/21/19	Mon 1/21/19
Install Fins	3 days	Mon 1/21/19	Wed 1/23/19
Payload Bay Bulkhead/Centering Ring Installation	4 days	Tue 1/22/19	Fri 1/25/19

Drill Pressure Ports and Switch Holes in AV Bay	0.5 days	Wed 1/23/19	Wed 1/23/19
Install Aft Rail Button	1 day	Wed 1/23/19	Wed 1/23/19
Install Motor Retainer	1 day	Wed 1/23/19	Wed 1/23/19
AV Wiring	3 days	Mon 1/28/19	Wed 1/30/19
Integrate Payload	7 days	Mon 1/28/19	Tue 2/5/19
Install AV Sled	2 days	Wed 1/30/19	Thu 1/31/19
Checklist Writing	7 days	Wed 1/30/19	Thu 2/7/19
Paint	1 day	Tue 2/5/19	Tue 2/5/19
Black Powder Demonstration	1 day	Thu 2/7/19	Thu 2/7/19
Full-scale Launch	0 days	Sat 2/9/19	Sat 2/9/19
FRR Milestone Report	**16 days**	**Mon 2/11/19**	**Mon 3/4/19**
General	1 day	Wed 2/13/19	Wed 2/13/19
Safety	8 days	Fri 2/15/19	Tue 2/26/19
Vehicle Criteria	8 days	Mon 2/18/19	Wed 2/27/19
Payload Criteria	8 days	Mon 2/18/19	Wed 2/27/19
Project Plan	3 days	Tue 2/26/19	Thu 2/28/19
Changes Since CDR	1 day	Fri 3/1/19	Fri 3/1/19
FRR Milestone Report Complete	0 days	Mon 3/4/19	Mon 3/4/19
NASA SL Competition	**4 days**	**Wed 4/3/19**	**Sun 4/7/19**
Travel to Huntsville	1 day	Wed 4/3/19	Wed 4/3/19
LRR	1 day	Wed 4/3/19	Wed 4/3/19

Launch Week Kick-Off	1 day	Thu 4/4/19	Thu 4/4/19
Launch Week Activities	2 days	Thu 4/4/19	Fri 4/5/19
Rocket Fair	1 day	Fri 4/5/19	Fri 4/5/19
Competition Launch	1 day	Sat 4/6/19	Sat 4/6/19
Awards Ceremony	0 days	Sat 4/6/19	Sat 4/6/19
PLAR Milestone Report	**10 days**	**Mon 4/15/19**	**Fri 4/26/19**
General	1 day	Mon 4/15/19	Mon 4/15/19
Vehicle Results	3 days	Tue 4/16/19	Thu 4/18/19
Payload Results	3 days	Tue 4/16/19	Thu 4/18/19
STEM Engagement	2 days	Mon 4/22/19	Tue 4/23/19
Project Plan	2 days	Mon 4/22/19	Tue 4/23/19
Summary	1 day	Tue 4/23/19	Tue 4/23/19
PLAR Milestone Report Complete	0 days	Fri 4/26/19	Fri 4/26/19

All Gantt charts are included in Appendix E of this document.

7. References

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8. Appendix A

8.1 Personnel Hazard Analysis

A description of potential personnel hazards, their causes, and the resulting effects are presented Table 8-1

Table 8-1 Personnel Hazard Analysis

Environment	Hazard	Causal Factors	Effects	Likelihood	Severity	Mitigation
Launch day	Lack of visibility	Cloud cover	Ground crew and spectators at risk of descending launch vehicle components	2	3	As NAR Safety Code does not allow for launches into cloudy conditions, low cloud cover will result in cancellation of launch, as human safety is at risk. Club members are instructed prior to and throughout launch day to be aware of ongoing launches. At least one club member will maintain visual contact with airborne launch vehicles. If a launch vehicle is within close proximity to personnel, visual contact will be maintained by all until the vehicle is static after touchdown.
	Slippery ground surfaces	Heavy precipitation	Injury of recovery sub-team members in the process of retrieving the separated launch vehicle components	1	3	Weather forecasts will be used to determine a range of launch dates with favorable conditions. Severe precipitation conditions will result in cancellation of launch, as human safety is at major risk. In the case of inconsistent to light precipitation conditions, launch will be carried forward with the RSO's approval. Waterproof materials will be brought to shelter the launch vehicle and its components for assembly prior to launch, and recovery after launch. Launch day procedures concerning recovery efforts detail actions and behaviors prioritizing human safety over project success in unfavorable recovery conditions. Additionally, the club safety officer will accompany the recovery sub-team throughout the

						launch vehicle retrieval process to ensure safety of the crew.
	Unpredictable launch vehicle flight and descent paths	High velocity cross-winds	Ground crew and spectators at risk of descending launch vehicle components Injury of recovery sub-team members in the process of retrieving separated launch vehicle components	2	3	Weather forecasts will be used to determine a range of launch dates with favorable conditions. NAR Safety Code prohibits launching in wind conditions exceeding 20 miles per hour, and windspeed will be requested from the RSO prior to launch if launch conditions are questionable. If under excessively windy conditions, launch vehicle assembly will be carried out in whatever shelter provided by the RSO or a team member's vehicle. Launch day procedures concerning recovery efforts detail actions and behaviors prioritizing human safety over project safety in unfavorable recovery conditions. The club safety officer will accompany the recovery sub-team throughout the launch vehicle retrieval process to ensure safety of the crew. Additionally, all team members will be instructed prior to and throughout launch day on ongoing launches and measures on steering clear of any potentially dangerous flight

		Complete or partial recovery system failure	Ground crew and spectators at risk of descending launch vehicle components	2	3	paths. At least one club member will maintain visual contact with airborne launch vehicles. If an airborne launch vehicle is within close proximity to personnel, visual contact will be maintained by all until the vehicle is static after touchdown. If the RSO's signals of a launch occurring cannot be heard from the team's work site, the RSO will be informed by the club safety officer to accommodate this situation.
	Drastically uneven ground surface conditions	Water features and non-level ground surfaces	Injury of recovery sub-team members in the process of retrieving the separated launch vehicle components.	2	3	Launch day procedures concerning recovery efforts detail actions and behaviors prioritizing human safety over project success in unfavorable recovery conditions. The club safety officer will accompany the recovery sub-team throughout the launch vehicle retrieval process to ensure safety of the crew. Additionally, all team members will be instructed prior to and throughout launch day on steering clear of possible walking hazards on the launch field.

	Live black powder charges within launch vehicle after descent	Severe humidity affecting altimeter calibration Altimeter Failure	Injury of recovery sub-team members in the process of retrieving the separated launch vehicle components.	1	3	Field Recovery Personnel listed in the Field Recovery Checklist in Appendix B will be equipped with nitrile gloves, leather gloves, safety glasses, and other equipment to handle black powder charges and disarm avionics system prior to handling. Launch day procedures concerning recovery efforts detail actions and behaviors prioritizing human safety over project safety in unfavorable recovery conditions. The club safety officer will accompany the recovery sub-team throughout the launch vehicle retrieval process to ensure safety of the crew.
Lab site	Unprotected chemical exposure (silicon dust, sanded fiberglass, epoxy resin)	Improper or no personal protective equipment used	Injury of team members engaging in the fabrication process	1	3	Prior to engaging activities in the lab site, all team members are briefed on how chemicals are used in fabrication, the respective personal protective equipment (gloves, safety glasses, face masks), and their location of these within the lab. Procedures will be posted around the lab site as a reminder of safety procedures respective to each material used. The Lab Safety Binder contains MSDS sheets on each material used within the lab, and procedures on reactionary measures for chemical exposure. Additionally, the club safety officer will accompany team members throughout the fabrication process.
	Flying shrapnel	Improper or no personal protective equipment used	Injury of team members engaging in fabrication process	1	3	Prior to engaging in activities in the lab site, all team members are briefed on the location of personal protective equipment within the lab. Procedures will be posted around the lab site as a reminder of safety procedures respective to each piece of equipment used. The Lab Safety Binder contains preventative and reactionary

						measures respective to equipment in operation around the lab site. Additionally, the club safety officer will accompany team members throughout the fabrication process.
	Unprotected exposure to Class 1, and 4 materials (motors, black powder, lithium polymer batteries)	Improper or no personal protective equipment used Improper storage of energetics	Injury of team members engaging in fabrication process	1	4	Prior to engaging in activities in the lab site, all team members are briefed on the location of personal protective equipment within the lab. Procedures will be posted around the lab site as a reminder of safety procedures respective to each energetic material used. The Lab Safety Binder contains preventative and reactionary measures respective to materials in storage and/or operation around the lab site. The club safety officer will accompany team members throughout the assembly and fabrication process. Concerning the motor and black powder, a minimum number of individuals will be allowed contact. The primary handlers of the motor are the motor assembly personnel, safety officer, and club advisors. In unforeseen circumstances, another club officer may be necessary, but this is unlikely. The team's adherence to manufacturer supplied instructions in the storage, handling, and assembly of the motor shall mitigate any motor failures due to misuse. The motor is stored in the flame and hazard cabinet secured in its original packaging and is not permitted to be assembled in any area not under NAR and/or TRA supervision.

						Additionally, all energetics material shall be stored securely in their original packaging within the flame and hazards cabinet. Lithium polymer batteries shall be stored in a cool, dry environment away from other materials that could cause damage to the batteries. When not in use, the batteries shall be returned to their storage container.

8.2 Environmental Hazard Analysis

Potential environmental hazards to the project, their causes and effects, and mitigation methods are identified in Table 8-2.

Table 8-2 Environmental Hazards to the Project

Hazard	Casual Factors	Effects	Likelihood	Severity	Mitigation
Water exposure to electronic components onboard launch vehicle	Heavy precipitation	Water exposure to electronics components could result in failure to launch the launch vehicle, failure to separate the launch vehicle, failure to deploy and launch UAV, and/or failure to receive altimeter data pertaining to the challenge.	1	3	Weather forecasts will be used to determine a range of launch dates with favorable conditions. Severe precipitation conditions will result in cancellation of launch, as project and human safety is at major risk. In the case of inconsistent to light precipitation conditions, launch will be carried forward with the RSO's approval. Waterproof materials will be brought to shelter the launch vehicle and its components for assembly prior to launch, and recovery after launch.
Significantly altered and unintended	Sustained high velocity cross-winds	High velocity wind conditions could result in violent launch vehicle flight, descent, and hinder/prevent UAV flight. High	2	3	Weather forecasts will be used to determine a range of launch dates with favorable conditions. NAR Safety Code prohibits

flight path and descent		velocity winds perpendicular to the launch rail's line of action pose a threat to the direction of flight for the launch vehicle – possibly resulting in a significantly lower apogee, violent parachute deployment and descent which may cause large drifting in descent and structural damage along the body tube, and violent ground impact causing structural damage. Damage to payload body tube and components may prevent UAV Containment Pod deployment. High velocity cross-winds could also put UAV performance at risk.			launching in wind conditions exceeding 20 miles per hour, and windspeed will be requested from the RSO prior to launch if launch conditions are questionable. See checklist item **X** for verifying potential weather conditions. The UAV design specifications have taken into consideration possibly high velocity cross-winds by increasing propeller size, battery capacity, and motor strength, and will undergo testing in similar conditions post-fabrication and prior to launch. If under excessively windy conditions, launch vehicle assembly will be carried out in whatever shelter provided by the RSO or a team member's vehicle.
Post-descent dynamic separated launch vehicle components	Non-uniform ground surface conditions including water features	Non-uniform ground surfaces such as trenches could compromise launch vehicle structural integrity and UAV performance. Water exposure to electronic components could result in failure to deploy and launch UAV, and failure to receive altimeter data pertaining to the challenge.	2	3	Inspect launch site for water features and non-uniform surfaces. If the safety officer or RSO deem that the field conditions pose a severe risk to launch vehicle or payload integrity post-landing, the launch will be cancelled. The launch vehicle shall be designed such that it can withstand being dragged across non-uniform terrain and water features.

Live black powder charges post-descent	Severe humidity	Severe levels of humidity could result in particular risks during assembly, launch vehicle flight and descent, UAV flight, and recovery efforts. Moisture in the air can compromise the integrity of the black powder charges, and the calibration of altimeters. These two issues also introduce the possibility of premature or latent separation that results in either an unstable flight or a ballistic descent. Any live black powder charges pose a risk to the recovery sub-team. Additionally, failures causing premature or latent separation may result in failure to deploy and launch the UAV.	2	3	Weather forecasts will be used to determine a range of launch dates with favorable conditions. If the humidity on the day of launch is higher than expected, components will be stored to limit exposure to atmospheric conditions, and RSO will be asked for guidance on issue.
Torn parachutes and tangled shroud lines during descent	Proximity to wooded area	Trees within the launch vehicle descent path can damage parachutes and shroud lines, and impede recovery efforts. Failure to reach the ground will result in failure to deploy the UAV, and retrieve altimeter data pertaining to the challenge. Any live black powder charges can also lead to an uncontrolled fire if the launch vehicle components are out of reach for the recovery sub-team.	1	2	Ensure wooded areas near the launch site are further away that the predicted wind drift of the launch vehicle. If the launch vehicle is suspended in foliage out of the recovery team's reach, the local fire department will be called to assist in retrieval – no trees will be cut down.

8.3 Project Risks to the Environment

Severity levels and likelihood levels for environmental hazards are summarized in Table 46 and Table 47, respectively.

Table 46Clarifications of Severity

Level	Description
1	Human safety and project safety at minimum risk due to active safety measures.
2	Human safety and project safety at lesser risk due to active safety measures.
3	Human safety and project safety at greater risk despite active safety measures.
4	Human safety and project safety at maximum risk despite active safety measures.

Table 47Clarifications of Likelihood

Level	Description
1	Minimum frequency of failure possible due to active safety measures.
2	Lesser frequency of failure possible due to active safety measures.
3	Greater frequency of failure possible despite active safety measures.
4	Maximum frequency of failure possible despite active safety measures.

Potential project risks to the environment, the causes and effects of them, and mitigation efforts are presented in Table 8-3

Table 8-3 Project Risks to the Environment

Hazard	Causal Factors	Effects	Likelihood	Severity	Mitigation	Verification
Fire at the launch site related to motor exhaust.	Motor exhaust creates a fire or damages the area surrounding the launch rail	The ground around the launch site becomes charred, killing any flora or micro fauna directly beneath or around the launch site	2	3	A blast deflector will be used beneath the launch vehicle, protecting the ground from exhaust in compliance with NAR Safety Code.	The safety officer will verify that a blast deflector is in place prior to each launch. If a launch pad fire occurs, a fire extinguisher will be available to extinguish the fire.

Fire around the launch vehicle due to a punctured battery.	Loose components during flight or improper handling during assembly punctures a battery.	The ground around the site of the fire becomes scorched, killing or seriously injuring any flora or fauna in the area. In more serious cases, the fire may grow and become out of control causing serious and lasting damage to the ecosystem.	2	3	All components used in the launch vehicle are designed to be strongly fastened to the vehicle during flight. Only designated, experienced members will be allowed to assemble the launch vehicle and its components.	The electronics lead and safety officer will verify that only batteries and electronics that have been handled and stored properly are used in the launch vehicle. The safety officer will also ensure that all electronics and batteries are inspected for leakages prior to their integration into the launch vehicle.
Fire around the launch vehicle due to a short or general failure in the electronics.	Exposed or faulty wiring creates an electrical short, or electronics overheat and start a fire.	The ground around the site of the fire becomes scorched, killing or seriously injuring any flora or fauna in the area. In more serious cases, the fire may grow and become out of control causing serious and lasting damage to the ecosystem.	2	3	The electronics lead, or safety officer, will verify that no wires are exposed in the launch vehicle prior to full vehicle integration. Electronics will be stored in a secure environment devoid of extreme temperature fluctuations or contact with other components that may inflict damage.	The team will verify the quality of the wiring and ensure that there are no exposed wires prior to each launch. Only electronics that are determined by the safety officer to be in good physical condition will be used in the vehicle.
Non-biodegradable waste is left at the launch site or surrounding environment.	Harmful components may be unintentionally expelled from the launch vehicle due to the forces of launch. Hazardous components in the launch vehicle may also be rendered unrecoverable through a failure of the recovery	Non-biodegradable components or waste may be ingested by local organisms and cause injury, sickness, or premature death. Waste may also be detrimental to plant life or soil/water quality in the	2	2	All components used in the launch vehicle are designed to be strongly restrained to the vehicle and no non-recoverable components will be used. Additionally, team members will thoroughly clean and	Potentially harmful components will be inspected prior to launch to ensure they are securely attached to the launch vehicle. The launch site and the landing zone will be inspected for components or debris that had fallen off the launch vehicle. Prior to leaving the launch field, the team will

	system. Additionally, the team may unintentionally leave debris at the launch field.	surrounding environment.			inspect the launch field before departing.	ensure to remove any waste left by their activities. Each of these inspections will be verified by the safety officer to ensure all waste has been collected.
High kinetic energy impact of the launch vehicle with the ground.	A failure of the recovery system in which the parachutes do not deploy, deploy too late, deploy incorrectly, or are not properly secured to components leading to freefall.	Components of the launch vehicle may be strewn across the ground, leaving material in the environment which may be ingested by local fauna and cause injury, sickness, or premature death. Waste may also be detrimental to plant life or soil/water quality in the surrounding environment.	2	4	Redundant ejection charges as well as a redundant altimeter, secondary to the primary altimeter and ejection charges, will be implemented in the launch vehicle. The redundant system will activate following a delay after the primary system, so, in the event the primary charges/altimeter fails, the redundant system will ensure recovery deployment. Parachutes will be folded using consistent techniques and stored in safe conditions when not in use.	All black power charges will be carefully measured and verified by the faculty advisor, Dr. Chuck Hall, and the safety officer, for accuracy. All altimeters will be programmed by the recovery lead, and verified by the recovery lead to ensure the black powder chargers are triggered at the proper time. A larger redundant charge will be used for each ejection event to ensure that proper and complete ejection occurs. The recovery lead shall inspect all quick link connections to ensure the security of the recovery harnesses. The structures lead shall conduct a bulkhead failure test to verify the security of the connection between the u-bolt and bulk as well as the bulkhead and body tube.
Battery acid or other electronic chemicals are leaked into the environment.	Improper handling or manufacturer error results in a puncture of the batteries installed in the launch vehicle.	Battery acid and other chemicals may be ingested by or cause injury to local flora and fauna. These hazardous	2	2	Batteries will be stored in a secure environment devoid of extreme temperature fluctuations or	The electronics lead and safety officer will verify that only batteries and electronics that have been handled and stored properly are used in the launch vehicle. The safety officer will

		components could also pollute the surrounding soil and water.			contact with other components that may inflict damage to the batteries. Prior to launch and after launch, batteries will be inspected and tested to verify that they are in suitable condition. If a battery is not operable it will be disposed of according the MSDS standards.	also ensure that all electronics and batteries are inspected for leakages prior to their integration into the launch vehicle.
Damage to trees in the vicinity of the launch site.	The launch vehicle lands in one or several trees near the launch area.	Removing vehicle components from a tree could result in lasting damage to the tree or complete destruction to the tree and the habitat it provides to other organisms.	2	2	The launch safety officer will verify wind speeds do not exceed recommended levels. The launch will be postponed in the event that high wind speeds makes landing in a tree more likely. Also, launch sites with trees nearby will be avoided where possible.	The team safety officer shall inspect the landing site and determine if the rocket can be retrieved without risk to personnel. If the rocket cannot be safely retrieved, the team shall acquire the proper equipment to retrieve the rocket safely at a later date.
Carbon Dioxide (CO_2) pollution due to club activities adds excess CO_2 to the environment.	CO_2 is released into the atmosphere from club related travel to the launch events and supply store.	Adding excess CO_2 to the atmosphere contributes to anthropogenic climate change, may be absorbed by water bodies to form carbonic acid which	3	1	The team will attempt to cut travel/shipping related carbon emissions when possible.	The team will carpool to all launch events. The team will also use driving over flying when travelling long distances. When ordering parts, local options will be preferred if part quality is deemed to be equal

		would have a negative impact on aquatic organisms especially those who use carbonate to form protective shells.				or superior to that of other options.

8.4 FMEA Tables

Table 8-4 Failure Modes and Effects Analysis

System	Subsystem/ Component	Failure Mode	Causal Factors	Failure Effects		Severity	Likelihood	Recommendations
				Subsystem	System			
Launch Vehicle	Nosecone	Structural fracture	Collision with object in flight path	Loss of nosecone recoverability	Loss of controlled and stabilized flight	2	1	The safety officer will ensure that skies are clear of any foreign objects per NAR operations prior to launch. The safety officer will confirm this on the launch day checklist. Any concerns will be reported to the RSO, and the launch will be halted until uncertainties regarding flight conditions are addressed.
			Manufacturing defect				2	Visual inspection after shipping and before assembly. Material inspection will be documented photographically and stored within the lab safety binder. Manufacturer and distributor will be contacted for a replacement prior to fabrication process.
			Damaged during handling within the lab, or handling and			2	2	Inspect for cracks, chips, or other damage and take photos every week of the season, and during assembly prior to launch. Material

			assembly prior to launch					inspection will be documented photographically and stored within the lab safety binder. The safety officer will confirm this action on the launch day checklist. physically and stored within the lab safety binder. The safety officer will confirm this action on the launch day checklist.
			Improper storage within lab and during transportation of component			2	2	Items shall not be stored on top of nose cone. Prior to departure, the safety officer will confirm this action on the packing checklist. Periodically inspect storage compartment throughout transport and make appropriate adjustments.
			Nosecone collides with other launch vehicle component during descent and recovery		Damage to itself and other launch vehicle components	2	3	The avionics and recovery subteam lead will ensure shock cord is long enough to separate nosecone from other components during design, packing, and assembly. The safety officer will confirm this action through the launch day checklist during assembly.
			Ground impact due to altimeter failure	Ballistic descent		2	2	Two different altimeters shall be used for redundancy in mission safety to prevent electronic errors. Conduct ground ejection tests of the calculated black powder charge masses using to verify separation of sections and

								functionality of altimeter system. Photograph and document results in lab safety binder, ad Periodically conduct ground altimeter redundancy system tests through simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity and simulated flight. The launch day checklist requires the initials of the recovery and avionics lead to confirm the altimeter wiring and functionality.
		Premature separation from midsection	Coupler damaged during handling and fabrication within lab, or handling and assembly prior to launch	Potential for permanent structural damage	Loss of controlled and stabilized flight	2	2	Inspect for cracks, chips, or other damage. In addition, take a photo every week of the season and during assembly prior to launch. Replace any damaged components if possible. Identify fabrication missteps and establish preventative measures to reduce error frequency.

			Improper installation of screws into T-nut fasteners during assembly prior to launch			2	1	Follow design specifications for sizing, inspecting, and installing T-nut fasteners and screws during fabrication and assembly prior to launch. Structures lead will coordinate this portion of the assembly process and confirm actions on launch day checklist.
			Epoxy for T-nut fastener blocks underneath coupler not cured or applied properly			2	1	Follow proper procedures for mixing, applying, and curing epoxy. With a flashlight, visually inspect connecting layer of epoxy between T-nut block and coupler for gaps. Structures lead will coordinate this portion of the assembly process and confirm actions on launch day checklist.
			Altimeter malfunction		Failure to launch	2	2	Conduct grounded ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through simulating flight pressure conditions. The safety officer will conduct the grounded ejection tests and follow all steps in the grounded ejection test

								checklist. The safety officer and avionics lead will conduct the ground altimeter redundancy system tests and follow all steps in the ground altimeter redundancy system tests. Throughout handling, fabrication, and assembly prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity and simulated flight
	G12 Fiberglass Airframe	Structural fracture	Manufacturing defect	Loss of structural integrity or usability of Fiberglass body sections or components	Premature separation of launch vehicle sections during flight	1	2	Visual inspection after shipping and before assembly. Material inspection will be documented photographically and stored within the lab safety binder. Manufacturer and distributor will be contacted for a replacement prior to fabrication process. replacement prior to fabrication process.

			Loads experienced beyond design specifications			1	2	Ensure body tube components can hold flight forces in accordance with design specifications. Ensure that all components can maintain a factor of safety of at least 2 during all regimes of flight.
			Damaged during handling and fabrication within the lab, or handling and assembly prior to launch			1	2	Inspect for cracks, chips, or other damage and take photos every week of the season, and during assembly prior to launch. Material inspection will be documented photographically and stored within the lab safety binder. The safety officer will confirm this action on the launch day checklist. Replace any damaged components if possible. Replace any damaged components if possible. Identify fabrication missteps and establish administrative controls to reduce error frequency.
			Improper storage within lab and during transportation of component			2	2	Do not store items on top of Fiberglass. Inspect storage compartment every week of the season for improper storage.

	Fins	Severe weather-cocking	Fin dimensions are not cut according to design	Loss of fin performance	Decreased flight stability, unpredictable flightpath, and possible damage to other components	2	2	A laser-cutting instrument is used to cut fins with manufacturing precision and accuracy to design specifications. Fins are measured post-component fabrication to ensure dimensions match design specifications.
			Fins not installed at even increments around fin can (90 degrees to each other)			2	2	Fin slots are cut by manufacturer and will be measured prior to fabrication to ensure dimensions match design specifications. Document visuals of fin slots in lab safety binder. Manufacturer and distributor will be contacted for a replacement prior to fabrication process.
			Assembled launch vehicle CG is too far forward (Stability Margin >> 2.0)			2	2	The Center of Pressure location will be calculated through analytical means to verify the Center of Pressure location given by simulations. The launch vehicle will be assembled prior to launch to measure the stability margin. Mass distribution within the launch vehicle will be analyzed for stability margins exceeding or under design specification.

		Fin separation	Loads experienced beyond design specifications	Loss of fin performance	Fin failures will result in additional failures which will decrease flight stability and launch vehicle structural integrity	1	2	Analyze flight data and ANSYS simulations to confirm that factor of safety is at a minimum of 1.5. Any components not meeting this requirement will be subject to redesign and/or additional fabrication.
			Damaged during handling within the lab, or handling and assembly prior to launch			1	2	Inspect fins and connections for cracks, chips, or other damage every week over the season, and during assembly prior to launch. Document visuals of fins and fin slots in lab safety binder. Replace any damaged components if possible. Identify fabrication and assembly missteps. Establish administrative controls to reduce error frequency.
			Fin flutter			2	3	Launch vehicle will not exceed velocity necessary to induce significant flutter.
			Ground impact			2	2	The recovery system shall be designed that the launch vehicle impacts the ground without sufficient energy to induce fin separation.

	Motor	Motor fails to ignite	Igniter not installed correctly	Failure of vehicle to start launch	Team member and RSO must insert new igniter and restart launch sequence	4	1	The launch pad checklist and mentor/RSO supervision shall be used to ensure correct igniter installation. The safety officer or mentor will confirm this action on the launch pad checklist.
			Faulty igniter used			4	1	A batch of igniters shall be tested prior to launch day to ensure quality and functionality.
			Motor assembled incorrectly			4	1	The safety officer will follow the motor assembly checklist and use mentor/RSO supervision to ensure correct assembly of the motor. The safety officer will confirm this action on the launch day checklist.
		Catastrophic motor failure	Damaged during handling within the lab, or handling and assembly prior to launch	Possible destruction of launch vehicle	Complete mission failure and additional hazard to ground crew and spectators	1	2	Carefully inspect for cracks, chips, or other damage during assembly, and document through photography. The safety officer and propulsion lead will confirm the action above on the packing and launch day checklist. Identify assembly missteps and establish preventative measures to reduce error frequency.
			Motor assembled incorrectly			1	1	The safety officer will follow the motor assembly checklist and use mentor/RSO supervision to assemble motor correctly. The safety

								officer will confirm this action on the launch day checklist.
			Motor casing dislodged during motor burn			1	2	Ensure all connection points between motor tube, centering rings, and fins are joined properly using epoxy. Perform careful inspection of joints prior to launch. The safety officer will confirm the actions above on the launch day checklist.
		Damage to motor casing	Superficial damage	Motor casing cannot be used	Launch vehicle is not safe to launch if damage is major	4	2	Carefully inspect for cracks, chips, or other damage during prior to departure, and during assembly. Motor casing will be stored in a secure location to reduce possibility of damage. Storage location will be checked every week. Prior to departure, motor casing will be inspected and deemed appropriate/inappropriate for launch by the propulsion lead and safety officer. The safety officer will document visuals in lab and affirm adherence to motor assembly through the launch day checklists. Damage deemed serious to the motor casing by the

								mentor will result in launch cancellation. Identify handling and assembly missteps and establish preventative measures to reduce error frequency.
		Propellant contamination	Launch vehicle fails to launch	Reduced performance of launch vehicle motor	Launch vehicle does not launch or perform as expected	2	2	Order from reputable source. Store and maintain motor fuel properly and in isolation from other materials in the flame and hazards storage cabinet. Motor fuel storage will be inspected and visually documented every week of the season.
			Over-oxidized reaction			2	2	
			Reduced fuel efficiency			3	2	
	Bulkheads	Bulkhead separation from airframe during motor burn	Manufacturing defect	Reduced performance of launch vehicle motor and severe damage to other launch vehicle components	Ballistic descent	1	2	Perform visual inspection after shipping and before fabrication. The safety officer and structures lead will visually document the material in the lab safety binder. Manufacturer and distributor will be contacted for a replacement prior to fabrication process.

			Loads experienced beyond design specifications			1	2	Perform structural analysis to ensure bulkhead composite can hold flight forces in accordance with design specifications. Ensure that all components can maintain a factor of safety of at least 2 during all regimes of flight through analysis.
			Damaged during handling within the lab, or handling and assembly prior to launch			1	2	Inspect each bulkhead for cracks, warping, chips, or other damage during fabrication. Replace any damaged bulkheads. Identify fabrication missteps and establish administrative controls to reduce error frequency. Store fabricated bulkheads safely to prevent damage.
			Epoxy not cured properly			1	2	Follow proper procedures for mixing, applying, and curing epoxy.

		U-bolt separation from bulkhead during recovery	Loads experienced beyond design specifications	Launch vehicle components not tethered to a parachute will continue accelerating during descent	Loss of safe and effective recovery system. Damage to body components Possible hazard to ground crew and spectators	1	2	Ensure U-bolt fasteners and bulkhead composites can handle near-instantaneous loading from parachute and shock cord deployment by simulating shearing force through application of sudden force equivalent to drogue and main deployment. Analyze testing to ensure that all components can maintain a factor of safety of at least 1.5 during all regimes of flight.
			Epoxy not cured properly			1	2	Follow proper procedures for mixing, applying, and curing epoxy.
	Rail Buttons/ Launch Rail	Vehicle does not leave launch rail as intended	Rail button(s) separate from launch vehicle	Vehicle leaves rail at unpredictable orientation and velocity	Probable mission failure and additional hazard to ground crew and spectators	1	2	Epoxy rail buttons into body tube to reduce risk of separation. Ensure rail buttons are secure to body tube prior to launch.
			Damaged during handling and fabrication within the lab, or handling and assembly prior to launch			1	2	Inspect each rail button and connection for cracks, warping, chips, or other damage during assembly. Replace any damaged rail buttons. Identify fabrication missteps and establish preventative measures to reduce error frequency.
			Launch rail breaks			3	2	Ensure that the rail is assembled correctly prior to launch. The safety officer will

								affirm the action above on the launch day checklist. Ground crew and spectators will be located away from the launch pad as instructed by the RSO, NAR regulation, and the club safety officer.
		Vehicle does not leave launch rail at all	Rail button(s) becomes stuck in launch rail	N/A	Mission failure as flight does not take place	2	1	Prior to launch, contact the RSO to verify that rail buttons match size of launch rail slot. Lubricate the launch rail and rail buttons. Visually confirm that the vehicle moves smoothly on the launch rail during assembly and launch rail erection.
	Shear Pins	Pins break before charge detonation	Manufacturing defect	Loose assembly of compartment	Premature launch vehicle separation and recovery system deployment	2	2	Perform visual inspection after shipping and before assembly. Manufacturer and distributor will be contacted for a replacement prior to assembly process.
			Damaged during handling within the lab, or handling and assembly prior to launch			2	2	Inspect each shear pin and connection for cracks, warping, chips, or other damage prior to launch day departure, during assembly. Replace any damaged shear pins prior to launch. The safety officer and structures lead will affirm the actions above on the packing and launch day checklists.

								Identify assembly missteps and establish administrative controls to reduce error frequency.
			Pins fall out of respective holes			2	2	Ensure size of holes drilled in body tube match diameter of shear pins. Additionally, the Recovery and Avionics Sub-team lead will inspect the vehicle prior to launch to verify that all shear pins shall be secured by electrical tape.
			Loads beyond design specifications			2	2	Ensure pins can hold flight forces in accordance with design specifications.
		Pins don't break at charge detonation	Manufacturing defect	Failure to separate compartment	Loss of safe and effective recovery system	1	2	Visual inspection after shipping and before assembly. Manufacturer and distributor will be contacted for a replacement prior to assembly process.
			Pins too tight in body tube holes			1	2	Ensure size of holes drilled in body tube match diameter of shear pins.

			Poor design			1	2	Use calculations to ensure that pins will break from forces of detonation. Prior to launch, simulate shear pin in-flight separation through ground ejection testing with the calculated black powder masses. Identify design and fabrication missteps and establish preventative measures to reduce error frequency.
	Shock Cord	Incorrect or partial deployment of shock cord	Snags, tears, or rips during ejection	Parachute no longer tethered to entirety of launch vehicle airframe	Loss of safe and effective recovery system	1	2	Inspect shock cord for damage prior to launch. Ensure high-strength shock cord is used with a maximum loading greater than 1,500 lb. Ensure shock cord is folded and stowed properly in launch vehicle. Reduce/eliminate sharp edges in design to reduce risk of snagging shock cord and parachutes.

			Shock cord disconnects from airframe or parachutes			1	2	Ensure that connections between the shock cord, airframe, and parachutes are tight and secure.
			Shock cord stuck within launch vehicle airframe	Parachute not entirely deployed		1	2	Ensure that the shock cord and parachutes are folded and stowed properly in launch vehicle. Reduce/eliminate sharp edges in design to mitigate risk of blocking shock cord and parachutes.
			Shock cords tangled		Rocket recoverable, Payload failure	3	2	Ensure shock cords and parachutes are folded correctly.

			Shock cord connections loose		Rocket recoverable, Payload failure	3	2	Test shock cord connections before flight, confirm security.
	Parachute Deployment	Drogue parachute fails to deploy correctly	Drogue shock cord tangling	Parachute does not deploy correctly	Launch vehicle is recoverable	2	2	Prior to launch, assemble shock cord and parachute system to confirm that accordion-style folding of the shock cords do not tangle.
			Shock cord and U-bolt connections come loose			2	2	Prior to launch, assemble the shock cord and parachute system to confirm that the quick link connection points between the shock cord and U-bolts are fastened.
			Parachute bag does not fully open			2	2	Prior to launch, assemble the parachute bags correctly and make sure nothing can snag bags within the body tube.
		Parachute does not perform as expected	Tears/holes due to black powder burns	Parachute deploys but does not perform as expected	Launch vehicle is recoverable	2	2	Inspect for tears, holes, or other damage periodically over the season, and during assembly prior to launch Manufacturer and distributor will be contacted for a replacement prior to assembly process. Prior to assembly, parachutes will be wrapped according to

								launch day procedures in nonflammable sheets or deployment bag.
		Main parachute fails to deploy correctly	Failed black powder charge detonation	Parachute does not deploy correctly	Separation is not successful, launch vehicle is not recovered safely	1	2	Conduct ground ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity and simulated flight.
			Main shock cords tangling		Launch vehicle is recoverable	2	2	Prior to launch, assemble shock cord and parachute system to confirm that accordion-style design for shock cords does not tangle.
			Shock cord and U-bolt connections come loose		Launch vehicle is not recovered safely	1	2	Prior to launch, assemble the shock cord and parachute system to confirm that the quick link connection points between the shock cord and U-bolts are fastened.

	Black Powder Charges	Single detonation failure	E-match fails to light	Failure of one or more black powder charges	Will result in loss of safe and effective recovery system if redundant black powder charge(s) do not detonate	2	2	Conduct ground ejection demonstrations of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity, and simulated flight.
			Altimeter Malfunction			2	2	
		Redundant detonation failure	E-match fails to light	Failure of both ejection charges	Failure of launch vehicle to separate and deploy parachutes	1	2	Conduct ground ejection demonstrations of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through simulating flight

			Altimeter Malfunction			1	2	pressure conditions. Throughout handling, fabrication, and assembly prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity, and simulated flight.
		Charge causes damage to any component other than shear pins	Charge is too large	Causes violent separation and/or damage to nearby components	Potential to cause permanent damage to bulkheads or shock cord, resulting in a possible failure of parachute deployment	2	1	Verify that charges are sealed properly, and the correct amount of black powder is used with pre-flight checklist. Conduct ground ejection tests of the calculated black powder charge masses to verify separation of sections, functionality of altimeter system, and minimal damage to separated launch vehicle components.
		Charge ignites but fails to cause separation	Charge is too small	No ejection	Failure of launch vehicle to separate and deploy parachutes	1	2	Conduct ground ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system.

	Altimeters	No power to altimeters	Uncharged or insufficiently charged batteries	Loss of real-time altitude data, failure to ignite e-match	Failure of parachute deployment	1	1	Install new/unopened batteries at each launch. Confirm that all batteries have the correct voltage before flight using a multimeter.
			Battery becomes disconnected from altimeter			1	2	Ensure that altimeters are properly wired and that wires are secure prior to launch. Listen for appropriate beeps when powering on altimeters.
			Wiring short			1	2	Ensure that all wire is properly insulated and that all wires are securely contained in their respective terminals.
		No launch detected	Manufacturing defect	Lack of flight data	Failure of parachute deployment	1	2	Conduct ground ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through

								simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity, and simulated flight. Listen for fault codes at launch site.
		False apogee detected	Manufacturing defect	Premature or delayed ejection of drogue parachutes	Increased load on drogue recovery hardware and bulkheads	2	2	Conduct ground ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity, and simulated flight. Listen for fault codes at launch site.

			Incorrect altimeter readings			2	2	Conduct ground ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through simulating flight pressure conditions. Throughout handling, fabrication, and assembly prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance to design specifications by testing continuity and simulated flight. Ensure that pressure ports are sized correctly and listen for fault codes at launch site.
		Main parachute deploys at wrong altitude	Incorrect pressure readings or improper programming	Main deployment between apogee and 900 ft	Excessive drift, but surface impact will remain below required maximums	2	2	Conduct ground ejection tests of the calculated black powder charge masses to verify separation of sections, and functionality of altimeter system. Periodically conduct ground altimeter redundancy system tests through simulating flight pressure conditions. Throughout handling, fabrication, and assembly

				Main deployment lower than 500 ft	Kinetic energy at surface impact will likely exceed 75 ft-lb	1	2	prior to launch, confirm the wiring, functionality, and component integrity of the avionics system is in accordance with design specifications by testing continuity and simulated flight. Verify each altimeter chirps the appropriate program at the launch site. Ensure pressure ports are sized correctly.
	GPS	Ground system failure	Loss of power to ground receiver or the laptop	Inability to receive data from the GPS	Inability to track and recover the launch vehicle in less than an hour	3	2	Ensure that the receiver and laptop are fully charged at least 6 hours prior to flight.
		Loss of signal	Environment or launch vehicle materials blocking signal			3	2	Perform range tests to ensure reliability of the system at simulated altitudes and ground distances.
		Radio interference	Multiple radio devices on the same local frequency and channel			3	2	Ensure that all transmitting devices are on separate channels and confirm with other teams and launch officials that no frequency conflict exists.

		Loss of power	Flight forces cause GPS to disconnect from power supply			3	2	Ensure that all GPS units are fully charged and use simulated load tests to determine the necessary procedures to secure the units.
	Containment Pod Deployment System	Failure to begin motion within the payload tube	Stepper motor failure	Prevention of Containment Pod exit from the payload tube	Team Mission Failure (failure of UAV to deploy)	4	3	Motor will be tested before installation for current, voltage, and output parameters. The motor will undergo an integrated test with the screw-drive deployment system. Finally, the motor will be simulated for compressive stress undergone during initial takeoff and separation stages.
			Failure of electronically activated latch release			4	3	Electronically activated latches will be tested prior to installation for mechanical and electrical operational success. Electronically activated latches will then undergo integration testing to prove that they release the Containment Pod under vertical and horizontal orientations.
		Failure to exit payload tube	Stepper motor failure			4	3	Motor was tested before installation for current, voltage, and output parameters. The motor

								underwent an integrated test with the screw-drive deployment system. Finally, the motor was simulated for compressive stress undergone during initial takeoff and separation stages.
			Buckling of threaded rod			4	2	Threaded rod will be tested for an ultimate stress, with a factor of safety of 1.5 from the reported maximum compressive stress provided in the material documentation of the part. Additionally, the threaded rod will be secured by a journal bearing on the open deployment direction to reduce compressive loading conditions.
			Centering Ring misalignment			4	2	Follow proper procedures for mixing, applying, and curing epoxy for the adhesion of the Centering Rings to inner payload body tube.
			Shock cord entanglement			4	2	Shock cord will be routed inline through channels positioned at the outer edges of the bulkheads to prevent an excess of shock cord disturbing the exit cavity. Additionally, the convex design of the Containment Pod's front end shifts any obstruction in the exit cavity out of its path.

		Failure to release Containment Pod	Shearing at pusher plate and threaded rod joint	Prevention of UAV Deployment	Team Mission Failure (failure of UAV to deploy)	4	3	Pusher plate material will be made of a 3D printed PLA for ease of manufacture and more accurate and precise construction. Additionally, a threaded collar will be inserted into the pusher plate to transfer loading from the thread rod joint to the area around the joint, effectively distributing the force over a larger area.
			Shearing at pusher plate and cantilevered rod joint			4	3	
			Shearing at pusher plate and support rod joint			4	3	
	Containment Pod	Failure to open Containment Pod in an upright position for UAV vertical takeoff	Elastic surgical tubing detachment	Prevention of UAV deployment	Team Mission Failure (failure of UAV to deploy safely)	4	3	The Containment Pod was designed to exit the payload body tube in multiple orientations on the cantilevered beam. The egg-shaped cross section design and the off-center center of gravity location prevents the Containment Pod from deploying in an "unfavorable orientation" as the mass of the UAV will right the pod.
	UAV Arm Deployment System	Failure to extend UAV arms to a fully deployed position	Avionics package-to-motor wiring failure	Hindrance of UAV performance	Possible Team Mission Failure	4	2	Avionics package-to-motor wiring will be given some slack to account for tensile stress experienced due to UAV Arm extension.

			Motor failure			4	2	Motor will be tested before installation for current, voltage, and output parameters. The motor will undergo an integrated test with the screw-drive deployment system. Finally, the motor will be simulated for compressive stress undergone during initial takeoff and separation stages.
			Improper installation of hinges			4	2	Hinges will be tested prior to launch under numerous angular acceleration conditions.
		Failure to secure UAV arms into a fully deployed position				4	2	Hinges will be tested prior to launch under numerous angular acceleration conditions, and rigidity of UAV Arm position.
	Body Structure	Structural integrity failure	Damage during launch vehicle flight	Hindrance of UAV performance	Team Mission Failure (failure to deploy UAV)	4	3	The Containment Pod shelters the UAV with an outer shell and an internal layer of padding foam to reduce loads experience on the UAV body structure. Additionally, a pair of pegs restricts the motion of UAV in five out of six degrees.

			Manufacturing defect			4	2	Visual inspection after shipping and before assembly. Manufacturer and distributor will be contacted for a replacement prior to fabrication process.
	Electronics System	Wiring disconnection	Damage during flight	UAV cannot complete mission	Team Mission Failure (drone performance hindered)	4	3	Test the structural integrity of the parts and run structural analysis.
			Damaged during handling and fabrication within the lab, or handling and assembly prior to launch	UAV cannot complete mission		4	2	Follow proper manufacturing technique.
			Damage during UAV operation	UAV cannot complete mission		4	2	Run tests to determine UAV capabilities.
		Jammed	Foreign objects get stuck in the gears/motor	UAV performance hindered		4	2	Run tests in similar conditions to landing site.
		Does not operate	Dead battery	UAV cannot complete mission		4	2	Ensure proper battery charging and handling techniques are followed.
			Signal is not sent properly	UAV cannot complete mission		4	2	Extensively test transceiver in all conditions.

			Programming bug	UAV cannot complete mission		4	2	Run tests on electronics system to ensure high performance.
	Battery	Low Charge	Improper charging techniques	UAV performance hindered	Team Mission Failure (drone performance hindered)	4	2	Adhere to proper charging technique.
			Improper storage	UAV performance hindered		4	2	Adhere to proper storage technique.
		Fire	Not following proper safety protocol	UAV cannot complete mission	Damage to payload	3	1	Maintain a high level of safety by monitoring battery quality prior to arrival to the launch field.

9. Appendix B

This Appendix contains the Launch Day Checklists used on February 9, 2019 at the full-scale vehicle demonstration flight. These checklists include all of the safety checks specified in the tables in Appendix A.

Time In: 0941

Full-scale Launch Checklist

Key:

PPE Required

Explosive - DANGER

AV BAY AFT BULKHEAD E-MATCH INSTALLATION:

Required Items:

- ☑ **AV Bay AFT Bulkhead**
- ☑ **Avionics HDX Box**
  - ☑ **(2) e-matches**
  - ☑ **3M electrical tape**
- ☑ **Launch Day Toolbox**
  - ☑ **Scissors**
  - ☑ **Wire Cutters**
  - ☑ **Wire Strippers**
  - ☑ **Small Flathead screwdriver**

Essential Personnel:

Role	Name	Initial
Safety Officer	Evan Waldron	EW
Team Lead	Harvey Hoopes	HH
Recovery Lead	Nathan Cox	NC
E-Match Personnel 1	Sean Clark	SC
E-Match Personnel 2	Sadie McCarthy	SM

Procedure:

PRIMARY:

- ☑ Unscrew all **unoccupied** terminal blocks on the AV Bay AFT bulkhead
- ☑ Trim the e-match to approximately 7 in length using wire cutters
- ☑ Remove red plastic protective e-match cover from e-match
- ☑ Separate the two leads
- ☑ Feed the e-match through the **DP** wire hole
  - ☑ The e-match head should be on the side with blast caps
- ☑ Strip the wire insulation from end of e-match
- ☑ Make a loop with the exposed wire
- ☑ Place exposed e-match leads into terminal block labelled **DP**
- ☑ Tighten down the screws in the **DP** terminal block
- ☑ Lightly tug on e-match wires coming out of the **DP** terminal block
  - ☑ Safety Officer Confirmation: EW
- ☑ Place e-match head within the blast cap labelled **DP**
- ☑ Bend the e-match wire such that it lies flat against the blast cap
  - ☑ Secure the e-match wire to bulkhead with a small piece of electrical tape, ensure that no holes are covered
- ☑ Confirm the e-match wire is curved over the outside edge of the blast cap
- ☑ Confirm the e-match head is flat on the cap bottom
- ☑ Using 3M electrical tape, tape the e-match wire to the outside of the of the blast cap
- ☑ Confirm the e-match in the **DP** blast cap is connected to the terminal block labeled **DP**

Time Out: 10:34

Time In: ____

- ☑ Safety Officer Confirmation: EW
- ☑ Confirm all labels are still visible

SECONDARY:

- ☑ Trim the e-match to approximately 7 in length using wire cutters
- ☑ Remove the red plastic protective e-match cover from e-match
- ☑ Separate the two leads
- ☑ Feed the e-match through the **DS** wire hole
  - ☑ The e-match head should be on the side with blast caps
- ☑ Strip the wire insulation from end of e-match
- ☑ Make a loop with the exposed wire
- ☑ Place exposed e-match leads into terminal block labelled **DS**
- ☑ Tighten down the screws in the **DS** terminal block
- ☑ Lightly tug on e-match wires coming out of the **DS** terminal block
  - ☑ Safety Officer Confirmation EW
- ☑ Place e-match head within the blast cap labelled **DS**
- ☑ Bend the e-match wire such that it lies flat against the blast cap
  - ☑ Secure the e-match wire to bulkhead with a small piece of electrical tape, ensure that no holes are covered
- ☑ Confirm the e-match wire is curved over the outside edge of the blast cap
- ☑ Confirm the e-match head is flat on the cap bottom
- ☑ Using 3M electrical tape, tape the e-match wire to the outside of the of the blast cap
- ☑ Confirm the e-match in the **DS** blast cap is connected to the terminal block labeled **DS**
  - ☑ Safety Officer Confirmation: EW
- ☑ Confirm all labels are still visible

Time Out: 1100

NC STATE UNIVERSITY

Time In: 1101

AV BAY FWD BULKHEAD E-MATCH INSTALLATION:

Required Items:

- ☑ **Avionics HDX box**
  - ☑ **(2) e-matches**
  - ☑ **3M electrical tape**
  - ☑ **Scissors**
  - ☑ **Wire Cutters**
  - ☑ **Wire Strippers**
  - ☑ **Small flathead screwdriver**
- ☑ **FWD Avionics Bay bulkhead**

Essential Personnel:

Role	Name	Initial
Safety Officer	Evan Waldron	EW
Team Lead	Harvey Hoopes	HWH
Recovery Lead	Nathan Cox	NC
E-Match Personnel 1	Meredith Patterson	MP
E-Match Personnel 2	Joseph Taylor	JST

Procedure:

PRIMARY:

- ☑ Unscrew all **unoccupied** terminal blocks on the AV Bay FWD bulkhead
- ☑ Trim the e-matches to approximately 7 in length using wire cutters
- ☑ Remove the red plastic protective e-match cover from e-match
- ☑ Separate the two leads
- ☑ Feed the e-match through the **MP** wire hole
  - ☑ The e-match head should be on the side with blast caps
- ☑ Strip the wire insulation from end of e-match
- ☑ Make a loop with the exposed wire
- ☑ Place exposed e-match leads into terminal block labelled **MP**
- ☑ Tighten down the screws in the **MP** terminal block
- ☑ Lightly tug on e-match wires coming out of the **MP** terminal block
  - ☑ Safety Officer Confirmation: EW
- ☑ Place e-match head within the blast cap labelled **MP**
- ☑ Bend the e-match wire such that it lies flat against the blast cap
  - ☑ Secure the e-match wire with a small piece of electrical tape
- ☑ Confirm the e-match wire is curved over the outside edge of the blast cap
- ☑ Confirm the e-match head is flat on the cap bottom
- ☑ Using 3M electrical tape, tape the e-match wire to the outside of the of the blast cap
- ☑ Confirm the e-match in the **MP** blast cap is connected to the terminal block labeled **MP**
  - ☑ Safety Officer Confirmation: EW

SECONDARY:

- ☑ Trim the e-match to approximately 7 in length using wire cutters
- ☑ Remove the red plastic protective e-match cover from e-match
- ☑ Separate the two leads
- ☑ Feed the e-match through the **MS** wire hole
  - ☑ The e-match head should be on the side with blast caps
- ☑ Strip the wire insulation from end of e-match
- ☑ Make a loop with the exposed wire

Time Out: 1112

Time In: ____

- ☑ Place exposed e-match leads into terminal block labelled **MS**
- ☑ Tighten down the screws in the **MS** terminal block
- ☑ Lightly tug on e-match wires coming out of the **MS** terminal block
  - ☑ Safety Officer Confirmation: EW
- ☑ Place e-match head within the blast cap labelled **MS**
- ☑ Bend the e-match wire such that it lies flat against the bulkhead
  - ☑ Secure the e-match wire with a small piece of electrical tape
- ☑ Confirm the e-match wire is curved over the outside edge of the blast cap
- ☑ Confirm the e-match head is flat on the cap bottom
- ☑ Using 3M electrical tape, tape the e-match wire to the outside of the of the blast cap
- ☑ Confirm the e-match in the **MS** blast cap is connected to the terminal block labeled **MS**
  - ☑ Safety Officer Confirmation: EW

Time Out: 1115

Time In: 11 15

AVIONICS BAY ASSEMBLY:

Required Items:

- ☑ FWD AV Bay Bulkhead
- ☑ AFT AV Bay Bulkhead
  - ✓ Assembled AV Sled
    - ✓ (3) Screw Switches
  - ✓ (2) pre-cut threaded rods
- ☑ AV Bay HDX Box
- ☑ AV Bay Section
- ~~☐ Ballast Box~~
- ☑ (2) 9V batteries
- ☑ Multimeter
- ☑ Plumbers Putty
- ☑ ½ in wrench
- ☑ ¼ in wrench
- ☑ 200mm adjustable wrench
- ☑ Zipties
- ☑ (4) #4-40 1 ½ in machine screws
- ☑ (4) #4-40 hex nuts
- ☑ (4) #4-40 washers
- ☑ Wire Cutters
- ☑ Needle Nose Pliers

Essential Personnel:

Role	Name	Initial
Safety Officer	**Evan Waldron**	
Team Lead	**Harvey Hoopes**	
Recovery Lead	**Nathan Cox**	
AV Bay Personnel 1	**Ashlee Bracewell**	

Procedure:

- ☑ Use multimeter to check primary battery voltages – 9V
  - ☑ If voltage is nominal, place 9V battery on AV sled and connect 9V plugs
  - ☑ Battery Voltage: 9.6
- ☑ Use multimeter to check secondary battery voltage – 9V
  - ☑ If voltage is nominal, place 9V battery on AV sled and connect 9V plugs
  - ☑ Battery Voltage: 9.6
- ☑ Place battery compartment cover over batteries and secure with four (4) #4-40 machine screws, four (4) #4-40 hex nuts, and four (4) #4-40 washers.
  - ☑ Recovery Lead Confirmation: ______
- ☐ At this point altimeters should not be activated until launch vehicle is on launch pad *Move to After Continuity*
- ☑ Activate GPS screw switch
- ☑ Use multimeter to check voltage on LiPo battery (3.7V, attached to GPS)
- ☑ Deactivated GPS Screw Switch
- ☑ Confirm GPS is securely attached to standoffs on reverse face of AV Sled by three (3) M3 screws
  - ☑ Recovery Lead Confirmation: ______
- ☑ Place Altimeter screw switches in the on position
- ☑ Confirm continuity on each screw switch by activation of altimeter

Time Out: 1139

Time In: 1145

- ☑ If continuity is present, place screw switches in the off position, else replace screw switch with one of the spares
- ☑ Confirm wires between primary altimeter and **DP** terminal block are still connected
- ☑ Confirm wires between secondary altimeter and **DS** terminal block are still connected
- ☐ Using the multimeter, confirm continuity on the wires attached to the aft AV bulkhead terminal blocks
  - ☐ Place one multimeter lead on the **DROGUE** screw on the Primary altimeter labeled **P**
  - ☐ Place the other multimeter lead inside the terminal block labeled **DP**
  - ☐ Repeat for the second **DROGUE** screw on the Primary altimeter
  - ☐ Place one multimeter lead on the **DROGUE** screw on the Secondary altimeter labeled **S**
  - ☐ Place the other multimeter lead inside the terminal block labeled **MS**
  - ☐ Repeat for the second **DROGUE** screw on the Secondary altimeter labeled **S**
- ☑ Confirm e-match wires are installed on the AFT AV Bulkhead
- ☑ Confirm the screw switch quick disconnects for the **GPS** are connected
  - ☑ Recovery Lead Confirmation: ______
- ☑ Confirm the AV Sled is ready to be inserted into the AV Bay
  - ☐ Recovery Lead Confirmation: ______
- ~~☐ Slide the AV Ballast Box onto the AV rails, open end up~~
- ☑ Slide the AV bay body tube over the AV sled and bulkhead assembly fully down until it is flush along the AFT bulkhead
  - ☑ Use the markings to align the sled correctly
- ☑ Probe pressure ports with small screwdriver to confirm they are clear
  - ☑ Safety Officer Confirmation: ______
- ☑ Ensure the **AFT** end of the AV bay is aligned with the **AFT AV** bulkhead
- ☑ Confirm the screw switches are visible through the screw switch holes
- ☑ Confirm e-match wires are installed on the FWD AV Bulkhead
  - ☑ Recovery Lead Confirmation: ______
- ☑ Connect the **MP** altimeter wires to the **MP** terminal block on the FWD AV Bulkhead
- ☑ Lightly tug on the **MP** altimeter wires coming out of the **MP** terminal block
  - ☑ Safety Officer Confirmation: ______
- ☑ Connect the **MS** altimeter wires to the **MS** terminal block on the FWD AV Bulkhead
- ☑ Lightly tug on the **MS** altimeter wires coming out of the **MS** terminal block
  - ☑ Safety Officer Confirmation: ______
- ☑ Slide the FWD AV bulkhead onto the threaded rods until flush with body tube
- ☑ Slide (1) washer onto each threaded rod
- ☑ Slide (1) 5/16 inch nut onto each threaded rod
- ☑ Slide (1) 5/16 inch cap nut onto each threaded rod
- ☑ Tighten until **SNUGG**
- ☑ Confirm ALL labels on AV Bay are still visible
  - ☑ Recovery Lead Confirmation: ______
- ☑ Confirm AV Bay assembly and bulkhead tightness
  - ☑ Recovery Lead Confirmation: ______
  - ☑ Safety Officer Confirmation: ______

Time Out: 12:05

Time In: 1203

UAV Assembly Checklist

Required Materials:

- ☑ UAV Box
  - ✓ (4) Emax Motor Cases
  - ✓ (1) Thread Locker
  - ✓ (8) Velcro™ Strips
  - ✓ (1) Box of Standoffs
  - ✓ (1) RunCam Box
- ☑ (1) Set of Vice Grips
- ☑ UAV HDX Box
  - ✓ (4) 18490 Batteries
  - ✓ (1) VTX Receiver
  - ✓ (1) VTX Antenna
  - ✓ (3) 3000 mAh 3S LiPo Batteries
  - ✓ (6) Battery Straps
  - ✓ (5) Red Lock Nuts
  - ✓ (2) Silver Lock Nuts
  - ✓ (6) Black Lock Nuts
  - ✓ (1) Bag of Rubber Bands
  - ✓ (12) Propellers
  - ✓ (3) Jacob's Allen Keys
  - ✓ (1) 8mm Socket Wrench
  - ✓ (1) Electrical Tape
  - ✓ (11) Spare Sled Screws
  - ✓ (7) Spare Hinge Bolts
  - ✓ (11) Spare Hinge Nuts
  - ✓ (8) Spare Hinges
  - ✓ (2) Spare XT60 Connectors
- ☑ Transmitter Case
  - ✓ (1) FrSky Taranis X-Lite Transmitter
  - ✓ (1) RTX Antenna

Essential Personnel:

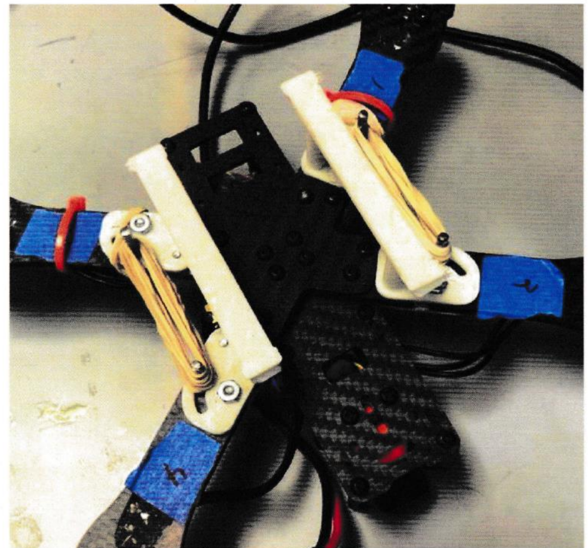
Role	Name	Initial
Safety Officer	Evan Waldron	EW
UAV Lead	Jacob Daye	JD
Payload Personnel 1	Sadie McCarthy	SM
Payload Personnel 2	Abhi Kondaguta	AK

Procedure:

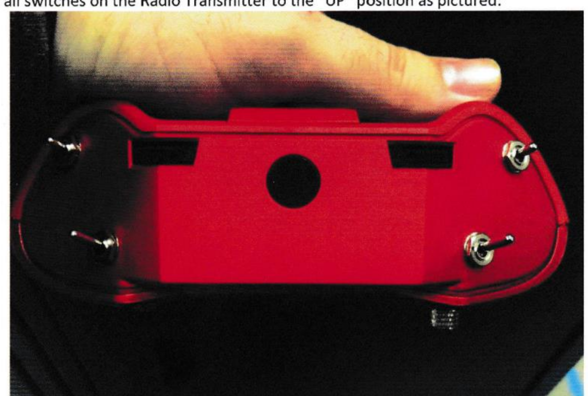
- ☑ Attach the LiPo battery to the drone body via Velcro™ straps
  - ☑ Align Battery Connectors with connector on Drone
  - ☑ UAV Lead Confirmation: JD
- ☑ Attach 8 rubber bands to the same side arm slot pins
  - ☑ See picture:

Time Out: _____

Time In: 1212



- ☑ UAV Lead Confirmation: JD
- ☑ Turn all switches on the Radio Transmitter to the "UP" position as pictured:



- ☑ UAV Lead Confirmation: JD
- ☑ Turn on the Radio Transmitter by holding the power button

Time Out: _____

Time In: 1213

- ☑ Note the battery level: 8.1
- ☑ Replace batteries if below 7.5V
- ☑ Attach the propellers to the UAV according to labels
  - ☑ CW propellers attach to the CW arms
  - ☑ CCW propellers attach to the CCW arms
  - ☑ Remove the blue tape labels
  - ☑ UAV Lead Confirmation: ______
- ☑ Confirm that the propellers will NOT hit any wires on the UAV
  - ☑ UAV Lead Confirmation: ______
- ☑ Screw red and black lock nuts over the propellers according to labels
  - ☑ RED on arm 2 and 3
  - ☑ BLACK on arm 1 and 4
  - ☑ Use an 8mm socket wrench to tighten
  - ☑ Tighten until tight
  - ☑ Do NOT over tighten
- ☑ Confirm the propellers do NOT rotate freely and can NOT slide up and down
  - ☑ UAV Lead Confirmation: ______
- ☑ Attach the video transmitter antenna to the video transmitter on the drone
- ☑ Connect the video receiver antenna to the video receiver
- ☑ Connect the LiPo to the matching power connector on the UAV
  - ☑ Motors will move slightly when power is connected
- ☑ Confirm three short beeps followed by two long beeps are heard
  - ☑ UAV Lead Confirmation: ______
- ☑ Turn on the video receiver
- ☑ Remove Lens cap from FPV Camera
- ☑ Confirm ALL flight critical components are on:
  - ☑ Flight Controller GREEN LED is ON
  - ☑ Flight Controller BLUE LED is ON or FLASHING
  - ☑ Flight Controller WHITE LED is ON
  - ☑ Video Transmitter is displaying the correct channel
  - ☑ Video Receiver is displaying the correct channel
- ☑ Confirm the Video Receiver is receiving video feed
  - ☑ UAV Lead Confirmation: ______

Time Out: 1245

Time In: 1240

Drogue Black Powder:

Required items:

- ☑ **AV Bay**
- ☑ **Paper Towels**
- ☑ **(2) 8.5x11, 20lb weight, 30% post-consumer recycled material copy paper**
- ☑ **Blue Tape**
- ☑ **Black Powder Charges**
  - ✓ **Drogue Primary charge (2.1g)**
  - ✓ **Drogue Secondary Charge (2.6g)**
- ☑ **Safety Glasses**
- ☑ **Nitrile Gloves**
- ☑ **Plumbers Putty**
- ☑ **3M electrical tape**
- ☑ **Scissors**

Essential Personnel:

Role	Name	Initial
Safety Officer	Evan Waldron	EW
Team Lead	Harvey Hoopes	HHH
Black Powder Personnel 1	Sean Clark	SC
Black Powder Personnel 2	Joseph Taylor	JST

Procedure:

- ☑ Confirm that all members around the launch vehicle are wearing safety glasses
  - ✓ Safety Officer Confirmation: ______
- ☑ Confirm the members handling black powder are wearing nitrile gloves
  - ✓ Safety Officer Confirmation: ______
- ☑ Turn Midsection so that the blast caps on the AFT avionics bulkhead are facing up
- ☑ Create a paper funnel using 1 sheet of copy paper and 1 piece of blue tape
  - ✓ Ensure inside of paper funnel is smooth
- ☑ Carefully pour the **Drogue Primary Charge** of black powder into the **DP** blast cap over the e-match head using the paper funnel for guidance
- ☑ Move the e-match so the black powder lies under the e-match head
- ☑ Fill the remaining space in the blast cap with finger tip sized pieces of paper towel
  - ✓ The paper towel should fill the space, but not be packed in tightly!
- ☑ Place small (2-3 in.) strips of black electrical tape on top of the **DP** blast cap to cover the blast cap completely
  - ✓ Do NOT have any major overlaps but leave no gaps with the electrical tape
  - ✓ Ensure all edges are covered
  - ✓ Safety Officer Confirmation: ______
- ☑ Wrap electrical tape all the way around the outside of the blast cap to keep the top layers tight
- ☑ Carefully pour the **Drogue Secondary Charge** of black powder into the **DS** blast cap over the e-match head using the paper funnel for guidance
- ☑ Move the e-match so the black powder lies under the e-match head
- ☑ Fill the remaining space in the blast cap with fingertip size pieces of paper towel
  - ✓ The paper towel should fill the space, but not be packed in tightly!
- ☑ Place small (2-3 in.) strips of black electrical tape on top of the **DS** blast cap to cover the blast cap completely
  - ✓ Do NOT have any major overlaps but leave no gaps with the electrical tape and

Time Out: 1255

Time In: 1300

- ✓ Ensure all edges are covered
- ✓ Safety Officer Confirmation: SW

☑ Wrap electrical tape all the way around the outside of the blast cap to keep the top layers tight
☑ Use plumber's putter to seal any holes in the bulkhead (E-match holes, etc.)
☑ Confirm all holes are sealed

- ✓ Safety Officer Confirmation: SW

☑ Turn the AV Bay over onto a sheet of white copy paper
☑ Turn the AV Bay back over

- ✓ Confirm that no black powder has leaked onto the copy paper
- ✓ If yes, Wipe copy paper clean and repeat the above steps
- ✓ Safety Officer Confirmation: SW

Time Out: 1302

Time In: ____

Main Black Powder:

Required items:

- ☑ **AV Bay**
- ☑ **Paper Towels**
- ☑ **(2) 8.5x11, 20lb weight, 30% post-consumer recycled material copy paper**
- ☑ **~~Scotch~~ Blue tape**
- ☑ **Black Powder Charges**
  - ✓ Main Primary charge (3.0g)
  - ✓ Main Secondary Charge (3.7g)
- ☑ **Safety Glasses**
- ☑ **Nitrile Gloves**
- ☑ **Plumbers Putty**
- ☑ **3M Electrical Tape**
- ☑ **Scissors**

Essential Personnel:

Role	Name	Initial
Safety Officer	Evan Waldron	SW
Team Lead	Harvey Hoopes	HH
Black Powder Personnel 1	Ashlee Bracewell	AB
Black Powder Personnel 2	Ashby Scruggs	CAS

Procedure:

☐ Confirm that all members around the launch vehicle are wearing safety glasses

- ✓ Safety Officer Confirmation: SW

☑ Confirm the members handling black powder are wearing nitrile gloves

- ✓ Safety Officer Confirmation: SW

☑ Make a paper funnel by rolling a sheet of copy paper and securing with a piece of ~~scotch~~ Blue tape
☑ Carefully pour the **Main Primary Charge** of black powder into the **MP** blast cap over the e-match head using the funnel for guidance
☑ Move the e-match so the black powder lies under the e-match head
☑ Fill the remaining space in the blast cap with fingertip size pieces of paper towel

- ✓ The paper towel should fill the space, but not be packed in tightly!

☑ Place small (2-3 in.) strips of black electrical tape on top of the **MP** blast cap to cover the blast cap completely

- ✓ Do NOT have any major overlaps but leave no gaps with the electrical tape ~~and~~
- ✓ Ensure all edges are covered
- ✓ Safety Officer Confirmation: SW

☑ Wrap electrical tape all the way around the outside of the blast cap to keep the top layers tight
☑ Carefully pour the **Main Secondary Charge** of black powder into the **MS** blast cap over the e-match head using the paper funnel for guidance
☑ Move the e-match so the black powder lies under the e-match head
☑ Fill the remaining space in the blast cap with pieces of paper towel

- ✓ The paper towel should fill the space, but not be packed in tightly!

☑ Place small (2-3 in.) strips of black electrical tape on top of the **MS** blast cap to cover the blast cap completely

- ✓ Do NOT have any major overlaps but leave no gaps with the electrical tape
- ✓ Ensure all edges are covered
- ✓ Safety Officer Confirmation: SW

Time Out: 1317

Time In: ____

- ☑ Wrap electrical tape all the way around the outside of the blast cap to keep the top layers tight
- ☑ Use plumber's putty to seal any holes in the bulkhead (E-match holes, etc.)
- ☑ Confirm all holes are sealed
  - ✓ Safety Officer Confirmation: EW
- ☑ Turn the AV Bay over onto a sheet of white copy paper
- ☑ Turn the AV Bay back over
  - ✓ Confirm that no black powder has leaked onto the copy paper
  - ✓ If yes, wipe copy paper clean and repeat the above steps
  - ✓ Safety Officer Confirmation: EW
- ☑ Clear the workspace of all black powder in preparation for ~~launch vehicle~~ Deployment System assembly

Time Out: 1321

Time In: 1334

Deployment System Assembly Checklist

Required Materials:

- ☑ Payload Deployment HDX Box
  - ☑ (1) Assembled Arduino
    - Stepper Motor Shield, 433 MHZ Receiver, (1) M3 screw, (1) M3 nut, (6) soldered wires
  - ☑ (1) Battery box lid
  - ☑ (2) AA Battery Packs with blue masking tape
  - ☑ (1) AA Battery Pack with Velcro
  - ☑ (12) AA Batteries
  - ☑ (1) 9V Battery
  - ☑ (5) M4 Screws
  - ☑ (1) Allen wrench labeled AK-4M
  - ☑ (1) Flathead screwdriver w/ orange top
  - ☑ (1) Relay pin sticky note
- ☑ Launch Day Toolbox
  - ☑ (1) Small zip tie
  - ☑ (1) Multimeter
  - ☑ (1) Forceps
- ☑ Nolan's Dremel Box
  - ☑ (1) 433 MHz Radio Transmitter Assembly
- ☑ (1) Payload Removable Bulkhead with Southco R4-EM latch and Stepper Motor attached
- ☑ Payload Pod Base
- ☑ (2) Payload Flaps
- ☑ Payload Pusher
- ☑ Payload Pod Tupperware
- ☑ Electrical Tape
- ☑ (4) 6-32 Screws
- ☑ Spare Body Tube
- ☑ Vise Grips
- ☑ Plumber's Putty
- ☑ Recovery Tupperware ☑ Assembled UAV

Essential Personnel:

Role	Name	Initial
Safety Officer	**Evan Waldron**	EW
Team Lead	**Harvey Hoopes**	HAH
Structures Lead	**Michelle Nursey**	MN
Recovery Lead	**Nathan Cox**	NC
Payload Integration Lead	**Josh Daniels**	JSD
Payload Communication Lead	**Nolan Hopkins**	NH
UAV Lead	**Jacob Daye**	JD

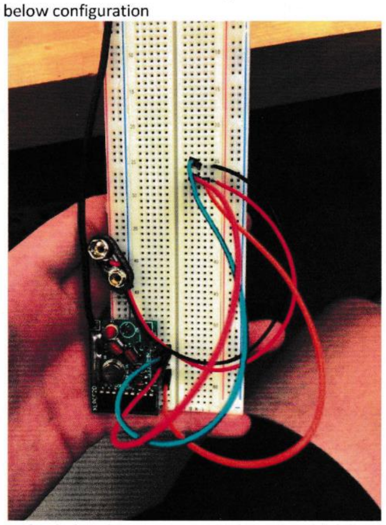
Procedure:

- ☐ Confirm that all members handling the launch vehicle are wearing safety glasses
  - ☐ Safety Officer Confirmation: ____
- ☑ Route shock cord end labeled **1** through aft end of payload bay centering rings
- ☑ Route shock cord end labeled **1** through payload bay bulkhead

Time Out: 1341

Time In: _____

- [x] Confirm the Latch is open
  - [x] Payload Communication Lead Confirmation: ____
- [x] Fully extend the Payload Pusher so that it is hanging outside the AFT end of the Payload Bay
- [x] Place the UAV on the Payload Pod Base
  - [x] Jacob crys and kisses his child goodbye
- [x] Align UAV Propellers with UAV Arms
- [x] While holding the UAV arms folded, place the two Payload Flaps on the base in unison
  - [x] Match the inner symbols together
  - [x] Payload Integration Lead Confirmation: ____
- [x] Hold the two flaps together and push the pod onto the cantilevered rod through the hole in the flat end of the pod
- [x] Slightly pull the flaps apart to confirm the cantilevered rod reaches the end of the pod
  - [x] Payload Integration Lead Confirmation: ____
- [x] Attach electrical tape to the joints labeled "TAPE"
- [x] Push the Pod assembly all the way into the payload bay open latch
  - [x] Confirm an audible click is heard
  - [x] Pull on the pod assembly to ensure the latch is closed
  - [x] Safety Officer Confirmation: ____
- [x] Use Plumber's putty to seal all holes around the exposed end of the Payload Pod
- [x] Set the Payload Bay assembly in the spare body tube
- [x] Confirm the Radio Transmitter circuit matches the picture below. If it does not, reattach the jumper wires in the below configuration

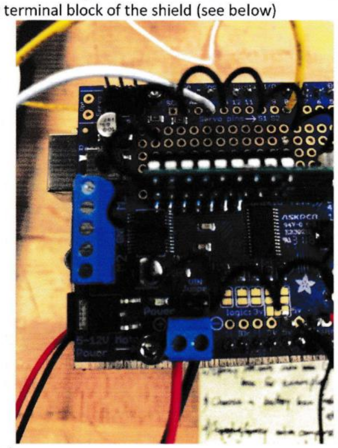


- [ ] Using the multimeter, check that there is continuity between the following leads:
  - [x] Receiver GND to Arduino GND
  - [ ] Receiver VDD to Arduino 5V

Time Out: 14 01

Time In: _____

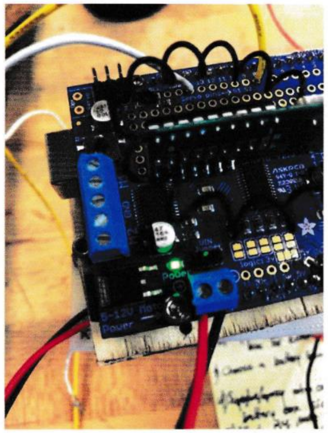
- [x] Receiver D2 to Arduino A0
- [x] Payload Comm. Lead Confirmation: NH
- [x] Using the multimeter, ensure all AA batteries possess a voltage of 1.25 V or greater.
  - [x] Replace if necessary
- [x] Insert 4 fresh AA batteries into each of the three battery packs
- [x] Insert a tiny black screw into the battery pack with Velcro™ on the side
- [x] Use the screwdriver with an orange top to secure the leads of the battery pack labeled "Shield Pack" into the Power terminal block of the shield (see below)



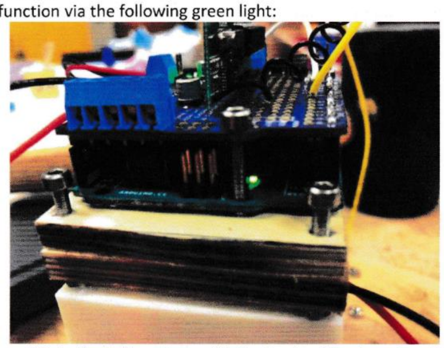
- [x] Turn on the Shield Pack
- [x] Insert the Shield Pack into the battery box with the leads of the pack on the side of the box labeled "shield pack"
- [x] Ensure the pack is functioning via the green light in the position below

Time Out: 14 04

Time In: _____



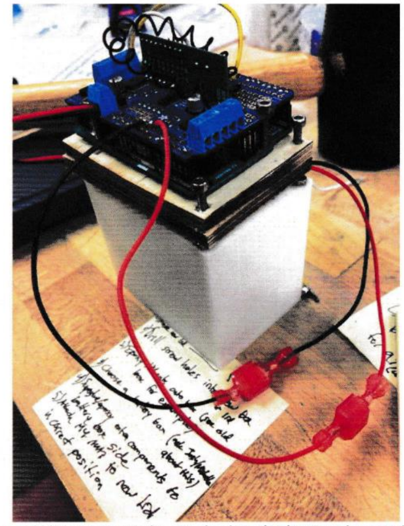
- ☑ Attach the female-lead quick disconnects of the Board pack to the male-lead disconnects soldered to the shield.
- ☑ Turn on the board pack
- ☑ Confirm proper function via the following green light:



- ☑ Insert the board pack into the battery box, with the leads of the board pack facing the side of the box labeled "board pack"
- ☑ Confirm the top of the battery box is flush with the battery packs
- ☑ Use the AK-4M "Nolan's" allen wrench to attach the box lid to the box via three M4 screws.
    - ☑ NOTE: the screws will only align with the three nuts on the box in a single orientation.
- ☑ Attach the Arduino and shield sub-assembly to the lid via two M4 screws in the holes of the Arduino as seen below.

Time Out: _____

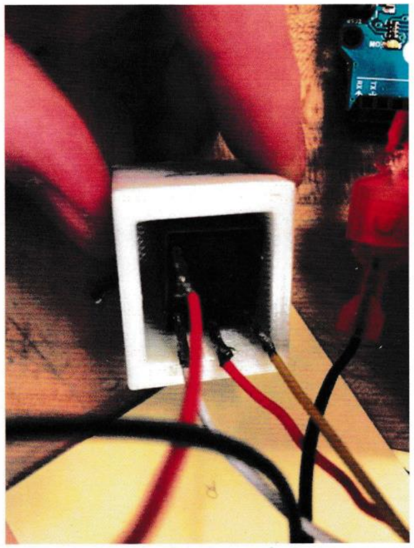
Time In: _____



- ☑ Confirm the Arduino and lid are securely attached to the battery box and that all wires are in their proper locations up to this point
    - ☑ Payload Comm. Lead Confirmation: NH
- ☑ Attach the following wires to the relay pins and secure firmly
    - ☑ Use the relay sticky note for further clarification if needed
    - ☑ Shield-Yellow: Relay pin 2
    - ☑ Shield-White: Relay pin 4
    - ☑ PCB-Red: Relay pin 5
    - ☑ Velcro Battery Pack-Red: Relay pin 3
- ☑ Confirm the leads are securely attached to the relay with a quick tug
    - ☑ Payload Comm. Lead Confirmation: NH
- ☑ Insert the electrical relay into the relay box affixed to the side of the battery box
    - ☑ Confirm the relay leads face outward
    - ☑ Secure in place with a small zip tie through the zip tie holes at the top of the relay box
- ☑ Confirm the finished product matches the picture below:

Time Out: 14[illegible]

Time In: _____



- ☑ Secure Velcro™ battery pack to the outside of the battery box
- ☐ Using the screwdriver with the orange tip, insert and secure the red and blue leads of the stepper motor into the M3 motor terminal block of the shield.
  - ☑ Red wire goes in the outermost terminal
- ☑ Using the screwdriver with the orange tip, insert and secure the green and black leads of the stepper motor into the M4 motor terminal block of the shield.
- ☐ Confirm the order of the stepper wires from outside to inside as:
  - ☑ RED
  - ☑ BLUE
  - ☑ GREEN
  - ☑ BLACK
- ☑ Confirm wire security with a quick tug.
  - ☑ Tighten any loose wires
  - ☑ Payload Comm. Lead Confirmation: NH
- ☑ Resume the **Main Parachute Recovery Assembly Checklist**

Time Out: 1410

Time In: 1412

Main Parachute Recovery Assembly:

Required items:

- ☑ **Recovery box**
- ☑ **Nosecone**
- ☑ **Assembled Payload Bay**
- ☑ **Main Parachute Bay**
- ☑ **AV Bay**
- ☑ **(5) Safety Glasses**
- ☑ **Main parachute (84in Iris Ultra)**
- ☑ **5.5 in Deployment Bag**
- ☑ **(2) Large nomex cloth**
- ☑ **Main parachute shock cord**
- ☑ **Philips head screwdriver (labeled POS)**
- ☑ **Recovery hardware box**

☑ Plumbers Putty

Essential Personnel:

Role	Name	Initial
Safety Officer	Evan Waldron	EW
Team Lead	Harvey Hoopes	HH
Structures Lead	Michelle Nursey	MN
Recovery Lead	Nathan Cox	NC
Recovery Personnel 1	Meredith Patterson	MP

Procedure:

☑ Safety Glasses: EW

- ☑ Tie a bowline knot on the end of the shock chord labeled **1**
  - ☑ Boy Scout Confirmation: HH
- ☑ Attached **quicklink 1** to **end of shock chord labeled 1**
  - ☑ Do NOT tighten
- ☑ Attach **quicklink 1** to **nosecone bulkhead 1**
  - ☑ Tighten by hand
- ☑ Confirm the **quicklink 1** is secured to the nosecone bulkhead U-bolt by visual inspection and pulling on shock cord
  - ☑ Recovery Lead Confirmation: NC
- ☑ Insert nose cone shoulder into payload bay using marks to align holes
- ☑ Use (4) #6-32 ½ inch screws to secure nose cone to payload bay
- ☑ Pull shock cord taught through payload bay
- ☑ Attach **quicklink 2 to loop 2**
  - ☑ Do NOT tighten
- ☑ Attach **quicklink 2** to **Nomex sheet 2**
- ☑ Seal perimeter of Payload Pod with Plumbers Putty
- ☑ Seal Around Shock Cord with Plumbers Putty
  - ~~☐ Structures Lead Confirm: ______~~
- ☑ Attach **quicklink 2** to **deployment bag loop 2**
  - ☑ Tighten by hand
- ☑ Fold length of shock cord **between loops 2 and 3** accordion-style ☑ Secure with Rubber Band
- ☑ Confirm the rubber band is NOT too tight and NOT covering any part of parachute
  - ☑ Two fingers should fit snugly under the rubber band
- ☑ Confirm the shock cord is still folded accordion style within the rubber band
  - ☐ If not repeat the previous steps

Time Out: 1428

Time In: ____

- ☑ Fold length of shock cord **between loops 3 and 4** accordion-style
- ☑ Secure with a single rubber band
- ☑ Confirm the rubber band is NOT too tight and NOT covering any part of parachute
  - ☑ Two fingers should fit snugly under the rubber band
- ☑ Confirm the shock cord is still folded accordion style within the rubber band
  - ☑ If not repeat the previous steps
- ☑ Final check that all rubber bands are removed from main parachute and shroudlines
  - ☑ The rubber bands on the shock cord will remain
- ☑ Attach **quicklink 3** to **loop 3**
  - ☑ Do NOT tighten
- ☑ Attach **Large Nomex Sheet** to **quicklink 3**
- ☑ Attach **quicklink 3** to **Main Parachute Loop 3**
  - ☑ Tighten by hand
- ☑ Carefully slide payload bay coupler into main parachute bay using marks to align shear pin holes
- ☑ Cut (2) 4-40 nylon shear pins so they are 1/2 in in length and insert into shear pin holes until tight
- ☑ If shear pins are loose, place small piece of electrical tape over shear pin heads
- ☑ Wrap Main Parachute deployment bag in large nomex sheet
- ☑ Route end of shock cord labeled 4 through the main parachute bay from the FWD end to the aft end
- ☑ Carefully insert the shock cord length **between loops 2 and 4** into main parachute bay from forward to aft
- ☑ Attach **quicklink 4** to **loop 4**
  - ☑ Do NOT tighten
- ☑ Attach **quicklink 4** to **AV Bay FWD bulkhead 4**
  - ☑ Tighten by hand
- ☑ Confirm the **quicklink 4** is secured to the AV Bay **FWD bulkhead 4** by visual inspection and pulling on shock cord
  - ☑ Recovery Lead Confirmation: NC
- ☑ Carefully insert the wrapped parachute into the space between stowed shock cords
  - ☑ The deployment bag loop **labeled 2** should be pointed toward the nosecone
  - ☑ The deployment bag should sit completely inside the main parachute bay
  - ☐ ~~Ensure that payload bay plug remains within the centering ring~~
- ☑ Slide FWD AV Bay coupler into main parachute bay using marks to align holes
- ☑ Use (4) #6-32 ½ inch screws to secure the two sections
  - ☑ Structures Lead Confirmation: MN
- ☑ The launch vehicle should be able to hold its own weight from shear pins alone
  - ☑ Hold at nosecone and let the launch vehicle hang
  - ☑ Structures Lead Confirmation: MN

Time Out: 1452

Time In: 14:52

Drogue Parachute Recovery Assembly:

Required items:

- ☑ **Recovery hardware box**
- ☑ **Fin can**
- ☑ **Completed Nosecone Midsection Assembly**
- ☑ **(5) Safety Glasses**
- ☑ **Drogue parachute (24in elliptical)**
- ☐ ~~**4 in deployment bag**~~
- ☑ **Small Nomex cloth**
- ☑ **Drogue parachute shock cord**
- ☑ **Electrical Tape**
- ☑ **Scissors**

Essential Personnel:

Role	Name	Initial
Safety Officer	Evan Waldron	EW
Team Lead	~~Harvey Hoopes~~	AV
Structures Lead	Michelle Nursey	MN
Recovery Lead	Nathan Cox	NC
Recovery Personnel 1	~~Ashby Scruggs~~ Ashlee Bracewell	ABB

Procedure:

- ☑ Confirm that all members near the launch vehicle are wearing safety glasses
- ☑ Use **quicklink 6** to attach nomex cloth to shock cord parachute **loop 6** — Safety officer: EW
  - ☐ ~~Tighten by hand~~
- ☑ Use **quicklink 6** to attach drogue parachute **eye-bolt 6** to **loop 6**
  - ☑ Tighten quicklink by hand
- ☑ Fold length of shock cord **between loops 5 and 6** accordion-style
  - ☑ 8 in folds
- ☑ Secure the length of shock cord **between loops 5 and 6** with a single rubber band
- ☑ Confirm the rubber band is NOT too tight and NOT covering any part of parachute
  - ☐ Two fingers should fit snugly under the rubber band
- ☑ Confirm the shock cord is still folded accordion style within the rubber band
  - ☑ If not repeat the previous steps
- ☑ Fold length of shock cord **between loops 6 and 7** accordion-style
- ☑ Secure the length of shock cord **between loops 6 and 7** with a single rubber band
- ☑ Confirm the rubber band is NOT too tight and NOT covering any part of parachute
  - ☑ Two fingers should fit snugly under the rubber band
- ☑ Confirm the shock cord is still folded accordion style within the rubber band
  - ☐ If not repeat the previous steps
- ☑ Attach **quicklink 5** to **loop 5**
  - ☑ Do NOT tighten
- ☑ Attach **quicklink 7** to **loop 7**
  - ☑ Do NOT tighten
- ☑ Attach **quicklink 5** to AV Bay aft **bulkhead 5**
  - ☑ tighten by hand
- ☐ Confirm the quicklink is secured to the AV Bay aft bulkhead U-bolt by visual inspection and pulling on shock cord
  - ☐ Recovery Lead Confirmation: NC

Time Out: 1503

Time In: 1503

- ☑ Attach **quicklink 7** to fin can **bulkhead 7**
  - ☑ tighten by hand
- ☑ Confirm the quicklink is secured to the fin can bulkhead U-bolt by visual inspection and pulling on shock cord
  - ❑ Recovery Lead Confirmation: ML
- ☑ Confirm the drogue parachute is properly ~~inserted into the deployment bag~~
- ☑ Remove rubber band securing drogue parachute
  - ☑ Hold it tightly
- ☑ Confirm all rubber bands are removed from parachute and shroudlines
- ☑ Wrap nomex cloth around ~~the deployment bag~~ parachute
  - ☑ Hold it tightly
- ☑ Carefully insert the shock cord length **between loops 6 and 7** into fin can cavity
- ☑ Carefully insert the drogue parachute deployment bag into the fin can cavity in the space between stowed shock cords
  - ☑ The yellow Fruity Chutes logo should be facing the fin can
- ☑ Carefully insert the shock cord length **between loops 5 and 6** into the fin can cavity
- ☑ Slide AV Bay coupler into fin can cavity using the marks to align the shear pin holes
  - ❑ Structures Lead Confirmation: MN
- ☑ Cut (2) 4-40 nylon shear pins so they are ½ in length and insert into shear pin holes until tight
  - ☑ If shear pins are loose, place small piece of electrical tape over shear pin heads
- ❑ Confirm the assembled launch vehicle is able to hold its own weight from shear pins alone
  - ☑ Hold nosecone and let fin can hang
  - ☑ Structures Lead Confirmation: MN

Time Out: 1509

Time In: ____

Motor Assembly:

Required items:

- ❑ AeroTech L1150R reload kit
- ❑ **AeroTech RMS 75/3840 motor casing with forward seal**
- ❑ **Vaseline Petroleum Jelly**
- ❑ **Nitrile Gloves**
- ❑ **Needle-nose pliers**
- ❑ **Baby wipes**
- ❑ **Alan/Jim**
- ❑ **Permanent Marker**
- ❑ **Painters tape**
- ❑ **Paper Towels**

Essential Personnel:

Role	Name	Initial
L3 Mentor	Alan Whitmore/Jim Livingston	
Team Lead	Harvey Hoopes	
Structures Lead	Michelle Nursey	
Motor Personnel 1	Abhi Kondagunta	

Procedure:

- ☑ Follow the manufacturer's instructions for motor assembly with L3 mentor
  - ○ A copy is listed at the end of this checklist
- ☑ Prep Ignitor
  - ○ Hold ignitor wire against the motor casing
  - ○ Designate appropriate length by marking wire with sharpie
  - ○ Separate ends of ignitor wire
  - ○ Strip ends of ignitor wire
  - ○ Recoil ignitor
  - ○ Store in field recovery toolbox
- ☑ Return to launch vehicle assembly location
- ☑ Unscrew motor retainer
- ☑ Slide motor casing into motor tube
- ☑ Secure motor casing using retainer screw
- ☑ Have a second team member confirm the motor retainer screw is tight
- ☑ Measure the center of pressure of the launch vehicle
  - ○ Center of pressure is at 72.64 in from the nosecone
  - ○ Team Lead Confirmation: HH
- ☑ Use a green circular sticker to mark the center of pressure of the launch vehicle
- ☑ Using the rope and fish scale, locate the center of gravity of the launch vehicle
  - ☑ Tie the rope around the middle of the launch vehicle
  - ☑ Move the rope until the launch vehicle balances
  - ☑ The balance point is the CG
  - ☑ Write the weight of the launch vehicle here: 39.2
  - ☑ Should be approximately ___
- ☑ Use a pink circular sticker to mark the CG
  - ☑ Measure the CG distance from the nosecone
  - ❑ Write the CG distance from the nosecone here: 59 13/64
  - ❑ Should be approximately 61.55 in

Time Out: ______

Time In: ____

- [x] Team Lead Confirmation: HH
- [x] Confirm the CG and CP are AT LEAST 11.0 in apart (preferably more)
- [ ] Calculate the stability margin of the launch vehicle in calibers
  - (CP-CG)/D
  - Write stability margin here: 2.32
  - Should be greater that 2.0
  - Team Lead Confirmation: HH
- [ ] Fill the Field Recovery Toolbox with the necessary materials at this point

Time Out: ______

Time In: ____

Launch Pad Procedure:

Required items:

- [ ] **Fully assembled launch vehicle with payload and motor installed**
- [ ] **Motor igniter**
- [ ] **Launch Rail**
  - **8ft x 1515 in Bayboro, NC**
  - **12ft x 1515 in Huntsville, AL**
- [ ] **Launch rail lubricant**
- [ ] **Stepladder (if necessary)**
- [ ] **Field Recovery Toolbox**
  - **(3) Nitrile Gloves**
  - **(1) Heavy Duty Gloves**
  - **(5) Safety Glasses**
  - **(1) Switch Screwdriver**
  - **(1) Terminal Block Screwdriver**
  - **(1) Adjustable Wrench**
  - **(6) Rubber Bands**
  - **(1) Phone**
  - **(1) Wire Cutters**
  - **(1) Wire Strippers**
  - **Blue Painters Tape**

Essential Personnel:

Role	Name	Initial
Safety Officer	Evan Waldron	EW
Team Lead	Harvey Hoopes	HH
Recovery Lead	Nathan Cox	NC
Launch Pad Personnel 1	Ashby Scruggs	AS
Launch Pad Personnel 2	Jacob Daye	JD

Procedure:

- [x] Confirm with RSO that field conditions are safe for launch
  - RSO Confirmation: ACW
- [x] Submit launch vehicle and flight card to RSO for review
  - RSO Confirmation: ACW
- [x] Confirm the blast deflector is mounted on the launch rail
  - Safety Officer Confirmation: EW
- [x] Grease launch vehicle rail buttons and launch rail track
- [x] Carefully slide launch vehicle onto launch rail
- [x] Rotate launch rail into upright position and lock into place
  - Launch vehicle must be pointed downwind and 5° from vertical
- [x] Confirm the launch rail is locked
  - Safety Officer Confirmation: EW
- [x] Take team picture in front of launch vehicle
- [x] Take Senior Design picture in front of launch vehicle
- [x] All non-essential personnel must be directed to leave the launch pad
- [x] Confirm all individuals remaining at launch pad wear safety glasses
  - Safety Officer Confirmation: EW

Arm both altimeters.

Time Out: ______

Time In: ____

- ☑ Turn GPS screw switch until tight. step stool
- ☑ Turn Primary screw switch until tight.
- ☑ Confirm the PRIMARY altimeter (StratoLogger) is beeping correctly
  - Refer to beep sheet
- ☑ Turn Secondary screw switch until tight.
- ☑ Confirm the SECONDARY altimeter (StratoLogger) is beeping correctly
  - Refer to beep sheet
- ☑ **CONFIRM BOTH ALTIMETERS ARE ON BEFORE PROCEEDING**
  - Safety Officer Confirmation: CW
- ☑ Attach igniter to wooden dowel
- ☑ Insert igniter fully into motor tube
- ☑ Tape igniter into place at the bottom of launch vehicle → reinstall red cap
- ☑ Confirm that launch pad power is cut off
- ☑ Connect igniter to launch pad power
- ☑ Ensure pad continuity
  - Readout should be between 1.5 and 3.5
- ☑ All personnel must navigate to safe locations behind launch table
- ☐ Pass the Primary Checklist and Field Recovery Toolbox to the Safety Officer
- ☐ LAUNCH!

Time Out: ______

Time In: ____

Main Altimeter (Top Key Switch) Beep Table - StratoLogger

Between each row there is a long beep

The Beeps: What do they mean	Write Beeps Here	Expected Output
A siren and error code if an error was encountered during the last flight.		Ignore, currently not important
A one-digit number (range of 1 to 9) corresponding to the currently-selected program preset.	1	Should be 1
A two second pause, and then a three- or four-digit number corresponding to the main deploy altitude setting.	600	IMPORTANT: Should be 600
*(optional) only if you have added an apogee delay to the currently selected preset: A two second pause, and then a **five second continuous tone** to warn you that your apogee firing is set to be delayed.*	—	IMPORTANT: SHOULD NOT SOUND
A two second pause, and then a three to six-digit number representing the apogee altitude of the last flight.	—	Ignore, currently not important
A two second pause, and then a two- or three-digit number representing the battery voltage in tenths of a volt (e.g. 9.2 volts would report as 92).	9.5	IMPORTANT: Should be between 8.8 and 11.0
A two second pause, and then continuity beeps repeated every 0.8 seconds – a single beep means drogue e-match continuity is OK, two beeps means main e-match continuity is OK, three beeps means both drogue and main have good continuity.		IMPORTANT: Should be 3

Time Out: ______

Time In: ____

Secondary Altimeter (Bottom Key Switch) Beep Table - StratoLogger

Between each row there is a long beep

The Beeps: What do they mean	Write Beeps Here	Expected Output
A siren and error code if an error was encountered during the last flight.		Ignore, currently not important
A one-digit number (range of 1 to 9) corresponding to the currently-selected program preset.	1	Should be 1
A two second pause, and then a three- or four-digit number corresponding to the main deploy altitude setting.	550	IMPORTANT: Should be 550
*(optional) only if you have added an apogee delay to the currently selected preset: A two second pause, and then a **five second continuous tone** to warn you that your apogee firing is set to be delayed.*		IMPORTANT: SHOULD SOUND
A two second pause, and then a three to six-digit number representing the apogee altitude of the last flight.		Ignore, currently not important
A two second pause, and then a two- or three-digit number representing the battery voltage in tenths of a volt (e.g. 9.2 volts would report as 92).	9.4	IMPORTANT: Should be between 8.8 and 11.0
A two second pause, and then continuity beeps repeated every 0.8 seconds – a single beep means drogue ematch continuity is OK, two beeps means main ematch continuity is OK, three beeps means both drogue and main have good continuity.		IMPORTANT: Should be 3

Time Out: ______

Time In: _____

Field Recovery Checklist

Required Materials:

- ❑ **Field Recovery Toolbox**
  - **(5) Nitrile Gloves**
  - **(1) Heavy Duty Gloves**
  - **(5) Safety Glasses**
  - **(1) Switch Screwdriver**
  - **(1) Terminal Block Screwdriver**
  - **(1) Adjustable Wrench**
  - **(6) Rubber Bands**
  - **(1) Phone**
  - **(1) Wire Cutters**
  - **(1) Wire Strippers**
  - **Blue Painters Tape**
  - **Plastic Shopping Bag**
  - **433mHz Transmitter**
- ❑ **Hand-Held Fire Extinguisher**

Essential Personnel:

Role	Name	Initial
Safety Officer	Evan Waldron	EW
Recovery Lead	Nathan Cox	NC
Payload Integration Lead	Joshua Daniels	JLD
Payload Communication Lead	Nolan Hopkins	NH
Field Recovery Personnel 1	Ashlee Bracewell	[illegible]
Field Recovery Personnel 2	Meredith Patterson	[illegible]

Procedure:

- ❑ Upon launch, watch the launch vehicle descend
- ❑ Observe where the launch vehicle lands
- ❑ Approach the launch vehicle on foot
- ❑ Once near the launch vehicle
  - ❑ Take note of whether all three sections of the launch vehicle are present
  - ❑ Take note of the state of all parachutes
- ❑ If the launch vehicle appears to be on fire or smoking, use the fire extinguisher to put out the flame
- ❑ All recovery team members put on safety glasses
  - ❑ Safety Officer Confirmation: EW
- ❑ Attach a 9V battery to the 433mH transmitter to deploy the payload pod
- ❑ Call the UAV Flight team to confirm the pod is deployed
- ❑ Wait for the UAV pilot to fly the UAV to the FEA
- ❑ If a parachute is open and pulling the launch vehicle
  - ❑ Do **NOT** grab hold of the shroudlines or shock cord
  - ❑ Approach the parachute from the billowed side without shroudlines
  - ❑ Use hands and body to pull down the parachute
  - ❑ Repeat for second parachute if necessary
- ❑ Use a rubber band to secure the Main Parachute
- ❑ Use a rubber band to secure the Drogue Parachute
- ❑ Listen to the altimeters to determine flight data
  - ❑ Use the beep sheets below to record flight data
- ❑ If beeps are NOT heard from one of the altimeters for more than 10 seconds assume a black powder charge did NOT go off
- ❑ If the launch vehicle did NOT separate, assume a black powder charge did NOT go off
- ❑ Team members manipulating the launch vehicle put on nitrile gloves

Time Out: _____

Time In: _____

- [x] Perform this step even if you think all the black powder charges went off
- [ ] Safety Officer Confirmation: ___________
- [x] Carefully pick up the FWD end of the midsection
- [x] Visually inspect the FWD Payload bulkhead for un-blown black powder charges
- [x] If there is an un-blown black powder charge:
  - [x] Equip heavy duty gloves before handling the body tube
    - Safety Officer Confirmation: ___________
  - [ ] Use the ~~black~~ screwdriver with the red tip to turn OFF the ~~rotary~~ switches
  - [ ] On the rotary switches the 220 position is OFF
- [ ] Carefully pick up the AFT end of the midsection
- [ ] Visually inspect the AFT Payload bulkhead for un-blown black powder charges
- [ ] If there is an un-blown black powder charge:
  - [ ] Equip heavy duty gloves before handling the body tube
    - Safety Officer Confirmation: ___________
  - [ ] Use the black screwdriver with the red tip to turn OFF the rotary switches
  - [x] On the rotary switches the 220 position is OFF
- [x] Take photographs
  - [ ] Nosecone showing bulkhead and u-bolt
  - [ ] Drogue parachute showing quick links
  - [x] Landing layout
  - [ ] All quicklinks
  - [x] Fin condition
  - [ ] Any body tube damage
- [ ] Inspect the landing site for non-biodegradable waste
  - [x] Pick up any waste
- [ ] Pack up the launch vehicle and travel back to the launch site

Time Out: _____

Time In: _____

Main Altimeter Beep Table – StratoLogger

Between each row there is a long beep

The Beeps: What do they mean	Write Beeps Here	Expected Output
An extra-long tone to indicate the start of the reporting sequence	✓	Ignore, currently not important
A three to six digit number representing the peak altitude in feet	~~[illegible]~~ 3566	Should be approximately 4090 Record
A long separator tone followed by a two to five digit number representing the maximum velocity during the flight in miles per hour	341	Record
If the "siren delay" number is set to a number greater than zero, the altimeter will wait for the specified siren delay time, and then emit a 10 second warbling siren tone.	✓	Ignore, currently not important
After a 10 second period of silence, the sequence repeats until power is disconnected.	✓	Ignore, currently not important

Time Out: _____

Time In: _____

UAV Flight Checklist

Get extra battery for video

Required Materials:

- ❑ Transmitter Case
  - (1) FrSky Taranis X-Lite Transmitter
  - (1) RTX Antenna
- ❑ Video Receiver
- ❑ Deployment Controller

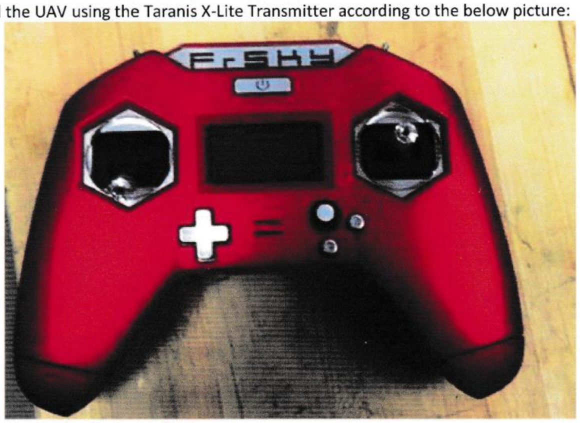
Essential Personnel:

Role	Name	Initial
Payload Communication Lead	**Nolan Hopkins**	
Payload Lead	**Jacob Daye**	[signature]
UAV Pilot	**Joseph Taylor**	[signature]
Flight Personnel 1	**Sadie McCarthy**	[signature]

Procedure:

Arming

- ☑ Turn on the Radio Transmitter
- ☑ Attach the antenna to the Radio Transmitter
- ☑ Turn on the Video Transmitter
- ☑ Confirm the Video Receiver is receiving video feed
  - UAV Lead Confirmation: [signature]
- ☑ Flip the arming switch to the ON (DOWN) position
- ☑ Control the UAV using the Taranis X-Lite Transmitter according to the below picture:



- ❑ Fly the UAV to the designated FEA
- ❑ Drop the Navigational Beacon
- ❑ Fly the drone to a designated SAFE area to land
- ❑ Reduce the throttle until the drone lands on the ground

Disarming

- ❑ Approach the UAV but do not engage

Time Out: _____

Time In: _____

- ☑ Flip the arming switch to the OFF position
  - UAV Lead Confirmation ________ X
- ☑ Confirm the UAV propellers are stopped
  - UAV Lead Confirmation: ________ X
- ☑ Unplug the LiPo battery from the UAV
- ☑ Power off the Video Receiver
- ☑ Remove the Video Receiver antenna
- ☑ Turn off the Taranis X-Lite Transmitter
- ☑ Remove the Taranis X-Lite antenna

Time Out:

10. Appendix C

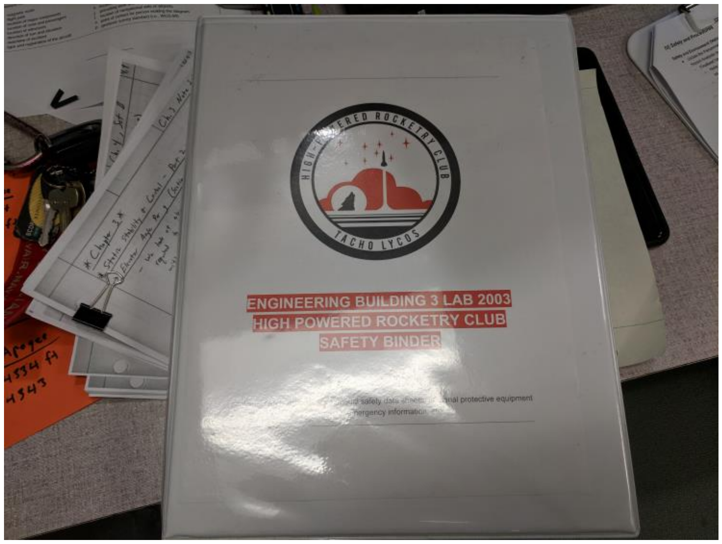


Figure 10-1 Lab Safety Binder

Figure 10-2 Launch field conditions on launch day

Figure 10-3 motor installation profile view prior to motor retainer attachment

Figure 10-4 Recovery electronics assembly process

Figure 10-5 Measuring the CG of the fully assembled launch vehicle

Figure 10-6 Blast plate location under the launch vehicle on the pad

Figure 10-7 Launch vehicle mounted on the launch pad

Figure 10-8 Ignition of the motor

Figure 10-9 Weathercocking after takeoff

Figure 10-10 Main parachute deployment at apogee

Figure 10-11 Launch vehicle landing orientation

Figure 10-12 Payload bay and nose cone orientation

Figure 10-13 UAV emerging from the pod with damaged antennae

Figure 10-14 Drogue parachute deployment charges after deployment

11. Appendix D

Bulkhead Failure Test
Materials Required:

- Assembled Sample
  - Bulkhead
  - U-Bolt
  - Fiberglass Tube
  - Removable Metal Bulkhead
- Quicklink
- Universal Testing Machine
- Dr. Kribs
- Computer
  - Bluehill 2 Software

Procedure:

- Confirm all participating members are wearing safety glasses
- Attach quicklink to U-bolt
- Place sample on the UTM
  - Secure using bolts into the metal bulkhead
- Adjust UTM until the clamp is secured on the quicklink
  - Tighten clamp until secure
- Calibrate the machine
- Set up the data recording software
  - Bluehill 2 software to record deflection and force
- Replace the plexiglass cover on the machine
- Confirm all participating members are a safe distance away from the machine
- Start the recording software and machine
- Test until failure

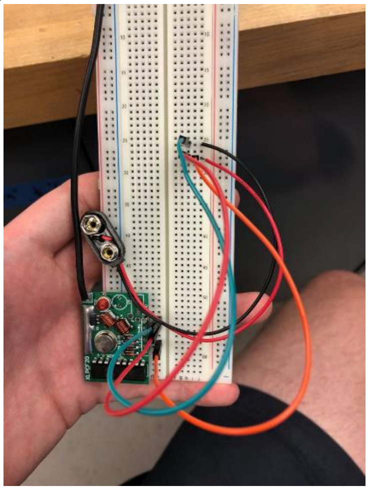
Payload Deployment Demonstration
Required Materials:

- UAV Box
    - (4) Emax Motor Cases
    - (1) Thread Locker
    - (8) Command Strips
    - (1) Graphite Lube
    - (1) Box of Standoffs
    - (1) RunCam Box
- (1) Set of Vice Grips
- UAV HDX Box
    - (4) 18490 Batteries
    - (1) VTX Receiver
    - (1) VTX Antenna
    - (3) 3000 mAh 3S LiPo Batteries
    - (6) Battery Straps
    - (5) Red Lock Nuts
    - (2) Silver Lock Nuts
    - (6) Black Lock Nuts
    - (1) Bag of Rubber Bands
    - (12) Propellers
    - (3) Jacob's Allen Keys
    - (1) 8mm Socket Wrench
    - (1) Electrical Tape
    - (11) Spare Sled Screws
    - (7) Spare Hinge Bolts
    - (11) Spare Hinge Nuts
    - (8) Spare Hinges
    - (2) Spare XT60 Connectors
- Payload Deployment HDX Box
    - (1) Assembled Arduino
        - Stepper Motor Shield, 433 MHZ Receiver, (1) M3 screw, (1) M3 nut, (6) soldered wires
    - (1) Battery box lid
    - (2) AA Battery Packs with blue masking tape
    - (1) AA Battery Pack with Velcro
    - (12) AA Batteries
    - (1) 9V Battery
    - (5) M4 Screws
    - (1) Allen wrench labeled AK-4M
    - (1) Flathead screwdriver w/ orange top
    - (1) Relay pin sticky note
- Launch Day Toolbox
    - (1) Small zip tie
    - (1) Multimeter
    - (1) Forceps
- Nolan's Dremel Box
    - (1) 433 MHz Radio Transmitter Assembly

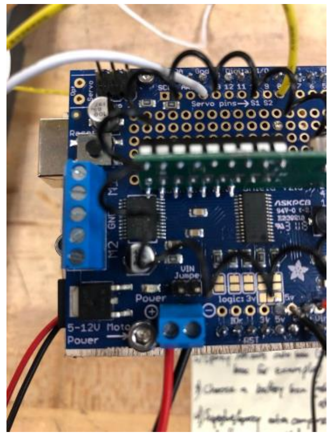
- (1) Payload Removable Bulkhead with Southco R4-EM latch and Stepper Motor attached
- Payload Pod Base
- (2) Payload Flaps
- Payload Pusher
- Payload Pod Tupperware
- Electrical Tape
- (4) 6-32 Screws
- Spare Body Tube
- Vise Grips
- Plumber's Putty
- Recovery Tupperware
  - Main Parachute Shock Cord

Procedure:

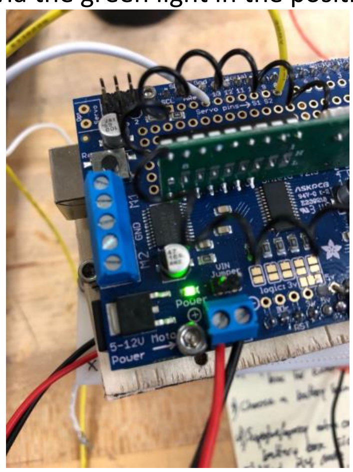
- Confirm the Radio Transmitter circuit matches the picture below. If it does not, reattach the jumper wires in the below configuration



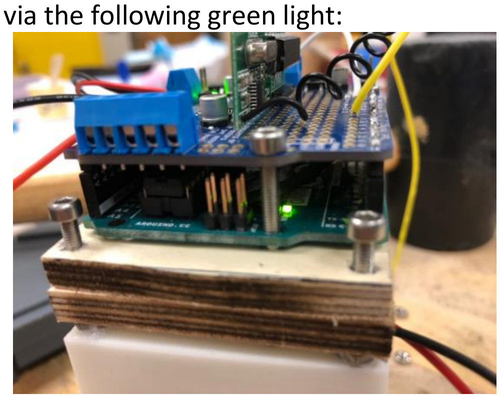
- Using the multimeter, check that there is continuity between the following leads:
  - Receiver GND to Arduino GND
  - Receiver VDD to Arduino 5V
  - Receiver D2 to Arduino A0
- Insert 4 fresh AA batteries into each of the three battery packs
- Insert a tiny black screw into each battery pack
- Via the quick disconnects, connect the leads of the battery pack labeled "Shield Pack" to the wires coming out of the Power terminal block of the shield (see below)



- Turn on the Shield Pack
- Attach the Shield Pack to the inside of the nosecone via Velcro™ strips
- Ensure the pack is functioning via the green light in the position below



- Attach the female-lead quick disconnects of the Board pack to the male-lead disconnects soldered to the shield.
- Turn on the board pack
- Confirm proper function via the following green light:



- Attach the board pack to the inside of the nosecone via the Velcro™ strips
- Confirm the Arduino assembly and lid are securely attached to the bulkhead
- Confirm the leads are securely attached to the relay with a quick tug
- Turn on the BLACK VELCRO battery pack
- Secure the BLACK VELCRO battery pack to the nosecone via Velcro™ strips

- Via quick disconnects, attach the BLACK VELCRO battery pack leads to the payload latch battery disconnects
- Confirm the order of the stepper wires in the M1 and M2 Terminal Blocks from outside to inside as:
  - RED
  - BLUE
  - GREEN
  - BLACK
- Confirm wire security with a quick tug.
  - Tighten any loose wires
- Connect the stepper motor wires to the leads coming out of the M1 and M2 terminals on the Arduino shield via quick disconnects
- Route shock cord end labeled **1** through aft end of payload bay centering rings
- Route shock cord end labeled **1** through payload bay bulkhead
- Confirm the Latch is open
- Fully extend the Payload Pusher so that it is hanging outside the AFT end of the Payload Bay
- Turn on the UAV Radio Transmitter by holding the power button
  - Note the battery level: ___________
  - Replace batteries if below 7.5V
- Connect the UAV LiPo to the matching power connector on the UAV
  - Motors will move slightly when power is connected
- Confirm three short beeps followed by two long beeps are heard
- Turn on the UAV video receiver
- Remove Lens cap from FPV Camera
- Confirm ALL flight critical components are on:
  - Flight Controller GREEN LED is ON
  - Flight Controller BLUE LED is ON or FLASHING
  - Flight Controller WHITE LED is ON
  - Video Transmitter is displaying the correct channel
  - Video Receiver is displaying the correct channel
- Confirm the UAV Video Receiver is receiving video feed
- Place the UAV on the Payload Pod Base
- Align UAV Propellers with UAV Arms
- While holding the UAV arms folded, fold the two Payload Flaps on the base in unison
- Hold the two flaps together and push the pod onto the cantilevered rod through the hole in the flat end of the pod
- Slightly pull the flaps apart to confirm the cantilevered rod reaches the end of the pod
- Confirm the duct tape on the outside of the pod is still present
- Push the Pod assembly all the way into the payload bay open latch
- Confirm an audible click is heard
- Pull on the pod assembly to ensure the latch is closed
- Connect a 9V battery to the Radio Transmitter
- Observe the payload deployment process
- Confirm the payload pod is pushed out of the payload bay
- Confirm the UAV deploys from the payload pod

Payload Maximum Operating Range Demonstration
Required Materials:

- (1) Radio Transmitter circuit
- (1) 9V Battery
- (1) Car
- (2) Team Members
- (1) Arduino Assembly
- (1) Laptop
  - Arduino Program
  - (1) USB Cord

Procedure:

- Confirm the Radio Transmitter circuit matches the picture below. If it does not, reattach the jumper wires in the below configuration
- Using the multimeter, check that there is continuity between the following leads:
  - Receiver GND to Arduino GND
  - Receiver VDD to Arduino 5V
  - Receiver D2 to Arduino A0
- Plug the Arduino Assembly into the Laptop via the USB cord
- Start up the Arduino program on the Laptop
- Team Member 1 stands at the end of a long road with the radio transmitter circuit and 9V battery
- Team Member 2 drives 0.6 miles down the road with the laptop and Arduino assembly
  - Team Member 2 calls Team Member 1 when they are 0.6 miles away
- Team Member 1 attaches the 9V battery to the battery clip on the radio transmitter circuit to transmit a signal to the Arduino
- Team Member 2 confirms that a radio transmission is received on the Arduino program

Page Break

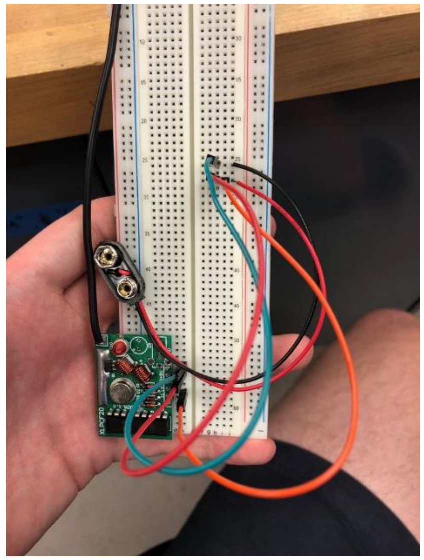
Payload Pad Endurance Test
Required Materials:

- UAV Box
  - (4) Emax Motor Cases
  - (1) Thread Locker
  - (8) Command Strips
  - (1) Graphite Lube
  - (1) Box of Standoffs
  - (1) RunCam Box
- (1) Set of Vice Grips
- UAV HDX Box
  - (4) 18490 Batteries
  - (1) VTX Receiver
  - (1) VTX Antenna
  - (3) 3000 mAh 3S LiPo Batteries
  - (6) Battery Straps
  - (5) Red Lock Nuts
  - (2) Silver Lock Nuts
  - (6) Black Lock Nuts
  - (1) Bag of Rubber Bands
  - (12) Propellers

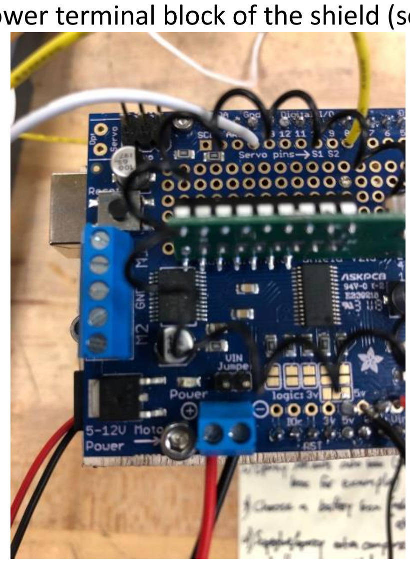
  - (3) Jacob's Allen Keys
  - (1) 8mm Socket Wrench
  - (1) Electrical Tape
  - (11) Spare Sled Screws
  - (7) Spare Hinge Bolts
  - (11) Spare Hinge Nuts
  - (8) Spare Hinges
  - (2) Spare XT60 Connectors
- Payload Deployment HDX Box
  - (1) Assembled Arduino
    - Stepper Motor Shield, 433 MHZ Receiver, (1) M3 screw, (1) M3 nut, (6) soldered wires
  - (1) Battery box lid
  - (2) AA Battery Packs with blue masking tape
  - (1) AA Battery Pack with Velcro
  - (12) AA Batteries
  - (1) 9V Battery
  - (5) M4 Screws
  - (1) Allen wrench labeled AK-4M
  - (1) Flathead screwdriver w/ orange top
  - (1) Relay pin sticky note
- Launch Day Toolbox
  - (1) Small zip tie
  - (1) Multimeter
  - (1) Forceps
- Nolan's Dremel Box
  - (1) 433 MHz Radio Transmitter Assembly
- (1) Payload Removable Bulkhead with Southco R4-EM latch and Stepper Motor attached
- Payload Pod Base
- (2) Payload Flaps
- Payload Pusher
- Payload Pod Tupperware
- Electrical Tape
- (4) 6-32 Screws
- Spare Body Tube
- Vise Grips
- Plumber's Putty
- Recovery Tupperware
  - Main Parachute Shock Cord

Procedure:

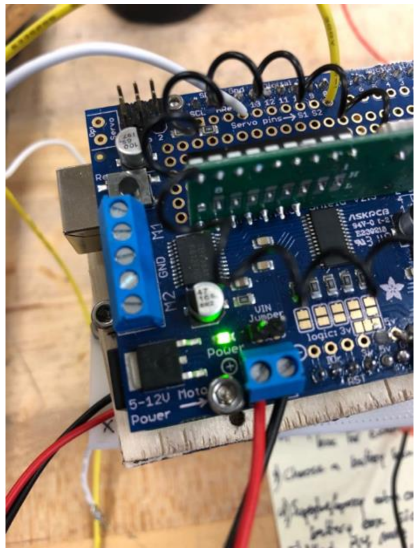
- Confirm the Radio Transmitter circuit matches the picture below. If it does not, reattach the jumper wires in the below configuration



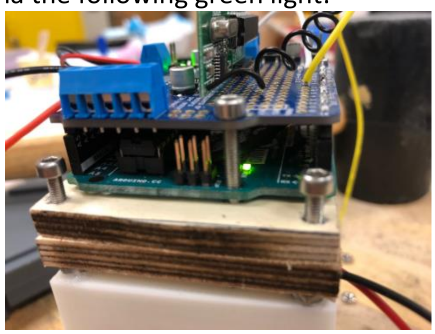
- Using the multimeter, check that there is continuity between the following leads:
  - Receiver GND to Arduino GND
  - Receiver VDD to Arduino 5V
  - Receiver D2 to Arduino A0
- Insert 4 fresh AA batteries into each of the three battery packs
- Insert a tiny black screw into each battery pack
- Via the quick disconnects, connect the leads of the battery pack labeled "Shield Pack" to the wires coming out of the Power terminal block of the shield (see below)



- Turn on the Shield Pack
- Attach the Shield Pack to the inside of the nosecone via Velcro™ strips
- Ensure the pack is functioning via the green light in the position below



- Attach the female-lead quick disconnects of the Board pack to the male-lead disconnects soldered to the shield.
- Turn on the board pack
- Confirm proper function via the following green light:



- Attach the board pack to the inside of the nosecone via the Velcro™ strips
- Confirm the Arduino assembly and lid are securely attached to the bulkhead
- Confirm the leads are securely attached to the relay with a quick tug
- Turn on the BLACK VELCRO battery pack
- Secure the BLACK VELCRO battery pack to the nosecone via Velcro™ strips
- Via quick disconnects, attach the BLACK VELCRO battery pack leads to the payload latch battery disconnects
- Confirm the order of the stepper wires in the M1 and M2 Terminal Blocks from outside to inside as:
    - RED
    - BLUE
    - GREEN
    - BLACK
- Confirm wire security with a quick tug.
    - Tighten any loose wires
- Connect the stepper motor wires to the leads coming out of the M1 and M2 terminals on the Arduino shield via quick disconnects
- Route shock cord end labeled **1** through aft end of payload bay centering rings
- Route shock cord end labeled **1** through payload bay bulkhead

- Confirm the Latch is open
- Fully extend the Payload Pusher so that it is hanging outside the AFT end of the Payload Bay
- Turn on the UAV Radio Transmitter by holding the power button
    - Note the battery level: ___________
    - Replace batteries if below 7.5V
- Connect the UAV LiPo to the matching power connector on the UAV
    - Motors will move slightly when power is connected
- Confirm three short beeps followed by two long beeps are heard
- Turn on the UAV video receiver
- Remove Lens cap from FPV Camera
- Confirm ALL flight critical components are on:
    - Flight Controller GREEN LED is ON
    - Flight Controller BLUE LED is ON or FLASHING
    - Flight Controller WHITE LED is ON
    - Video Transmitter is displaying the correct channel
    - Video Receiver is displaying the correct channel
- Confirm the UAV Video Receiver is receiving video feed
- Place the UAV on the Payload Pod Base
- Align UAV Propellers with UAV Arms
- While holding the UAV arms folded, fold the two Payload Flaps on the base in unison
- Hold the two flaps together and push the pod onto the cantilevered rod through the hole in the flat end of the pod
- Slightly pull the flaps apart to confirm the cantilevered rod reaches the end of the pod
- Confirm the duct tape on the outside of the pod is still present
- Push the Pod assembly all the way into the payload bay open latch
- Confirm an audible click is heard
- Pull on the pod assembly to ensure the latch is closed
- Leave the Payload Bay turned ON and ASSEMBLED for 2 hours

Shear Pin Failure Test

Materials Required:

- (5) Shear Pins
- (2) Large Washers
- (2) Small Washers
- (1) #4-40 Nut
- (2) Aluminum Dogbone Specimens
- Interactive Instruments Model 1K Universal Materials Tester
- Computer

Procedure:

- Confirm all members present are wearing safety glasses
- Insert Shear pin through one small washer, then one large washer
- Place shear pin through aligned holes in dogbone specimens
- Secure shear pin with large washer, then small washer, then with #4-40 nut
- Confirm the orientation is correct for proper loading
- Set up the data recording software
- Apply a load at 0.01 in/s until failure
- Repeat for (5) shear pins

Payload Retention Test
Materials Required:

- Payload Pod
- Payload Removable Bulkhead
  - Southco Latch
- (2) Quicklinks
- Shock Cord
- 35 lb weights

Procedure:

- Loop shock cord until 2 feet in length
- Attach quicklink to payload pod eyebolt
- Attach quicklink to looped shock cord
- Team Member 1 holds up the payload pod while Team Member 2 supports the weight
- Slowly release weight onto the eyebolt
- Support weight after approximately 1 second
- Repeat in increments of 5 lb for 25-35 lb
- Repeat for the Southco Latch

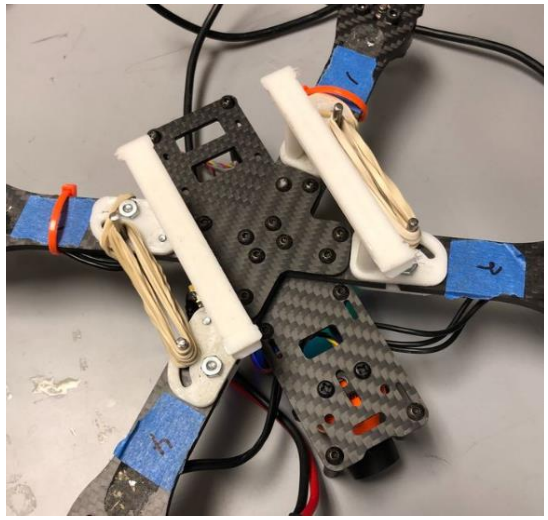
UAV Hover Test

Required Materials:

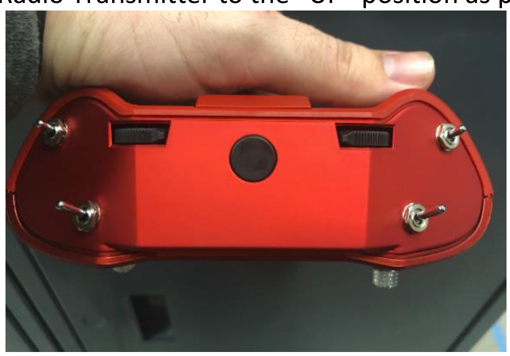
- UAV Box
    - (4) Emax Motor Cases
    - (1) Thread Locker
    - (8) Command Strips
    - (1) Graphite Lube
    - (1) Box of Standoffs
    - (1) RunCam Box
- (1) Set of Vice Grips
- UAV HDX Box
    - (4) 18490 Batteries
    - (1) VTX Receiver
    - (1) VTX Antenna
    - (3) 3000 mAh 3S LiPo Batteries
    - (6) Battery Straps
    - (5) Red Lock Nuts
    - (2) Silver Lock Nuts
    - (6) Black Lock Nuts
    - (1) Bag of Rubber Bands
    - (12) Propellers
    - (3) Jacob's Allen Keys
    - (1) 8mm Socket Wrench
    - (1) Electrical Tape
    - (11) Spare Sled Screws
    - (7) Spare Hinge Bolts
    - (11) Spare Hinge Nuts
    - (8) Spare Hinges
    - (2) Spare XT60 Connectors
- Transmitter Case
    - (1) FrSky Taranis X-Lite Transmitter
    - (1) RTX Antenna
- (1) Anemometer

Procedure:

- Use the anemometer to measure wind speed
    - Proceed if less than 5 mph
- Attach the LiPo battery to the drone body via Velcro™ straps
    - Align Battery Connectors with connector on Drone
- Attach 8 rubber bands to the same side arm slot pins
    - See picture:



- Turn all switches on the Radio Transmitter to the "UP" position as pictured:



- Attach the propellers to the UAV according to labels
    - CW propellers attach to the CW arms
    - CCW propellers attach to the CCW arms
    - Remove the blue tape labels
- Confirm that the propellers will NOT hit any wires on the UAV
    - Screw red and black lock nuts over the propellers according to labels
    - RED or SILVER on arm 2 and 3
    - BLACK on arm 1 and 4
    - Use an 8mm socket wrench to tighten
    - Tighten until tight
    - Do NOT over tighten
- Confirm the propellers do NOT rotate freely, can NOT slide up and down, and are NOT wobbly
- Attach the video transmitter antenna to the video transmitter on the drone
- Connect the video receiver antenna to the video receive
- Turn on the UAV Radio Transmitter by holding the power button
    - Replace batteries if below 7.5V
- Connect the UAV LiPo to the matching power connector on the UAV
    - Motors will move slightly when power is connected
- Confirm three short beeps followed by two long beeps are heard
- Turn on the UAV video receiver
- Remove Lens cap from FPV Camera
- Confirm ALL flight critical components are on:

  - Flight Controller GREEN LED is ON
  - Flight Controller BLUE LED is ON or FLASHING
  - Flight Controller WHITE LED is ON
  - Video Transmitter is displaying the correct channel
  - Video Receiver is displaying the correct channel
- Confirm the UAV Video Receiver is receiving video feed

Arming

- Turn on the Radio Transmitter
- Attach the antenna to the Radio Transmitter
- Turn on the Video Transmitter
- Confirm the Video Receiver is receiving video feed
- Flip the arming switch to the ON (DOWN) position
- Control the UAV using the Taranis X-Lite Transmitter
- Keep the UAV in hover until the Transmitter displays 85% discharge
- Fly the drone to a designated SAFE area to land
- Reduce the throttle until the drone lands on the ground

Disarming

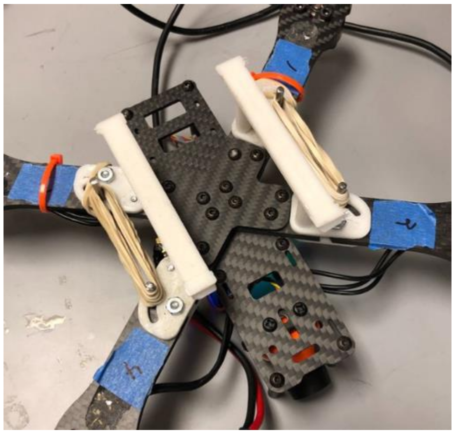
- Approach the UAV but do not engage
- Flip the arming switch to the OFF position
- Confirm the UAV propellers are stopped
- Unplug the LiPo battery from the UAV
- Replace the LiPo with a freshly charged one
- Repeat the arming and flight procedure for 3 fully charged LiPo batteries
- Power off the Video Receiver
- Remove the Video Receiver antenna
- Turn off the Taranis X-Lite Transmitter
- Remove the Taranis X-Lite antenna

Adverse Conditions UAV Flight Test
Required Materials:

- UAV Box
    - (4) Emax Motor Cases
    - (1) Thread Locker
    - (8) Command Strips
    - (1) Graphite Lube
    - (1) Box of Standoffs
    - (1) RunCam Box
- (1) Set of Vice Grips
- UAV HDX Box
    - (4) 18490 Batteries
    - (1) VTX Receiver
    - (1) VTX Antenna
    - (3) 3000 mAh 3S LiPo Batteries
    - (6) Battery Straps
    - (5) Red Lock Nuts
    - (2) Silver Lock Nuts
    - (6) Black Lock Nuts
    - (1) Bag of Rubber Bands
    - (12) Propellers
    - (3) Jacob's Allen Keys
    - (1) 8mm Socket Wrench
    - (1) Electrical Tape
    - (11) Spare Sled Screws
    - (7) Spare Hinge Bolts
    - (11) Spare Hinge Nuts
    - (8) Spare Hinges
    - (2) Spare XT60 Connectors
- Transmitter Case
    - (1) FrSky Taranis X-Lite Transmitter
    - (1) RTX Antenna
- (1) Anemometer

Procedure:

- Use the anemometer to measure wind speed
    - Proceed if above 10 mph
- Attach the LiPo battery to the drone body via Velcro™ straps
    - Align Battery Connectors with connector on Drone
- Attach 8 rubber bands to the same side arm slot pins
    - See picture:



- Turn all switches on the Radio Transmitter to the “UP” position as pictured:

- Attach the propellers to the UAV according to labels
    - CW propellers attach to the CW arms
    - CCW propellers attach to the CCW arms
    - Remove the blue tape labels
- Confirm that the propellers will NOT hit any wires on the UAV
    - Screw red and black lock nuts over the propellers according to labels
    - RED or SILVER on arm 2 and 3
    - BLACK on arm 1 and 4
    - Use an 8mm socket wrench to tighten
    - Tighten until tight
    - Do NOT over tighten
- Confirm the propellers do NOT rotate freely, can NOT slide up and down, and are NOT wobbly
- Attach the video transmitter antenna to the video transmitter on the drone
- Connect the video receiver antenna to the video receive
- Turn on the UAV Radio Transmitter by holding the power button
    - Replace batteries if below 7.5V
- Connect the UAV LiPo to the matching power connector on the UAV
    - Motors will move slightly when power is connected
- Confirm three short beeps followed by two long beeps are heard
- Turn on the UAV video receiver
- Remove Lens cap from FPV Camera
- Confirm ALL flight critical components are on:
    - Flight Controller GREEN LED is ON
    - Flight Controller BLUE LED is ON or FLASHING

  - Flight Controller WHITE LED is ON
  - Video Transmitter is displaying the correct channel
  - Video Receiver is displaying the correct channel
- Confirm the UAV Video Receiver is receiving video feed

Arming

- Turn on the Radio Transmitter
- Attach the antenna to the Radio Transmitter
- Turn on the Video Transmitter
- Confirm the Video Receiver is receiving video feed
- Flip the arming switch to the ON (DOWN) position
- Control the UAV using the Taranis X-Lite Transmitter
- Fly the UAV in 0.1 mile loops until the transmitter displays 85% discharge
- Record the distance traveled: ____________
- Fly the UAV to a designated SAFE area to land
- Reduce the throttle until the drone lands on the ground

Disarming

- Approach the UAV but do not engage
- Flip the arming switch to the OFF position
- Confirm the UAV propellers are stopped
- Unplug the LiPo battery from the UAV
- Replace the LiPo with a freshly charged one
- Repeat the arming and flight procedure for 3 fully charged LiPo batteries
- Power off the Video Receiver
- Remove the Video Receiver antenna
- Turn off the Taranis X-Lite Transmitter
- Remove the Taranis X-Lite antenna

Altimeter Demonstration

Required Materials:

- (2) PerfectFlite StratoLogger CF Altimeter
- (1) StratoLogger CF Manual
- (2) 9V Batteries with connectors
- (1) Altimeter Testing Sled
- (1) Vacuum Chamber
- (1) Venturi Tube
- (2) Small Wires

Procedure:

- Place the lead connector on each 9V battery
- Insert a 9V battery into each battery slot on the Test Sled
- Connect the leads from a battery to each altimeter being tested as per manufacturer wiring specifications
- On the board, you will observe two pairs of LED lights, each containing one red and one green
- Connect the green LED circuit to the drogue terminal blocks on the first altimeter being tested
- Connect the corresponding red LED circuit to the same altimeter just connected
- Repeat the above two steps for the remaining altimeter and test circuit
- Use the first length of wire to wire together the switch terminal ports for one of the altimeters
- Check startup beeps against manufacturer specifications
- Check continuity beeps
  - If one or both circuits are not getting continuity, flip the leads to account for LED polarity
- Repeat the past three steps for the remaining altimeter
- If both altimeters beep good continuity, proceed with the test
  - If not, remove for electrical troubleshooting
- Place the test sled in the vacuum chamber so that the test LEDs can be viewed through the viewport
- Seal the vacuum chamber
- Attach the chamber hose to the Venturi tube, you may need to tape this junction
- Have one person observe the test LEDs through the viewport while the other operates the air line
- Roll on the air valve until maximum pressure is being pulled
- Wait a few seconds for one of the green LEDs to go off
- Once it goes off, or if it does not, after a few seconds slowly roll off pressure
- During roll-off, both green LEDs should flash brightly soon after the roll-off procedure begins
- When the valve is nearing closed, both red LEDs should flash brightly
- If all 4 LEDs flashed properly, the post-flight beeps are reasonable, and the flight data profile looks reasonable to the times and pressures pulled, then the altimeters are considered flight ready
- This status should be noted on the spreadsheet on the team computer

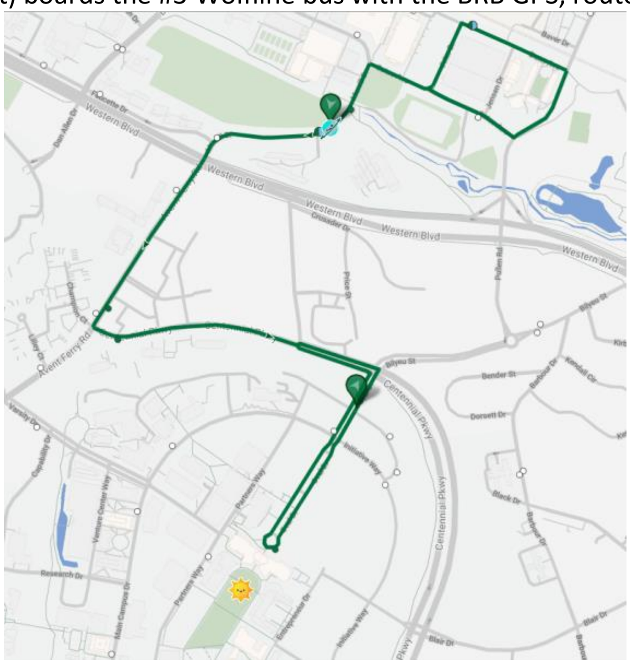
GPS Functionality Demonstration

Required Materials:

- (1) BigRedBee GPS
- (1) GPS Receiver
- (1) Club Laptop
- (1) Phone
- (1) Wolfline Bus

Procedure:

- Plug the power connector into the BRB GPS
- Wait 30s for the GPS light to turn on
- Confirm the GPS light is ON or FLASHING
- Confirm the GPS receiver is receiving satellites and signal from the BRB GPS
- Team Member 1 (Sun) waits outside on Centennial Campus at NC State with the GPS Receiver
- Team Member 2 (Planet) boards the #3 Wolfline bus with the BRB GPS, route below:



- Team Member 1 (Planet) rides the #3 Wolfline bus with the BRB GPS for one full route
- After returning, the GPS Receiver is plugged into the club laptop
- Google Earth is used to map the GPS's route
- The GPS's route is compared to the #3 Wolfline Route above

Recovery Electronics Pad Endurance Test

Required Materials:

- (2) StratoLogger CF Altimeters
- (4) 9V Batteries
- (1) Avionics Sled Assembly
- (1) Multimeter
- (1) Timer

Procedure:

- Use a multimeter to measure the voltage of each battery
  - Record: _____ _____
- Attach the StratoLogger CF altimeters to the 9V batteries via battery clips
- Start the timer
- Confirm the StratoLogger CF is starting its power up beep sequence
- At the 2-hour mark, detach the altimeters from the batteries
- Use a multimeter to check the voltage of each battery
  - Record: ______ ______
- Confirm the voltage is not below 9.0V
- Repeat for 2 new 9V batteries

Black Powder Ejection Demonstration
Required Items:

- Avionics HDX Box
    - (2) e-matches
    - Small Flathead screwdriver
- Launch Day Toolbox
    - Wire Cutters
    - Wire Strippers
- FWD AV Bay Bulkhead
- AFT AV Bay Bulkhead
    - (2) pre-cut threaded rods
- Paper Towels
- (2) 8.5x11, 20lb weight, 30% post-consumer recycled material copy paper
- Blue Tape
- Black Powder Charges
    - Drogue Primary charge (2.1g)
    - Main Primary charge (3.0g)
- Safety Glasses
- Nitrile Gloves
- Heavy Duty Gloves
- Plumbers Putty
- Recovery hardware box
- Fin can
- Drogue parachute (24in elliptical)
- Drogue parachute shock cord
- Nosecone
- Assembled Payload Bay
- Main Parachute Bay
- AV Bay
- Main parachute (84in Iris Ultra)
- 5.5 in Deployment Bag
- (3) nomex cloth
- Main parachute shock cord
- Philips head screwdriver (labeled POS)
- Payload plug

Procedure:

- This procedure is to be executed on two bulkheads at the same time
- Remove red plastic protective e-match cover from e-match
- Feed the e-match through the **P** wire hole
    - The e-match head should be on the side with blast caps
- Place e-match head within the blast cap labeled **P**
- Bend the e-match wire such that it lies flat against the blast cap
    - Secure the e-match wire to bulkhead with a small piece of blue tape, ensure that no holes are covered
- Confirm the e-match wire is curved over the outside edge of the blast cap
- Confirm the e-match head is flat on the cap bottom
- Using blue tape, tape the e-match wire to the outside of the of the blast cap
- Confirm all labels are still visible

- Slide the AFT AV bulkhead through the AV Bay body tube
    - Feed e-match wire through hole in switchband
- Slide the FWD AV bulkhead onto the threaded rods until flush with body tube
- Slide (1) washer onto each threaded rod
- Slide (1) 5/16 inch nut onto each threaded rod
- Slide (1) 5/16 inch cap nut onto each threaded rod
- Tighten until **SNUG**
- Confirm ALL labels on AV Bay are still visible
- Confirm AV Bay assembly and bulkhead tightness
- Confirm that all members around the launch vehicle are wearing safety glasses
- Confirm the members handling black powder are wearing nitrile gloves
- Turn Midsection so that the blast caps on the AFT avionics bulkhead are facing up
- Create a paper funnel using 1 sheet of copy paper and 1 piece of blue tape
    - Ensure inside of paper funnel is smooth
- Carefully pour the **Drogue Primary Charge** of black powder into the **DP** blast cap over the e-match head using the paper funnel for guidance
- Move the e-match so the black powder lies under the e-match head
- Fill the remaining space in the blast cap with finger tip sized pieces of paper towel
    - The paper towel should fill the space, but not be packed in tightly!
- Place small (2-3 in.) strips of blue tape on top of the **DP** blast cap to cover the blast cap completely
    - Do NOT have any major overlaps but leave no gaps with the electrical tape
    - Ensure all edges are covered
- Wrap blue tape all the way around the outside of the blast cap to keep the top layers tight
- Use plumber's putty to seal any holes in the bulkhead (E-match holes, etc.)
- Confirm all holes are sealed
- Turn the AV Bay over onto a sheet of white copy paper
- Turn the AV Bay back over
    - Confirm that no black powder has leaked onto the copy paper
    - If yes, Wipe copy paper clean and repeat the above steps
- Carefully pour the **Main Primary Charge** of black powder into the **MP** blast cap over the e-match head using the funnel for guidance
- Move the e-match so the black powder lies under the e-match head
- Fill the remaining space in the blast cap with fingertip size pieces of paper towel
    - The paper towel should fill the space, but not be packed in tightly!
- Place small (2-3 in.) strips of blue tape on top of the **MP** blast cap to cover the blast cap completely
    - Do NOT have any major overlaps but leave no gaps with the electrical tape and
    - Ensure all edges are covered
- Wrap blue tape all the way around the outside of the blast cap to keep the top layers tight
- Use plumber's putty to seal any holes in the bulkhead (E-match holes, etc.)
- Confirm all holes are sealed
- Turn the AV Bay over onto a sheet of white copy paper
- Turn the AV Bay back over
    - Confirm that no black powder has leaked onto the copy paper
    - If yes, wipe copy paper clean and repeat the above steps
- Clear the workspace of all black powder in preparation for launch vehicle assembly
- Route shock cord end labeled **1** through the aft end of the payload plug
- Wrap the payload plug rubber band around the plug

- Route shock cord end labeled **1** through aft end of payload bay centering rings
- Route shock cord end labeled **1** through payload bay bulkhead
- Confirm the Latch is open
- Fully extend the Payload Pusher so that it is hanging outside the AFT end of the Payload Bay
- Hold the two flaps together and push the pod onto the cantilevered rod through the hole in the flat end of the pod
- Slightly pull the flaps apart to confirm the cantilevered rod reaches the end of the pod
- Confirm the duct tape on the outside of the pod is still present
- Push the Pod assembly all the way into the payload bay open latch
- Confirm an audible click is heard
- Pull on the pod assembly to ensure the latch is closed
- Tie a bowline knot on the end of the shock chord labeled **1**
- Attached **quicklink 1** to **end of shock chord labeled 1**
  - Do NOT tighten
- Attach **quicklink 1** to **nosecone bulkhead 1**
  - Tighten by hand
- Confirm the **quicklink 1** is secured to the nosecone bulkhead U-bolt by visual inspection and pulling on shock cord
- Insert nose cone shoulder into payload bay using marks to align holes
- Use (4) #6-32 ½ inch screws to secure nose cone to payload bay
- Pull shock cord taught through payload bay
- Attach **quicklink 2 to loop 2**
  - Do NOT tighten
- Attach **quicklink 2** to **Nomex sheet 2**
- Insert the plug into the plug hole
- Seal Around Shock Cord with Plumbers Putty
- Attach **quicklink 2** to **deployment bag loop 2**
  - Tighten by hand
- Fold length of shock cord **between loops 2 and 3** accordion-style
- Confirm the rubber band is NOT too tight and NOT covering any part of parachute
  - Two fingers should fit snugly under the rubber band
- Confirm the shock cord is still folded accordion style within the rubber band
  - If not repeat the previous steps
- Fold length of shock cord **between loops 3 and 4** accordion-style
- Secure with a single rubber band
- Confirm the rubber band is NOT too tight and NOT covering any part of parachute
  - Two fingers should fit snugly under the rubber band
- Confirm the shock cord is still folded accordion style within the rubber band
  - If not repeat the previous steps
- Final check that all rubber bands are removed from main parachute and shroudlines
  - The rubber bands on the shock cord will remain
- Attach **quicklink 3** to **loop 3**
  - Do NOT tighten
- Attach **Large Nomex Sheet** to **quicklink 3**
- Attach **quicklink 3** to **Main Parachute Loop 3**
  - Tighten by hand
- Route end of shock cord labeled 4 through the main parachute bay from the FWD end to the aft end

- Carefully slide payload bay coupler into main parachute bay using marks to align shear pin holes
- Cut (2) 4-40 nylon shear pins so they are 1/2 in in length and insert into shear pin holes until tight
- If shear pins are loose, place small piece of electrical tape over shear pin heads
- Wrap Main Parachute deployment bag in large nomex sheet
- Cover the Payload Plug using the nomex sheet labeled **2**
- Carefully insert the shock cord length **between loops 2 and 4** into main parachute bay from forward to aft
- Attach **quicklink 4** to **loop 4**
    - Do NOT tighten
- Attach **quicklink 4** to **AV Bay FWD bulkhead 4**
    - Tighten by hand
- Confirm the **quicklink 4** is secured to the AV Bay **FWD bulkhead 4** by visual inspection and pulling on shock cord
- Carefully insert the wrapped parachute into the space between stowed shock cords
    - The deployment bag loop **labeled 2** should be pointed toward the nosecone
    - The deployment bag should sit completely inside the main parachute bay
    - Ensure that payload bay plug remains within the centering ring
- Slide FWD AV Bay coupler into main parachute bay using marks to align holes
- Use (4) #6-32 ½ inch screws to secure the two sections
- Confirm the launch vehicle can hold its own weight from shear pins alone
    - Hold at nosecone and let the launch vehicle hang
- Confirm that all members near the launch vehicle are wearing safety glasses
- Use **quicklink 6** to attach nomex cloth to shock cord parachute **loop 6**
    - Tighten by hand
- Use **quicklink 6** to attach drogue parachute **eye-bolt 6** to **loop 6**
    - Tighten quicklink by hand
- Fold length of shock cord **between loops 5 and 6** accordion-style
    - 8 in folds
- Secure the length of shock cord **between loops 5 and 6** with a single rubber band
- Confirm the rubber band is NOT too tight and NOT covering any part of parachute
    - Two fingers should fit snugly under the rubber band
- Confirm the shock cord is still folded accordion style within the rubber band
    - If not repeat the previous steps
- Fold length of shock cord **between loops 6 and 7** accordion-style
- Secure the length of shock cord **between loops 6 and 7** with a single rubber band
- Confirm the rubber band is NOT too tight and NOT covering any part of parachute
    - Two fingers should fit snugly under the rubber band
- Confirm the shock cord is still folded accordion style within the rubber band
    - If not repeat the previous steps
- Attach **quicklink 5** to **loop 5**
    - Do NOT tighten
- Attach **quicklink 7** to **loop 7**
    - Do NOT tighten
- Attach **quicklink 5** to AV Bay aft **bulkhead 5**
    - tighten by hand
- Confirm the quicklink is secured to the AV Bay aft bulkhead U-bolt by visual inspection and pulling on shock cord

- Attach **quicklink 7** to fin can **bulkhead 7**
    - tighten by hand
- Confirm the quicklink is secured to the fin can bulkhead U-bolt by visual inspection and pulling on shock cord
- Confirm the drogue parachute is properly folded
- Remove rubber band securing drogue parachute
    - Hold it tightly
- Confirm all rubber bands are removed from parachute and shroudlines
- Wrap nomex cloth around the drogue parachute
    - Hold it tightly
- Carefully insert the shock cord length **between loops 6 and 7** into fin can cavity
- Carefully insert the drogue parachute into the fin can cavity in the space between stowed shock cords
    - The yellow Fruity Chutes logo should be facing the fin can
- Carefully insert the shock cord length **between loops 5 and 6** into the fin can cavity
- Slide AV Bay coupler into fin can cavity using the marks to align the shear pin holes
- Cut (4) 4-40 nylon shear pins so they are ½ in length and insert into shear pin holes until tight
    - If shear pins are loose, place small piece of electrical tape over shear pin heads
- Confirm the launch vehicle can hold its own weight from shear pins alone
    - Hold AV Bay and let fin can hang
- Take assembled rocket and hard foam outside
- Set up hard foam against a brick wall and on the ground such that they are perpendicular to each other
- Lay the rocket horizontally on the ground
- Attach the alligator clips of the ejection testing switch to the Drogue Deployment E-Match
- Confirm all present are wearing safety glasses
- Attach the 9V battery to the ejection testing switch
- After a five second countdown, turn the switch to the 1 position to complete the circuit
- Observe the subsequent black powder detonation
- Remove the 9V battery from the ejection testing switch
- Approach the rocket wearing heavy duty gloves
- Move the rocket such that the AV Bay Aft bulkhead (#5) is against the wall
- Attach the alligator clips of the ejection testing switch to the Main Deployment E-Match
- Attach the 9V battery to the ejection testing switch
- After a five second countdown, turn the switch to the 1 position to complete the circuit
- Observe the subsequent black powder detonation
- Clean up

12. Appendix E

Task Name	Duration	Start	Finish
Proposal	21 days	Wed 8/22/18	Wed 9/19/18
PDR Milestone Report	22 days	Thu 10/4/18	Fri 11/2/18
Subscale Construction	14 days	Wed 10/31/18	Sat 11/17/18
CDR Milestone Report	40 days	Mon 11/19/18	Fri 1/11/19
Testing	36 days	Fri 1/11/19	Fri 3/1/19
Fullscale Construction	21 days	Mon 1/14/19	Sat 2/9/19
FRR Milestone Report	16 days	Mon 2/11/19	Mon 3/4/19
NASA SL Competition	4 days	Wed 4/3/19	Sun 4/7/19
PLAR Milestone Report	10 days	Mon 4/15/19	Fri 4/26/19

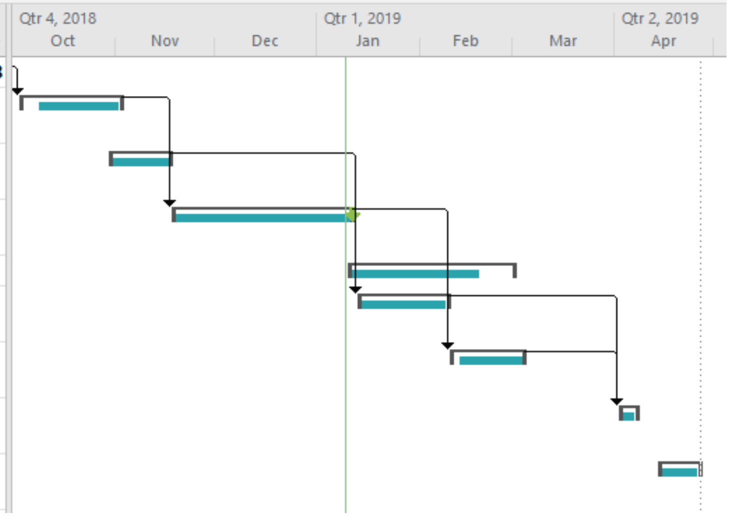


Figure 12-1 2018-2019 Competition Year Gantt Chart

Task Name	Duration	Start	Finish
Subscale Construction	**14 days**	**Wed 10/31/18**	**Sat 11/17/18**
Lasercut Bulkheads and	2 days	Wed 10/31/18	Thu 11/1/18
Cut Airframe Tul	3 days	Wed 10/31/18	Fri 11/2/18
Altimeter Testin	1 day	Thu 11/1/18	Thu 11/1/18
Bulkhead Fabrication	4 days	Fri 11/2/18	Wed 11/7/18
Payload Bay Bulkhead Installation	1 day	Mon 11/5/18	Mon 11/5/18
Nosecone Bulkhead	1 day	Mon 11/5/18	Mon 11/5/18
AV Bay Bulkhead	1 day	Tue 11/6/18	Tue 11/6/18
Fin Can Bulkhead/Cente Ring Installation	5 days	Tue 11/6/18	Mon 11/12/18
Drill Pressure Ports and Switch Holes in	0.5 days	Tue 11/6/18	Tue 11/6/18
Lasercut AV Sled	1 day	Tue 11/6/18	Tue 11/6/18
Install Motor Tul	1 day	Tue 11/6/18	Tue 11/6/18
Checklist Writin	7 days	Tue 11/6/18	Wed 11/14/18
AV Sled Fabricat	3 days	Wed 11/7/18	Fri 11/9/18
Install Fwd Rail Button	1 day	Wed 11/7/18	Wed 11/7/18
Install Fins	3 days	Thu 11/8/18	Mon 11/12/18
AV Wiring	3 days	Mon 11/12/18	Wed 11/14/18
Install Aft Rail Button	1 day	Mon 11/12/18	Mon 11/12/18
Install Motor Retainer	1 day	Mon 11/12/18	Mon 11/12/18
Install AV Sled	2 days	Thu 11/15/18	Fri 11/16/18
Paint	1 day	Thu 11/15/18	Thu 11/15/18
Black Powder Demonstration	1 day	Fri 11/16/18	Fri 11/16/18
Subscale Launch	0 days	Sat 11/17/18	Sat 11/17/18

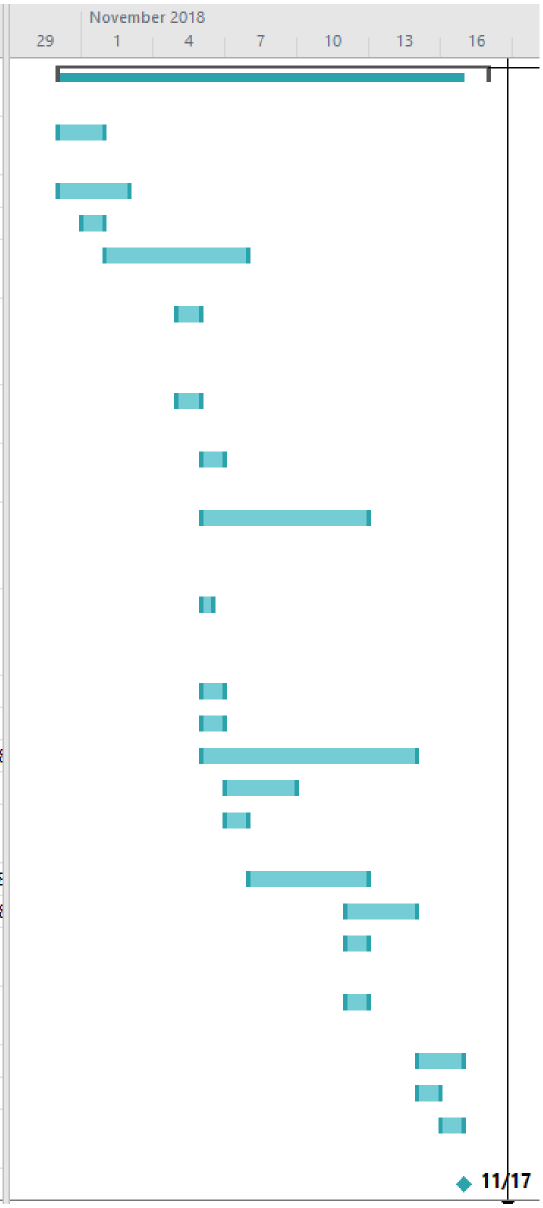


Figure 12-2 Subscale Construction Timeline

Task Name	Duratio	Start	Finish
Testing	**36 days**	**Fri 1/11/19**	**Fri 3/1/19**
Bulkhead Failure Testing	3 days	Fri 1/11/19	Tue 1/15/19
Real Conditions Endurance	2 days	Fri 1/18/19	Sun 1/20/19
Payload Pad Endurance Testing	3 days	Mon 1/21/19	Wed 1/23/19
Payload Deployment Demonstration	2 days	Mon 1/21/19	Tue 1/22/19
Payload Retention Testing	2 days	Thu 1/24/19	Fri 1/25/19
Recovery Electronics Endurance	3 days	Tue 1/29/19	Thu 1/31/19
Hover Endurance Testing	2 days	Fri 2/1/19	Sun 2/3/19
Altimeter Demonstration	1 day	Fri 2/1/19	Fri 2/1/19
Black Powder Ejection Demonstration	1 day	Thu 2/7/19	Thu 2/7/19
GPS Testing	2 days	Thu 2/14/19	Fri 2/15/19
Payload Operation Range Testing	2 days	Fri 2/15/19	Mon 2/18/19

Figure 12-3 Testing Timeline

Task Mode	Task Name	Duratio	Start	Finish
	Fullscale Construction	**21 days**	**Mon 1/14/19**	**Sat 2/9/19**
	Lasercut Bulkheads and	2 days	Mon 1/14/19	Tue 1/15/19
	Altimeter Testin	1 day	Mon 1/14/19	Mon 1/14/19
	Bulkhead Fabrication	4 days	Tue 1/15/19	Fri 1/18/19
	Cut Airframe Tul	3 days	Wed 1/16/19	Fri 1/18/19
	Fin Can Bulkhead/Cente Ring Installation	6 days	Thu 1/17/19	Thu 1/24/19
	Lasercut AV Slec	1 day	Thu 1/17/19	Thu 1/17/19
	Install Motor Tul	1 day	Thu 1/17/19	Thu 1/17/19
	AV Sled Fabricat	3 days	Fri 1/18/19	Tue 1/22/19
	Install Fwd Rail Button	1 day	Fri 1/18/19	Fri 1/18/19
	AV Bay Bulkhead	1 day	Mon 1/21/19	Mon 1/21/19
	Nosecone Bulkhead	1 day	Mon 1/21/19	Mon 1/21/19
	Install Fins	3 days	Mon 1/21/19	Wed 1/23/19
	Payload Bay Bulkhead/Cente Ring Installation	4 days	Tue 1/22/19	Fri 1/25/19
	Drill Pressure Ports and Switch Holes in	0.5 days	Wed 1/23/19	Wed 1/23/19
	Install Aft Rail Button	1 day	Wed 1/23/19	Wed 1/23/19
	Install Motor Retainer	1 day	Wed 1/23/19	Wed 1/23/19
	AV Wiring	3 days	Mon 1/28/19	Wed 1/30/19
	Integrate Payloa	7 days	Mon 1/28/19	Tue 2/5/19
	Install AV Sled	2 days	Wed 1/30/19	Thu 1/31/19
	Checklist Writin	7 days	Wed 1/30/19	Thu 2/7/19
	Paint	1 day	Tue 2/5/19	Tue 2/5/19
	Black Powder Demonstration	1 day	Thu 2/7/19	Thu 2/7/19
	Fullscale Launch	0 days	Sat 2/9/19	Sat 2/9/19

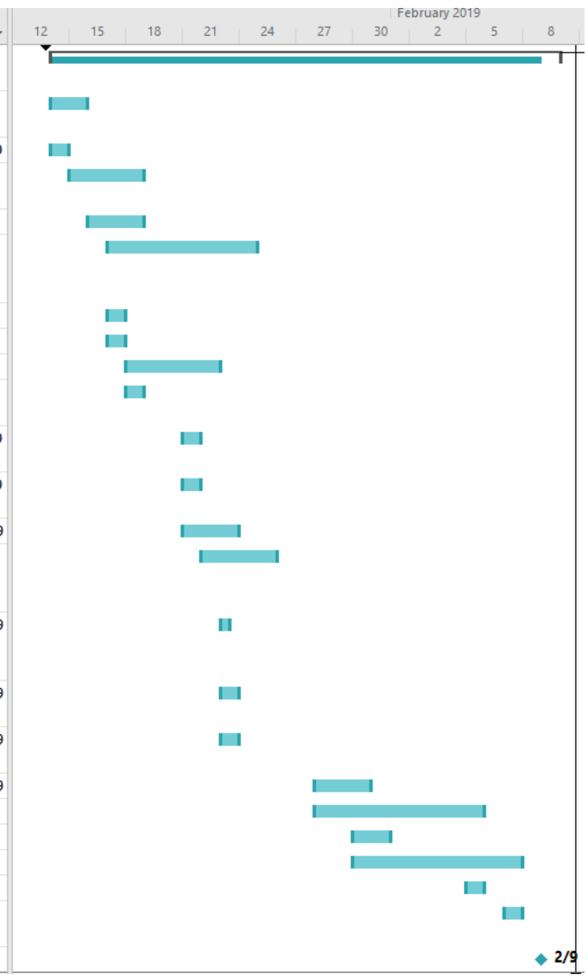


Figure 12-4 Full-scale Construction Timeline