NC STATE UNIVERSITY

Tacho Lycos
2020 NASA Student Launch
Flight Readiness Review

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

March 2, 2020

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
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
RFP	=	Request for Proposal
RSO	=	Range Safety Officer
SL	=	Student Launch
SLS	=	Space Launch System
SME	=	subject matter expert
SOW	=	statement of work
STEM	=	Science, Technology, Engineering, and Mathematics
TAP	=	Technical Advisory Panel (TRA)
TRA	=	Tripoli Rocketry Association

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1. Summary of FRR Report

1.1Team Summary

1.1.1 Team Name and Mailing Address

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TRA Certification: 02204/Level 3

1.2 Launch Vehicle Summary

1.2.1 Size and Mass

The current leading launch vehicle design is 108.06 inches long with a diameter of 6 inches. The mass of the leading launch vehicle design with the leading motor option is 47.5 lbs.

1.2.2 Motor Choice

The current leading motor option is the Aerotech L1520T-PS.

1.2.3 Official Target Altitude

The official target altitude is 4420 ft.

1.2.4 Recovery System

The current leading design uses a duel-deployment recovery system using two PerfectFlite StratologgerCF altimeters, a Fruity Chutes 24" Compact Elliptical drogue parachute deployed at apogee, and a Fruity Chutes 120" Iris Ultra Compact main parachute deployed at 500 ft altitude.

1.3 Payload Summary

1.3.1 Bilateral Uptake Rover for Regolith Ice Transport Operations (BURRITO)

The payload has been designated BURRITO, an acronym that stands for Bilateral Uptake Rover for Regolith Ice Transport Operations. The BURRITO rover will deploy from the payload bay of the launch vehicle on landing. Deployment will be completed by means of a pusher plate moving along two threaded rods, which will push the rover out of the payload bay. The rover itself consists of two parallel drive wheels powered by electric motors and mounted to a plywood chassis, as well as two stabilization wheels that deploy following removal from the payload bay. The rover will be radio-controlled by an operator who will drive it away from the payload bay toward a simulated ice recovery site. There, BURRITO will deploy its SICCU (Simulated Ice Collection and Containment Unit) system, a set of two scoops that will pick up a 10 mL sample of simulated ice. Once the sample has been scooped up, the operator will drive the rover away from the recovery site by 10 linear feet.

2. Changes Made Since CDR

Table 2-1, below lists all changes made to the full-scale launch vehicle since CDR submission.

Table 2-1 Launch Vehicle Changes Since CDR

Description of Change	Reason for Change
The EggFinder TX has been relocated from the backside of the AV sled to inside the nosecone forward of the nosecone bulkhead.	The threaded rods running through the length of the AV bay are likely to attenuate the range of the signal, so the transmitter has been moved into the nosecone to provide maximum range. As a side effect, the transmitter is much further from the altimeters with numerous bulkheads separating them, eliminating the need for shielding within the AV bay.
The AV sled has been shortened from 10 inches long to 7.5 inches long.	The removal of the transmitter allowed for a shortened sled.
The piston ejection system has been replaced by a plug over the payload centering ring.	Due to the coupler section joining the main parachute bay and payload bay being permanently attached on the main parachute side, the coupler piece of the plug would be stopped by the coupler and create a sealed section without inducing separation. As a result, a plug protecting the payload section of the rocket has been implemented.
Ejection charges have been resized according to ejection test results.	Section 3.5.7 details on the resizing of ejection charges.
The LiPo battery for the Eggfinder TX has been replaced with a 9V battery, and the LiPo battery for the Eggfinder RX was replaced with 3x AA batteries.	The availability of 9V batteries compared to LiPo batteries was deemed enough of an advantage to switch to their use for the TX. The TX will be in the nosecone and inaccessible by the night before launch, so an external switch is necessary and reduces the importance of battery life. An AA battery holder was included in the RX Bluetooth case, and the ability to quickly exchange batteries was deemed suitable for the purposes of battery life.
Nosecone Bulkhead design was changed	The nosecone bulkhead now features 6 L-Brackets as opposed to the previous 4. This layout allows for more contact points to the bulkhead, which leads to increased security of the bulkhead. This decision was a cautionary measure rather than a necessary one.
Nosecone Bulkhead Location was changed	This was done to accommodate the threaded rods from the payload retention system.

Table 2-2, below lists all changes made to the payload since CDR submission.

Table 2-2 Payload Changes Since CDR

Description of Change	Reason for Change
Chassis plates adhered with wood glue.	Wood glue is sufficiently strong to bond two pieces of wood glue; simpler to apply than epoxy.
Upper chassis plate made removable.	See section 4.4.1
Chassis plate holes altered and multiplied.	See section 4.4.1
Added L-shaped wood pieces to lower chassis plate.	See section 4.4.1
Divots drilled into drive motor axles.	See section 4.4.2

Caster wheel arms retained by servo arms.	See section 4.4.2
Electronics bay expanded and modified.	See section 4.4.3
Switch added to BURRITO electronics.	See section 4.4.3
Buck converter added to BURRITO electronics.	See section 4.4.3
Added disconnects to drive motors.	See section 4.4.3
Voltage indicators removed from design	See section 4.4.3
SICCU Gear Diameter Reduced	Enable greater amount of clearance below the BURRITO
SICCU Scoop Profile Geometry Changed	Enable greater amount of clearance below the BURRITO
SICCU Brace Added	Increased SICCU reliability increased by ensuring proper gear-to-gear engagement
Radial Supports span the entire payload bay and now located every 90-degree offset.	To minimize flexing of the lead screws and to ensure deployment
Drive motor upgraded to a 205 oz-in motor Retention motor to 650 oz-in motor	Needed additional torque to appropriate deploy and unlock the rover.

Table 2-3, below, lists all changes made to the project plan since CDR submission.

Table 2-3 Project Plan Changes Since CDR

Description of Change	Reason for Change
Removal of Piston Ejection Test	No longer necessary since piston ejection cannot be used.

3. Vehicle Criteria

3.1 Launch Vehicle Mission Statement

The mission of the launch vehicle is to safely reach the declared target apogee and return to the ground in a reusable condition. The mission of the launch vehicle is also to support the mission of the payload by safely landing it within the competition area.

3.2 Launch Vehicle Mission Success Criteria

Mission success is first defined as compliance with both the NASA SL requirements in section 7.3 and the team derived requirements section 7.4. Success is further defined as follows in Table 3-1.

Table 3-1 Launch Vehicle Mission Success Criteria

Level of Success	Definition
Complete Success	Launch vehicle recoverable Nominal launch vehicle takeoff and descent Rover is undamaged and fully functional following the flight of the launch vehicle Launch operations can be repeated the same day
Partial Success	Launch vehicle repairable Successful launch vehicle takeoff and descent Rover is repairable following the flight of the launch vehicle
Partial Failure	Launch vehicle repairable Successful launch vehicle takeoff and unsuccessful descent Rover is repairable following the flight of the launch vehicle
Complete Failure	Launch vehicle unrecoverable Rover unrecoverable

3.3 Launch Vehicle Design

The following are a collection of dimensions and their built counterpart. This proves that the rocket has been built in its entirety.

3.3.1 Full Assembly

The completed launch vehicle is shown below along with dimensions. All launch vehicle sections are connected to each other via shear pins or fasteners. Separation points are connected by shear pins, while non-separation points are connected by fasteners. Separations points are between the AV bay and fin can, and between the AV bay and main parachute bay. Non-separation points are between the main parachute bay and the payload bay, and between the payload bay and the nosecone. All sections do not have issues connecting, and no lubricant is needed.

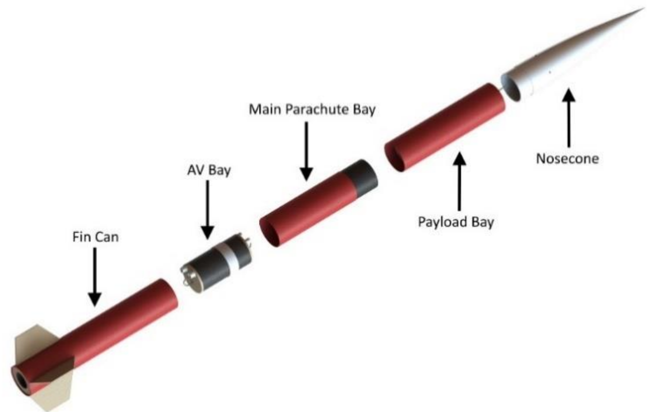

Figure 3-1 Launch Vehicle Components

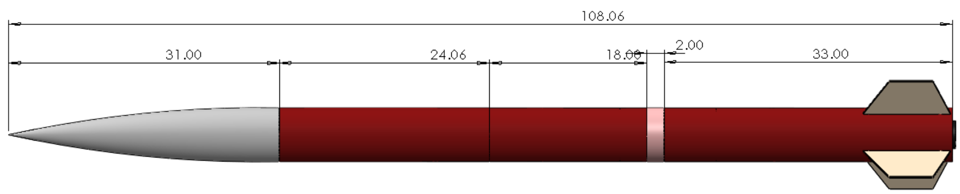

Figure 3-2 Full Dimensioned Launch Vehicle

Figure 3-3 Full Launch Vehicle

3.3.2 Fin Can

There are a few dimensional changes to the fin can from the originally planned design. The center centering has seen a slight shift to its position due to fin tab issues, but it is by an arbitrary amount. Additionality, the centering is now 0.75" as opposed to the original 0.5". Other bulkhead sizes remain the same. Fins are the same size as planned.

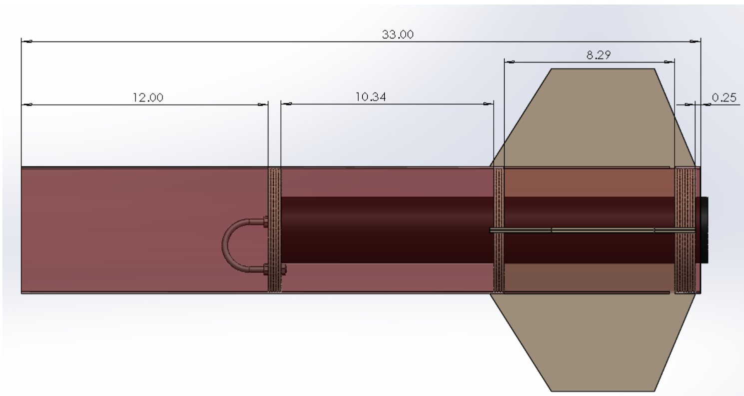

Figure 3-4 Dimensioned Fin Can

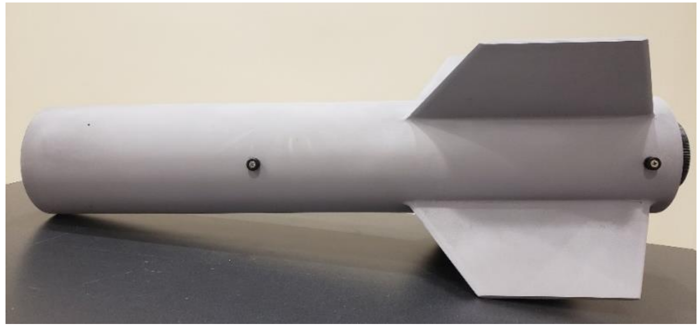

Figure 3-5 Fin Can Assembly

3.3.3 AV Bay

There were no major changes to the dimensions of the AV bay. A manufacturing error caused the body tube section to be 5.94" from the aft section of the coupler instead of the intended 6", but this should not be an issue. All bulkhead dimensions remain the same.

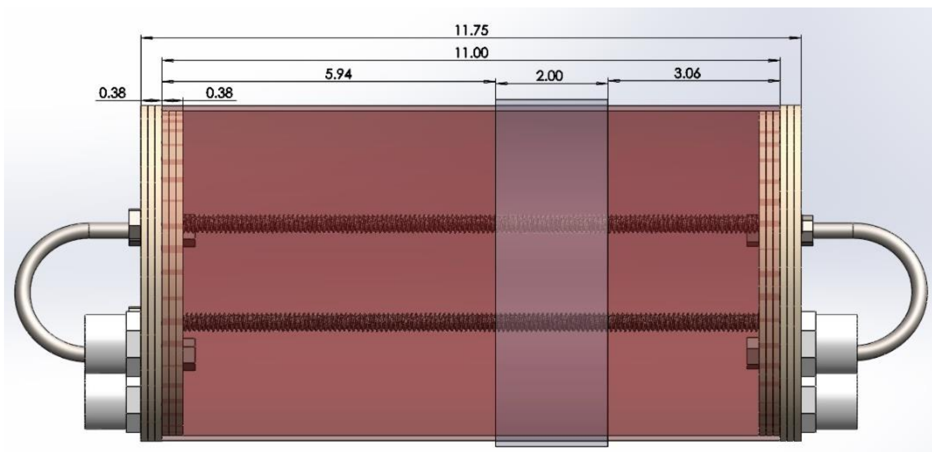

Figure 3-6 Dimensioned AV Bay

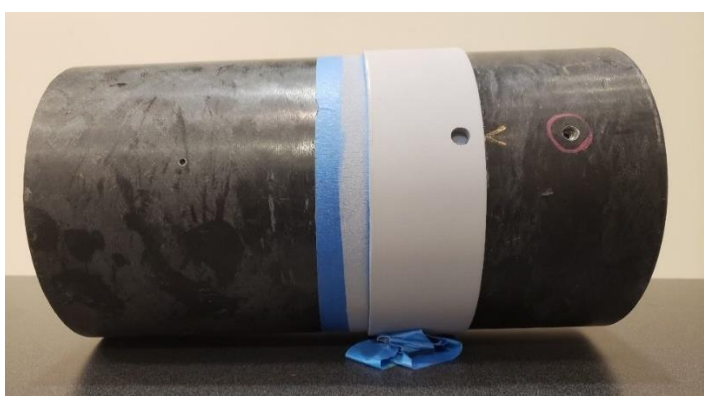

Figure 3-7 AV Bay

3.3.4 Main Parachute Bay

There were no dimensional changes to the main parachute bay.

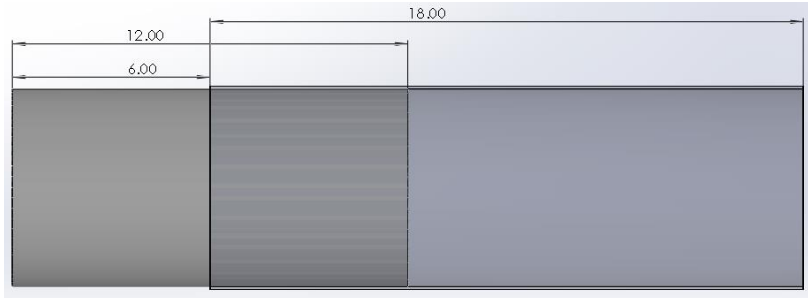

Figure 3-8 Dimensioned Parachute Bay

Figure 3-9 Parachute Bay

3.3.5 Payload Bay

The dimensions of the payload bay have not been changed.

Figure 3-10 Dimensioned Payload Bay

Figure 3-11 Payload Bay

3.3.6 Nosecone

The nosecone bulkhead has moved further forward into the nosecone than originally designed. This is because space needed to be made to accommodate the lead screws from the payload retention system. These lead screws are inserted into the nosecone bulkhead. This system is described further in section 4.5.

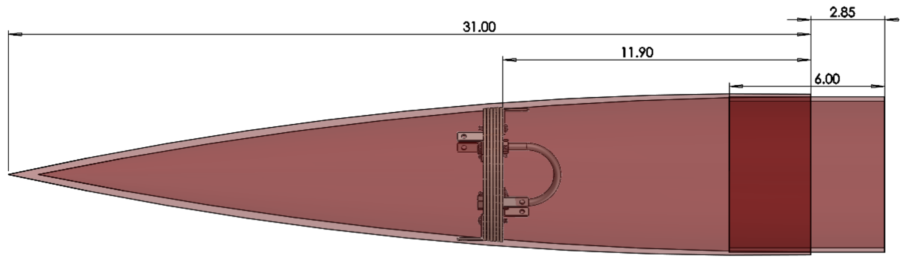

Figure 3-12 Dimensioned Nose Cone

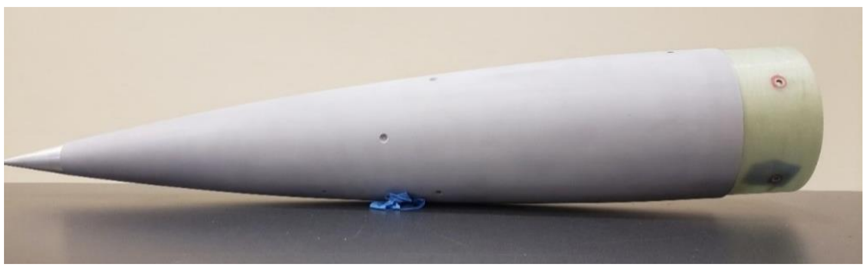

Figure 3-13 Nose Cone

3.3.6.1 Nosecone Bulkhead

Additionally, the design of the nosecone bulkhead was altered. The nosecone bulkhead now features 6 L-Brackets as opposed to the previous 4. This is seen in Figure 3-14. This layout allows for more contact points to the bulkhead, which leads to increased security of the bulkhead. This decision was a cautionary measure rather than a necessary one. The nosecone bulkhead is the main structural element holding the payload bay during recovery, so it is best to give that element a high factor of safety of 8. The downside of this design is the alignment issues that come with more contact points being introduced. Properly inserting the nosecone bulkhead is now more difficult, but not difficult enough to the invalidate the design. The process has become faster with practice.

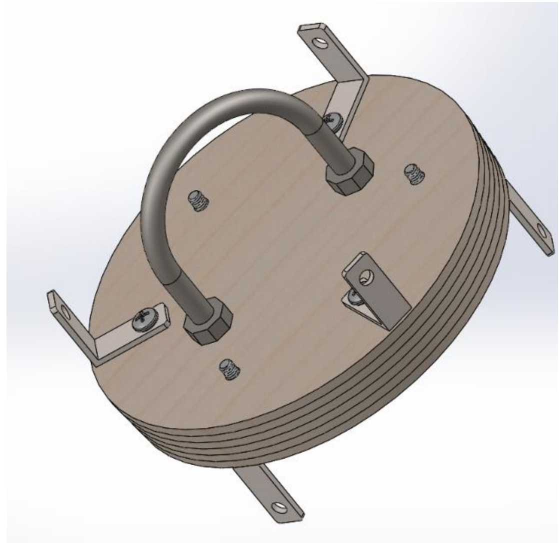

Figure 3-14 Nose Cone Bulkhead

3.3.7 Flight Reliability

3.3.7.1 Body Tube Material

The rocket's G12 fiberglass airframe will ensure the reliability and reusability of the launch vehicle. This composite material provides sufficient strength to bear flight forces. It is thick enough to negate common puncture and compressive forces. The body tube is rated for 27 ksi of compressive stress. The launch vehicle is only expected to experience 8.5 ksi of stress, giving the airframe a factor of safety of 3.17**.**

Additionally, G12 fiberglass is resistant to moisture damage. This eliminates the chance that the airframe would be harmed by previous exposure to moisture.

3.3.7.2 Bulkhead Material

Bulkheads were constructed of 1/8" aircraft grade plywood. This provides a step up in strength from normal plywood, included added moisture resistance. Additionally, aircraft grade plywood must past standards for strength, so there is little chance that the team would use a compromised piece of plywood. While it was more costly, it was imperative that we used to this material to ensure the integrity of the bulkheads. 1/8" plywood is used as the team has access to a laser cutter than can accurately cut plywood of this dimension. Any material thicker would be harder/impossible to cut accurately. Layers are help together using the layup process described in section 3.4.3.

3.3.7.3 Bulkhead Design

Bulkheads were all designed to have the appropriate thickness to ensure that they are retained in their appropriate section. Increased thickness decreases bending due to deployment and increases surface area for epoxy to attach to. The appropriate thicknesses were determined through Finite Element Analysis and then verified using testing described in section 7.1

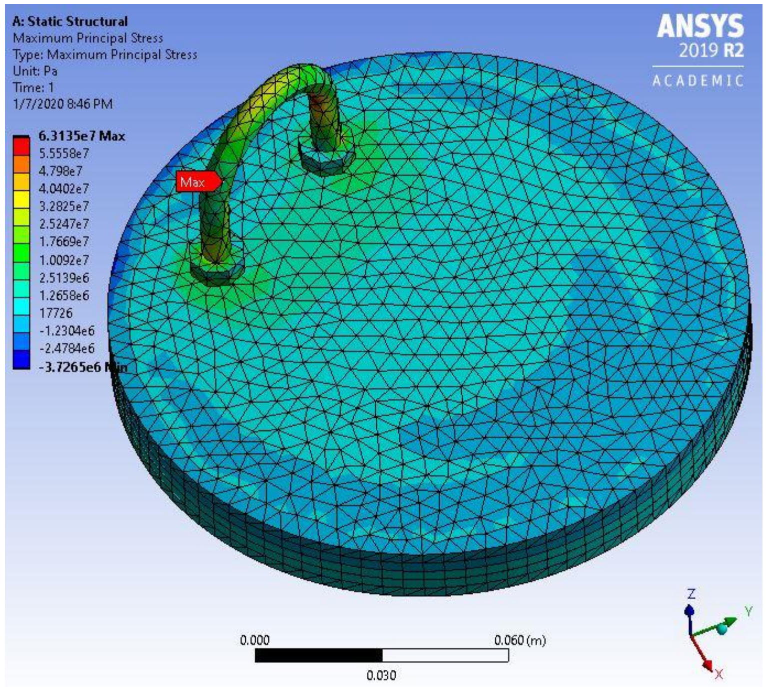

Figure 3-15 FEA on Fin Can Bulkhead

Figure 3-15 is an example of FEA testing done to ensure the integrity of our bulkhead designs. The ultimate stress of ordinary plywood is 30MPa, so the design needs to keep bulkhead stress below that amount. Since the actual bulkhead is utilizing aircraft grade ply, this ultimate stress will be higher in the actual bulkhead. However, to ensure a high factor of safety, the ultimate stress of regular plywood was used as the standard.

3.3.7.4 U-Bolts

All shock cords are connected to U-Bolts that are secured into the bulkheads. The U-Bolts are made of galvanized steel which as a yield strength of 1075 lbs. This more than enough to endure recovery loads. This yield strength also doesn’t indicate complete failure. If a U-Bolt yields it will deform but it will not rupture. It will secure its respective shock cord. Additionally, U-Bolts have two points of contact to each bulkhead, mitigating the chances of a U-Bolt shearing out of bulkhead.

3.3.7.5 Body Tube to Bulkhead Connections

3.3.7.5(a) Epoxy

The location of the bulkhead from the end of the body tube was measured and marked around the entire inside diameter of the body tube. Then, both the inside of the body tube and the circumference of the bulkhead were sanded with low grit sandpaper. Two-part epoxy was then applied around the inner circumference of the body tube. The bulkhead was then slid into place inside the body tube. Once the epoxy completely cured, fillets were applied to the contact areas between the bulkhead and fin can. Fillets consist of two-part epoxy mixed with 404 silica filler.

The epoxy that was used is West System 105 epoxy with 206 slow hardener. This epoxy was chosen because of its ability to create high strength moisture resistant bonds as well as its extended working and cure time. The cured epoxy has a tensile strength of 7,300 psi and a compression yield of 11,500 psi.

3.3.7.5(b) Bolts + L-Brackets

The #8 bolts used to connect bulkheads to the body tube are rated to withstand 1,200 lbf. The maximum expected load on the bulkheads is 900 lbf, so there is a factor of safety of 8 on all bolts securing bulkheads.

3.3.7.5(c) AV Bulkheads

AV Bulkheads are secured to each other via 0.25" steel rods that span the length of the AV bay coupler. The stainless-steel threaded rods used have an ultimate stress of about ~3400 lbs. Between the two threaded rods, this gives an ultimate stress of ~6800 lbs. This is more than enough strength to withstand recovery loads. Additionally, the tests shown in section 6.6.2 show that that the U-Bolts will not shear out during recovery.

3.3.7.6 Fin Security

Fins are initially secured into slots on the fin can using two-part epoxy. Then, epoxy fillets were added to both sides of the fins as well as at the leading edge of the fins where the fins join the body tube. These remove stress concentrations along contact surfaces to prevent fracturing or failure of adhesives. These connections will provide more than enough strength to secure fins during flight as the fins are not bearing a significant load.

3.4 Launch Vehicle Construction

3.4.1 Cutting Body Tubes

Body tubes were cut using NCSU's drop bandsaw. A drop bandsaw allowed for clean and easy cuts as G12 fiberglass is a hard material to cut with less powerful tools. Body tubes were placed on the cutting area of the bandsaw, and then leveled using a telescoping stand. This ensured that body tubes were cut properly.

To ensure that that all body tube sections were level, the body tubes were placed on a level surface of ground and then a bubble level was used to check if the tube stood straight. No body tubes needed to be fixed.

Figure 3-16 Drop Bandsaw

3.4.2 Assemble Body Tubes and Couplers

Three coupler pieces needed to be attached to body tubes. This was for the payload, parachute, and AV Bay. Contact areas on both the body tubes were premeasured. These sections were then sanded in order to roughen the surface to allow for a stronger surface bond. Two-part epoxy was applied to the end of the body tube and the coupler section was inserted. Care was taken to ensure that the coupler stood out 6 inches where applicable. Sections were laid horizontally to dry to prevent the pieces from slipping.

3.4.3 Bulkhead Assembly

3.4.3.1 Laser Cutting

Each bulkhead layer was designed in SolidWorks. The CAD file was imported to a Universal Laser Systems VLS6.60 laser cutter. A single sheet of 1/8 inch aircraft-grade birch plywood was loaded into the laser cutter. As many layers as could fit on a single sheet were cut at the same time. A team member observed the cutting process and checked the dimensions of each part following each cut. This process was repeated until all required layers were completed. The scrap plywood was saved in case smaller parts needed to be cut in the future.

3.4.3.2 Layups

After the layers had been laser cut, all faces were sanded with low grit sandpaper. This was done in order to create more surface area on the faces that were glued creating a stronger bond. Next, 0.25" dowel rods were cut to the thickness of the bulkhead. All layers of the bulkhead were then dry fit together using the dowel rods in order to ensure that the individual layers were lined up properly. Before the parts were glued, the vacuum bagging area was prepared. Vinyl was laid out over the surface to be used and peel ply was laid over that. Two-part epoxy was then mixed and applied liberally to each layer's contact face. The layers were then stacked once again using the dowel rods for alignment. Another layer of vinyl was then placed over top and a seal was created using plumber's putty. A vacuum line was inserted creating a vacuum under the vinyl. Each layup was then left to cure for 24 hours before removing it from the vacuum.

Figure 3-17 Bulkhead/Centering Ring Layup

3.4.3.3 Hardpoint Attachment

Once the bulkheads finished curing, any required hardpoints, such as U-Bolts and L-brackets, were attached. To do this, first, the installation points were measured and marked on the bulkhead. Appropriately sized holes were then drilled through the bulkhead with a drill press. For U-Bolt installation, a washer was installed on each end of the U-Bolt, then the U-Bolt was inserted into the holes on the bulkhead. The U-Bolt was then fastened using a washer and nut on each end and tightened using two adjustable wrenches. For L-Bracket installation, the bracket was aligned in the proper orientation over the hole. A bolt was then inserted through the hole, and two nuts were used to fasten the bolt.

3.4.4 AV Bay Assembly

The AV Bay assembly began by cutting to length one length of coupler and one length of outer body tube according to the dimensions in Figure 3-6. These sections were then bonded together using West Systems 2-part epoxy. After curing, the drill press was used to drill all necessary pressure ports into the AV bay switch band.

3.4.5 Fin Can Assembly

The fin can was the most difficult part of the rocket to assemble and needed to be done as a sequenced process. There were issues with the initial fin can ordered with Mad Cow rocketry in that the fin slots were too thin. The slots were 0.125 inches thick and the planned fin tabs would be 0.25 inches thick. Excessive sanding and effort were put into making the fin slots larger.

Initially, the forwardmost bulkhead was installed into the fin can. The location of this bulkhead was premeasured and then the contact area was sanded. Epoxy was applied to the contact area and the bulkhead was inserted.

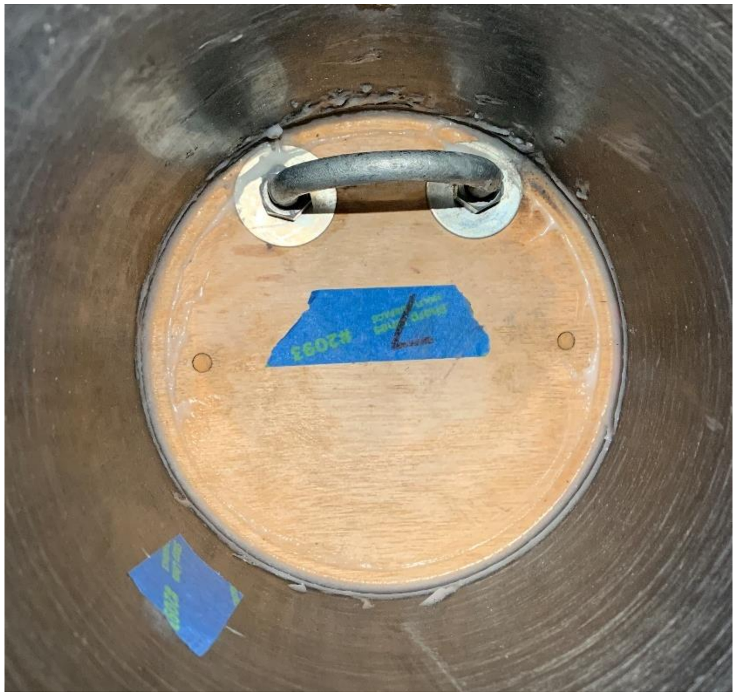

Figure 3-18 Fin Can Forward Bulkhead; Recovery Harness Point 7

Figure 3-19 Motor Block and Motor Retainer

Once the epoxy completely cured, fillets were applied to the contact areas between the bulkhead and fin can. Fillets consists of two-part epoxy mixed with 404 silica filler. This is pictured in Figure 3-18.

The motor tube was then marked and treated where the centering ring will be attached. Epoxy was then applied to that area and the centering ring was inserted. Fillets were applied to the forward side of the centering ring, but not the aft end. This is because these fillets would interfere with the fin tabs once inserted.

Figure 3-20 Centering Ring Attachment

Once the motor tube was attached to the fin can, the fins were inserted into the fin can. This were inserted into the aforementioned fin slots. Non-filled epoxy was applied to the contacts points between the fins and the motor and between the fins and fin can. Fins were held in place by a fin jig that the team constructed, pictured in Figure 3-20. This was left to set for 24 hours. After this had set, a fin had to repositioned. This is because it had become unaligned while setting. This was done using acetone. Once repositioned, it was re-epoxied to its respective contact points.

Figure 3-21 Fin Jig

After this, fillets were applied to these same contacts. Additionally, fillets were applied to the center centering ring and the motor tube. These fillets were given 24 hours to set.

The final bulkhead inserted was the aft most centering ring. This bulkhead was designed to be flush with the fin tabs, so its position did not need to be premeasured. After surface prep and epoxy application to the contact area, the bulkhead was pushed into the fin can until it was stopped by the fin tabs. After the piece was allowed to set for 24 hours the bulkhead was filleted around the accessible contact areas.

The motor retainer used for the launch vehicle was an Aero Pack 75mm retainer, which is mounted with adhesives. Before applying epoxy, the moto retainer was dry fit to ensure that the retainer sat level with the motor tube. The contact point between the motor tube and the motor retainer was prepped, and epoxy was applied. After this piece current, fillets were added to the base of the motor container and the construction process was finished.

3.4.6 Nosecone

3.4.6.1 Coupler Attachment

The nosecone was attached to the rest of the rocket via insertion of the nosecone coupler into the payload bay. Four holes were drilled through the coupler at 90-degree angles to each other. A #8 nut was attached to the inside of each hole with metal JB-Weld. When the nosecone coupler was inserted into the payload bay, the holes in the coupler were aligned with matching holes in the payload bay. A #8 bolt was then screwed into each nut to secure the two sections together.

3.4.6.2 Nosecone Bulkhead

The nosecone bulkhead features 6 L-brackets that are used to attach the nosecone bulkhead into the nosecone. These brackets use #8 bolts and nuts that pass through holes in the nosecone to secure the bulkhead. The bulkhead also has a U-Bolt that is used as one endpoint of the main parachute recovery harness. This U-Bolt is secured as described in section 3.4.3.3**.**

3.4.7 Shear Pin and Fastener Mounts

Shear pin holes were drilled through the body tube and coupler between the payload bay and main parachute bay as well as the AV bay and fin can. The holes were drilled using a hand drill with a 3/32-inch bit to fit 4-40 shear pins. Fastener mounts were drilled to fit #8 screws. Each hole was countersunk using a countersinking drill bit.

3.4.7.1 Attaching Nuts

Nuts on the inside of the airframe for fastener mounts are currently attached using metal JB-Weld. There were separation issues that occurred during flight; however, these did not compromise the integrity of the launch vehicle. These are shown in Figure 3-22. In order to make these mounts more secure, the nuts will be re-attached using two-part epoxy.

Figure 3-22 Nut Detachment in Nose Cone

3.5 Recovery Subsystem

3.5.1 Summary

The recovery system is controlled by two PerfectFlite StratologgerCF altimeters. One altimeter acts as the primary flight computer, while the other is a redundant system. Both the altimeters and their respective batteries and switches are mounted on an avionics sled created out of laser cut 3/16" birch plywood and supported by two parallel threaded rods. After the vehicle is mounted on the launch rail, the altimeters are armed using two independent screw switches, accessible from the outside through holes in the airframe large enough to fit a screwdriver that also serve as pressure sampling ports for the altimeters.

At apogee, the primary altimeter detonates a black powder charge separating the fin can and midsection. The redundant altimeter detonates another charge to achieve the same goal 1 second later in case of failure in the primary system. The two sections separate and descend under a Fruity Chutes 24" Classic Elliptical drogue parachute tethered to the two sections by a 40 ft length of 5/8" tubular Kevlar shock cord and protected by two overlapped sheets of Nomex. Loops at the end of the shock cord are connected to U-bolts on bulkheads in the airframe by ¼" quick links. The fin can is tethered by a permanent bulkhead, while the midsection is tethered by a bulkhead that is part of the AV Bay assembly. This bulkhead is held in place by a threaded rod and nuts compressing the bulkhead and a companion bulkhead on the opposite end of a length of coupler. This assembly contains the altimeter electronics and ejection charges and can be prepared separate from the rest of the vehicle during launch procedures. At 500 ft, the primary altimeter detonates a black powder charge separating the nosecone and midsection. At 450 ft, the redundant altimeter does the same. Figure 3-23 shows the expected performances of the recovery system.

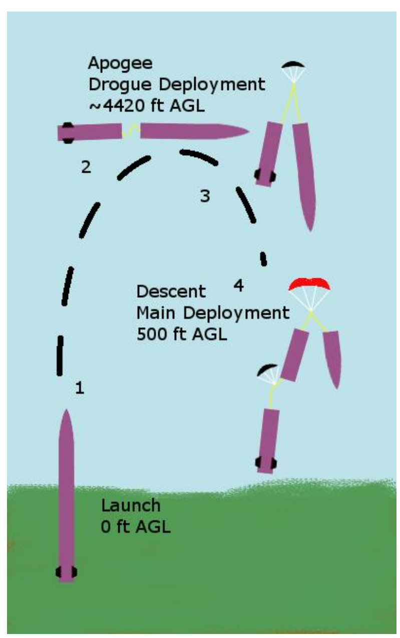

Figure 3-23 Recovery CONOPS

The nosecone and midsection are tethered by an identical length of shock cord as the drogue recovery harness and uses the same ¼" quick links to connect to bulkheads. The midsection is tethered to the AV bay bulkhead on this side, described earlier, while the nosecone is tethered by a removable bulkhead in the nosecone. This removable bulkhead is beyond the payload section, and as such a length of shock cord is routed through a hole in the payload bay centering ring to reach the bulkhead in the nose. Supporting this recovery harness is a Fruity Chutes 120" Iris UltraCompact parachute. The parachute is stored and deployed by a Nomex deployment bag. The payload bay is sealed off from ejection gases using a removable plug, a pseudo bulkhead that is puttied between the parachute and payload bay and attached to the shock cord with a U-bolt.

3.5.2 Structural Components

3.5.2.1 AV Bay Bulkheads

Bulkhead assembly and structure are analyzed further in section 3.3.

3.5.2.2 Avionics Sled

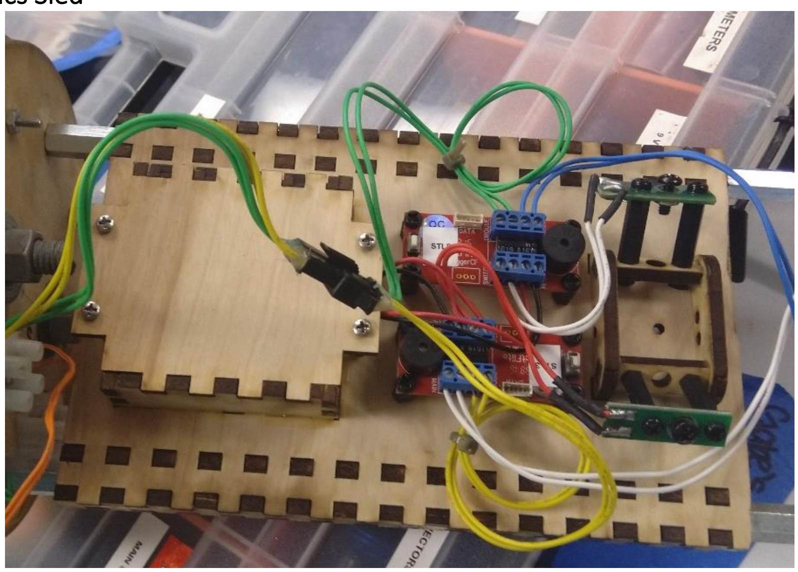

Figure 3-24 AV Sled as Built

Pictured above is the fully assembled AV sled, with all electronics and required hardware mounted. The sled is constructed out of laser cut 3/16" birch plywood and wood glued together with the exception of the battery compartment cover on the left side. The sled is held in place within the AV bay by the threaded rods running through the length of the bay. The tilted pieces to the right hold the screw switches in place at a 90° angle to each other. The screw switches are attached to these pieces using 1" standoffs to elevate the screw switches and make them easier to locate and activate on the launch pad. The arced pieces holding these in place are slotted through holes in the sled and kept in place with bolts running through the tabs on the bottom side. The altimeters are mounted using ½" standoffs to ensure the pressure sensors, located on the bottom of the board, are given adequate space to properly measure the pressure in the AV bay. The altimeters are mounted in opposite directions so that the battery and switch wires could run through the space between the altimeters, while e-match wires ran on the outside edge, making wiring slightly more convenient. The box to the left houses two 9V batteries for the altimeters. The top piece of this box is fit onto the sides via the jigsaw cutouts and held in place once the batteries are connected via screws that extend through the base plate and terminate with nuts on the opposite side.

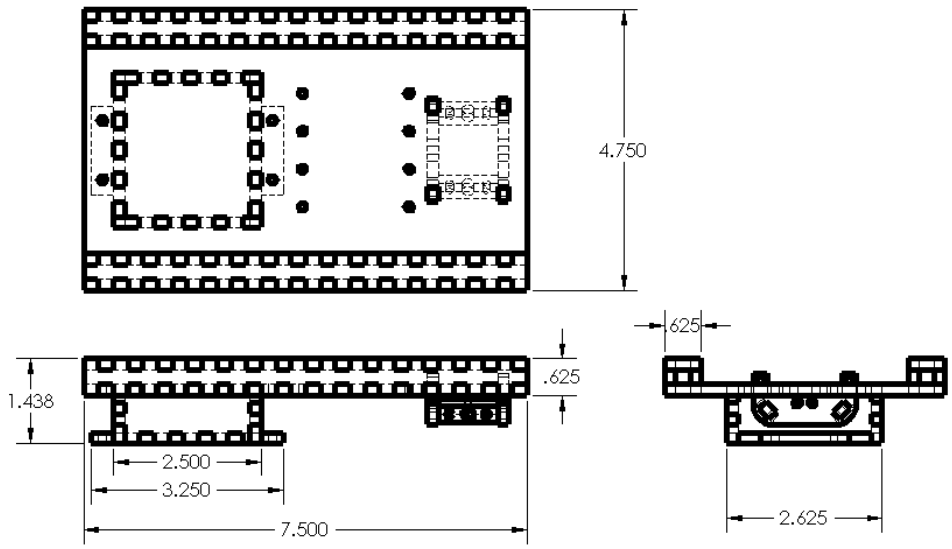

Figure 3-25 Avionics Sled Dimension Drawing

Figure 3-25 shows the assembled avionics sled as built with important dimensions included in inches. The sled without any additional electronics mounted is what is depicted.

3.5.2.3 Quick links

Quick links will be used to tether all body sections and recovery hardware to the recovery harness described in section 3.5.4. All quick links are at least ¼" steel, rated upwards of 1200 lbs. Larger quick links are used to tether the vehicle sections due to the large U-bolts utilized, while more moderate quick links are utilized to attach parachutes and recovery hardware.

3.5.2.4 Pressure Sampling Holes

For the altimeters to properly detect the altitude of the vehicle at all points of the rocket's flight, pressure sampling holes are located on the AV bay body tube. These static ports are recommended by PerfectFlite, the altimeter manufacturer. The StratoLoggerCF altimeter user manual suggests placing these holes at least 4 to 5 times the body diameter away from the nosecone shoulder, and using 4 holes at 90° intervals, especially for larger diameter rockets. These help to avoid any fluctuations in the read static pressure due to wind, angle of attack, or any turbulence or irregularities produced by the body upstream of the static port. The holes are sized according to the following equation, provided by the user's manual[1]:

$$d = D * D * L * .0008$$

Where d is the diameter of the switch hole, D is the inner diameter of the AV bay, and L is the interior length of the AV bay. With an inner diameter of 5.775" and an interior length of 10.5", d is approximately 9/32", and as such all static ports are this size. The ports are aligned to the sled within the AV bay to allow for two of the neighboring static ports to serve as access to the primary and secondary screw switches which activate the altimeters.

3.5.3 Parachute Selection

The vehicle uses a Fruity Chutes 24" Classic Elliptical parachute for drogue recovery, and a Fruity Chutes 120" Iris UltraCompact parachute for main recovery. These parachutes have been chosen based on team availability, descent time, drift, and kinetic energy performance. Vehicle descent speed under parachute can be calculated using the terminal velocity formula below[2].

$$v = \sqrt{\frac{2\, g\, m}{A\, C_D\, \rho}}$$

In the equation above, m is the burnout mass of the launch vehicle, g is the acceleration due to gravity, ρ is the density of air, A is the area of the parachute, and C_D is the coefficient of drag of the parachute. While the area and drag of the vehicle sections themselves do contribute to the velocity at which they fall, their contribution is negligible in comparison to the parachute. The current launch vehicle as built has a burnout mass of 1.342 slugs.

3.5.3.1 Drogue Parachute

The 24" Classic Elliptical was chosen as the drogue parachute for its high descent speed and team ownership, in accordance with TDR 3.3. The 24" Classic Elliptical has a reference area of 3.14 ft^2 and a C_D of 1.47, causing the vehicle to descend at a steady state speed of 88.0 fps. This descent speed allows the vehicle to descend at a fairly rapid rate, reducing descent time and wind drift while still complying with TDR 3.2 – drogue descent velocity shall be less than 100 fps.

3.5.3.2 Main Parachute

The Fruity Chutes 120" Iris UltraCompact has been chosen for the main parachute primarily for its wind drift, descent time, and kinetic energy performance. The 120" Iris UltraCompact has a reference area of 78.4 ft^2 and a C_D of 2.11, resulting in a descent rate of 14.72 fps. In addition, the team already possesses a Fruity Chutes

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[1] *SLCF.* http://www.perfectflite.com/SLCF.html. Accessed 29 Feb. 2020.
[2] *Fluid Friction*. http://hyperphysics.phy-astr.gsu.edu/hbase/airfri2.html. Accessed 7 Nov. 2019.

120" Iris UltraCompact parachute, conserving funds as with the drogue parachute and satisfying TDR 3.3.

3.5.4 Recovery Harness

The recovery harnesses are 40' x 5/8" Kevlar shock cord. This shock cord is rated for loads upward of 2000 lb, and current mass and acceleration predictions suggest a maximum load of 300 lb in the case of 40 g's on the midsection and fin can during main deployment . The drogue shock cord has a bowline knot tied in each end as well as a loop one third of the way along its length. The drogue parachute and two Nomex cloths are attached by a single quick link to this loop. The shorter end of the shock cord is attached by quick link to the midsection, while the longer end is attached to the fin can. This causes the midsection to hang above the fin can during drogue descent. This prevents the fin can from collapsing the main parachute upon deployment and reduces the risk of entangling shock cord and shroud lines at main deployment. The main shock cord is fed through the hole in the payload centering ring and terminated in a bowline knot to which a quick link is affixed and tethered to the nosecone bulkhead. Approximately 6" from the aft most point of the payload centering ring is another loop to which the plug is tethered. Approximately 6" from this loop is another loop to which the deployment bag for the main parachute is attached by quick link. Another 11' from this loop is the loop to which the main parachute itself is tethered, placed here in order to create at least a shroud line's distance between the two loops to ensure the main parachute fully deploys from the deployment bag. The other end of the shock cord again terminates in a bowline knot which is tethered to the midsection.

3.5.5 Avionics

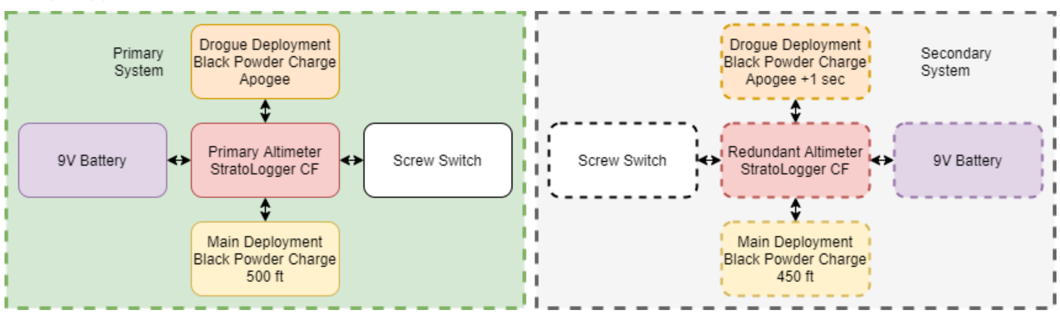

Figure 3-26 Recovery Electronics Diagram

The diagram above illustrates the components housed within the AV bay and how all of them are wired to each other. The dashed green box contains all the components of the primary altimeter recovery system. This system contains the competition altimeter which will record the team's official apogee, as well as all the components necessary for the required recovery events. The altimeter has 4 pairs of terminal screws that are connected to a 9V battery, a screw switch, and 2 E-matches. One E-match is in the drogue compartment and triggered at apogee, while the other is in the main parachute compartment and triggered at 500 ft. A fresh, tested battery is installed with each flight to ensure the altimeter has enough power to detonate both charges and record flight data.

The dashed grey box houses the secondary altimeter recovery system, which is nearly identical to the primary system, with the black powder charges being the only difference. The drogue charge is programmed to detonate one second after apogee, while the main charge is set to detonate at 450 ft. Both systems are independently capable of safely recovering the launch vehicle, and as they are not connected in any fashion this creates a redundancy in the system. If any one component is to fail, the other system will activate in its place and allow for safe recovery.

3.5.5.1 Altimeters

The vehicle's recovery events are controlled by two PerfectFlite StratoLoggerCF altimeters, one primary altimeter and one redundant altimeter. The primary altimeter serves as the nominal operation point for the recovery procedure and act as the team's competition reporting altimeter. The primary altimeter detonates its drogue charge at apogee and its main charge at 500 ft AGL, while the secondary, redundant altimeter delays its detonations by one second and 50 ft respectively. These delays are implemented to prevent the simultaneous detonation of both charges and result in over pressurization of the parachute cavities. The StratoLoggerCF is precise, with prior team flights using two StratoLoggers having a measured apogee difference less than 10 ft. The team already owns multiple StratoLoggers, which satisfies requirement TDR 3.3 – the launch vehicle shall use recovery devices that the team owns. The StratoLoggerCF allows for programming an apogee delay in seconds as well as main deployment in 1 ft increments. These factors make the StratoLoggerCF suitable as both a primary and redundant altimeter.

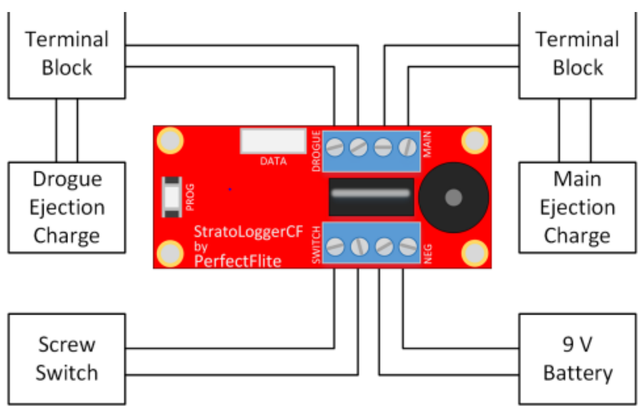

Figure 3-27 StratoLoggerCF Wiring Schematic

Figure 3-27 shows the wiring of the PerfectFlite StratoLoggerCF altimeter.

3.5.5.2 Screw Switches

Two screw switches are mounted on the avionics sled as described in section 3.5.2.2. Each screw switch is independently connected to the switch terminals on one of the altimeters. Each of the screw switches is accessible via a screwdriver and the Pressure Sampling Holes described in section 3.5.2.4. This allows for the entire vehicle to be assembled and brought to the pad without a continuous connection between an E-match and a power source. Once the vehicle is on the launchpad and in the upright position, a team member may arm the altimeters using a screwdriver. These switches protect team members from premature black powder charge detonations and conserve battery life for the altimeters. Screw switches may also be tightened significantly in order to ensure that altimeter power is retained despite any flight forces or jostling of the AV bay or launch vehicle.

3.5.5.3 Batteries

Both altimeters are powered by fresh 9V batteries for each flight. Before each flight, an unused 9V battery is tested to ensure a voltage of at least 9V, before being connected to the system and enclosed in the battery compartment of the AV sled. The battery compartment of the sled is designed to create a tight fit such that as long as the lid of the compartment is on, there shall be no way for the batteries to become disconnected from their connectors, ensuring uninterrupted power regardless of flight or external forces. The model of battery used has been tested with the team’s altimeters as detailed in section 7.1 to ensure proper battery life, lasting at least 3 hours without issue.

3.5.5.4 Redundancy Features

The recovery electronics system contains two separate recovery systems within. There are two entirely independent altimeters, screw switches, 9V batteries, drogue e-matches, and main e-matches. If any one component of a system were to fail, the second system would be just as capable of safely recovering the launch vehicle. In addition to this, the redundant altimeter is connected to slightly larger black powder charges. In the event the primary recovery system function as designed and the charges are detonated, but body sections fail to separate, a larger charge on the redundant system increases the chances of the system properly separating upon the redundant charge’s detonation. The use of two separate systems creates redundancy that protects against component failure, while the larger charges on the redundant system protect against miscalculations or aberrations in the force necessary to separate the sections.

3.5.6 Tracking Device

The launch vehicle is located using an Eggfinder GPS. The system consists of a standard Eggfinder Transmitter TX with the included stick antenna and a 9V battery, transmitting to a Bluetooth Eggfinder RX dongle. The transmitter is located in the nosecone forward of the nosecone bulkhead, with a screw switch accessible from outside the vehicle. The transmitter and attached battery are attached within the nosecone using strips of hook and loop fastener against the inner wall of the nosecone. The switch is mounted directly against the inner wall with electrical tape to make the screw easily accessible. The transmitter is paired with a receiver, programmed to the same frequency of 913 MHz on ID 3. The transmitter operates on a transmission power of 100 mW, satisfying requirement NASA 2.22.9. The transmitter has demonstrated a range of at least 3000 ft, maintaining connection throughout the ascent of the vehicle demonstration flight. Even if the range does not exceed the apogee of the flight, the receiver should be able to reacquire signal during descent given that the vehicle shall descent within 2500 ft of the launch pad. The receiver is mounted in a plastic case which also houses a 3x AA battery holder and Bluetooth module. The receiver is paired to the phone of a team member on the field recovery team via Bluetooth. The GPS data is then plotted using the app Rocket Locator on the phone. The app plots the vehicle's location on satellite imagery as well as giving the vehicle's distance, altitude, and an azimuth line from the current location to the vehicle. The vehicle's latitude and longitude are also available in the logs of the app. A redundant tracking device is not included in the vehicle due to the tracking device serving as a secondary method to visual identification of the vehicle during descent. Additionally, another tracking device would have to be located in close proximity to the current tracking device, increasing the likelihood of interference between the transmissions of both devices.

3.5.6.1 Sensitivity to Transmitters

The locating transmitter will be located 60 inches from the nearest e-match or altimeter, severely limiting the effect of radio transmissions on premature detonations. The altimeters are also by design not sensitive to RF radiation, though additional barriers help increase the level of confidence in this lack of sensitivity. 2 bulkheads and the entirety of the payload system as well as 2 pairs of threaded rods help to attenuate the effect of RF radiation in the AV bay.

3.5.7 Ejection Charge Sizing

Black powder charges were sized according to the ideal gas equation, shown below:

$$PV = mRT$$

Where P is the pressure produced by the black powder gas, V is the volume of the cavity it fills, m is the mass of black powder in the charge, R is the gas constant, and T is the combustion temperature of black powder. With a 6" inner diameter for both sections, and a length of 7 inches in the drogue compartment and 21 inches in the main compartment, this gives a volume of 197.9 in^3 and 593.8 in^3 respectively. Rocketry forums recommend 15 psi as an appropriate separation pressure for most rockets, with tighter fits possibly requiring 20 psi. In order to reach 20 psi, the drogue charge was initially projected to be 2.0 grams and the main 6.1 grams. An experienced team member suggested upping the drogue charge to 2.5 grams, which team decided to do. Upon preliminary ejection testing, both charges were deemed to be excessive, especially the main charge. The charges were subsequently downsized to 2.3 grams and 5.5 grams respectively, creating a pressure of 22.5 psi and 17.9 psi respectively. These charges were also deemed to be appropriately sized following the ground ejection test detailed in section 7.1. In order to create redundancy against miscalculations and aberrations in flight conditions, the redundant charges are slightly larger than the primary ones. These charges were arbitrarily determined to be 2.7 grams and 6.0 grams for the drogue and main redundant charges respectively.

3.6 Mission Performance Predictions

3.6.1 Launch Day Target Altitude

The team's declared launch day target altitude is 4,420 feet.

3.6.2 Flight Profile Simulations

Once the full-scale vehicle was assembled and measured, the models in RockSim were updated to more accurately predict the flight performance of the launch vehicle. Primarily, the total mass and center of gravity location were overridden in the RockSim file. From information collected from www.weatherunderground.com the atmospheric conditions were updated in RockSim to reflect the conditions expected at the launch site, this data is discussed further in section 5. The altitude plots from these simulations can be seen below in Figure 3-28. The altitude predictions were verified using the Barrowman Equations and is discussed further in section 3.6.3.

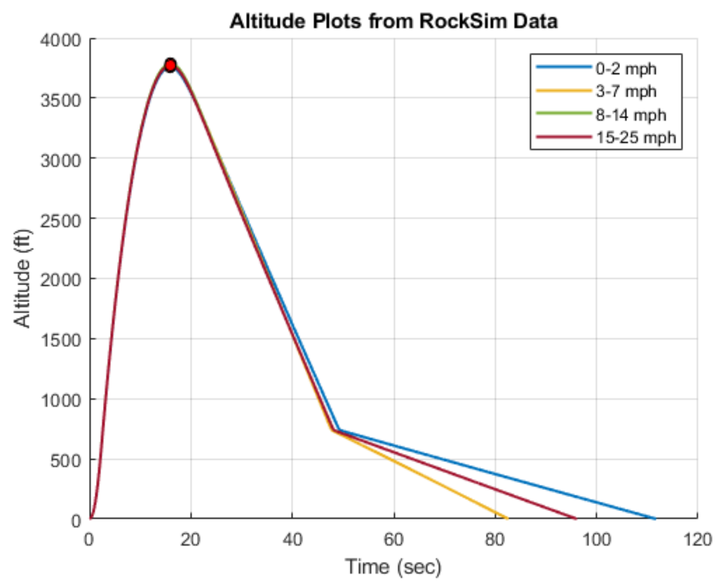

Figure 3-28 RockSim Altitude Predictions of As-Built Launch Vehicle

The simulated thrust curve of the Aerotech L1520T that was used for all simulations can be found below in Figure 3-29.

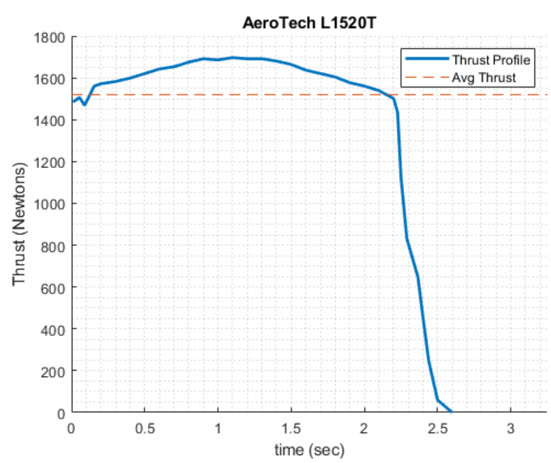

Figure 3-29 Aerotech L1520T Thrust Curve

From Figure 3-28 it is noted that simulations were conducted across a range of pre-loaded wind conditions that RockSim offers. From these simulations the predicted apogee of the full-scale vehicle is 3,775 feet, a rail exit velocity of 70.1 feet per second, and a maximum velocity of 497 feet per second or Mach 0.45. These values comply with NASA requirements 2.16 and 2.227, respectively.

3.6.3 Altitude Verification

The altitude mentioned in the previous section was verified using Barrowman's equations. From this set of equations, the calculated apogee was 3,649 feet. This gives a percentage difference of 3.5% compared to RockSim's value of 3,775 feet. This minimal difference ensures the accuracy of the predicted apogee.

3.6.4 Stability Margin Simulation

The center of gravity and final mass of the launch vehicle were updated in RockSim so that the stability margin of the launch vehicle could be accurately predicted. Fortunately, all changes were relatively minor, and no major impact was made on the launch vehicle's stability margin. However, the final mass of the vehicle ended up being nearly 3 pounds heavier than expected. Estimates before the assembly of the vehicle predicted the stability margin to be 2.18 calibers, once the vehicle was fully assembled it was determined that the stability of the assembled vehicle was 2.15. The stability was again measured on the launch vehicle once the motor was inserted into the vehicle and it was then determined that the true stability of the vehicle on rail is 2.17 calibers which complies with NASA requirements 2.14. The final CG and CP locations are shown in Figure 3-30.

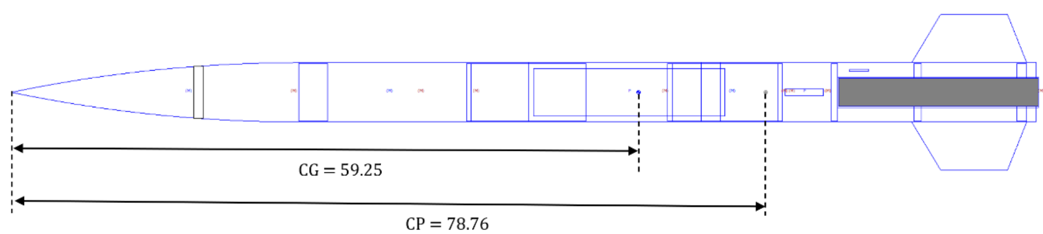

Figure 3-30 CG and CP locations of the Final Launch Vehicle as Built

3.6.5 Kinetic Energy at Landing

Kinetic Energy can be calculated using the following equation, where KE is the kinetic energy of the object, m is its mass, and V is its velocity[3]:

$$KE = \frac{1}{2}mV^2$$

[3] *Kinetic Energy – The Physics Hypertextbook*. https://physics.info/energy-kinetic/. Accessed 7 Nov. 2019.

At landing, the vehicle will be descending under the main parachute. Thus, the velocity under main shall be used to calculate the kinetic energy for each section as seen in the table below. The mass of each section was weighed on a scale as built.

Table 3-2 Kinetic Energy at Landing

Section	Mass	Main Velocity	Kinetic Energy at Landing
Nose cone	.5532 slugs	14.72 ft/s	60.0 ft-lbs
Midsection	.3916 slugs	14.72 ft/s	42.4 ft-lbs
Fin can	.3792 slugs	14.72 ft/s	41.1 ft-lbs

With the heaviest section of the launch vehicle descending with a kinetic energy of 60.0 ft-lbs, the vehicle has a large margin between this value and the maximum as given by requirement NASA 3.3.

3.6.5.1 Alternative Calculation Method

Kinetic energy at landing was also calculated using RockSim as a method of verifying the results of hand calculations. The RockSim model has been mass-locked to the rocket in its fully assembled and ready-for-launch status. The descent velocity as calculated by RockSim under no-wind conditions has been used with the mass of each body section as described above to calculate the kinetic energy.

Table 3-3 RockSim Kinetic Energy at Landing

Section	Mass	Main Velocity	Kinetic Energy at Landing
Nose cone	.5532 slugs	15.39 ft/s	65.5 ft-lbs
Midsection	.3916 slugs	15.39 ft/s	46.4 ft-lbs
Fin can	.3792 slugs	15.39 ft/s	44.9 ft-lbs

The table above tabulates the kinetic energy of each section and shows only a minor increase from hand calculations. There is approximately a 0.7 ft/s difference between the RockSim and hand calculated descent rates due to the method by which RockSim determines the descent velocity of parachutes. RockSim accounts for the spill hole of the parachute and uses an assigned C_D rather than determining it based on manufacturer ratings. Even with a slightly higher descent rate, the nose cone descends with a margin of approximately 10 ft-lbs.

3.6.6 Descent Time

Descent time has been calculated as a necessary component of the wind drift calculations and is detailed further in the following section.

3.6.7 Wind Drift

Wind drift calculations were done by assuming that the rocket traveled straight up to the projected apogee, deployed its drogue parachute, immediately started descending at terminal velocity under drogue, deployed the main parachute at 500 ft, and immediately accelerated to terminal velocity under the main parachute. From apogee to landing, the rocket is assumed to travel in a single direction at constant speed equal to the wind condition. While not wholly accurate to actual performance, this model covers the time between recovery events well. Assuming the rocket immediately reaches terminal velocity at apogee will reduce descent time by a few seconds, while assuming it immediately reaches terminal velocity at main loses a second or two, as the main parachute takes a second or so to fully deploy and accelerate the rocket. Assuming the rocket travels at wind speed in a single direction is also a worst-case scenario.

Given the distance between apogee, main deployment, landing and the rate at which the rocket is falling between these locations, the descent time of the rocket can be simply calculated as such, where t is the descent time, z_d is apogee, z_m is main deployment altitude, v_d is descent rate under drogue, and v_m is descent rate under main[4]:

$$t = \frac{z_d - z_m}{v_d} + \frac{z_m}{v_m}$$

The selected parachutes along with an apogee of 4420 and main deploy altitude of 500 give a descent time of 79 seconds using the equation above. Multiplying this descent time by the speed of a given wind condition gives the distance traveled by the rocket constantly sustaining these winds, as seen in the table below.

Table 3-4 Descent Time and Drift Distance

Wind Speed	Apogee	Descent Time	Drift Distance
0 mph	4420 ft AGL	79 s	0 ft
5 mph	4420 ft AGL	79 s	576 ft
10 mph	4420 ft AGL	79 s	1151 ft
15 mph	4420 ft AGL	79 s	1727 ft
20 mph	4420 ft AGL	79 s	2303 ft

In 20 mph winds, the worst-case scenario considered, the vehicle is projected to descend in 79 seconds, 11 seconds less than the required maximum, and cover 2303 ft, approximately 200 ft less than the required maximum. Given these numbers, this parachute combination is satisfactory and leaves a large enough margin to remain robust to uncertainty.

3.6.7.1 Alternative Calculation Method

In order to verify the validity of hand calculated results, wind drift calculations were also performed using RockSim. A test case was run for each wind speed setting listed in the table below, assuming a constant wind speed throughout the flight. RockSim models position two dimensionally, so the vehicle is assumed to be launched into the wind at a 5° angle and drift in the direction of the wind after apogee. Drift

[4] *Equations of Motion – The Physics Hypertextbook*. https://physics.info/motion-equations/. Accessed 7 Nov. 2019.

distance is calculated by finding the difference between the range at apogee and range at landing data points provided in the details of the flight. Descent time is similarly calculated, using the time at apogee and time at landing data points. This finds the descent time and wind drift of the rocket assuming descent starts directly above the launch pad.

Table 3-5 RockSim Descent Time and Drift Distance

Wind Speed	Apogee	Descent Time	Drift Distance
0 mph	4420 ft AGL	67 s	0 ft
5 mph	4420 ft AGL	67 s	490 ft
10 mph	4420 ft AGL	66 s	976 ft
15 mph	4420 ft AGL	66 s	1443 ft
20 mph	4420 ft AGL	63 s	1855 ft

The table above shows the results of the RockSim calculations. Drift values begin to drastically decrease in comparison to the hand calculations as wind speed increases. This is likely a combination of the previously mentioned faster descent time in RockSim from parachute calculations and the fact that wind speed can in some cases increase the vertical descent speed with the RockSim model. As such, RockSim calculations provide a large margin for satisfying requirements NASA 3.10 and NASA 3.11. RockSim produced a result of 23 seconds of leeway in descent time and over 600 ft of space in drift distance at the highest considered winds.

4. Payload Criteria

4.1 Payload Mission Statement

The payload mission is the collection of a suitable sample size of simulated lunar ice from a location near the launch vehicle landing site by a remotely controlled rover following the deployment of said rover from the launch vehicle. Following sample collection, the rover is to move a set distance from the sample collection area as per the requirements of the NASA Student Launch Competition.

4.2 Payload Success Criteria

Payload success is defined firstly by the requirements set forth by the NASA Student Launch Competition as defined in section 7.3 as well as the team derived requirements set forth by the team derived requirements defined in section 7.4. Additional success criteria as well as levels of success and failure are further defined below in Table 4-1.

Table 4-1 Payload Success Criteria

Level	Project Aspect	Human Aspect
Complete Success	Successful sample recovery, rover movement, and payload deployment Recoverable rover Unimpeded payload deployment and operation	No near misses and/or injuries to team members and/or spectators related to operational or non-operational factors
Partial Success	Successful sample recovery, rover movement, and payload deployment Rover repairable Payload deployment or operation impeded or otherwise delayed during operation	Near miss incidents involving team members and/or spectator related to operational or non-operational factors
Partial Failure	Failure to recover required sample Payload fails to deploy Repairable damage to rover or deployment Rover repairable	Minor team member and/or spectator injuries treatable with basic first aid due to operational or non-operational factors
Complete Failure	Deployment system fails in a manner that leads to severe airframe damage Unrecoverable rover	Severe team member and/or spectator injury due to operational or non-operational factors

4.3BURRITO Design

The design for the payload vehicle is a rover with two coaxial, independently motorized wheels utilizing a plywood body and standard wheels. Because of its two-wheeled design, the rover is designated BURRITO: Bilateral Uptake Rover for Regolith Ice Transport Operations. The two drive wheels are each driven by their own motor; these motors and their shared battery are housed inside the BURRITO chassis. The control systems of BURRITO consist of a microcontroller relaying signals from a radio receiver to the rover's motor controller and servos. The control electronics are housed in a box in the center of the rover chassis called the electronics bay. To maintain stability while driving, the BURRITO features two spring-loaded arms with caster wheels attached to them. These arms deploy from the rover's back end such that, when the rover drives forward, the caster wheels prevent the body from rolling backward. On the underside of the chassis, the simulated ice collection device, designated SICCU, is mounted, with its servos placed inside the chassis. A model of the BURRITO design (as-built) can be seen in Figure 4-1, Figure 4-2 and Figure 4-3. Figure 4-1 shows the stowed configuration of the rover, viewed from the front. Figure 4-2 is an exploded view of the BURRITO that shows the subsystems of the rover. Figure 4-3 shows the major dimensions of BURRITO, in inches.

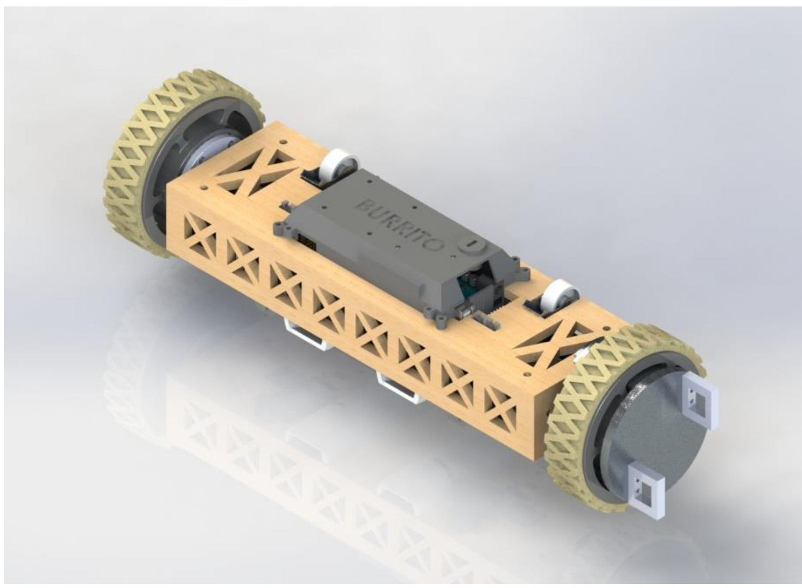

Figure 4-1 BURRITO Front View, Spring-Loaded Caster Wheels Stowed[5]

5 "Hitec HSB-9380TH Servo | 3D CAD Model Library | GrabCAD." [Online]. Available: https://grabcad.com/library/hitec-hsb-9380th-servo-1. [Accessed: Dec-2019].
"L298N | 3D CAD Model Library | GrabCAD." [Online]. Available: https://grabcad.com/library/l298n-7. [Accessed: Dec-2019].
"FrSky X8R w/o antennas | 3D CAD Model Library | GrabCAD." [Online]. Available: https://grabcad.com/library/frsky-x8r-w-o-antennas-1. [Accessed: Dec-2019].
"Files – Resources – AndyMark Inc." [Online]. Available: https://www.andymark.com/pages/resources-files?prefix=STEP%20Files/. [Accessed: Dec-2019].

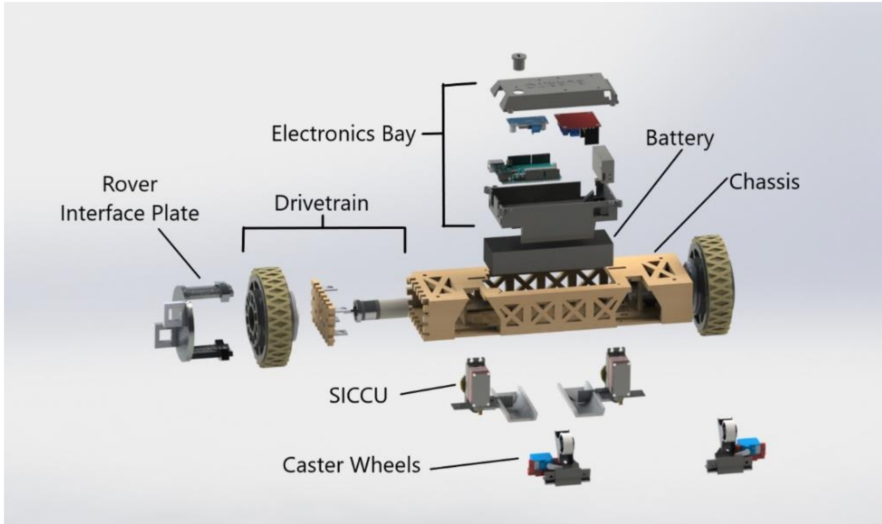

Figure 4-2 BURRITO Exploded View with Labelled Subsystems

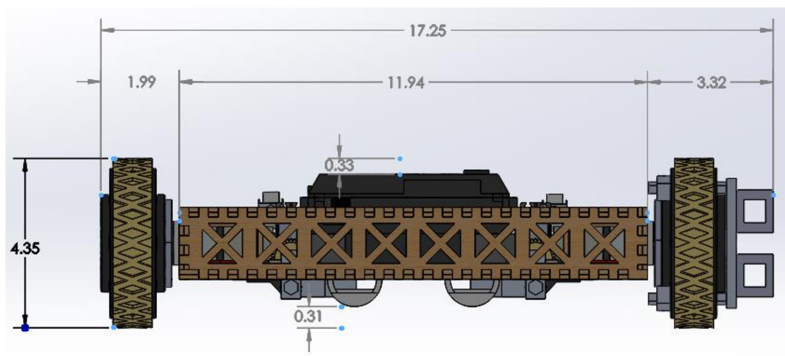

Figure 4-3 BURRITO Front View with Dimensions in Inches

4.3.1 Chassis Structure

BURRITO's chassis is constructed out of birch plywood plates, which were laser cut to shape and adhered together using wood glue. This kind of plywood structure has been

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"Blank Hub with 0.125 in. Dimple." [Online]. Available: https://www.andymark.com/products/hub-aluminum-blank-with-125-dimple?via=Z2lkOi8vYW5keW1hcmsvV29ya2FyZWE6OkNhdGFsb2c6OkNhdGVnb3J5LzVhZjhhYjY0YmM2ZjZkNWUzNmYyMzM1ZA. [Accessed: Dec-2019].

"Arduino UNO and MEGA 2560 | 3D CAD Model Library | GrabCAD." [Online]. Available: https://grabcad.com/library/arduino-uno-and-mega-2560-1. [Accessed: 11-Dec-2019].

"LM2596 | 3D CAD Model Library | GrabCAD." [Online]. Available: https://grabcad.com/library/lm2596-5. [Accessed: 1-Mar-2020].

"Servo Hitec HS-55 | 3D CAD Model Library | GrabCAD." [Online]. Available: https://grabcad.com/library/ servo-hitec-hs-55-1. [Accessed: 1-Mar-2020].

"1/4" Bore 32 Inch Shaft Mount Pinion Gears." [Online]. Available: https://www.servocity.com/0-250-1-4-bore-32p-shaft-mount-pinion-gears. [Accessed: 1-Mar-2020].

"Set Screw Shaft Couplers." [Online]. Available: https://www.servocity.com/ set-screw-shaft-couplers. [Accessed: 1-Mar-2020].

used in previous years in the avionics bays of rockets and is thus capable of sustaining the high accelerations of launch while remaining lightweight. The plates that make up the chassis' sides have rectangular teeth that allow them to interlock with one another, forming a robust structure once glued or bolted together. Each of the plates consists of two 0.125" thick layers of plywood, bonded together with wood glue. The plates feature holes cut such that the motor shafts, servo gears, caster wheel arms, and parts of the electronics bay can protrude from the inside of the structure. Triangular, patterned holes on the front, top, and back sides form a truss-like structure that removes some of the weight of the chassis without sacrificing significant amounts of strength. These holes have an added benefit of creating a small amount of visibility and access to the BURRITO internals, easing the process of any repairs. To allow greater access to the inside of the chassis, the two side plates and upper plate of the chassis are bolted on, rather than glued in place. The bolts attach adjacent plates together via L-brackets at the corners of the side plates. This was be helpful during construction, as it would have otherwise been impossible for the motors to be attached and wired into place. The structure consists of a total of 8 separate plate pieces; the rendering in Figure 4-4 shows the plates assembled into the chassis.

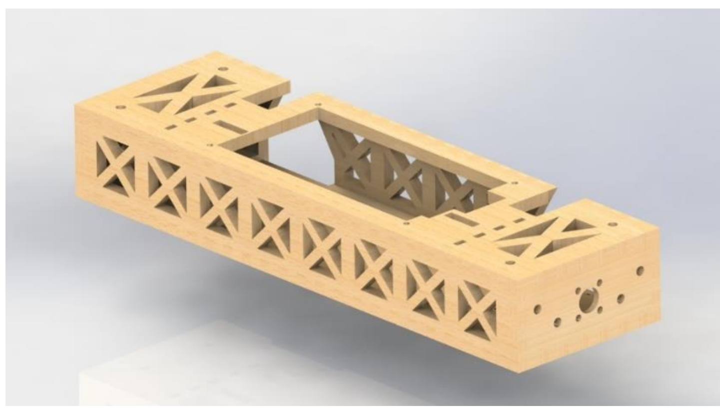


Figure 4-4 BURRITO Chassis Assembled

4.3.2 Drivetrain

The drivetrain of BURRITO consists of two wheels 4.35 inches in diameter, each powered by a DC electric motor. The selected wheels are manufactured by Andymark, and feature "plaction" wedgetop treads, whose malleability allows the wheels to maintain a large contact area with the ground, providing high traction. The selected motors are 350 RPM Premium Planetary Gear Motors from Actobotics; these meet the torque and rotational speed requirements for the rover's operation. The mathematical rationale for these motors is detailed in the section about the powertrain selection calculations ("powertrain" referring to only the motors and battery).

Between the wheels and the motors are modified nylon washers. As BURRITO is launched while resting on the face of one of its wheels, the loads of launch would normally transfer through the thin axle of the connected motor, potentially causing damage. The nylon rings provide a buffer for the rover's weight to rest on; they serve to take compressive loads off the motors' axles. Additionally, the washers have a low coefficient of friction of 0.06

when placed against the aluminum wheel hubs, allowing the motors to spin freely while BURRITO drives.[6] The distance created by the thickness the washers also ensures that the bolts that partially protrude from the wheel hubs do not collide with the rover chassis.

Both motors are powered (through a motor driver) by the same battery, a DRIVE 11.1V 20C 3S LiPo battery with a capacity of 4000 mAh. It was calculated that this capacity would be enough to carry the rover the maximum possible distance to the ice recovery site, with some leftover capacity. The selection of a LiPo battery was ideal due to the high energy density of this type.[7] The same battery also supplies power to the control electronics of BURRITO and the servos (through a buck converter). The sizing and selection of the battery is detailed in the powertrain selection calculations in section 4.3.3. Figure 4-5 shows BURRITO with only its powertrain and some structure to illustrate the arrangement of these parts.

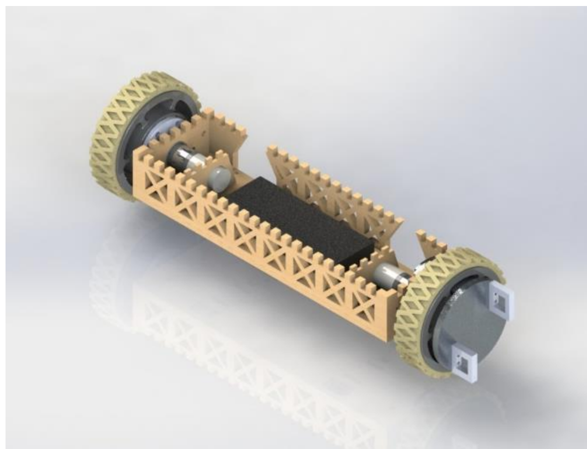


Figure 4-5 BURRITO Powertrain

On the backside of the rover are two spring-deployed arms with caster wheels on their ends. The purpose of these is to provide stability when the rover drives forward; without them, BURRITO's chassis would rotate backwards, preventing forward driving. The arms are connected to spring-loaded hinges, such that, once deployed, the arms can retain their position with some flexibility. A pair of small Hitec HS-55 servos prevent the spring hinges from deploying the caster wheels early; their arms (also known as "horns") block the outward movement of the caster arms. Each arm is 3D-printed such that, when the rover is stowed, a small tab contacts the adjacent servo's horn and holds the caster arm in position. When the caster wheel arm deploys, a separate tab on the arm's underside prevents it from extending too far; each arm holds a caster wheel such that they swivel as the rover turns. Figure 4-6 and Figure 4-7 show the retracted and deployed configurations of one of the caster wheel arms.

6 "Material Contact Properties Table." [Online]. Available: http://atc.sjf.stuba.sk/files/mechanika_vms_ADAMS/Contact_Table.pdf. [Accessed: Jan-9-2020].
7 "LiPo vs NiMH: Comparison of Two Most Popular Battery Type on The Market." AMPOW. [Online]. Available: https://blog.ampow.com/lipo-vs-nimh/#LiPo_vs_NiMH_Weight. [Accessed: Jan-9-2020].

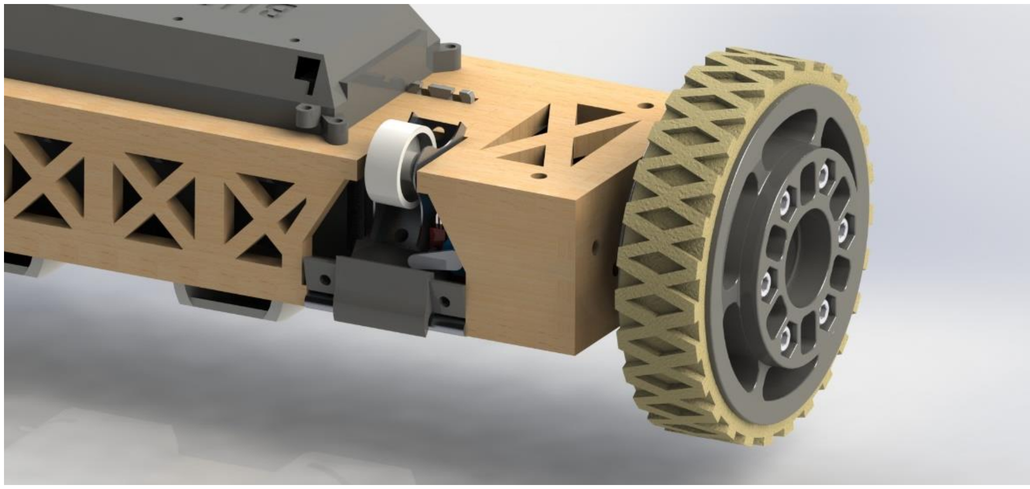


Figure 4-6 BURRITO Caster Wheel Arm Stowed

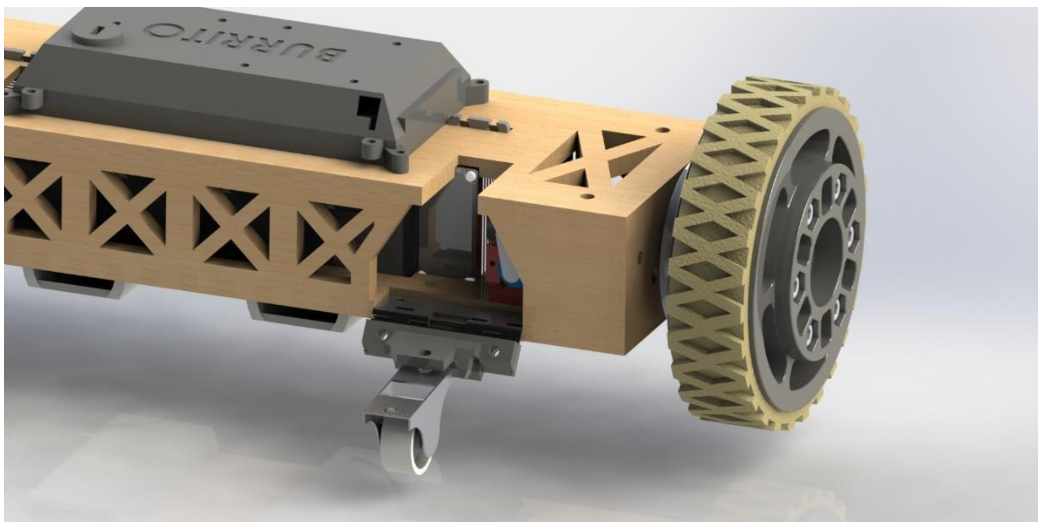


Figure 4-7 BURRITO Caster Wheel Arm Deployed

4.3.3 Powertrain Selection Calculations

An online sizing tool was used to determine the motor and battery specifications required for BURRITO.[8] The following series of equations were taken from the tutorial page on this tool; these equations detail how to produce the battery and motor specifications from rover characteristics.[9]

Though BURRITO was intended to operate on a relatively flat competition field, it was unknown exactly how much resistance the rover would encounter to its forward movement. The online motor sizing tool suggested that a decent approximation of the

[8] robotshopmascot, "Drive Motor Sizing Tool." RobotShop, 2013. [Online]. Available: https://www.robotshop.com/community/blog/show/drive-motor-sizing-tool. [Accessed: Dec-2019].
9 cbenson, "Drive Motor Sizing Tutorial." RobotShop, 2014. [Online]. Available: https://www.robotshop.com/community/blog/show/drive-motor-sizing-tutorial. [Accessed: Dec-2019].

resistance from driving could be obtained by modelling the rover as accelerating on an incline of a specified angle, based on the assumption that the traction between the wheels and the surface was perfect. The following equation was then used to produce a worst-case estimate for the required stall torque (e.g. maximum torque) of the drive motors.

$$T = \frac{100}{e}\frac{RM\big(a + gsin(\theta)\big)}{N}$$

In the above equation, R is the radius of the wheel, M is the mass of the rover, a is the desired acceleration of the rover, g is the acceleration due to gravity, and θ is the angle of the incline, e is the efficiency of the motors, and N is the number of motors.

As the motors needed to run for a specified time, the power they consumed had to be estimated to determine the capacity of the required battery. The first property determined was how fast the motors would need to spin to maintain the desired rover speed. The following equation determined the rpm of the motor that would produce the needed velocity for the rover.

$$\omega = \frac{u}{R}$$

In the above equation, ω is the rotational speed (in rad/s) of the required motor (this is normally converted to rpm), while u is the voltage of the motor's power source and R is the radius of the attached wheel.

Not only did the rotational velocity of the motors need to be known, but the time the battery needed to operate for had to be determined. The following equation determined the time of operation based on the rover's speed and the distance it had to travel.

$$\mathrm{t} = \frac{D}{V}$$

In the above equation, t is the time the rover must operate for, D is the distance the rover must travel, and V is the desired speed for the rover.

Once the needed rotational speed and time of operation were obtained, the following equation was used to determine the capacity of the battery needed to supply the motors with power.

$$c = \frac{T\omega}{V}t$$

In the above equation, c is the amp-hour capacity of the battery needed, T is the torque of the motors being used, ω is the rotational speed of the motors, V is the voltage of the battery, and t is the time the battery needs to operate for. It should be noted that the capacity c is *per motor*, meaning that the total capacity needed for BURRITO would be c multiplied by the number of motors.[10]

The amount of current the battery needed to supply each motor was also determined, using the following equation.

$$I = \frac{T\omega}{V}$$

In the above equation, I is the current required per motor, T is the torque of each motor, ω is the rotational speed of the motors, and V is the voltage of the battery. The current, like the capacity, is also per motor, meaning that the battery will need to supply enough current for both motors combined.

The sizing tool used the equations to determine the motor and battery specifications the rover would need to have. In order to correctly determine the battery size, a battery needed to be preselected so that its mass could be added to the total mass of the rover in the calculations. Likewise, motors needed to be preselected so that their weight would be included. The preselected battery was the Hyperion G5 50C 3S 4000mAh LiPo Battery, as it exceeded previous estimates for the capacity required and fit well inside the chassis of BURRITO. The preselected motors were the family of Premium Planetary Gear Motors by Actobotics, as many of them shared the same mass and only varied in their torque and rotational speed, making selection more flexible.

With the preselected components in place, Table 4-2 was used to add up the weights of the components for BURRITO; the total mass from this was then used with the aforementioned equations in the online tool to determine if the batteries and motors were of the correct specification. It should be noted that the total mass at the end of the table is not the same as the rover's as built mass; these calculations were completed prior to actual assembly of the rover. The rover's as-built mass is 4.76 lbs (note that this includes the added weight of the SICCU system and the interface plate for retention whereas original estimates did not).

Table 4-2 List of Weights for Final Rover Components

Product Name	Weight (lbf)
(2x) 350 RPM Premium Planetary Gear Motor	0.4
Hyperion G5 50C 3S 4000mAh LiPo Battery	0.65
(2x) 4" Plaction Wheel	0.98
(2x) Blank Hub	0.3
HiLetgo L298N Motor Driver	0.01
(2x) 1" Diameter Rigid Caster Wheel	0.04
(2x) Spring Hinge	0.06

[10] cbenson, "Drive Motor Sizing Tutorial." RobotShop, 2014. [Online]. Available: https://www.robotshop.com/community/blog/show/drive-motor-sizing-tutorial. [Accessed: Dec-2019].

FrSky Taranis Compatible Receiver X8R	0.04
(2x) Planetary Gear Motor Mount A	0.04
(Birch Plywood)	0.25
TOTAL	**2.77**

Once the weight of the rover was known, the other characteristics of the design could be entered into the online calculation tool. Table 4-3 outlines the inputs that were used for the final design. Some of the inputs were left to their default values provided by the tool; this was done to remain consistent with the tool's estimates for motor efficiency and rover traction. The speed of the rover was assumed to be 4 mph, slightly above walking speed, such that driving the rover would not take up significant time. The maximum distance was taken to be 2550 ft, approximately the farthest distance a rocket could land from a recovery site based on the field map for the Student Launch competition. The speed and distance combined yielded an operating time of 7.24 minutes. It should be noted that the estimated distance was higher than in the requirements established for the rover; the higher estimate was considered more accurate and resulted in the addition of range buffer that was assumed to account for some of the additional power draw of driving over rough terrain.

Table 4-3 Final Rover Design Calculation Inputs

Variable Name & Units	Value	Default?
Total weight, lbf	2.77	N
No. of drive motors	2	N
Radius of wheels, in.	2.175	N
Velocity, ft/s	5.87	N
Maximum incline, deg	20	Y
Supply voltage, V	11.1	N
Desired acceleration, m/s^2	0.2	Y
Desired operating time, s	7.24	N
Total efficiency, %	65	Y

The tool returned specifications which were compared against the preselected battery and motors; they are listed in the Table 4-4.

Table 4-4 Final Rover Design Calculation Outputs

Variable Name & Units	Value
Motor rotational speed, rpm	309
Motor stall torque, oz-in.	26.9
Max current (total), A	1.10
Battery capacity (total), mAh	2674

The resulting rotational speed and torque specifications were well within the capabilities of the 350 RPM Premium Planetary Gear Motor from Actobotics, whose stall torque is

79.2 oz-in[11]. The preselected Hyperion battery also exceeded the required specifications by a large margin, with a maximum current of 100 A and a capacity of 4000 mAh.[12] Though the battery model was later changed to the DRIVE instead of the Hyperion brand, the output voltage and capacity. With large margins in both motor specifications and battery specifications, the final design for BURRITO was deemed capable of traversing even the maximum distance possible from the ice recovery sites.

4.3.4 Electronics

The electronics of BURRITO consist of a microcontroller connecting a radio receiver to a motor speed controller and four servos; the microcontroller and servos are powered by a buck converter. The microcontroller, receiver, motor controller, and buck converter are all housed in a protective casing to shield the components from dirt and moisture. This casing, known as the electronics bay, is 3D printed out of ABS, ensuring a perfect fit with the plywood chassis of the rover and the electronics inside. The bay has a removable lid such that the electronics are easily accessible; this lid is bolted into place on each corner to prevent accidental opening during operation. The electronics bay also features holes on all sides that allow power and signal wires to be connected between the battery, motor, servos, and the components inside the bay. Additionally, the underside of the electronics bay holds the LiPo battery in place within the chassis. The bay itself is bolted to the chassis' upper plywood plate on its corners and is removable to allow access to the battery. Figure 4-8 shows the arrangement of components inside the electronics bay; the lid has been separated from the bay and flipped 180° position to show the attached electronics.

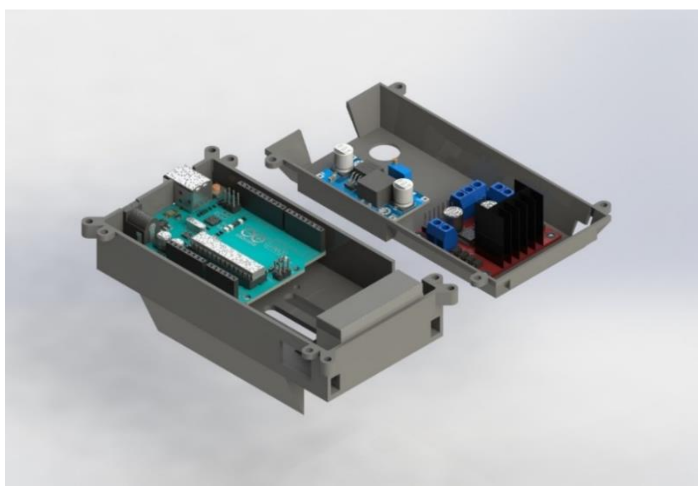


Figure 4-8 BURRITO Electronics Bay Interior

[11] "350 RPM Premium Planetary Gear Motor." ServoCity, 2019. [Online]. Available: https://www.servocity.com/350-rpm-premium-planetary-gear-motor. [Accessed: Dec-2019].
[12] "Hyperion G5 50C 3S 4000mAh LiPo Battery." RobotShop, 2019. [Online]. Available: https://www.robotshop.com/en/hyperion-g5-50c-3s-4000mah-lipo-battery.html. [Accessed: Dec-2019].

The microcontroller is an Arduino Uno. The simplicity of the Uno's programming language, along with the availability of online tutorials for connecting it to motor and servo systems, made the Arduino an ideal choice for the simple control application of BURRITO. The motor controller is the L298N Motor Driver, a commonly used chip with the ability to power two motors from the same power supply. Because it utilizes an H-bridge circuit, it can drive the connected motors forward as well as in reverse.[13] The radio receiver is an FrSky X8R, which operates on the same band (2.4 GHz) as the compatible X-Lite transmitter the team already owns. The X8R features 8 PWM channels, more than enough to control two motors and four servos. The buck converter is an LM2596, capable of receiving and outputting a wide range of voltages.

The Arduino Uno is wired such that it receives signals from the X8R and translates those signals to movements in the servos and the motors, going through the L298N to send motor signals. The connections between the Arduino Uno, X8R, servos, and L298N Motor Driver transmit PWM (Pulse-Width-Modulation) signals. As for power transmission, the DRIVE 11.1 V battery directly connects to the L298N Motor Driver and the LM2596 buck converter. The L298N transfers power to the drive motors on command, while the buck converter regulates the voltage down to 7.0 V so as not to damage the connected Arduino and servos. Figure 4-9 illustrates this setup in the form of a flow chart.

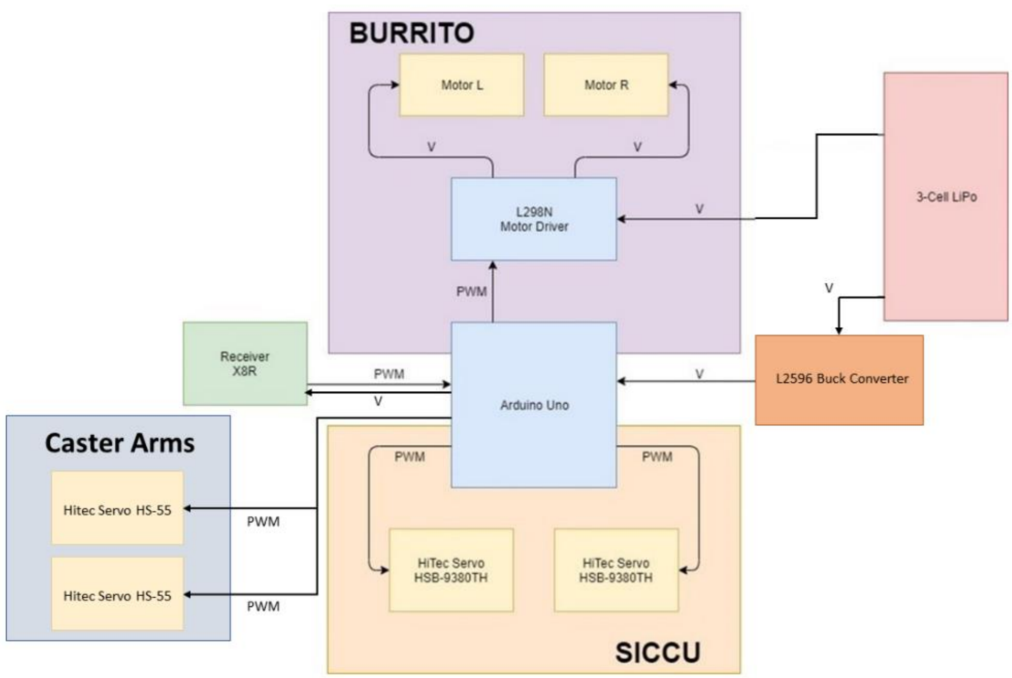


Figure 4-9 BURRITO Electronics Flow Chart

[13] Dejan, "Arduino DC Motor Control Tutorial – L298N | PWM | H-Bridge." HowToMechatronics, 2019. [Online]. Available: https://howtomechatronics.com/tutorials/arduino/arduino-dc-motor-control-tutorial-l298n-pwm-h-bridge/. [Accessed: Dec-2019].

The following scenario illustrates exactly how data flows through the electronics systems to drive the rover. First, the operator of BURRITO moves the left stick of the radio transmitter upward. The signal of this movement is received by the X8R, which causes it to activate the corresponding channel out of the 8 that it has. A wire carries a PWM signal from this channel to the Arduino Uno. The Arduino Uno's software interprets the PWM input using its onboard program; it then sends a PWM output on three different output pins to the L298N Motor Driver. Upon receiving the three signals, the L298N translates the PWM input to a voltage output and direction for the left motor. Because the signals are received on the left side of the L298N's inputs, the voltage output is applied to the left motor. The PWM signals on two of the pins carry information on which direction the motor should rotate, and the third determines how quickly the motor should spin. As the operator moves the left stick up, the left motor rotates forward. This process is largely the same for operating the servos in the SICCU ice collection system and the caster wheel deployment system but does not require the medium of a motor driver. The servos for the scoops of the SICCU collection system are actuated by moving the left and right controller sticks to their left and right. The servos for the caster wheel deployment system are moved by flipping a switch on the back of the controller.

Figure 4-10 is a schematic showing the electrical layout of the BURRITO systems. The five channels connected from the X8R receiver to the Arduino Uno carry the signals received from the operator's remote controller. After the Arduino interprets these signals, ports connected to the servos and the motor controller command the movement of the servos and motors. It should be noted that a switch controls power flow from the battery; this must be flipped to the "on" position prior to launch.

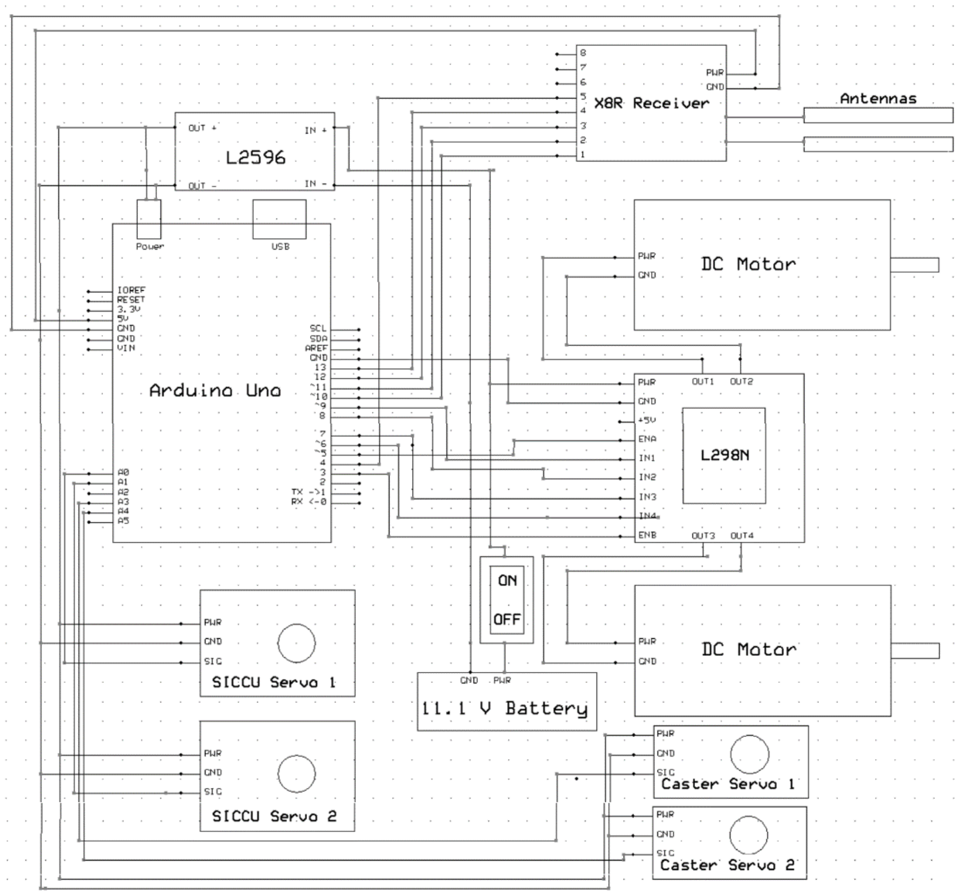


Figure 4-10 BURRITO Electronics Schematic

4.3.5 SICCU Mounting

In order to maintain BURRITO's clearance off the ground, a large portion of the SICCU system is mounted inside the chassis of the rover; namely the servos. The servos selected for SICCU are just thin enough to fit between the drive motors and the battery, and short enough to be sandwiched between the upper and lower plates of the chassis. Both of these chassis' plates feature cutouts such that the servos are constrained from shifting in all directions. Additional cutouts allow enough room for the servo signal and power wires to loop back into the electronics bay. Another pair of cutouts allow gears to transmit rotation from the servos to the scoops below. The rendering in Figure 4-11 shows how the SICCU system will interface with the structure of the BURRITO chassis; the front chassis plate has been removed for visibility.

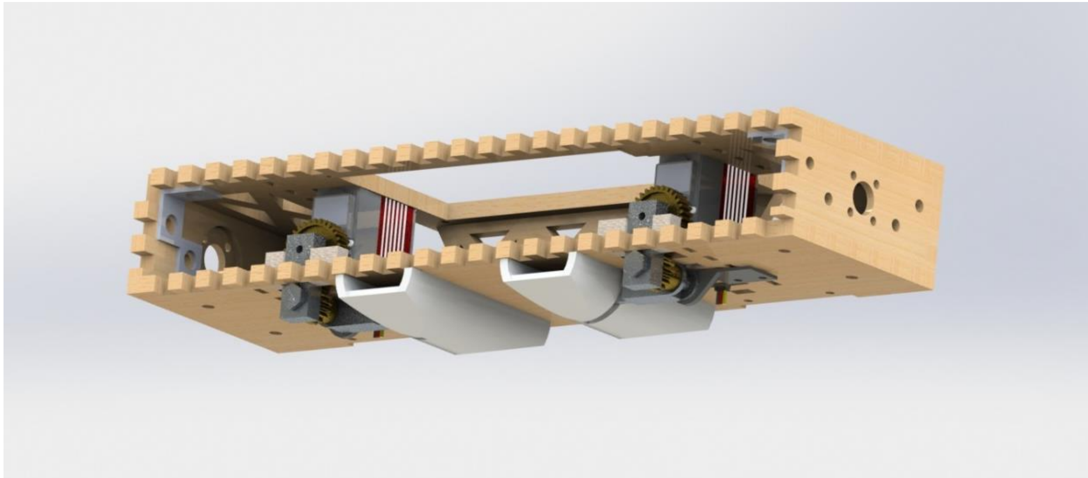


Figure 4-11 BURRITO Interface with SICCU

4.3.6 SICCU

The SICCU consists of four major subsystems being the scoop, the arm, gear system and the servo. Together, they function in concert to provide the capability of acquiring and retaining a sample of simulated lunar ice. The entirety of the system with the chassis of the rover can be seen in Figure 4-12. The governing dimensions of the SICCU System can be seen in Figure 4-13 and Figure 4-14.

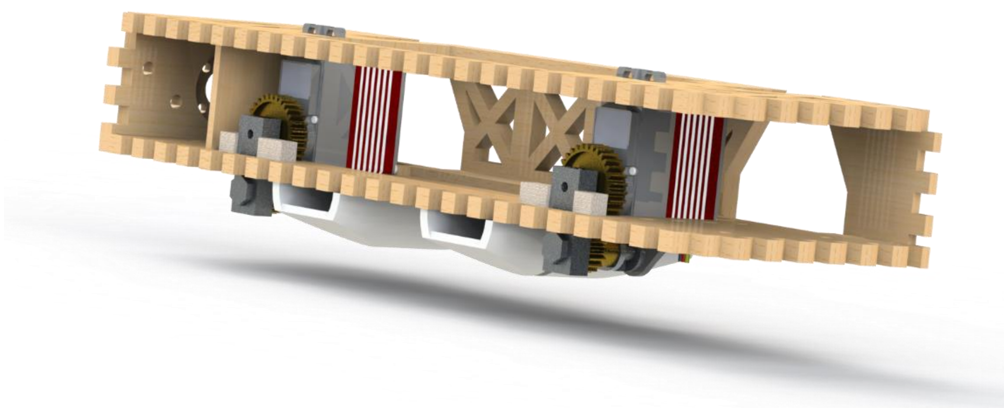


Figure 4-12 Angled View of SICCU

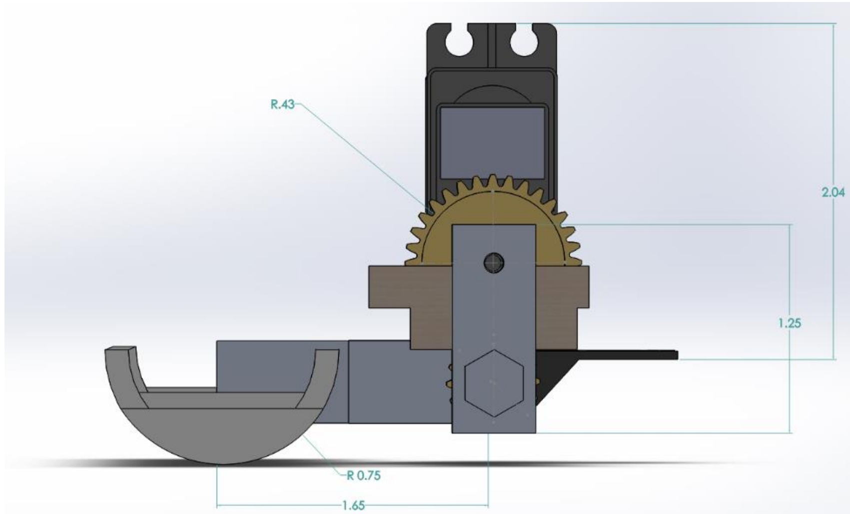


Figure 4-13 Dimensioned SICCU Profile

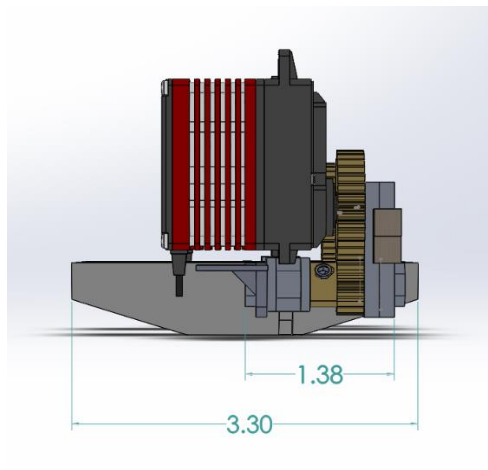


Figure 4-14 Dimensioned SICCU Side

4.3.6.1 Scoops

The scoops are made from 0.75” Schedule-40 PVC pipe. This pipe has been cut axially and deformed such that the width has increased while the depth decreased. This was done for the purpose of ensuring a suitable internal volume while maintaining favorable clearance for the BURRITO relative to the terrain and can be seen in Figure 4-15. The front and rear ends of the scoops are cut at an angle to better facilitate the fit of the BURRITO in the payload bay as seen in Figure 4-16.

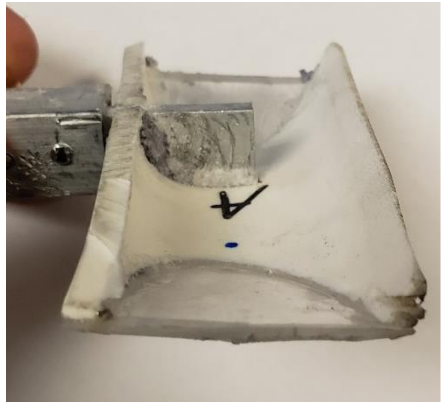


Figure 4-15 Angled Profile View of SICCU Scoop

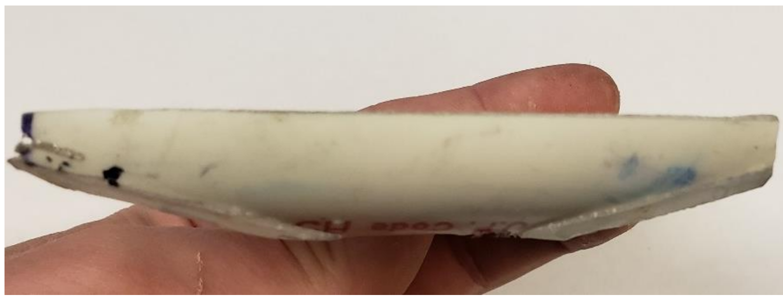


Figure 4-16 Side View of SICCU Scoop

4.3.6.2 Arm

The method for connecting the scoop to the gear to the arm is through an aluminum arm that is made up of two parts being the Arm Shell and the Arm Tab. The Shell is a 0.875” section of 0.5” channeled aluminum. This portion of the arm functions to provide structural strength while the scoop digs. The Arm Shell also as serves as the attachment point between the arm and the gear via JB Weld. The Arm Tab is a 1.45” piece of 0.5” aluminum bar. The Arm Tab serves as the mechanical member attaching the Scoop to the rest of the arm. The Arm Tab and Arm Shell are pinned to each other at two positions 0.35” apart.

Figure 4-17 Profile View of the Arm

4.3.6.3 Gear System

The gear system is the critical subsystem of the SICCU due to its role in delivering the power to the rest of the SICCU. The components are as follows the Cover, the Gears, the Brace, and the Rod. The Cover is made of 3D-Printed PLA and serves to keep the Rod aligned and in-place. The exposed gear is a 0.25" Bore 32 Pitch Shaft Mount Pinion Gear with a pitch diameter 0.5". This gear is engaged with the interior gear that is a 32P, 25T 3F Spline Mount Servo Gear with a pitch diameter of 1". The Brace is made of two aluminum bars that a are 1.2" long. It has a 0.25" hole and 0.09" hole drilled through both bars that are 0.65" apart. The Brace serves to keep the two gears properly engaged. Connecting all of these components together is a 0.25" threaded rod.

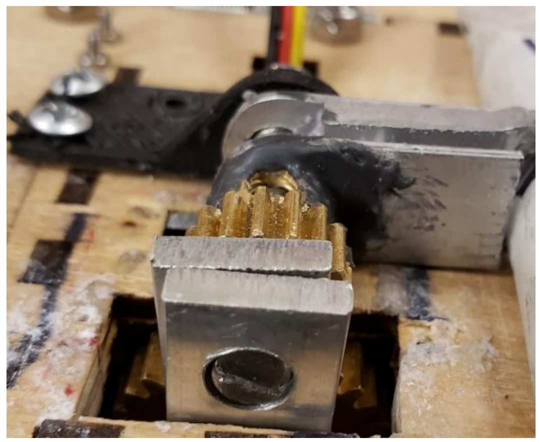


Figure 4-18 Gear System

4.3.6.4 Servo

The Servo is a HiTec D951TW model and was chosen due to its high-torque capability. According to the manufacturer since the servos are operated at ~7.0V it is specified to have ~486 oz-in of output.

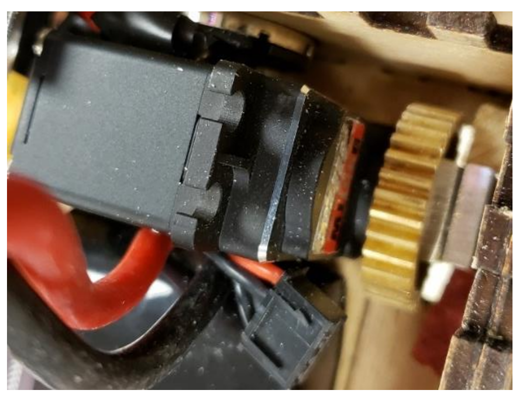


Figure 4-19 SICCU Servo

4.4 BURRITO Construction

The following subsections describe how BURRITO progressed from a design to a working payload vehicle. The manufacturing processes involved are covered, as well as the design changes that resulted from issues with construction.

4.4.1 Chassis Structure

Construction of the chassis began with the CAD models of the vehicle chassis. A 2-D sketch of each piece to be laser cut was created at 1:1 scale, and laser cut out of 1/8" aircraft-grade birch plywood. Each plate of the chassis was created using two nearly identical sheets of cut plywood, with the inner and outer plates differing slightly to provide wells in which certain components sit and are prevented from moving such as the motors, servos, and caster wheel hinges.

Each of these near identical plates was glued to its mate using wood glue, and the front, back, and bottom plates were glued to each other along their jigsaw piece connections using wood glue.

In order to access and install the drive motors, the left and right plates had to be made removable and installable over the drive motor. These side plates were installed using L-brackets bolted to the bottom plate. Bolts were fastened through the side plates to the L-brackets, and nuts were used to hold them in place. Holes were countersunk on the side plates to prevent the bolts from interfering with wheel movement. Figure 4-20 shows the L-brackets that held the side plates to the bottom plate.

Figure 4-20 An L-bracket securing the BURRITO Plates

The top plate of the chassis was initially intended to be glued together along with the front, back, and bottom plates, but this concept was modified after considerations were made to the modification or repair of components. Having the top plate permanently affixed would have made removal of certain components such as the drive motors impossible, in addition to greatly increasing the complexity of wiring components together inside the chassis. As a result, the design was modified to make the top plate removable. The top plate was affixed to the rest of the rover using L-brackets bolted to the side plates. The top portion of the L-bracket had a bolt adhered with JB Weld to it such that the threaded end stands straight up, shown in Figure 4-21. The top plate, with corresponding holes, was fit over these bolts and into the jigsaw edges, then held in place with nuts threaded on the freestanding threads of the bolts. This made the nuts easily accessible with a wrench if the top needed to be removed from the rover.

Figure 4-21 L-Bracket with adhered bolt

Small L-shaped pieces were cut out of spruce and glued on the two sides of each of the SICCU gear bracket, which served to keep the gears powering the scoops mechanically connected to one another. This was done because the slots originally cut for the gear brackets were too large and the brackets would rotate within the slots. The L-shaped wood pieces provided structural filler to prevent such movement. The wood pieces can be seen on either side of the gear bracket in Figure 4-22.

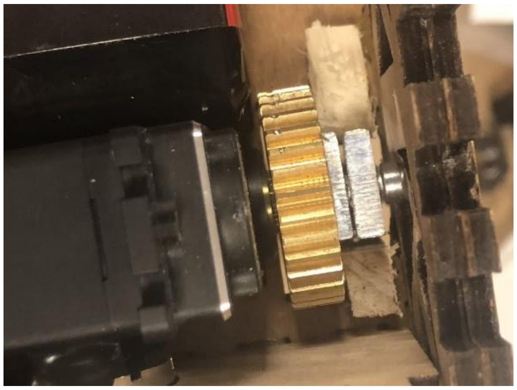


Figure 4-22 Shaped Wood to Hold Gear Bracket in Place

When it was decided that additional servos were needed for the caster wheel system, as well as when the SICCU was installed, additional holes were drilled into the bottom plate of the chassis.

During installation of the battery and electronics bay, extensions to the hole that held the electronics bay were made so that power wires coming from the battery and routing to the Arduino Uno’s barrel port had enough room to pass.

4.4.2 Drivetrain

Construction of the drivetrain began after the rover chassis was completed. The drive motors were held in place by holes cut in the wooden chassis and by bolts on the motors' front faces. Connectors were soldered onto the motor's power tabs after it was determined that a breakable connection to the electronics bay was needed. Divots were drilled into the keyed portion of the motor axles for reasons explained in the following paragraphs. Both the bolts holding a motor in place and a divot drilled in its axle can be seen in Figure 4-23.

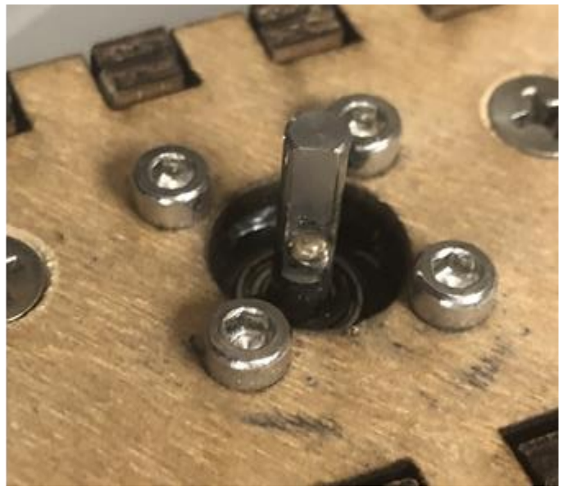


Figure 4-23 DC Motor Mounted to Chassis

It was determined that a divot needed to be drilled in the motor axles because the wheels relied on a set screw using friction to stay attached. It was found that the wheels could be pulled off the axle easily, so divots were drilled into the axles so that the set screws would set inside them. By doing so, the divots prevented the set screws, and thus the wheels, from sliding off their axles.

The wheels themselves were built from a primary wheel part bolted onto a hub by three bolts. At the center of this hub was a 0.5-inch diameter hole that accommodated an axle adapter. The axle adapter had holes for set screws on each end of it. The one inside of the hub had a 0.5-inch long set screw placed in it that was long enough to go through both the axle adapter's hole and a corresponding hole drilled into the side of the hub. This 0.5-inch set screw prevented the axle adapter from sliding into or out of the wheel. At first, adapter movement into the wheel was rendered impossible when the 0.5-inch diameter hole was not drilled deep enough; this prevented proper installation of the axle adapter. This problem was remedied when new hubs were ordered that featured a 0.5-inch through-hole.

In the initial design, nylon washers that provided a slick surface and axial support for the wheels were to be laser cut from a larger section of material. Instead, existing washers were purchased and then drilled to have holes that could accommodate the protruding heads of the bolts holding the motor in place. The washers were also cut on a scroll saw such that the set screws that retained the wheels to the axles could be accessed once the wheels were slid into place and the set screws were positioned over the divots in the motor axles. Figure 4-24 shows the wheel assembly, along with the nylon washer surrounding the axle adapter and the black set screw used to attach the wheel.

Figure 4-24 Wheel Assembly with Nylon Washer

During manufacturing of the caster wheel system, it was realized that the payload bay of the rocket would not be capable of holding the caster wheel arms closed due to its diameter being larger than assumed. As a result, it was decided that small servos needed to be added such that their arms could hold the caster wheel arms shut against the force of the spring hinges. Since the servos to deploy the caster wheels were added after the chassis was already laser cut, 3D-printed supports were needed to provide a surface for the servos to mount to. These were printed on the team's Rostock Max V2 3D printer, and featured holes such that the servos could be bolted onto them and the parts themselves could be bolted into the lower plate of the chassis. Once new holes were drilled in the chassis, the small servos were attached in place next to the caster wheel arms. One of the two caster deployment assemblies is shown in Figure 4-25.

Figure 4-25 Caster Wheel Deployment Assembly

To create the arms that held the caster wheels, a CAD model of the caster wheel arms was sent to the team's Rostock Max V2 3D printer and printed. After the first attempt resulted in support material filling a necessary slot, the parts were split in two in CAD. These parts, however, were of low quality when printed due to their small size. It was also realized at this time that small servos would need to retain the caster wheel arms, so the shape of the arms had to be altered to facilitate this. For the next iteration of these arms, the files were sent to a correspondent with access to a high-resolution 3D printer with dissolvable supports. The resulting parts were stronger and had more precise shapes. Once it was demonstrated that these arms could be held back by the caster deployment servos, the caster wheels were bolted along with washers to the ends of the arms. The spring hinges were bolted on one end to the caster arms, and on the other end to the lower chassis plate. One of the two completed caster wheel assemblies is shown in Figure 4-26.

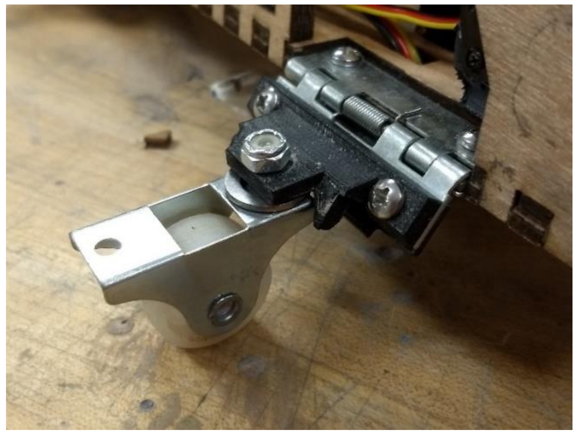


Figure 4-26 Deployed Caster Wheel

During initial ordering of the parts, the Hyperion G5 11.1V 4000mAh LiPo battery was replaced by the DRIVE 11.1V 4000mAH LiPo battery. This was because the Hyperion batteries were out of stock; the replacement was acceptable due to the two batteries having the same output.

4.4.3 Electronics

The electronics bay and lid were 3D printed on a Rostock Max V2 3D printer. The lid was the first element modified for manufacturing and was redesigned to included chamfered sides which increased the internal volume of the electronics bay. The previous design was flat and allowed components to protrude through the top unprotected. Once the new lid was printed, the electronic components were placed in the electronics bay, with the Arduino Uno, L298N motor driver, and X8R receiver placed farther apart than originally intended to increase available volume for wired connections. Initially, the Arduino and motor driver were mounted using standoffs within the electronics bay. However, due to the lack of space within the electronics bay, the standoffs on the motor driver (and, once introduced, the buck converter) were removed. The motor driver was attached with a piece of packing foam sandwiched between it and the underside of the lid; this prevented the protruding points of the component's pins from being damaged when the driver was bolted in place.

Another design modification was the addition of the LM2596 buck converter. It was discovered that the Arduino needed a lower voltage than provided from the direct battery connections and that Arduino did not provide the power necessary to drive the servos. The buck converter reduced the battery-supplied 11.1 V to 7 V, which was usable by both the Arduino and servos. It was mounted to the electronics bay lid in the same fashion at the motor driver. Initially, it was mounted using standoffs; these were removed for the reasons stated already.

When it was found how many wires needed to reach outside the electronics bay to reach the battery, servos, and Arduino, a rectangular hole was cut to allow these wires to be routed. When it was found that the Arduino barrel port was inaccessible to a power plug, the upper plywood plate was modified so that there was a larger hole around the barrel port. Additionally, a power switch was deemed necessary so that the power to the whole rover could be toggled without disconnecting and reconnecting the battery. A 0.5-inch diameter hole was bored into the electronics bay lid, and a rotary power switch was mounted and connected via directly soldering wires. The rotary power switch was selected as it was less likely to be switched on or off accidentally. The modifications to the electronics bay and the plywood chassis can be seen below.

Figure 4-27 Holes in Electronics Bay Lid

Drive motor power was provided to the motors from the motor driver via quick-disconnects, shown in Figure 4-28. A permanent connection was not used, as it would prevent the electronics bay from being removed if needed.

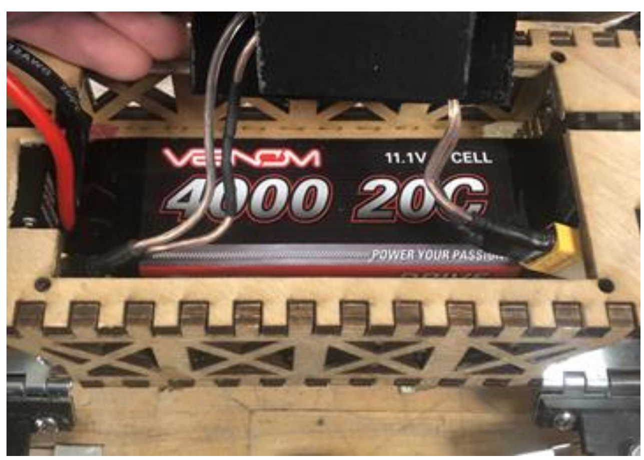


Figure 4-28 Quick Disconnect attachments

Within the electronics bay, power to the buck converter and motor driver were provided by multi-threaded wires soldered or screwed into place, and power to Arduino Uno was provided by a barrel-jack connector. Any signal connections between components were achieved through Dupont-style jumper cables. Wire connections were all cut-to-length as needed to reduce excess volume. The antennas of the receiver protruded through a hole in the lid, which had to be widened after printing. The arrangement of wires and components inside the electronics bay can be seen in Figure 4-29. The electronics bay was successfully bolted closed on all four corners with the components inside. Once closed, the bay was successfully bolted on all four corners to the upper plate of the chassis.

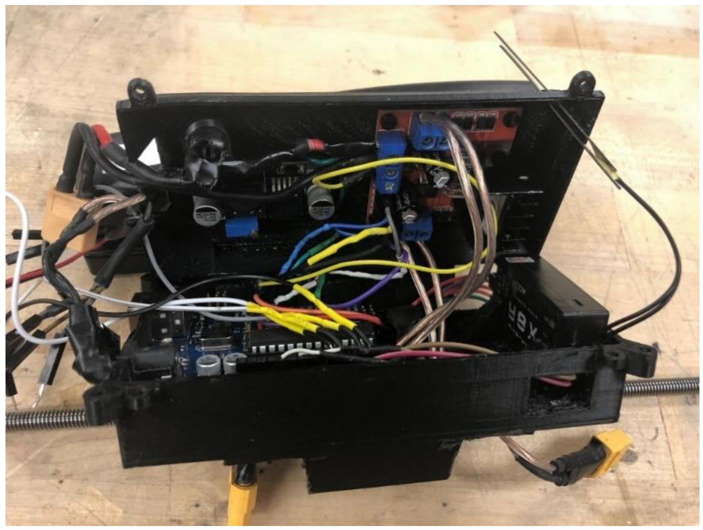


Figure 4-29 Open Electronics Bay

It should be noted that the voltage indicators were removed from the design; this was because there was no justifiable need for them. The rover would be fully charged prior to launch, and the amount of distance it would need to travel could not be controlled. As such, the driver of the rover would be working with a full battery with a set distance to travel. The amount of remaining charge could not give the driver any information to act on, as they would try to drive the distance no matter how large it was.

4.4.4 System Integration

The designed plate for connecting the rover to the retention system was successfully installed on BURRITO's left drive wheel. Figure 4-30 shows how this plate protrudes through the spokes of the wheel and fastens to the other side.

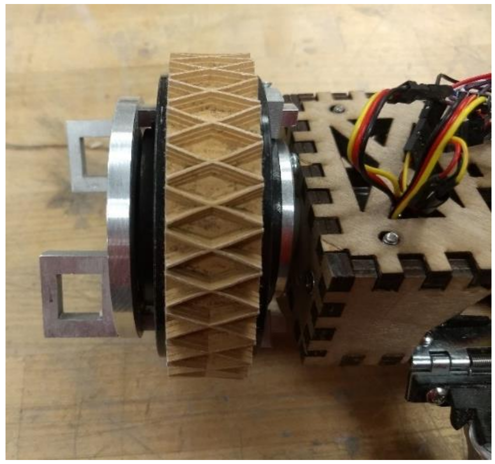


Figure 4-30 Placement of Retention Plate

4.5 Payload Integration Design

The payload retention system consists of three primary sub systems which will be covered in the following order: mechanical latch, rover interface, and radial supports. Following the predicted maximum of 40 g's and the initial rover weight of 6 pounds, the system has been built to withstand a minimum of 360 lbf. The following sections will break down each component of the system, as built, how it has performed under testing.

4.5.1 Mechanical Latch

4.5.1.1 Base Plate and Guide Tracks

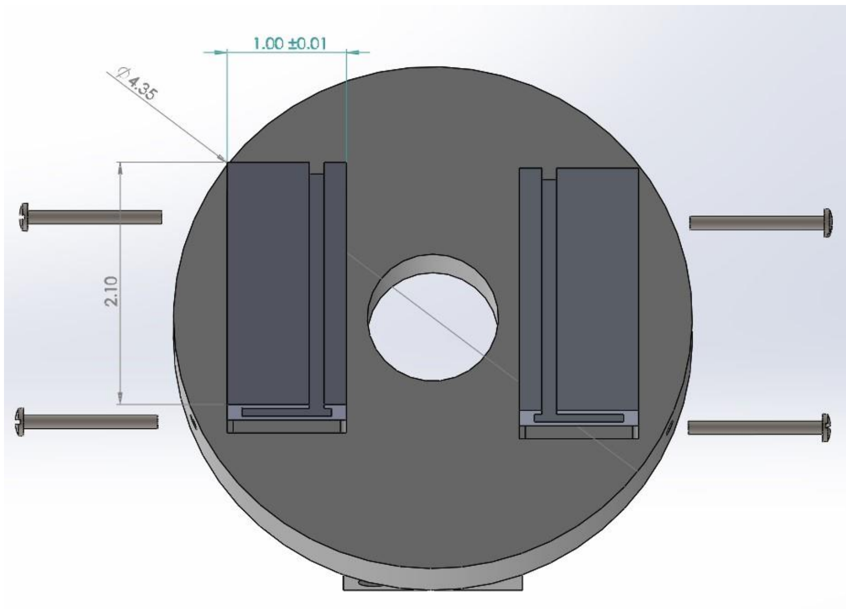


Figure 4-31 Base Plate Design

The dimensions of the guide tracks and retention plate, as well as the rest of the payload retention and deployment systems have stayed within 0.01 inches of the reported values during the design phase. All components were 3D printed to size, modeled specifically off the manufacturer's specifications or sent to NCSU's MAE precision machine shop. The inside wall of the guide tracks were tapped, and four C4-40 bolts were threaded through the taps and into the PLA base plate, securing the guide tracks to the retention plate.

4.5.1.2 Linear Actuated Locking

As previously stated, all dimensions have stayed consistent to the those presented within the CDR documentation to 0.01 inches. Figure 4-32 shows a side view of the retention plate. Most of the load during main chute ejection is transferred through the guide tracks and an additional 0.2 inches of PLA was included to the thickness of the retention plate underneath the tracks to offer additional support. A second modification was made to the plate in order to connect the retention plate to the electronics bay of the overall system. This modification can be seen on the bottom of the plate's sideview in Figure 4-32, which shows two holes sized to fit quarter inch dowel rods that were used to secure the two components. The red circles within the following images denote problem areas that had to be addressed during the manufacturing of the system and are covered within section 4.6.

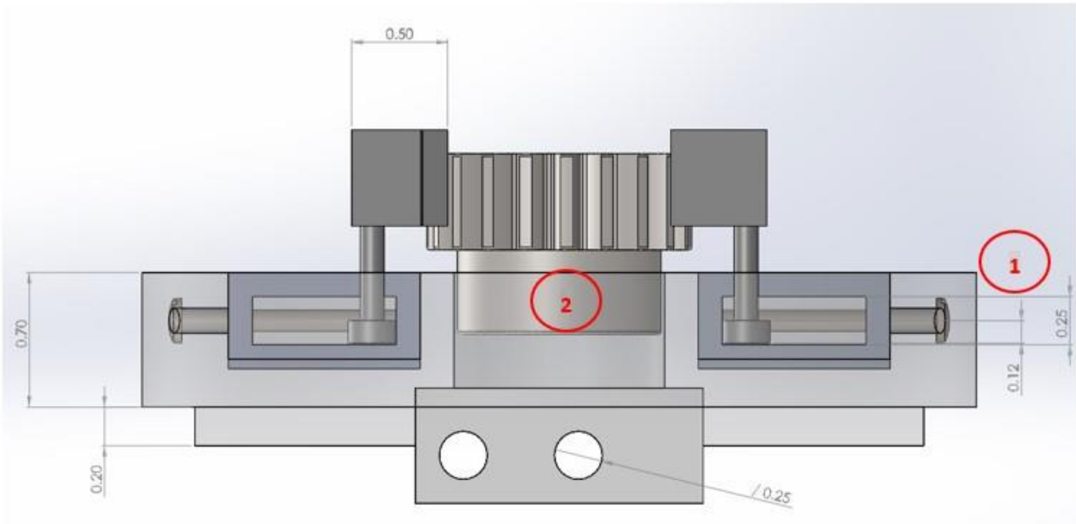


Figure 4-32 Retention Plate Side View

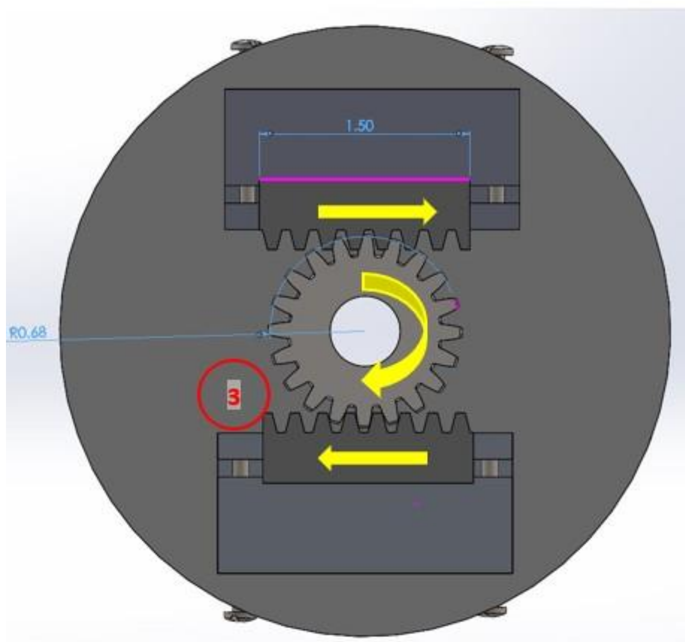


Figure 4-33 Retention Plate Front View

4.5.2 Rover Interface

The most complex piece of the retention system can be seen in Figure 4-34 and Figure 4-35. This component is permanently fixed to the rover and is only fixed to the rocket throughout the flight phase. The piece was machined from an aluminum block the two 2.25-inch legs fit through the spokes in the BURRITO and the C4-40 holes through the legs allow for a locking "ring" to be placed on the aft side of the rover wheel, securing the plate to the rover. The bottom left sub-image in Figure 4-34 also depicts two pairs of additional C4-40 holes, that secure two square locking brackets to the retention plate that can be seen in Figure 4-35.

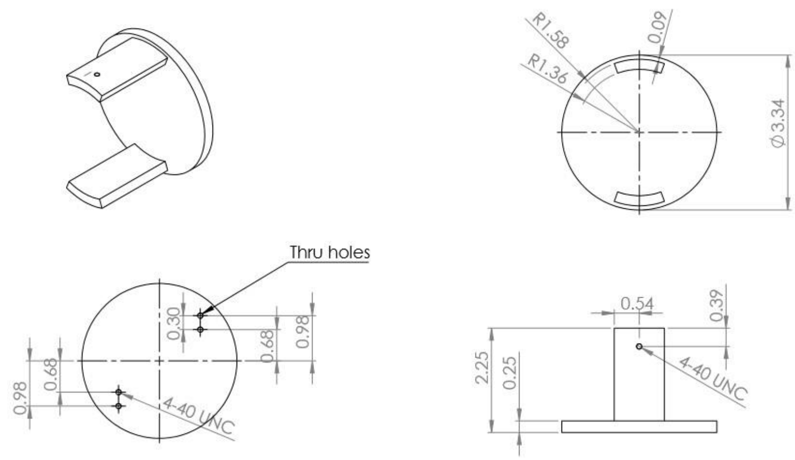


Figure 4-34 Rover Interface Drawings

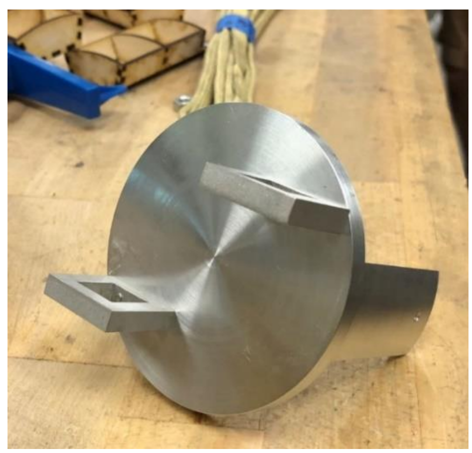


Figure 4-35 Assembled Rover Interfacing Plate

The gear racks protrude .365 inches (0.615in including the thickness of the bracket) through the locking brackets. The retention motor provides significant resistance and the retention gear is unable to rotate on its own accord. Therefore, there is no possible way for the rover to become unlatched in an open environment and this is further reinforced with the confined environment from the payload body tube and additional supports.

4.5.3 Supports

4.5.3.1 Radial Supports

The design of the radial supports has stayed consistent with what was presented in the CDR. The individual pieces of the radial supports were cut with a laser cutter from 1/8th inch aircraft grade birch plywood. The individual pieces were then glued together with wood glue and an assembled CAD model can be viewed in Figure 4-36.

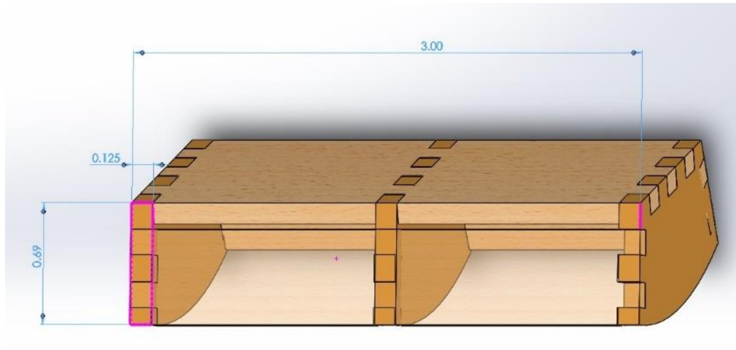


Figure 4-36 CAD of Radial Support

4.5.3.2 Centering Ring

The centering ring is the last form of radial support, which also allows for utilization of three inches of space of the coupler section at the aft end of the payload bay. The centering ring itself was constructed of four layers of the birch plywood. Each of the laser cut layers had three slots to interface with the PVC extrusion, and a slot for the shock cord. Two of the layers had pre-cut holes where the lead screws are fixed into place. The CAD model depicting the finalized design for this system is displayed in Figure 4-37.

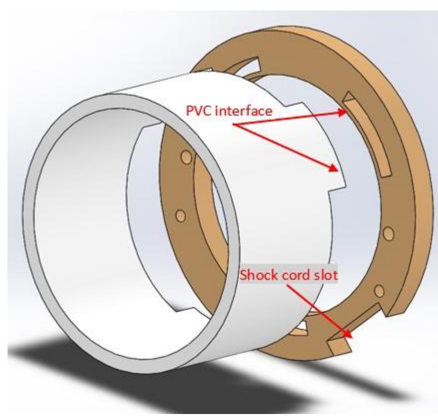


Figure 4-37 Payload Centering Ring

4.5.4 Payload Deployment

4.5.4.1 Drive Plate

The deployment mechanism works off a linear actuated system, where a motor drives a gear train that turns two nuts pushing the rover and the integration systems towards the aft end of the payload bay body tube. The model shown in Figure 4-38 shows

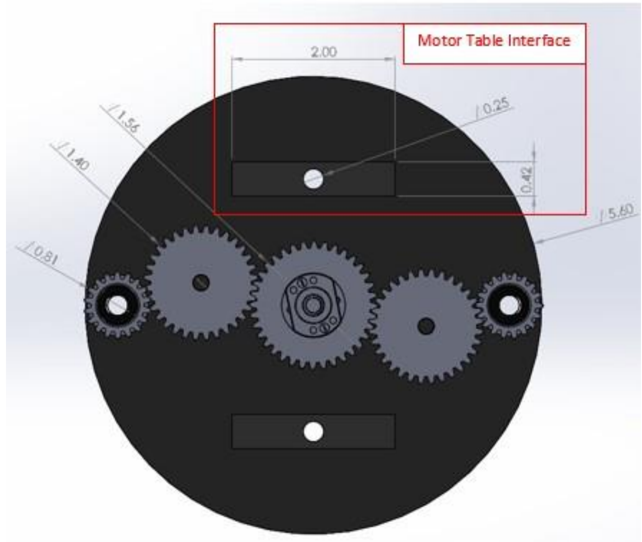


Figure 4-38 Drive Plate Dimensions

Figure 4-39 shows how each of the gears are mounted and how the system is connected to the lead screws that drive the system out of the body tube. The hub of the nut is slid through the drive plate and is secured to the system through two set screws on each of the external gears. The mid gears were secured from a bolt bonded into the motor table. The drive gear (hidden behind motor table) is mounted by two set screws into a 0.5-inch coupler that is friction fitted to the drive gears bore. The two holes at the bottom of Figure 4-39 show were quarter inch dowel rods will secure the drive plate to the electronics bay. The only change from the CDR is that the motor table was widened at the top to allow the mid gear mounting rods to attach to the table.

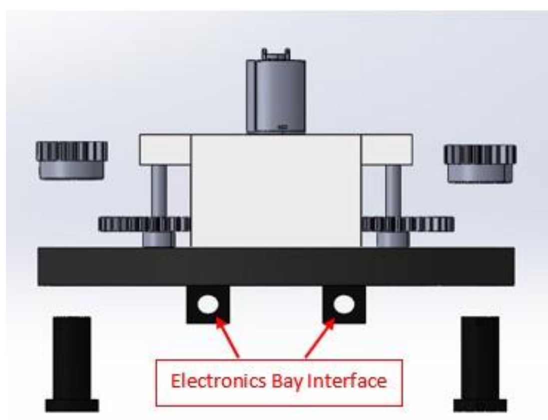


Figure 4-39 Gear Mounting

4.5.5 Electronics Bay

4.5.5.1 Overall Design

Outside of the drive motor at the forward end of the integration system, all other electronics are contained within the electronics bay. These electronics include the power supply, retention motor, Bluetooth module, the Sparkfun Redboard microcontroller, and the Ardumoto motor shield. The orientation of the components within the electronics bay are displayed in their final states and can be seen in Figure 4-40.

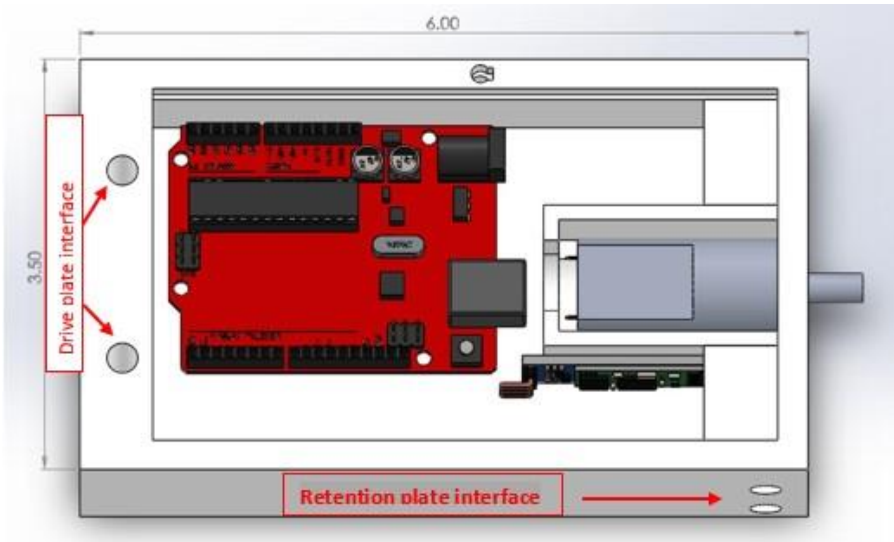


Figure 4-40 Electronics Bay

The image also displays how the electronics bay component is connected to each of the forward and aft plate. Not depicted in the image is the battery, which is secured to the bottom of the electronics bay via a hook and loop strip and a zip-tie is wrapped around the entire system. It should also be noted that the electronics bay is not an open system and has a lid that is also secured into place through the zip-tie.

4.5.5.2 Programming

The programming of the electronics has also stayed consistent with the CDR documentation. The team will utilize an application called BLE Terminal, available in the apple store or google play store. The Redboard has been loaded with a code that changes the operational states of each of the independent motors. The commands presented in Table 4-5 can be entered into the BLE Terminal application to deploy and unlock the retention system.

Table 4-5 Deployment Commands

Command	Operational State
0	Motor 1 OFF
1	Motor 1 OUT
2	Motor 1 IN
3	Motor 2 OFF
4	Motor 2 UNLOCK
5	Motor 2 LOCK

Figure 4-41 shows the general logic that controls the deployment system. Once the rocket has successfully landed and the recovery team approaches the rocket, a member can connect to the integration system via Bluetooth communication and the BLE Terminal application on their smart phone. Once connected, the commands listed in Table 4-5 will be utilized to control the deployment procedure which will be covered in the payload deployment construction section.

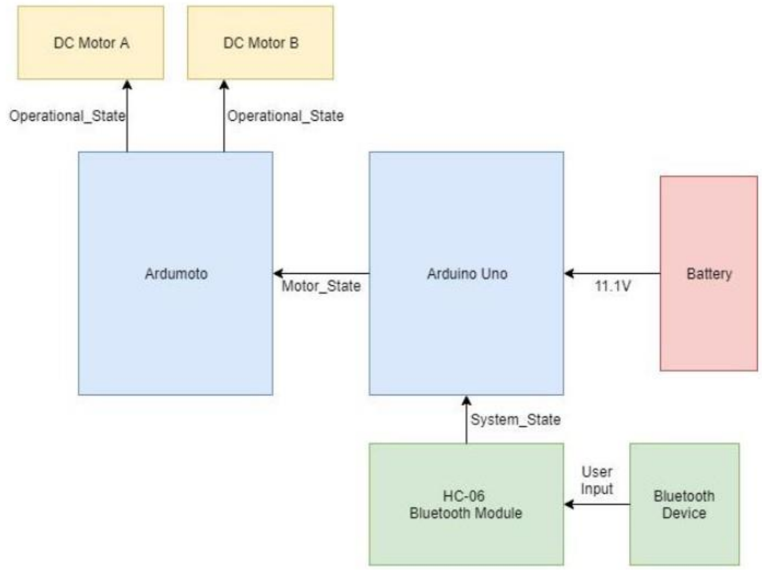


Figure 4-41 Deployment Sequence Logic

4.6 Payload Integration Construction

4.6.1 Mechanical Latch

The slot cut in each of the guide tracks was slightly too large for the shoulder bolt (discussed in the Linear Actuated Locking section), which allowed the gear racks to slightly rotate about the axial axis of the guide tracks and can be seen in Figure 4-42.

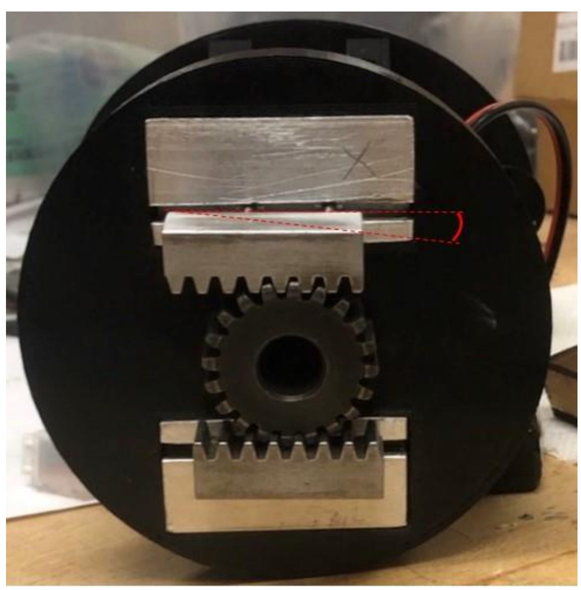


Figure 4-42 Initial Plate Iteration

This play in the system caused a higher frictional force between the unlocking mechanism and the guide tracks, which prevented the system for operating as intended. To minimize the rotation in the system, two shims were created for each side of the slot. The largest shim, located on the long side, depicted as shim 1 in Figure 4-43, was 3D printed and sanded down to a friction fit before being wedged into the guide tracks. On the short side, additional shims made up of two sheets of an aluminum soda can and denoted as shim 2.

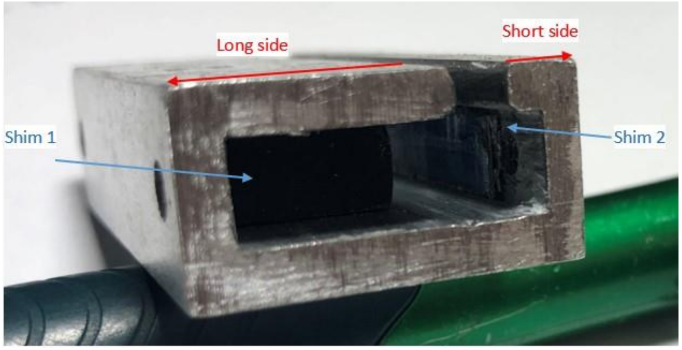


Figure 4-43 Guide Track Design

The inside channel of the guide tracks was also lined with lithium grease to reduce as much friction as possible and provide less strain on the retention motor.

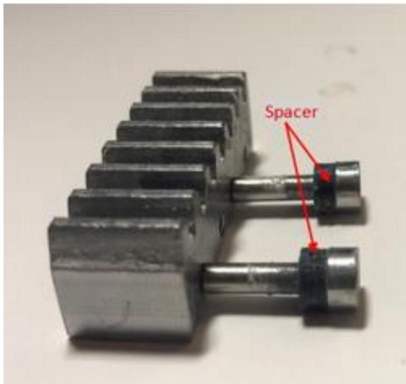


Figure 4-44 Gear Rack with Spacers

The first modification, as denoted in Figure 4-42, was to add a spacer to fill the 0.125-inch gap that existed between the top face of the shoulder on the shoulder bolt and the upper face of the guide track channel. This gap also contributed to the rotational play of the gear rack system and allowed the gear racks to move vertically (axially within the rocket). The addition of these spacers and the shims as discussed in the previous section significantly reduced the amount of “wobble” that was initially in the system. The actual spacers are shown in Figure 4-44 and the improvements to motion of the gear racks can be seen in Figure 4-45. The offset angle relative to the horizontal is dramatically reduced, which can be noticed by comparing Figure 4-45 to Figure 4-42. The second modification made was to tap a set screw hole in the locking gear in order to fix it in place with the shaft coupler of the retention motor. There was no way to access this set hole and an access port was drilled through the retention plate. This hole was created approximately at the location of the circle numbered ‘2’ in section 4.5.1.2

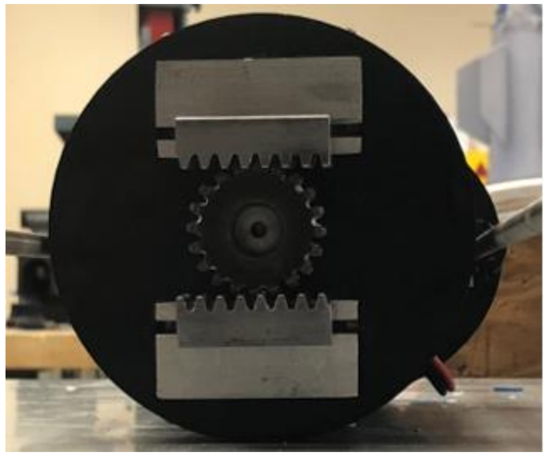


Figure 4-45 Image depicting reduced motion in gear racks

The third modification, depicted in section 4.5.1.2, was a reduction in the length of the gear racks from 2in to 1.5in in order to reduce weight. The final modification to this part of the retention system was to swap the 104 oz-in retention motor for a 650 oz-in motor. After loading the BURRITO into the payload bay for the first time, it was determined that the additional friction from the cantilever effects of the rover were too great to overcome and that this motor adjustment was necessary for successful deployment.

4.6.2 Rover Interface

The only modification to this design from the proposed plan in CDR is the locking “ring”. In the CDR, it was stated that there would be four legs on the retention plate and that the plate would be secured to the rover by two bolts running through a pair of legs. However, the geometry and available spacing did not accommodate this course of action. The alternative was to create two arced pieces that fit around the legs and would secure the plate to the rover by screwing a 4-40 through each side of the locking rings and through the legs of the plate. Each piece is a 55 degree arc that was water jetted by the machine shop. This is shown by an image of the updated CAD model in Figure 4-46 and the finalized piece in Figure 4-47.

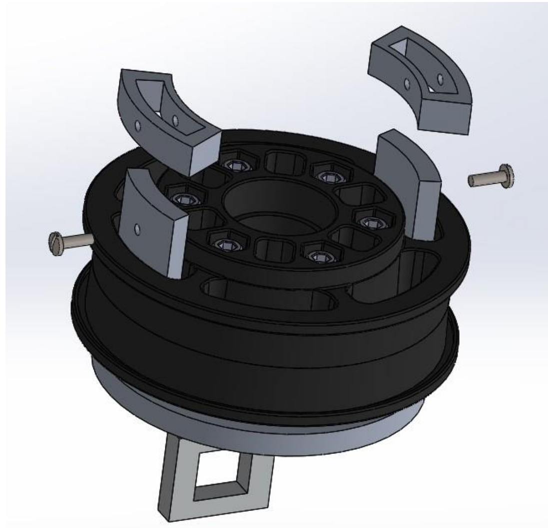


Figure 4-46 Updated rover plate model with finalized locking rings

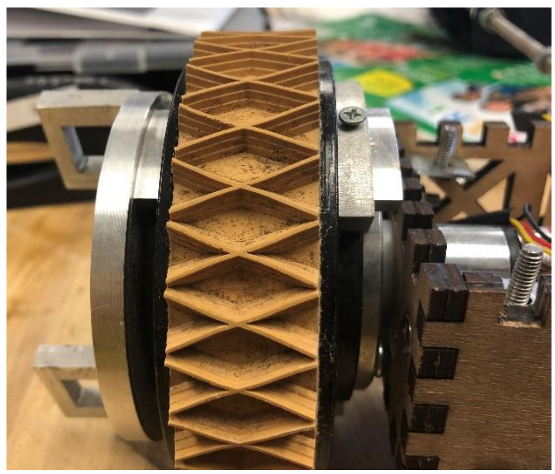


Figure 4-47 Image depicting the assembled rover interface plate secured to the rover wheel

4.6.3 Supports

4.6.3.1 Radial Supports

The initial design for these supports included two pairs of the supports shown in Figure 4-36 instead of lining the entire payload bay to save weight. These supports would have been placed flush with the centering ring and where the rover's forward wheel would rest during the flight phase. However, it was discovered from preliminary deployment testing that the lead rods would not be able to support the weight of the rover when the system reached the approximate halfway point of deployment. There were two modifications that had to be performed to ensure that the flexing of the rod would be reduced to a negligible amount. The first was to increase the number of supports, such that the supports span the entirety of the payload bay. However, these supports only mitigated the flexing if the rocket landed with the lead screws horizontal relative to the ground. A second modification called for the system to be supported every 90 degrees and a second pair of radial supports were created to line the payload bay. The new supports act on the main driving plate of the deployment mechanism. The combination of the wooden supports and newly 3D printed supports offer a normal force pushing the rover and overall system toward the center of the payload bay. These supports allow for smooth deployment and restrict any radial motion of the payload and integration systems during the flight phase. These modifications have been updated in the most recent CAD model, which can be seen in Figure 4-48 and the actual supports that have been bonded into the payload bay is shown in Figure 4-49.

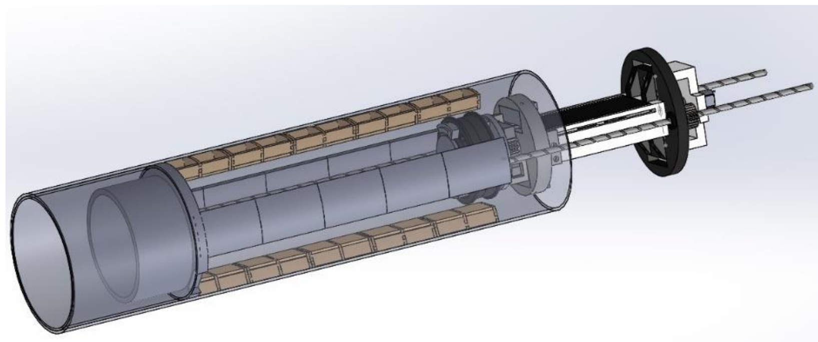


Figure 4-48 SolidWorks model of updated radial support design

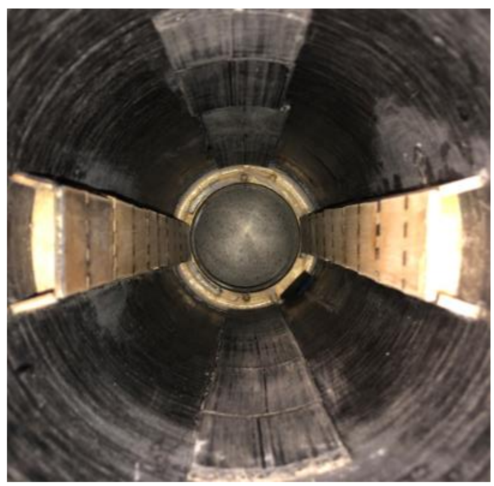


Figure 4-49 Assembled Radial Supports

A final note on the support pieces is that all individual pieces were coated with a layer of clear nail polish. This gave the supports a much smoother finish in order to reduce friction during the deployment process.

4.6.3.2 Centering Ring

The PVC had to have material cut from one end to create legs that would fit through the slots within the centering ring. The legs were then epoxied into the centering ring and Bondo was applied to fill in any gaps in order to improve the structural integrity of the resultant component. Holes were also drilled out of the PVC in order to reduce its weight, which can be seen in Figure 4-50. The final centering ring was then epoxied and bolted six inches above the aft end of the payload bay due to the requirement of a full body diameter of coupler between separating sections.

Figure 4-50 Centering ring and PVC extrusion

The inner diameter of the PVC ended up perfectly patching the outer diameter of the rover's wheel. There is enough tolerance so that it is not friction fitted and will not resist the deployment mechanism, but a tight enough fit to ensure that there will be no radial movement of the rover during the flight. The tolerance between these two components is shown in Figure 4-51.

Figure 4-51 Aft Rover wheel in centering ring

The centering ring radial support concludes the construction and modification of the retention mechanism.

4.6.4 Payload Deployment

4.6.4.1 Drive Plate

The only major modification required for the assembly and success of the drive plate portion of the deployment system was a motor swap. The same brand of motor was used for its ideal dimensions and weight, but the team opted to downgrade the

RPMs so that the system would be given a higher torque. The assembled drive plate can be viewed in Figure 4-52. The motor table snapped into the drive plate and dowel rods were covered in super glue and bonded to the inside of the drive plate and a bore hole within the motor table legs. The motor was friction fitted within the bore hole in the center of the motor table before being super glued into the top. A shaft coupler connected the motor shaft to the drive gear's bore hole and secured through two set screws. The exterior gears were placed over the nuts hub and secured through two set screws. Once the positioning of the mid gears was appropriate to allow all gears to freely rotate, the position on the drive plate and motor table were marked. The inner diameter of the middle gears was 11/64th of an inch and the most convenient mounting rod was determined to be trimmed drill bits. The motor hole's position was drilled through and a small hole was also drilled into the drive plate. The trimmed drill bit was then super glued into the holes.

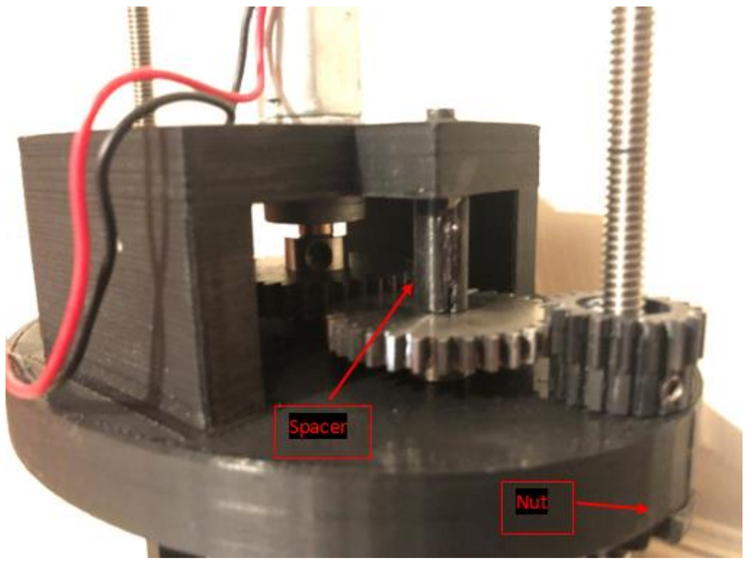


Figure 4-52 Assembled Drive Plate

The small modifications made to this design are highlighted in the figure above. The mid gears were free to move vertically which could easily lead to a dislodged gear and failure to deploy post landing. A hollow cylinder split into two equal pieces were 3D printed and used as a spacer, which were placed around the drill bit and glued together. This successfully restrained the mid gears. The second minor modification came after the initial deployment test. The flange of the nut initially extruded past the drive plate and caused the system to become stuck. The flange of each nut was sanded via a Dremel until it was flush with the plate on all sides.

To conclude the construction of the drive plate assembly, it was found during the initial rocket assembly that the holes for the lead screws in the nosecone bulkhead were too close to the edge of the bulkhead to allow for nuts that would restrict the screws ability to rotate. In order to completely secure the lead screws in all degrees of freedom, a rectangular component with two thru holes for the lead screws was 3D printed. Nuts were secured forward and aft of this component to eliminate the screws ability to rotate while in the rocket. This component is shown in Figure 4-53 and is positioned forward of the drive motor and aft of the nosecone bulkhead.

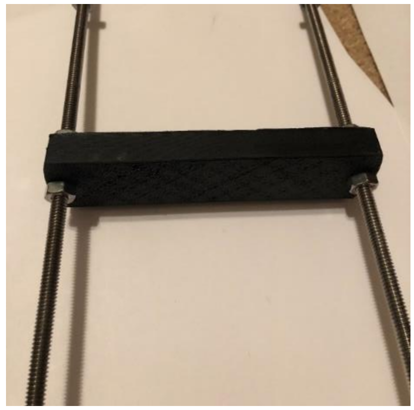


Figure 4-53 Rectangular rotational locking component

4.6.4.2 Electronics Bay

The fully assembled and connected (to drive and retention plates) electronics bay is displayed in Figure 4-54. A layer of white padding can be seen on the floor of the bay, which cushions the electronics from the vibrations during the flight phase. The microcontroller is bolted to the structure by two 4-40 screws. The HC-06 Bluetooth module was superglued to the side of the motor container. The motor is friction fitted with the back end of the motor container, but two shims made from two pieces of taped popsicle sticks were placed on either side of the motor to fix it in place. These shims were also super glued to the motor container. Power access holes were drilled in the bottom of the bay to receive power from the 11.1V 1500 mAh battery as well as in the side of the bay to provide power to the drive motor. The swap to the 1500 mAh battery was not necessary but provides a safety factor greater than five to the power systems and if needed can operate for a full day.

The image also depicts both sets of dowel rods that connect all components of the system together. On the left side of the image, two approximately 2-inch dowel rods were superglued into the connection holes within the drive plate and the electronics bay. On the right side of the electronics bay, one of the dowel rods connecting the retention plate to the electronics bay can be seen. There are four dowel rods (two on each side) that connect the retention plate to the electronics bay.

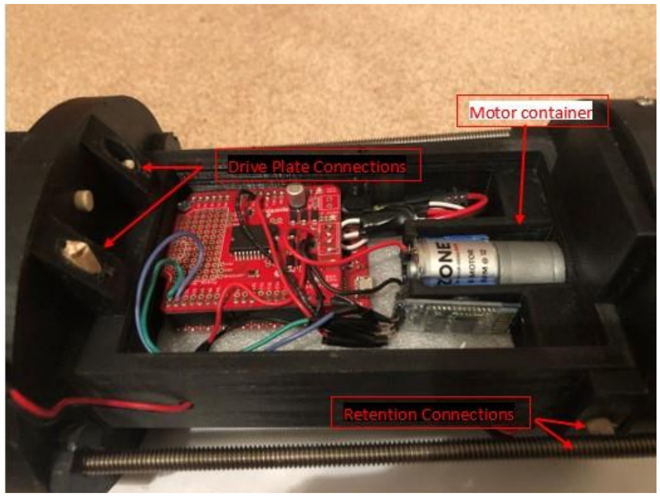


Figure 4-54 Assembled Electronics Bay

4.6.4.3 Deployment Procedure

Using the commands discussed in presented in section 4.5.5.2, once the rocket has safely landed and the recovery team has connected to the system through the BLE Terminal application the procedure will go as followed.

The user will give the system an input of 1 until approximately halfway through the system where the deployment progress will be halted by inputting 0. At this stage, the user will free the rover from its interface by sending command 4, quickly followed by command 3 to turn the retention motor off. The user will then proceed with the deployment procedure and press 1 until the rover is free of the payload bay.

The reasoning for this deployment procedure was through the initial deployment and unlocking procedure. The cantilever effects from the fully deployed rover create too much resistance to overcome and the retention motor stalls. This has not yet been tested with the new addition of the 650 oz-in motor, so it cannot be said whether this is still impossible. However, the above procedure is a guaranteed method of successfully unlocking the rover while it is still supported by the radial supports before proceeding with the deployment process.

4.6.4.4 Full System

The following images show the entirety of the fully assembled system, with some final notes and minor modifications.

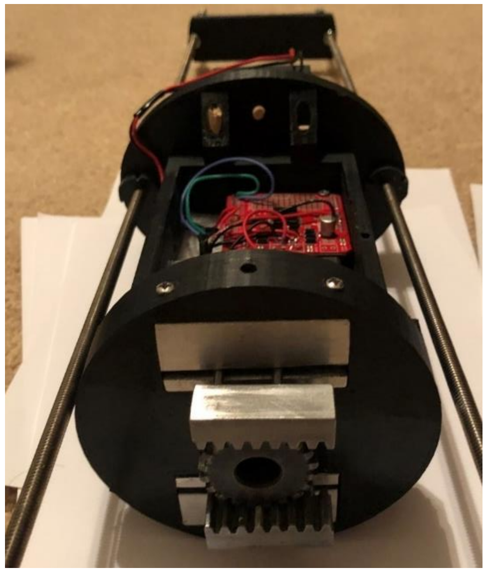


Figure 4-55 Aft end view of assembled integration system

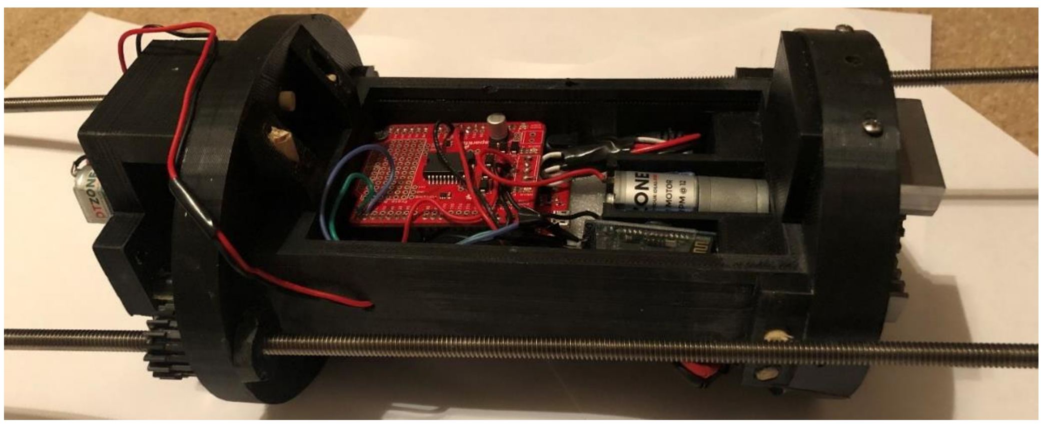


Figure 4-56 Top view of assembled integration system

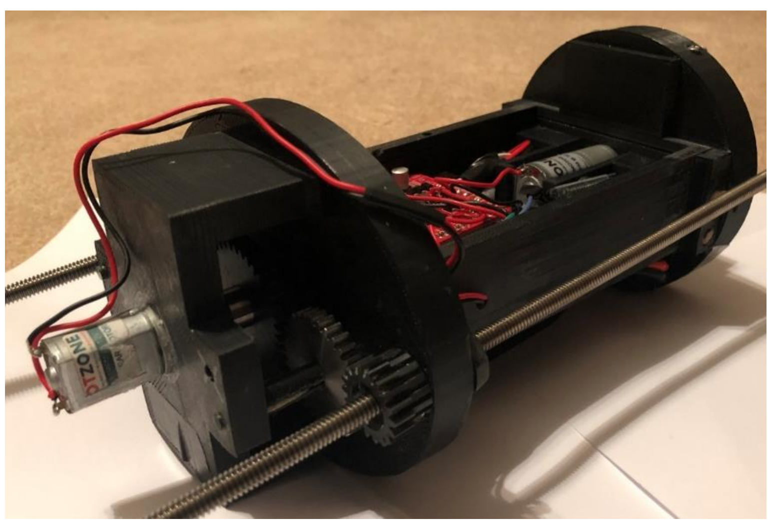


Figure 4-57 Side-Top view of assembled integration system

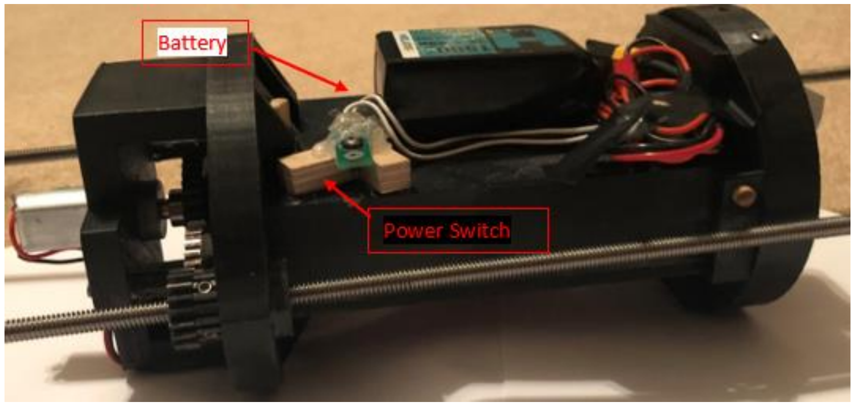


Figure 4-58 Side-bottom view of assembled integration system

Figure 4-58 shows a power switch that was implemented into the system. In case the team has any timely issues to address during the competition the switch was implemented if the team desires to turn off the power to save battery life. The access port to this switch was drilled through the nosecone and can be turned on or off with a screwdriver.

The final weight of the payload integration system (both deployment and retention) came to 3.34 pounds. This result along with the final rover weight of 4.76 lb stays consistent with the initial requirement that the payload systems will remain under eight pounds. The length of the system from the aft face of the gear rack to the leads of the drive motor is 10.25 inches, which unfortunately does violate the initial requirement set back in September that the integration system be no longer than 10 inches.

5. Demonstration Flight

5.1Vehicle Demonstration Flight

On February 23, 2020, the team successfully executed the first flight of the full-scale launch vehicle in Bayboro, NC. This launch satisfies the requirements of both the Vehicle Demonstration Flight and the Payload Demonstration flight. The payload demonstration results are discussed in section 5.2. Table 5-1, below, shows a summary of flight data from this launch.

Table 5-1 February 23 Flight Data

Demonstration Flight Data	
Date	2/23/2020
Location	Bayboro, NC
Temperature (°F)	58
Pressure (mmHg)	30.34
Wind (mph)	6
Motor Flown	L1520T
Ballast Flown (lb)	0
Payload Flown	Yes
Airbrakes	N/A
Target Altitude (ft)	4,420
Predicted Altitude (ft)	3,775
Measured Altitude (ft)	3,187

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. 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 5.2. The fields have rows of dead corn stalks that make traversing the terrain difficult and slow.

Figure 5-1 the field conditions on the day of the launch. The ground was wet and there was no cloud cover. The temperature at the time of launch was 58 F with a sea level pressure of 30.34 mmHg. The wind speeds in Bayboro on launch day were sustained 6 mph winds from the west. These values were entered into RockSim to generate the altitude plots discussed in section 3.6.2.

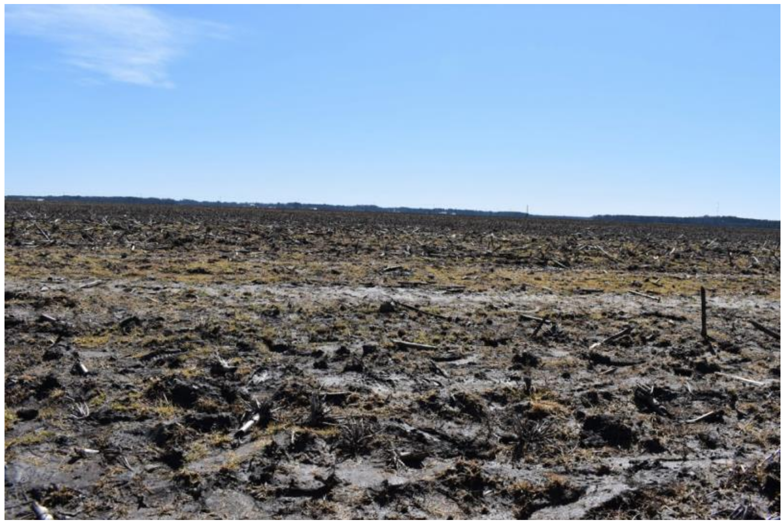


Figure 5-1 2/23/20 Launch Field Conditions

5.1.1 Analysis of Flight

Overall, the flight was successful. The vehicle experienced some slight wobble during the end of the boosted phase. However, these oscillations did not appear detrimental as the vehicle continued to fly directly upward. Sometime after motor burnout the vehicle began to tip to one side and slowly began following a more 2-dimensional parabolic path. Since the rocket did not entirely travel directly upwards, as the simulations showed, it is believed that this tipped motion led to increased drag and a lower apogee. A picture of the launch vehicle's ascent can be found in Figure 5-2, below.

The vehicle safely landed in a muddy region on the launch field. The main parachute was still deployed and resulted in the rocket body dragging along the ground. Unfortunately, the payload bay and nosecone were dragged into an irrigation ditch that has a few inches of rainwater in the basin of the ditch. The consequences of this are described in section 5.2 as the payload electronics were most affected.

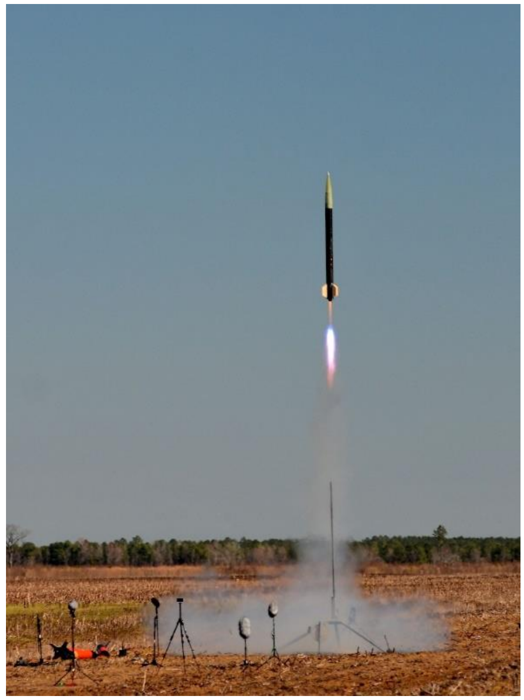


Figure 5-2 Launch Vehicle Flight

All recovery systems functioned as expected and as described in section 3.5.1. Figure 5-3 shows the fully deployed recovery system on launch day. No damage was sustained to any recovery devices.

Figure 5-3 Deployed Recovery System

The apogee experienced by the launch vehicle was approximately 550 feet below the predicted apogee by RockSim. Figure 5-4 shows the altimeter data from the primary altimeter that was used on launch day plotted with the apogee predicted by RockSim.

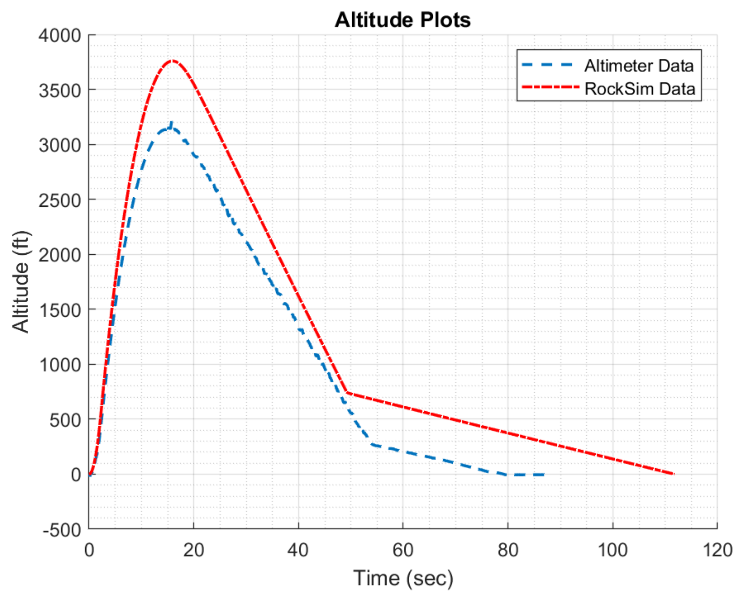


Figure 5-4 Primary Altimeter Altitude Data

5.1.1.1 Sources of Error

Error in the altitude prediction may have come from many places within the estimates. Primarily, the models assumed a fairly smooth surface of the launch vehicle however the vehicle was not painted or even primed before launch. This surface roughness ended up affecting the apogee significantly.

In addition to this, the vehicle came in 3 pounds heavier than expected. A significant amount of this weight is understood to be from the large amount of epoxy that was used to hold pieces of the launch vehicle together.

Lastly, the atmospheric pressure at the day of launch was significantly high. The team's mentors refer to this as "heavy air" and have informed the team that this air can significantly lower the apogee of a launch vehicle.

5.1.1.2 Estimated Drag Coefficient

Using RockSim the drag coefficient was overridden until the apogee predicted by RockSim matched the apogee achieved at launch. The conditions that were listed in section 5.1 were kept the same and only the drag coefficient was adjusted. It was determined that the estimated drag coefficient was 0.735. This value was verified by substituting this new drag coefficient into Barrowman's equations which resulted in an apogee of 3,083 feet. This gives a percentage difference of 3.3% compared to the true apogee of the launch vehicle.

Figure 5-5 shows an altitude plot of the launch vehicle with the adjust drag coefficient.

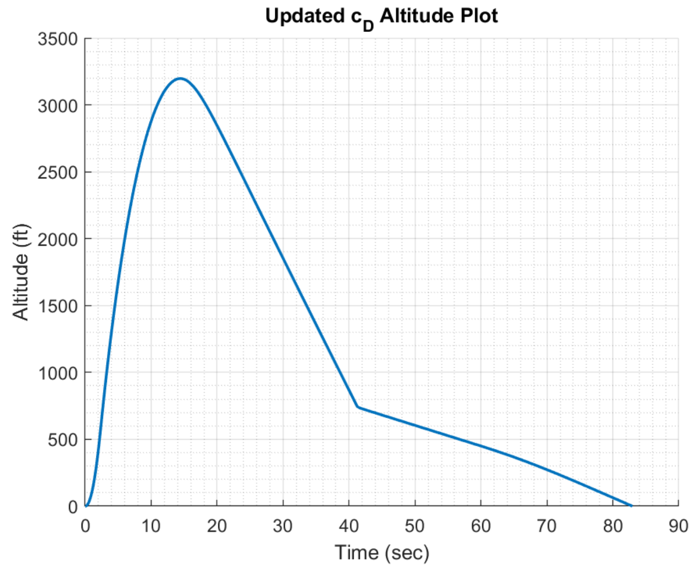


Figure 5-5 Altitude Plot with updated Drag Coefficient

5.1.1.3 Subscale Comparison

The subscale and full-scale vehicles experienced successful flight demonstrations, and both achieved similar apogees. For the subscale flight the vehicle experienced coning during its ascent. After speaking with the team's mentors, it was determined that the chord length of the fin should be increased to reduce coning affects in the future. The team then increased the overall chord length and the span length. These adjustments resulted in a 33% increase in the total fin planform area. During the full-scale launch the vehicle experienced a very slight coning just before motor burnout. As mentioned, this wobbling was minimal, and the vehicle maintained its orientation.

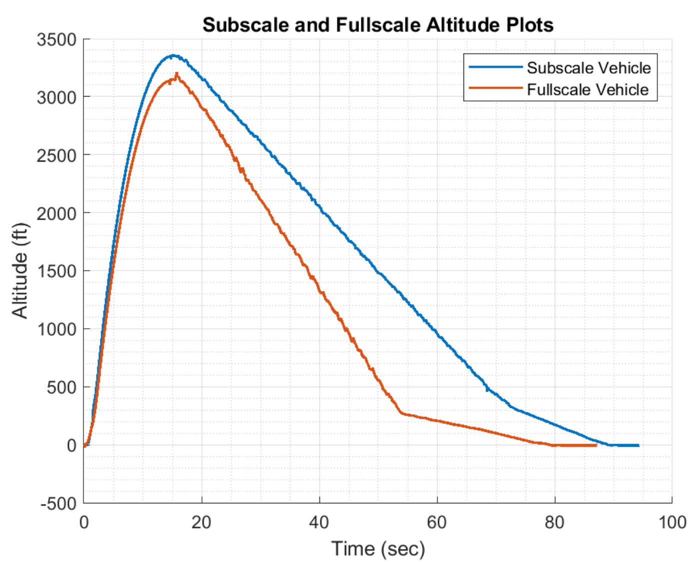


Figure 5-6 Altitude Plots of Full-scale and Subscale Launch Vehicles

5.2 Payload Demonstration Flight

The flight described in section 5.1 for the vehicle demonstration also qualified as the payload demonstration per communication with the NASA SL project management team. Flight analysis can be found in section 3.6.2. The success criterion for the payload demonstration flight is that the payload must be retained for the duration of the flight.

Upon landing, the nose cone and payload bay were dragged by the main parachute into an irrigation ditch. Due to excessive rainfall the week prior, the irrigation ditch was filled with standing water. The payload bay which housed the retention system and BURRITO was soaked and retaining water when the team approached the vehicle. Team members took immediate action by securing the parachutes to prevent further movement, then assessed the damages. Figure 5-7, below, shows the submerged nose cone and payload bay as found on launch day.

Figure 5-7 Submerged Payload Bay

The team recovered the section and removed the water, as seen in Figure 5-8. Because the payload electronics were wet, the team did not want to risk damaging them further by operating the payload at the field. The team confirmed retention by pulling on the rover after landing. A picture of the retained BURRITO can be seen in Figure 5-9.

Figure 5-8 Removing Water from Payload Bay

Figure 5-9 Retained BURRITO

5.2.1 Payload System Performance

The payload was fully retained through the duration of the flight. The team did not feel it was safe for future mission success nor personnel to operate the deployment system after landing in water. Payload deployment has been ground tested as described in section 7.2. The BURRITO itself was also not operated at the launch site due to water exposure. The BURRITO has been ground tested as described in section 7.2.

5.2.2 Flight Damages

After the launch, exposed electronics where placed in a tub of rice as pictured in Figure 5-10, below. The electronics were kept in the rice until the following day when they were cleaned with isopropyl alcohol to limit corrosion. The electronics were returned to the rice for another day, then tested. No payload electronics were damaged. The payload systems were reassembled, and shortened versions of the payload tests described in section 7.2 were performed to prove functionality.

Figure 5-10 Recovering BURRITO with rice

6. Safety

6.1 Fault Tree Analysis

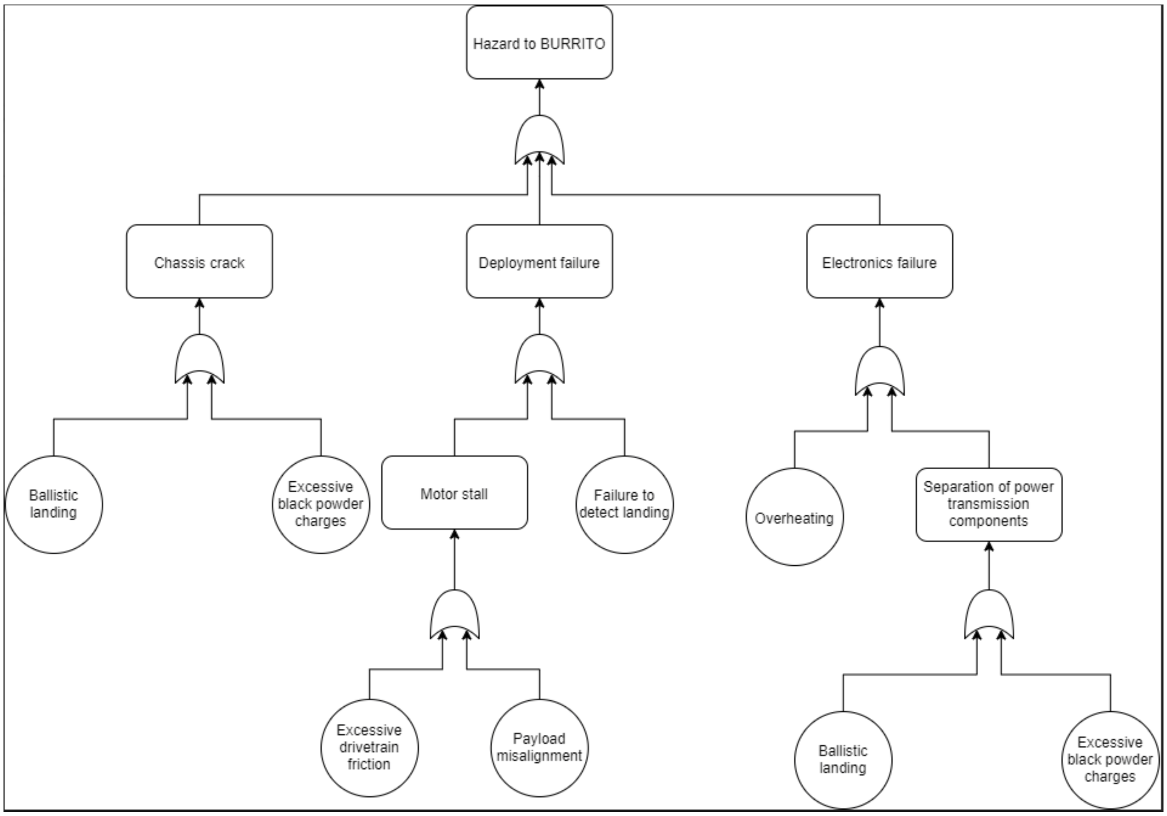


Figure 6-1 BURRITO Fault Tree

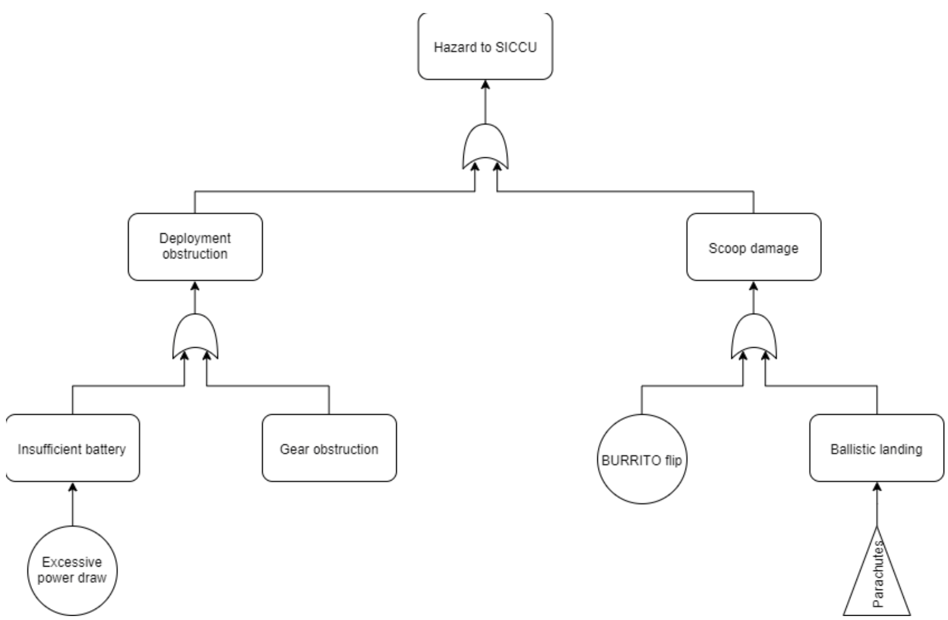


Figure 6-2 SICCU Fault Tree

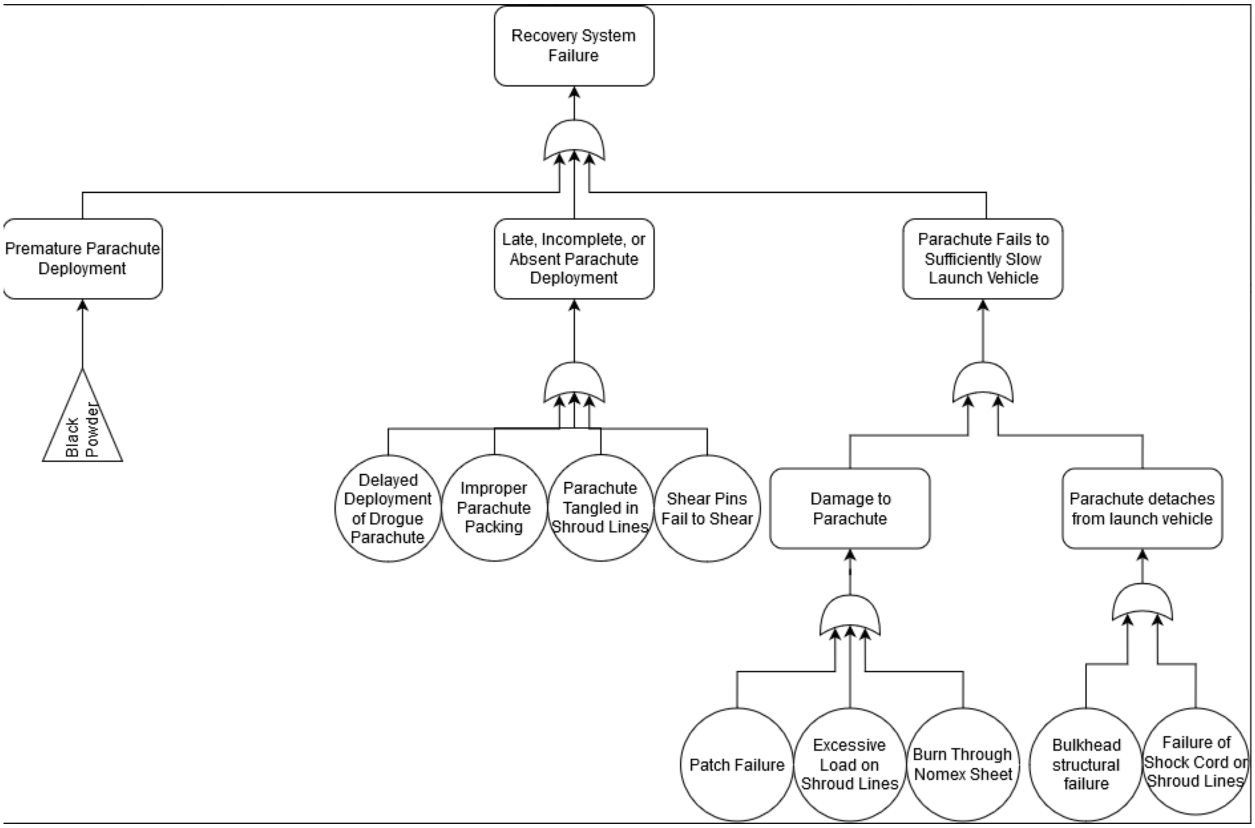


Figure 6-3 Recovery Fault Tree

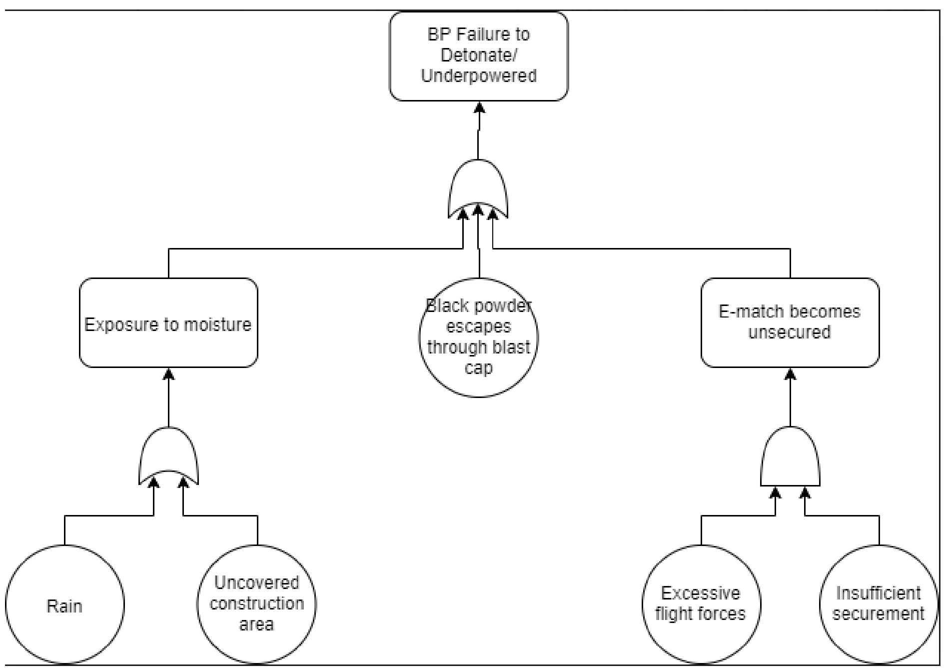


Figure 6-4 Failure to Detonate Fault Tree

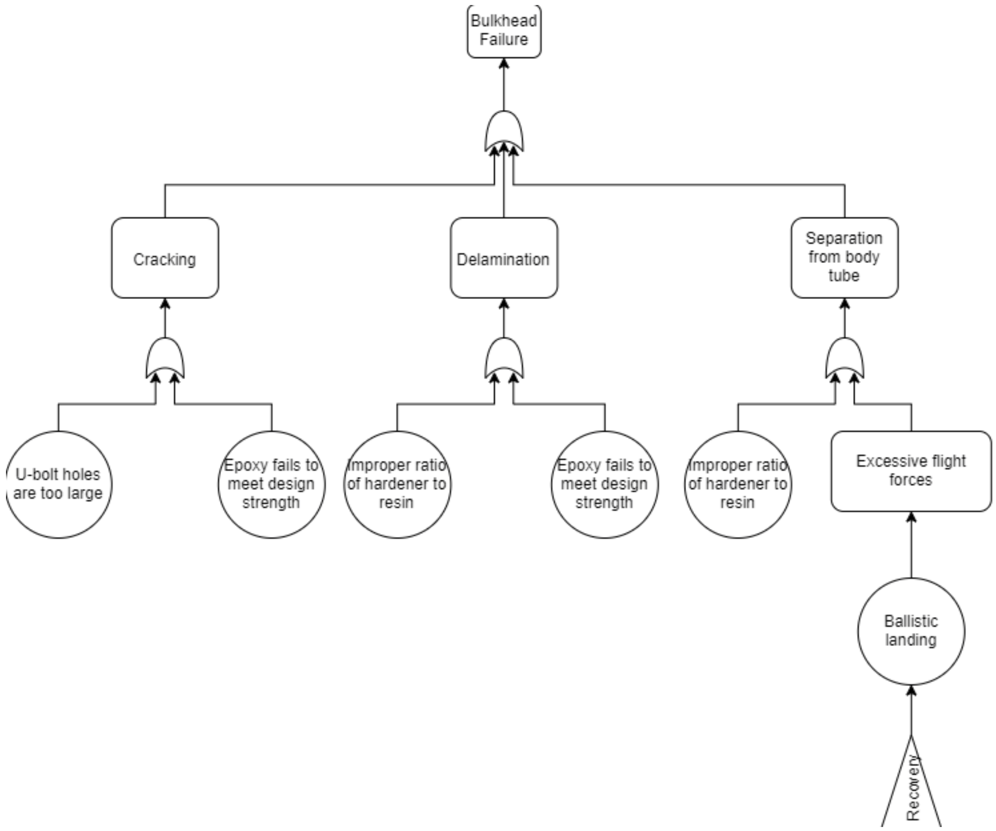


Figure 6-5 Bulkhead Fault Tree

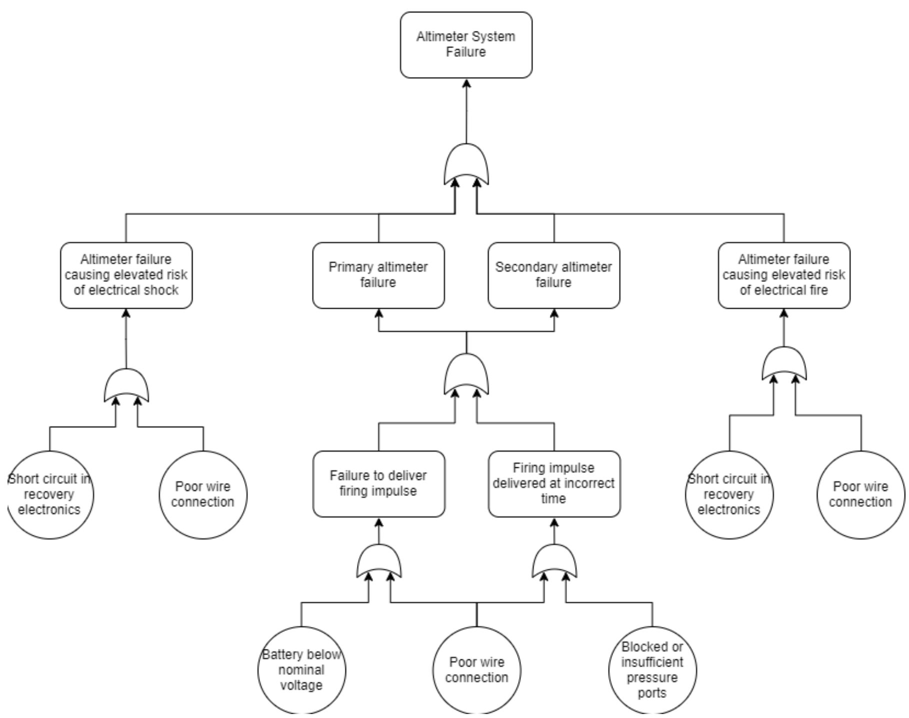


Figure 6-6 Altimeter Fault Tree

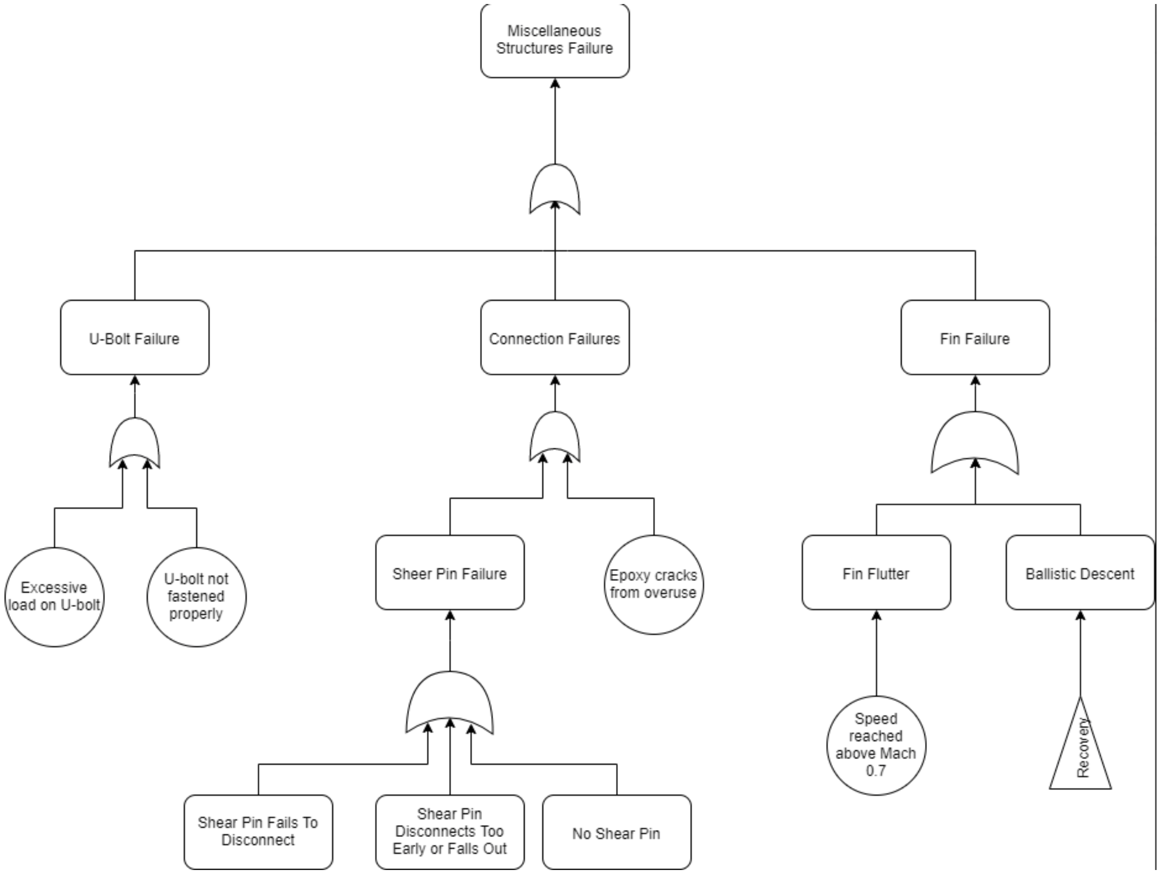


Figure 6-7 Structures Fault Tree

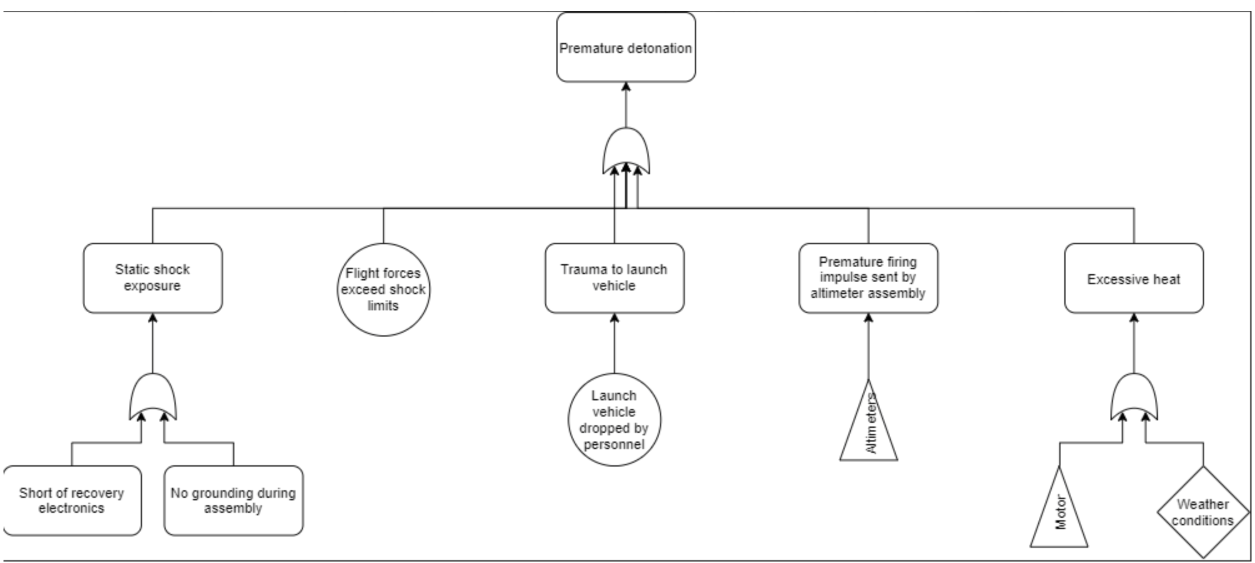


Figure 6-8 Premature Detonation Fault Tree

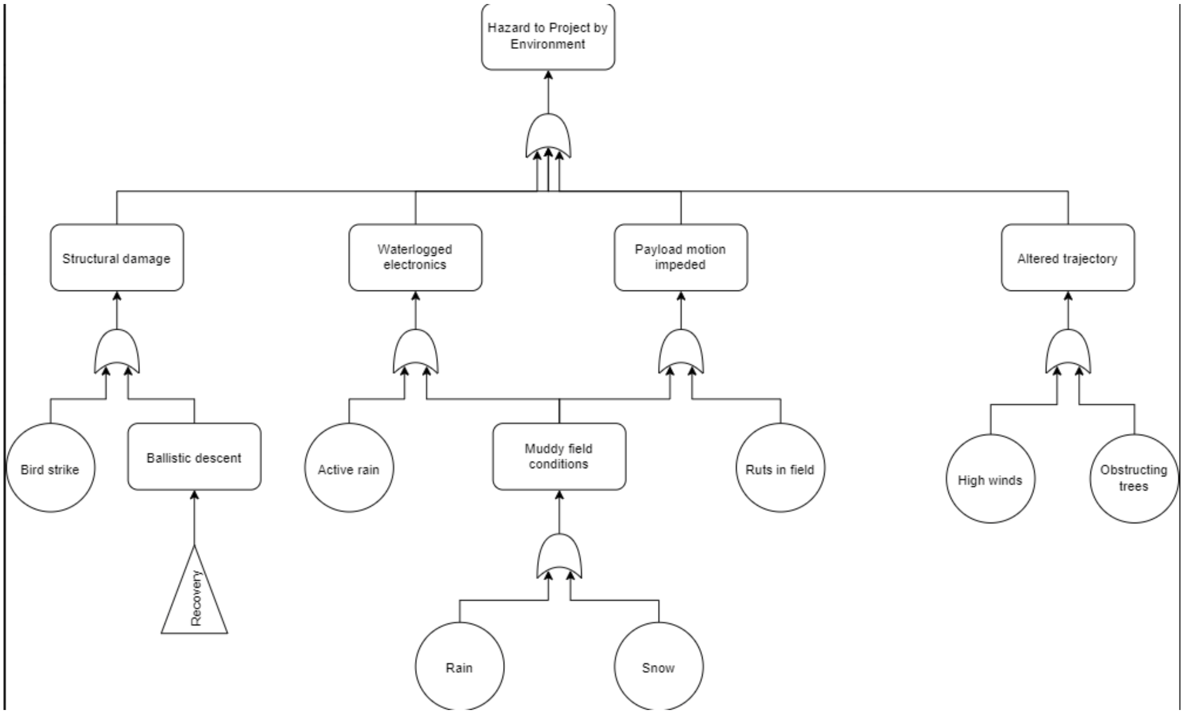


Figure 6-9 Hazard to Project Fault Tree

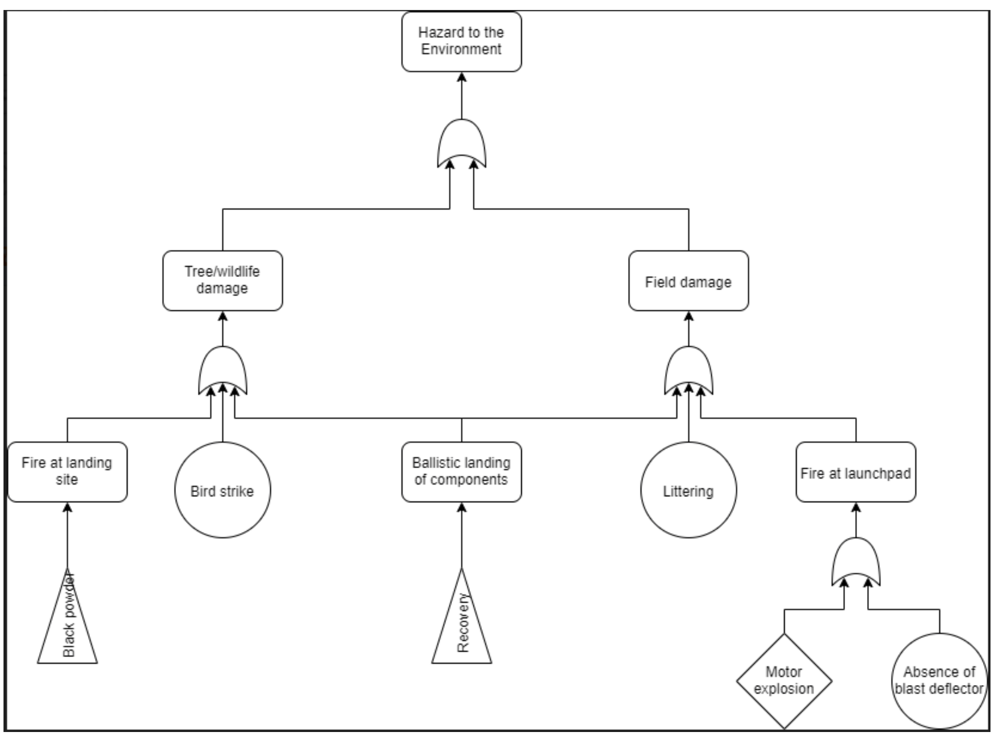


Figure 6-10 Hazard to the Environment Fault Tree

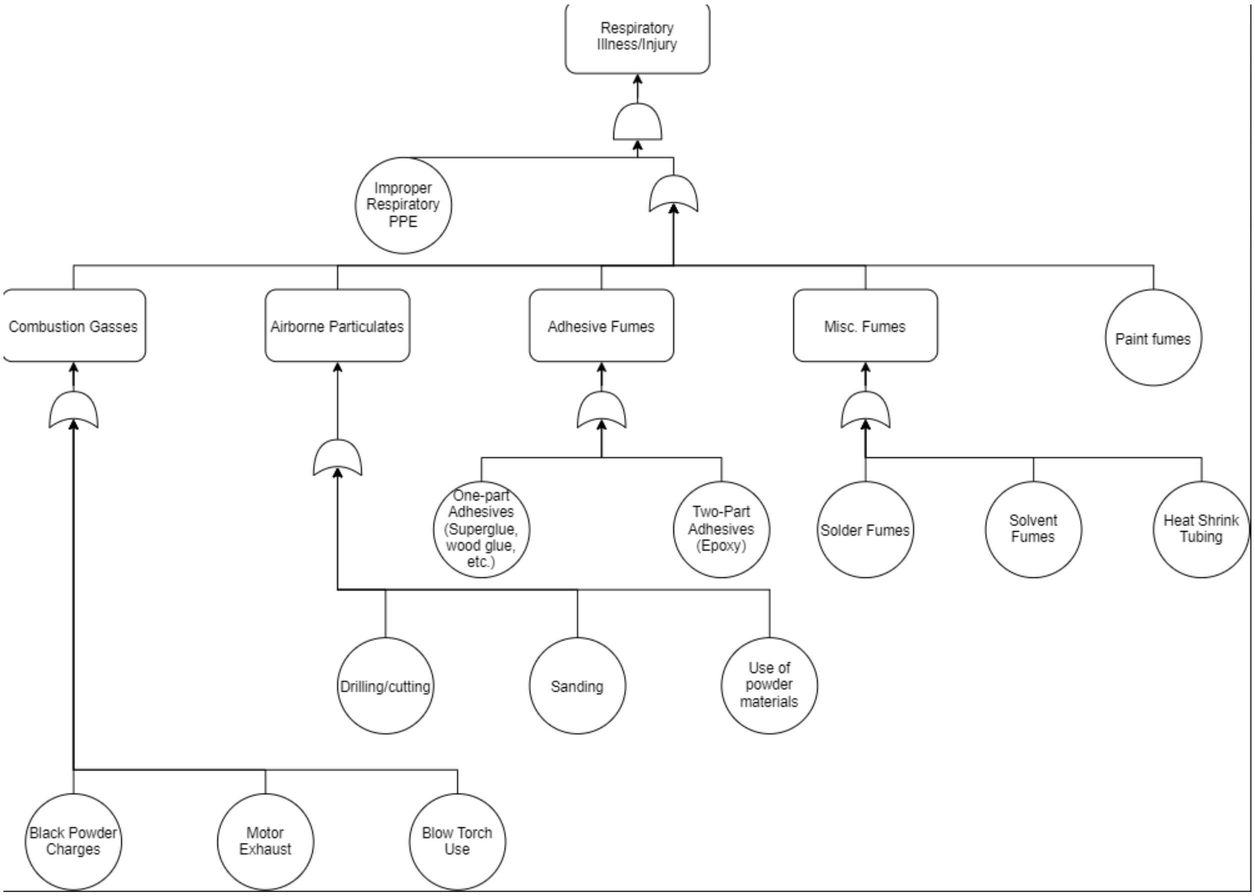


Figure 6-11 Respiratory Injury Fault Tree

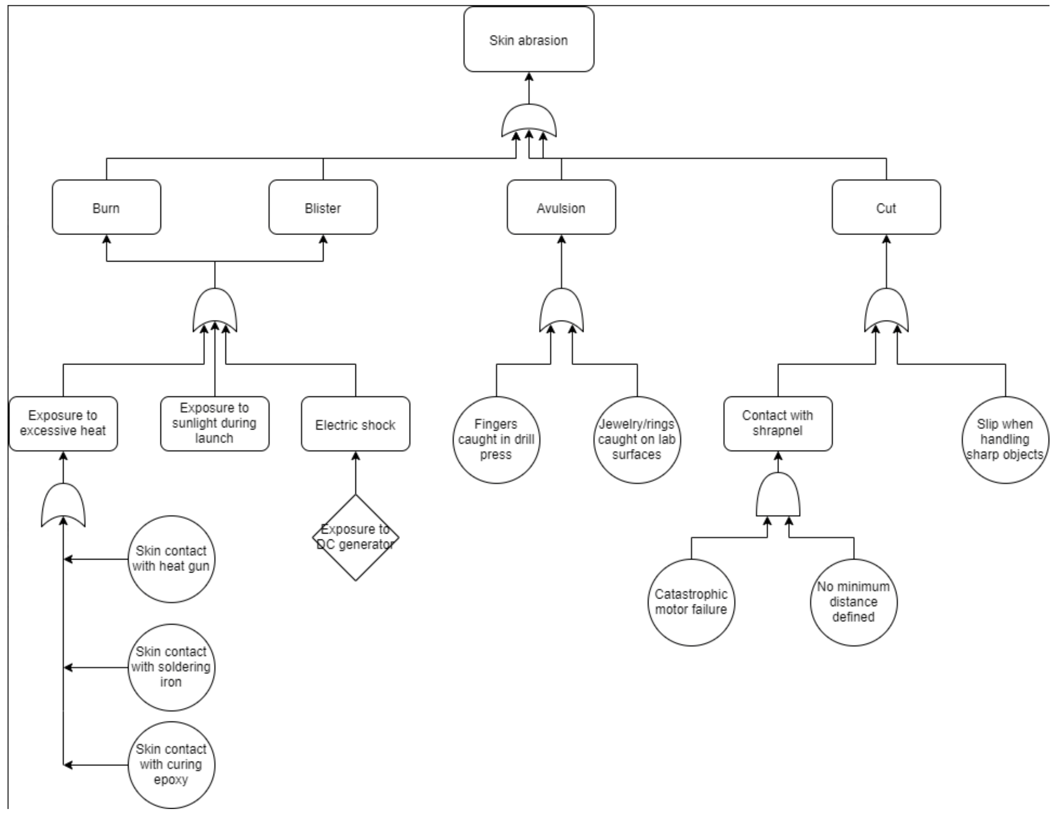


Figure 6-12 Skin Abrasion Fault Tree

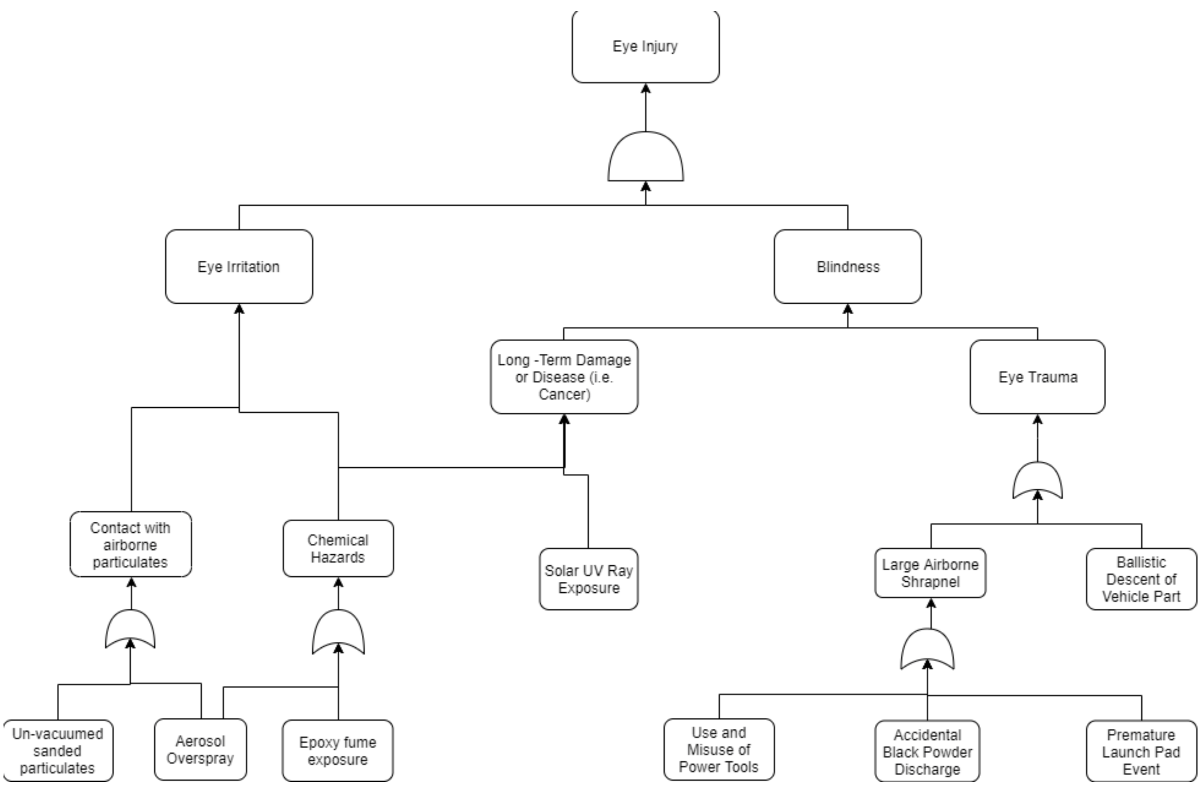


Figure 6-13 Eye Injury Fault Tree

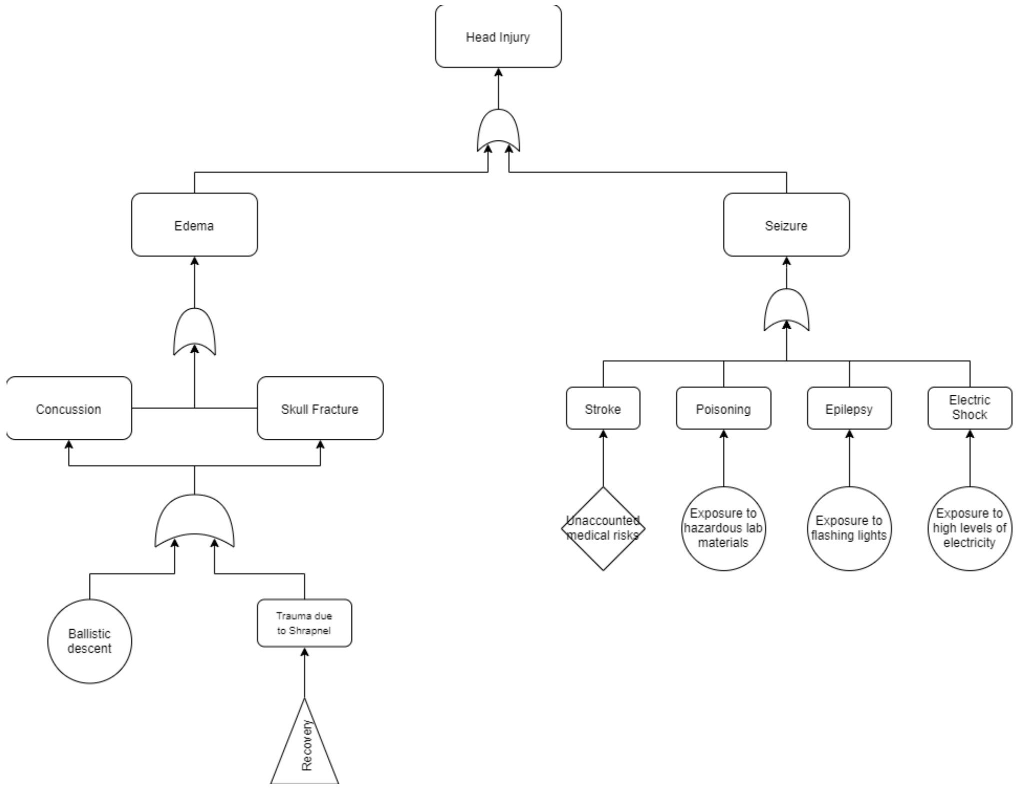


Figure 6-14 Head Injury Fault Tree

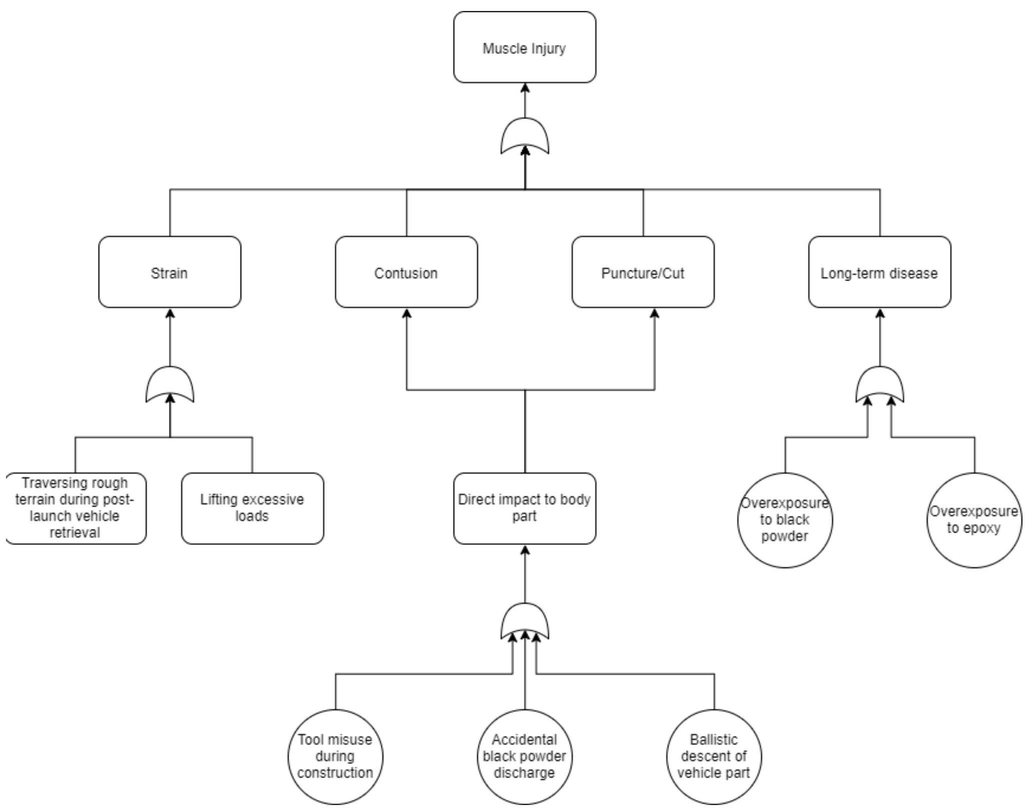


Figure 6-15 Muscle Injury Fault Tree

6.2 Risk Analysis

Table 6-1, below, defines levels of severity as associated with likeliness of occurrence.

Table 6-1 Hazard and Likelihood Classifications

		Level of Severity			
		1 Low Risk	2 Medium Risk	3 High Risk	4 Severe Risk
Likeliness of Occurrence	A Very Unlikely	1A	2A	3A	4A
	B Unlikely	1B	2B	3B	4B
	C Likely	1C	2C	3C	4C
	D Very Likely	1D	2D	3D	4D

Hazard and likelihood classifications are used to determine the importance of mitigation of a system component. Any component with a hazard level of 3+ or likelihood of C+ is required to be mitigated in some form to decrease the likelihood of the failure occurring and the severity of the outcome. Classifications are detailed below:

Hazard Level 1:

- No personnel injury occurs
- Damage done to launch vehicle is reversible
- Mission success

Hazard Level 2:

- Any personnel injury can be treated with minimal on-site first aid
- Damage done to launch vehicle is repairable within 1-2 weeks
- Partial mission failure; successful flight

Hazard Level 3:

- Moderate personnel injury; manageable with launch field first aid

- Damage done to launch vehicle is repairable but in poorer condition than before flight
- Partial mission failure; partially successful flight

Hazard Level 4:

- Personnel severely injured or killed; hospitalization is required
- Damage done to launch vehicle is irreparable
- Total mission failure; catastrophe

6.3 Personnel Hazard Analysis

Table 6-2 details hazards to personnel and their mitigations by injury type.

Table 6-2 Personnel Hazard Analysis

Hazard	Causal Factors	Effects	LS Rating	LS Mitigated	Mitigation	Verification
			Bone Injury			
Contact with large airborne shrapnel	Catastrophic failure of recovery and motor components (see motor and recovery FMEA)	Bone bruising	3B	3A	A minimum distance will be defined between personnel and the launchpad. Personnel are alerted through a horn sounding that launch vehicle components are drifting overhead. See aerodynamics and propulsion FMEA for catastrophic motor failure mitigations.	NAR Safety Code #6, NASA 5.4
Slips, trips, and falls	Uneven or wet ground surfaces during launch	Fracture	3B	3A	Launches will not occur during or following adverse weather or field conditions. The RSO has the final say on the status of launches and the team will follow the guidelines set by the RSO.	NAR Safety Code #9, NASA 5.4
	Tripping hazards (wires, trash, lab equipment, etc) in work area				All wires, their outlets, and their inputs are to be contained in one area to minimize chords on the floor. Equipment and materials are to be	Power strips are located on the center desk and on walls

					kept on the center table or the soldering desk.	surrounding the lab.
Eye Injury						
Eye contact with airborne particulates	Residual material particulates from sanding, drilling, and cutting wood and metal	Eye irritation	1D	1A	Protective eyewear is provided to all personnel working on and around power tools with potential to create airborne particulates. A shop vac is used while drilling, sanding, and cutting to reduce risk of particles becoming airborne.	TDR 5.8; The shop vac is located next to all major desktop lab power tools.
	Working with aerosol paints				All personnel working with and around aerosol paints shall wear protective eyewear. All spray painting is carried out in a ventilated paint room or outdoors and away from bystanders.	TDR 5.8
Contact with small airborne shrapnel	Catastrophic failure of recovery and motor components (see motor and recovery FMEA)	Blindness	4C	4A	A minimum distance will be defined between personnel and the launchpad. Personnel are alerted through a horn sounding that launch vehicle components are drifting overhead. See aerodynamics and propulsion FMEA for catastrophic motor failure mitigations.	NAR Safety Code #6, NASA 5.4
	Cutting or drilling metal				All personnel working on and around power tools with potential to create	TDR 5.8; The shop vac is

					airborne particulates wear protective eyewear. A shop vac is used while drilling, sanding, and cutting to reduce risk of particles becoming airborne.	located next to all major desktop lab power tools.
Head Injury						
Contact with large airborne shrapnel	Live black powder charges detonating after launch in the presence of recovery personnel	Concussion	3B	3A	Redundant altimeters will be used to ensure all charges detonate. Members will avoid generation of static and will wear PPE to protect against flames.	NASA 2.3; NASA 3.4
	Motor explosion (see motor FMEA)	Skull fracture	4B	4A	A minimum distance will be defined between personnel and the launchpad. Personnel are alerted through a horn sounding that launch vehicle components are drifting overhead. See aerodynamics and propulsion FMEA for catastrophic motor failure mitigations.	NAR Safety Code #6, NASA 5.4
Loss of Limb						
Motor ignition among personnel	Premature motor ignition (see motor FMEA)	Limb loss or severe injury that warrants amputation	4B	4A	A minimum distance will be defined between personnel and the launchpad. Personnel are alerted through a horn sounding that launch vehicle components are drifting overhead. See aerodynamics and propulsion FMEA for catastrophic motor failure mitigations.	NAR Safety Code #6, NASA 5.4
	No minimum distance defined					
Black powder ignition among personnel	Premature black powder ignition (see recovery FMEA)				Black powder charges are the final component in assembling the launch vehicle. Once black powder charges are inputted, no personnel are permitted in the area behind which the black powder charges are stored.	Checklist section: Main/Drogue Black Powder Installation

	Live black powder charges contained in launch vehicle after landing				Recovery personnel wear Nomex gloves when approaching the launch vehicle and turn off altimeters before handling the launch vehicle.	Checklist section: Main/Drogue Black Powder Installation
Collision of personnel with ballistic launch vehicle component	Improper parachute deployment				The launch vehicle is angled away from personnel before flight, and personnel are given a heads up through the sound of a horn when launch vehicle components are overhead.	NAR Safety Code #9
Soft Tissue Injury						
Slips, trips, and falls	Uneven or wet ground surfaces during launch	Bruising	1D	1A	Recovery personnel walking to collect the launch vehicle will walk carefully to minimize tripping risk. Closed toed and gripping shoes are worn to prevent slips.	NAR Safety Code #13
	Tripping hazards (wires, trash, lab equipment, etc) in work area	Sprain	2C	2A	All wires, their outlets, and their inputs are to be contained in one area to minimize chords on the floor. Equipment and materials are to be kept on the center table or the soldering desk.	Power strips are located on the center desk and on walls surrounding the lab.
Respiratory Injury						
Inhalation of lung irritants	Exposure to fumes from working with epoxy resin	Lung irritation, difficulty breathing, lightheadedness, and/or long-term effects such as tumors and lung infection	3C	3A	An oxygen monitor is used to measure the concentration of epoxy in the lab air. If oxygen concentration becomes too low, lab ventilation is increased. Personnel working with epoxy additionally wear particulate masks.	An oxygen monitor will be located on the center table during fabrication using epoxy.
	Exposure to airborne particulates from drilling,				All personnel working on and around power tools with potential to create airborne particulates wear protective	TDR 5.8; The shop vac is located next to

	cutting, sanding, and/or creating fillet epoxy				eyewear. A shop vac is used while drilling, sanding, and cutting to reduce risk of particles becoming airborne.	all major desktop lab power tools.
	Exposure to fumes from working with spray paint				The team shall provide respirators to personnel working with aerosol products.	TDR 5.8
	Exposure to fumes from off gassing of stored chemicals				Hazardous materials are stored in a flame cabinet. Personnel seeking to use materials in the cabinet must wear particulate masks.	TDR 5.8; The flame cabinet is located in between the two lab doors.
Skin Abrasion						
Exposure to excessive heat	Skin contact with soldering iron	Mild to severe burns, blistering, and skin damage			Solder temperature is restricted. Those working with solder are trained by experienced team members.	TDR 5.1
	Skin contact with curing epoxy			3A	West System 206 Epoxy is used. This epoxy does not reach temperatures required to burn skin.	Safety Handbook: 206 Hardener
	Skin contact with heat gun or heat gun exhaust		3C		Personnel working with heat guns wear Nomex gloves and fireproof PPE.	TDR 5.8
Sunburn	Exposure to excessive sunlight during launch				The team will provide shade from the sun at all outdoor events.	TDR 5.6
Electric shock	Skin contact with direct current generator					
Fingers caught in blade or bit of bandsaw or drill press	Jewelry or gloves worn while working with power tools	Avulsion and degloving of fingers' skin		2A	A jewelry and glove box is placed in the lab.	The jewelry and glove box is located by the door on the metal shelving unit.

Contact with shrapnel	Catastrophic failure and no defined minimum distance				A minimum distance will be defined between personnel and the launchpad. Personnel are alerted through a horn sounding that launch vehicle components are drifting overhead. See aerodynamics and propulsion FMEA for catastrophic motor failure mitigations.	NAR Safety Code #6, NASA 5.4
Slipping or tripping when handling sharp objects	Uneven or wet ground surfaces	Cuts in skin	2D		Launches will not occur during or following adverse weather or field conditions. The RSO has the final say on the status of launches and the team will follow the guidelines set by the RSO.	NAR Safety Code #6
	Tripping hazards (wires, trash, lab equipment, etc) in work area				All wires, their outlets, and their inputs are to be contained in one area to minimize chords on the floor. Equipment and materials are to be kept on the center table or the soldering desk.	Power strips are located on the center desk and on walls surrounding the lab.

6.4 Failure Modes and Effects Analysis

Failure mode and effect analysis (FMEA) tables allow clear identification of failure possibilities, failure causes, and their effect on the project. They also assign a likelihood-severity (LS) rating, identify how the causes will be mitigated, and preliminary verification steps. When all possible failures are identified the team can effectively mitigate such possibilities which will minimize personnel injuries and flight failures. The tables are organized into six columns: mission component, hazard type, causes, effects, likely-severity rating, and mitigation.

Table 6-3 Recovery FMEA

Hazard	Cause	Effect	LS Rating	LS Mitigated	Mitigation	Verification
			Shear Pins			
Delayed/lack of shear pin breakage	Shear pins of excessive diameter	Ballistic descent; excessive kinetic energy upon landing	4B	4A	Proper size 4-40 shear pins will be tested for strength and used.	FRR 7.1.4: Shear pin shear loading test completed on 01/15/2020 NASA 3.9
Delayed/lack of shear pin breakage	Insufficient black powder charges	Ballistic descent; excessive kinetic energy upon landing	4B	4A	Proper black powder charge will be calculated mathematically and will be demonstrated via ejection testing well before launch.	FRR 7.1.9: Full-scale Ejection Test completed on 2/21/20
Premature shear pin breakage	Shear pin ejection	Premature section separation; final apogee lower than expected	3B	3A	Shear pin holes will be drilled to the same diameter as shear pins; tape will be used to secure loose shear pins.	Checklist section: Main/drogue parachute recovery assembly

	Shear pins of insufficient diameter		3B	3A	Proper size 4-40 shear pins will be tested for strength and used.	FRR 7.1.4: Shear pin shear loading test completed on 01/15/2020 NASA 3.9
	Premature black powder detonation		3B	3A	Altimeters will be tested for functionality using pressure vessel prior to installation on the launch vehicle.	FRR 7.1.7: Altimeter operational test completed on 01/20/2020
Parachute Assembly						
Parachute assembly disconnection	U-Bolt shear U-Bolt disconnection Bulkhead crack Bulkhead separation	Ballistic descent; excessive kinetic energy upon landing	4B	4A	Shear tests will be performed on bulkheads and U-bolts.	FRR 7.1.3: Bulkhead tensile loading test was performed 12/03/2019. Bulkhead did not fail at 1.5x anticipated load. FRR 7.1.3: AV Bay bulkhead tensile loading test completed on 01/15/2020
Limited parachute deployment	Shock cord tangling Parachute collapse	Excessive kinetic energy upon landing	3B	3A	At least 3 team members including the recovery lead and the safety officer will be present for shock cord/parachute folding and installation.	NASA 5.3.1.6 TDR 5.2, 5.3
Late parachute deployment	Delayed E-match burning Defective altimeter Delayed black powder detonation	Excessive shock upon parachute deployment causing airframe damage (i.e. “zippering”)	3C	3A	Altimeters will be tested before launch; black powder and E-match assembly will be inspected by the safety officer and recovery lead during assembly to ensure proper packing.	FRR 7.1.7: Altimeter operational test completed on 01/20/2020 Checklist section: E-match installation; Main/drogue black powder

No parachute deployment	Lack of section separation	Ballistic descent; excessive kinetic energy upon landing	4C	4A	Battery voltage will be checked prior to battery installation and then again once altimeters are armed.	NASA 2.7
	No power supplied from battery to altimeter					FRR 7.1.6: Recovery electronics battery life demonstration completed on 01/20/2020
False apogee detection	Incorrect pressure readings	Parachute deployment during ascent; damage to airframe or recovery harness	2C	2A	Altimeters will be tested for functionality using pressure vessel prior to installation on the launch vehicle.	FRR 7.1.7: Altimeter operational test completed on 01/20/2020
	Defective altimeter					
Altimeters						
Excessive pressure in parachute bay	Detonation of primary charge causing detonation of secondary charge	Airframe and recovery harness damage	3C	3A	Black powder charges will be placed on opposite sides of the bulkhead to reduce the chance of sympathetic detonation.	Checklist section: Avionics bay assembly
	Altimeter error			3A	Altimeters will be tested for functionality using pressure vessel prior to installation on the launch vehicle.	FRR 7.1.7: Altimeter operational test completed on 01/20/2020
Avionics exposed to black powder charge	AV bulkhead fails to provide proper seal	Electronics damage or destruction; altimeter failure in flight	3C	3A	Assembly personnel will tug on seal with force greater than expected during flight.	Checklist section: Avionics bay assembly
GPS/Recovery						
Poor GPS Signal	Signal interference	Inability to locate rocket in the event that visual tracking is insufficient	3C	3B	GPS signal will be confirmed before inserting the AV sled into the rocket, and again before taking the rocket to the launch pad.	FRR 7.1.8: GPS Operation test completed on 01/25/2020
	Insufficient range capabilities of GPS					Checklist section: Launchpad procedure

Table 6-4 Structures FMEA

Hazard	Cause	Effect	LS Rating	LS Mitigated	Mitigation	Verification
			Bulkheads			
Nosecone bulkhead failure	Improper epoxy application	Nose cone enters a ballistic descent during recovery	3C	3A	Bulkhead connections to body tube will have a factor of safety of 1.5.	The team tested bulkheads to a maximum force of 1000 lb on 12/06/2019.
Motor tube bulkhead failure	Improper epoxy application	Motor separates from launch vehicle	4B	4A	Bulkhead connections to body tube will have a factor of safety of 1.5.	The team tested bulkheads to a maximum force of 1000 lb on 12/06/2019.
AV bay bulkhead failure	Excessive loading during recovery events	Ballistic descent of all body section not attached to main parachute shock cord				
Bulkhead delamination	Excessive loading during recovery events	Cracks in body tube	2A	1A	Bulkhead layer connections will have a factor of safety of 1.5.	
			Airframe			
Elevated pressure within body tube	Undrilled or too small pressure ports	Airframe rupture	4B	4A	The team will use 5/16" size pressure ports, shown to allow proper pressure balance	FRR 3.4.2: Six 5/16" size pressure ports are drilled.
Launch vehicle exposure to excessive moisture	Adverse weather, bad recovery position	Weakens structural integrity of launch vehicle	3C	2B	The launch vehicle's airframe will be made of G12 fiberglass, a moisture resistant material.	FRR 7.1.3: G12 fiberglass is the material selection for launch vehicle body tube.
					The team will not launch in inclement weather conditions.	NAR Safety Code #9

Motor separation from motor tube	Excessive loading on epoxy	Dangerous and unpredictable flight	4A	4A	Epoxy resin to hardener ratio will be 1:5 to meet load specifications.	Safety Handbook Epoxy Procedure
Launch vehicle sections colliding during descent	Shock cord improperly sized	Cracks and chips on body tube	3B	2A	Shock cord will be 40 inches such that body sections will be sufficiently distributed along recovery harness and sections will not knock together.	FRR 3.4.1: Optimal shock cord length is in between 27 and 45 ft. The team owns 40 ft shock chord.

Table 6-5 Payload FMEA

Hazard	Cause	Effect	LS Rating	LS (Mitigated)	Mitigation	Verification
BURRITO (chassis, drivetrain, control electronics)						
Rover movement impeded by terrain	Impacting raised terrain thus bottoming out the rover	Rover unable to move; inability to complete mission	3D	3B	The rover will be built with a chassis high enough above the ground so that raised terrain present little issue.	FRR 1.3.1
	Rover becomes entangled with debris on field	Rover movement impeded; inability to complete mission or severe delay in mission completion	3C	3B	The rover operator will closely follow the rover such that potential obstacles can be spotted ahead of time and avoided.	Checklist section: Payload
	Landing in or entering an irrigation ditch	In the event of rover inability to exit ditch; inability to complete mission				
Damage to rover control system and circuitry	Drivetrain becomes embedded in simulated ice material	Rover movement impeded; inability to complete mission	3C	2B	Rover operator will drive slowly on simulated ice such that the wheels do not spin out and dig into the pit.	Checklist section: Payload

	Exposure of rover to significant amounts of water	Shorting of circuitry leading to loss of rover control and permanent damage to affected components	3C	2B	Electronics will be encased in a plastic electronics bay.	FRR 4.3
					Payload operator will avoid puddles.	Checklist section: Payload
	Overheating from environmental or operational factors	Irreparable damage to rover components if exposure is severe and prolonged; mission delay or inability to complete mission	2B	1B	All rover components will be tested for their ability to withstand the mission's voltage and current demands.	Testing plan
	Damage to wiring connections during launch, landing, or rover operations	Partial rover failure; partial or full inability to complete mission. Shock hazard for recovery personnel	2B	2A	Most connections will be contained inside the electronics bay, preventing direct damage and hazard to personnel.	FRR 4.4
Rover flipped during operation	Sudden stopping of the rover; uneven terrain encountered	Rover unable to continue movement; inability to complete mission	2C	2C	Two guiding wheels will be implemented to stabilize BURRITO.	FRR 4.3: Drivetrain
Damage to rover chassis	Loads during launch, landing, or deployment exceed design loads	Rover is unable to be reused without significant repair; inability to complete mission	2C	2B	The rover chassis will be made of treated plywood and the rover itself will be securely fastened during flight.	FRR 1.3.1
Rover drivetrain jams	Debris lodged in drivetrain elements	Rover motion impeded; unable to continue mission or delay in mission completion	2C	2A	Chassis and wheel connection will be shielded by a piece sitting flush to the rover.	FRR 4.3
	Motor stall torque reached during driving		2B	2A	The motor will have a higher stall torque than peak operating torque during driving.	FRR 4.3
Separation of rover power transmission	Terrain impacts exceeding	Rover damaged; unable to continue mission	2A	2A	During rover assembly, multiple team members will confirm	Checklist section: Payload

components (wheels, stabilizing arm, etc.)	maximum design loading criteria				securement of rover components.	
	Improper securing of attachment points	Rover unintentionally disassembled; unable to continue mission	2A	2A	Rover operator will not exceed a speed of 4 mph.	TDR 4.2
Payload separation from rocket during recovery sequence	Failure of payload retention system combined with unusual attitude of the forward recovery section	Ballistic landing of payload; hazard to personnel or bystanders	4A	4A	The latch will be designed to retain greatest anticipated load with a safety factor of 1.5.	TDR 2.7
Insufficient battery longevity for mission completion	Incorrect battery sizing	Rover loses power before mission completion	3C	3A	Battery drainage tests will be performed to ensure power supply system meets pad and flight time requirements.	BURRITO Nominal Performance Test completed on 01/28/2020
	Unanticipated current draw				Components will utilize standby mode when not in operation to conserve battery power.	Checklist section: Payload
Payload Deployment/Retention						
Failure to detect landing	Flight sequence thresholds not detected	Payload deployment sequence not initiated; mission not completed	3B	3B	Anticipated maximum acceleration levels will be tested in RockSim and flight sequence thresholds will be programmed for a factor of safety of 1.5 of these anticipated loads.	Acceleration levels were determined to be no higher than 40 Gs in RockSim in tests conducted on 11/12/2019

Failure to initiate deployment operation	Payload deployment system wiring fault Programming fault	Payload does not deploy; mission not completed	2B	2A	The deployment mechanism's wiring and programming will be verified by pre-flight testing.	BURRITO Nominal Performance Test completed on 01/28/2020
Deployment motor stall	Payload misalignment Excessive drivetrain friction	Damage to or overheating of deployment motor; inability to complete payload deployment	2C	2A	Radial supports in payload bay will guide the rover.	FRR 4.5.3
In-flight failure of payload retention latch	In-flight loads exceed expected design loads	Payload unsecured within rocket; potential for damage to airframe and payload, potential for payload separation leading to ballistic payload descent	4B	4A	The payload retention latch will be built to withstand 60 Gs of force with a factor of safety of 1.5.	FRR 4.5.1
Slipping or binding of deployment system power train	Loss of drivetrain alignment Lodging of foreign debris in drivetrain	Inability to drive deployment mechanism; inability to deploy payload	2B	2A	Power transmission mechanism will be placed under protective housing.	FRR 4.5.4
Failure of the latch to actuate during payload deployment sequence	Control system fails to actuate latch	Payload trapped in launch vehicle; unable to continue mission	2B	2A	Latch actuation will be tested prior to launch.	Deployment System Operational Demonstration completed on 02/17/2020
	Binding or debris in latch mechanism				Latch will be sufficiently powerful to dislodge any debris.	FRR 4.5.1
Sample Ice Collection System						
Insufficient battery longevity for mission completion	Incorrect battery sizing	Rover loses power before mission completion; inability to complete mission	3A	3A	Battery drainage tests will be performed to ensure power supply system meets pad and flight time requirements.	BURRITO Nominal Performance Test completed on 01/28/2020

	Unanticipated current draw				Components will utilize standby mode when not in operation to conserve battery capacity.	FRR 4.3
Excessive loading on scoop	Signal error	Damage done to scoop; delay in sample collection or inability to collect sample	3B	3A	Wiring and avionics will be tested for continuity.	Checklist section: AV Bay Assembly
	Mechanical failure				The addition of a cover will maintain that the gears are coplanar.	FRR 4.3
	Unexpected ground resistance				Scoop prototypes will be tested in sample site analog prior to launch.	SICCU Operational Test completed on 02/11/2020
Inadequate sample collected	Mechanical failure of the scoop mechanism	Scoops are unable to collect sufficient material for analysis resulting in mission failure	3B	2A	The scoop is designed to withstand varied loading conditions.	FRR 4.3
	Incorrect design volume				The scoop will have more than 10 mL internal volume for required sample size.	FRR 4.3
Damage to scoop during deployment	Mechanical blockage; excessive loading on scoop	Inability to collect sample	3B	2B	The scoop will not be deployed if doing so would damage the payload or launch vehicle.	Checklist section: Payload
Gear obstruction	Dirt, rocks, or other obstructions embedded in teeth	Inability to collect sample	4B	4A	A mechanical barrier to obstructions will be built around exposed gear system.	FRR 4.3
	Misalignment of gears				The addition of a cover will maintain that the gears are coplanar.	FRR 4.3

Table 6-6 Aerodynamics FMEA

Hazard	Cause	Effect	LS Rating	LS Mitigated	Mitigation	Verification
Trajectory						
Undesirable flight trajectory during flight immediately after rail exit	Unexpected large gust of wind	Apogee change, potential loss of launch vehicle control, potential loss of launch vehicle if severe enough	4A	4A	Stability margin of the launch vehicle is at or above 2.0.	TDR 2.5
					No launches will occur in sustained gusts of greater than 20 mph.	NAR Safety Code #9
Undesirable glide trajectory after parachute deployment	Partial/complete failure of parachute deployment, unexpected large gust of wind, weight overestimation	Vehicle will land farther away from launch site, vehicle retrieval becomes complicated, payload is unable to deploy	2C	2B	Launch vehicle weight and parachute size are compatible such that the launch vehicle lands with slightly greater than 75 ft-lbf of kinetic energy.	NASA 3.3
					No launches will occur in sustained gusts of greater than 20 mph.	NAR Safety Code #9
Unintended Thrust Curve	Poorly loading the solid propellent into the motor casing	Unintended flight trajectory and a potentially less than ideal static margin of the vehicle	2C	2A	Motor assembly is carried out under supervision of experienced Tripoli L3 mentors. Motor will be examined beforehand for external flaws.	NASA 1.1
	Motor nozzle failure					
Motor						
Motor failure during burn	Fuel grain defect	Loss of launch vehicle	4A	3A	The team will use Aerotech motors, commercially available and shown to be reliable.	FRR 1.2.2; NASA 2.10
	Incorrect motor assembly				Motor assembly is carried out under supervision of	NASA 1.1

					experienced Tripoli L3 mentors. Motor will be examined beforehand for external flaws.	
Motor fails to ignite	Faulty igniter	Launch vehicle fails to leave launch rail	3C	1B	The team will bring multiple igniters to the launch site and replace the faulty igniter using a contingency checklist.	TDR 2.9
	High humidity				The team will not launch in high humidity.	NAR Safety Code #6
Fin flutter	Mach number of launch vehicle greater than 0.7	Fin structure damage and alteration of aerodynamic stability	4B	4A	Maximum Mach number will be identified in RockSim to ensure a peak freestream Mach number of less than 0.7. Fin assembly will be tested beforehand for proper angles and secure attachment to fin can.	TDR 2.2

6.5 Environmental Hazard Analysis

The team has performed an environmental hazard analysis on the risks to the environment due to the project and vice versa. The team found, through both induction and deduction (FTA and FMEA) that the risks posed to and by the environment can be successfully mitigated through team action.

Table 6-7 Risks to Project Due to Environment

Hazard	Cause	Effect	LS Rating	LS Mitigated	Mitigation	Verification
Altimeter shortage during flight	Water exposure from inclement weather	Inoperable altimeters	2C	2B	The launch vehicle will be directed away from water features.	NAR Safety Code #9
Payload electronics shortage during flight		Inoperable payload electronics				
Body tube water saturation		Body tube expansion, resulting in an inability to separate and a ballistic landing	4B	4A	Full-scale body tube will be constructed of water-resistant fiberglass.	FRR 7.5.1: Budget; Table 7-23
		Compromised launch vehicle structure and an inability to relaunch the launch vehicle				
Payload component rusting		Payload components become damaged and must be replaced	3A	2A	Payload chassis will be treated to be water resistant and use non-rusting materials; any water collected will be disposed of and cleaned immediately after recovery.	FRR 7.5.1: Budget; Table 7-23
Black powder water saturation		Black powder ignition failure and explosion hazard to recovery personnel			Pre-flight moisture exposure will be minimized through the use of a tent under which preflight assembly will take place.	TDR 4.7

Significantly altered launch trajectory	High-velocity crosswinds	Failure of vehicle to reach intended apogee	2C	1A	The launch vehicle shall maintain a stability margin of 2.0 upon exiting the launch rail to prevent an alteration in launch trajectory due to wind gusts.	NASA 2.14
High vehicle drift rate during descent		Excessive recovery distance and/or damage to nearby property	2C	1A	The team shall not launch in winds over 20 mph.	NAR Safety Code #9
Live black powder charges post-descent	Severe humidity	Risk of bodily harm from explosion	3B	3A	Pre-flight moisture exposure will be minimized.	TDR 5.7
	Avionics failure					
Launch vehicle landing site in trees, wooded areas, or bushes	High velocity crosswinds	Rips and tears in recovery parachutes, shroud lines, and body tube	2C	2A	Launch vehicle will be directed away from wooded areas and team shall not launch in winds over 20 mph.	NAR Safety Code #9
	Prematurely deployed parachutes (see avionics/recovery FMEA)	Launch vehicle stuck in tree, unable to deploy rover	4C	4A		
BURRITO stuck in ruts on field after deployment	Muddy and uneven field conditions	Impaired rover motion and deployment ability; inability to satisfy mission requirements	4C	4B	BURRITO will be designed to traverse rough terrain.	FRR 4.3
Launch vehicle lands in rut on field before BURRITO deployment					Launch vehicle will be directed away from undesirable field locations (ditches, water features, trees, etc.)	NAR Safety Code #9

Table 6-8 Risks to Environment Due to Project

Hazard	Cause	Effect	LS Rating	LS Mitigated	Mitigation	Verification
Risks to Environment Due to Project						
Fire at launchpad	Motor ignition and exhaust	Fire around launch/landing site, posing risk nearby animals/property	3C	2A	A blast deflector will be used at the base of the launch rail to deflect all flames away from the dry grass of the field.	NAR Safety Code #7
Fire at recovery site	Overheated electronics		3B	3A	Electronics will be chosen on their ability to withstand the current and voltage specifications of the project.	FRR 4.3: The current draw meets or exceeds 2000 mA and the voltage draw meets or exceeds 12V.
	Internal fire from black powder charge ignition		4D	4A	See recovery FMEA	See recovery FMEA
Abandonment of nonbiodegradable waste	Unrecovered launch vehicle components	Harm to local wildlife and waterways	2C	2B	Recovery team will be sent out to assess damage and recover all system components when safe to do so.	Checklist: Launch Vehicle Recovery
	Waste from launch preparation				All team members will participate in post-launch cleanup to eliminate littering.	TDR 5.8
Launch vehicle landing in trees or other natural features	High velocity crosswinds	Tree damage or loss of life	2C	2B	See section 1.1	See section 1.1
	Prematurely deployed parachutes (see avionics/recovery FMEA)					

Avionics or payload battery puncture	Loose or broken launch vehicle components free to move within launch vehicle sections	Battery chemical leakage/fire at launch/landing site	2B	2A	Batteries will be secured to an enclosed AV Bay, ensuring that if leakage occurs, waste does not escape.	FRR 3.4.2: An avionics sled is contained within a sealed avionics bay.
High kinetic energy impact of launch vehicle on ground	Late or no parachute deployment	Ruts and pits in the launch vehicle that impede wildlife traversal and agriculture	2C	2B	Ejection systems will be thoroughly tested and perfected prior to launch day.	Ejection testing completed on 02/20/2020

6.6 Launch Operation Procedures

6.6.1 Standard Procedures

The team's launch day checklists can be found in Appendix A at the end of this document. These have been reformatted for better flow and easier task accountability.

6.6.2 Emergency Procedures

The team's emergency checklists can be found in Appendix A at the end of this document.

7. Project Plan

7.1 Launch Vehicle Tests

Table 7-1 Launch Vehicle Test Suite

Test	Requirement Verified	Required Facilities	Required Personnel	Scheduled Date
Subscale Ejection Demonstration	NASA 3.2	N/A	Recovery Lead	11/17/2019
Subscale Demonstration Flight	NASA 2.17; NASA 2.17.2	Paul Farm, Bayboro, NC	Team Lead	11/23/2019
Bulkhead Tensile Loading Test	TDR 2.7	Universal Testing Machine	Structures Lead	12/3/2019
Shear Pin Loading Test	TDR 2.7	Universal Testing Machine	Structures Lead	1/15/2020
Fastener Shear Loading Test	TDR 2.7	Universal Testing Machine	Structures Lead	1/15/2020
Recovery Electronics Battery Life Demonstration	NASA 3.4	Vacuum Container	Recovery Lead	1/20/2020
Altimeter Operational Demonstration	NASA 2.7	N/A	Recovery Lead	1/20/2020
GPS Tracker Operational Demonstration	NASA 3.12; NASA 3.12.2	Wolfline Bus	Recovery Lead	1/25/2020
Full-scale Ejection Demonstration	NASA 3.1; NASA 3.1.3; NASA 3.2	N/A	Recovery Lead	2/18/2020
Full-scale Demonstration Flight	NASA 2.1; NASA 2.4; NASA 2.6; NASA 2.18; NASA 2.18.1; NASA 2.18.1.1; NASA 2.18.2.1; NASA 2.19.2; NASA 2.19.3; NASA 3.1.1; NASA 3.1.2; NASA 3.6; NASA 3.7; NASA 3.10; NASA 3.11; NASA 3.13; NASA 3.13.1; NASA 3.13.2; NASA 3.13.3; NASA 3.13.4; NASA 5.4; NASA 5.5; TDR 5.6	Paul Farm, Bayboro, NC	Team Lead	2/22/2020

7.1.1 Subscale Ejection Demonstration

Per requirement NASA 3.2, a demonstration of successful recovery deployment is necessary prior to each launch. A failure to pass this demonstration is defined as a failure to meet any of the following success criteria. If a failure occurs, ejection charge sizes will be adjusted, and the demonstration repeated until success occurs. The below described procedure is a demonstration of the deployment of recovery devices for the subscale launch vehicle, performed on 11/17/2019. The demonstration was successful, and the team proceeded with the subscale demonstration flight.

Table 7-2 Subscale Ejection Demonstration Success Criteria

Success Criteria	Met? (Y/N)
Vigorous and complete separation at the main parachute bay.	Yes
Vigorous and complete separation at the drogue parachute bay.	Yes
No damage to recovery devices.	Yes
No damage to launch vehicle.	Yes

7.1.1.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Ejection Charge Size

7.1.1.2 Procedure

See Appendix A for the field assembly checklist used for launch.
In contrast to the launch checklist the following changes are made:

- The e-match wires are not trimmed whatsoever
- The sled and all mounted electronics are not placed in the avionics bay
- The e-match wires are fed through holes in the AV bay to the exterior
- Motor assembly and launch pad procedure is not performed
- Once the rocket is fully assembled, it is placed on top of foam with the motor backing against the wall, with another piece of foam between the wall and the rocket
- With all team members in attendance at a safe distance and out of the path of the nosecone, one designated member approaches the rocket and attaches the launch switch to the drogue e-match wires with alligator clips
- Retreating to a safe distance, the battery is attached to the switch, and the switch is thrown to detonate the drogue charge
- The fin can is placed out of the way and the remaining midsection is placed back up against the wall
- The same wiring and detonation process is repeated with the main charge

7.1.1.3 Results and Conclusions

During the Subscale Ejection Demonstration, all success criteria were met. The planned amount of black powder was sufficient to separate both the main and drogue parachute bays without damaging the launch vehicle or the recovery devices.

7.1.2 Subscale Demonstration Flight

Per requirement NASA 2.17, a successful flight of a subscale launch vehicle is required prior to the CDR Milestone. A failure to pass this demonstration is defined as a failure to meet any of the following passing criteria. If the demonstration flight were to fail, any alterations necessary to the launch vehicle would be made and the procedure repeated. The team successfully launched the subscale launch vehicle on 11/23/2019.

Table 7-3 Subscale Demonstration Flight Success Criteria

Success Criteria	Met? (Y/N)
Successful motor ignition	Y
Successful drogue parachute deployment at apogee	Y
Successful main parachute deployment at 500 ft	Y
Minimal damage (defined as able to launch again on same day)	Y
Apogee recorded by on-board avionics	Y

7.1.2.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Motor Selection
- Launch Vehicle Weight
- Ejection Charge Size
- Altimeter Selection

7.1.2.2 Procedure

The subscale demonstration flight procedure approximately follows the checklists found in Appendix A.

7.1.2.3 Results and Conclusions

During the Subscale Flight Demonstration, all of the success criteria were met. There were no problems with motor ignition and drogue deployed at apogee. Upon descending to 500 feet, the main parachute separated without problems with minimum damage to the rocket. Apogee was recorded successfully at 3,353 feet by the StratoLoggerCF altimeters.

7.1.3 Bulkhead Tensile Loading Test

Per requirement TDR 2.7, a minimum factor of safety of at least 1.5 is required. This procedure determines the structural characteristics of both an epoxy-filleted bulkhead and a bolted bulkhead. A failure to pass this demonstration is defined as a failure to meet any of the following passing criteria below. Failing this test means the bulkhead would have to be redesigned and tested again until it met the minimum factor of safety stated in TDR 2.7. The test sample is an 8" long piece of 6" G12 Fiberglass airframe. On one end, a ½" thick plywood bulkhead is held in place via two-part epoxy. On the other end, ½" thick plywood bulkhead is held in place by 4 aluminum L-Brackets. The L-Brackets are attached into the body tube by 4 #6 stainless steel screws. There is an outward facing U-Bolt attached to each bulkhead.

Table 7-4 Bulkhead Tensile Loading Success Criteria

Success Criteria	Met? (Y/N)
The test sample withstands a load of over 1000 lbf.	Y
The test sample withstands a load of over 900 lbf applied over 10 seconds.	Y
The test sample has no visible damage after test completion.	Y

7.1.3.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Bulkhead Material
- Bulkhead Thickness
- Location of U-Bolt
- Airframe Material
- Force Applied

7.1.3.2 Procedure

The test execution procedure is as follows:

- Ensure that all personnel are wearing safety glasses
- Attach a quick link to the U-Bolts attached to both bulkheads
- Insert the quick links into either side of the universal testing machine
- Inspect all connections to make sure the test sample is properly secured
- Begin to increase force on testing article in increments of 50 lbf.
- Once the force passes 800 lbf, reduce the increment to 25 lbf.
- Give the test sample ~5s to settle between increments.
- Continue process until the sample breaks

7.1.3.3 Results and Conclusions

At 1517 lbs. the bolted in bulkhead sheared out of the sample airframe. Additionally, it endured 800 lb. loads for 10 seconds. Once the bulkhead failed there was visible damage, but there was no displayed damage at the required load of 800 lbs. Thus, this test passes all the required test criteria.

Figure 7-1 Bulkhead Tensile Loading Test Set up

Failure occurred in both the airframe and the bolts themselves. In Figure 7-3 it can be seen that the airframe was damaged, but also the head of the bolt sheared away from the body. In a perfect test, all four bolts should have sheared away simultaneously, but this is not seen here. Here only two bolts are seen damaged. This can be attributed to uneven loading during testing. While this is unpreferable, it is does not invalidate the results of the tests. Bending can be found in the bolts that were not sheared, meaning that they still received forces pass their yield point at the failure stress. In its current design, the bolted bulkhead does meet its requirements, and would most likely be okay being used in the full-scale design. However, in order to make the design more robust, the final launch vehicle utilizes #8 bolts instead of #6 bolts. The reliability of these bolts is shown in section 0.

Figure 7-2 Epoxied Bulkhead – Before and After Testing

The epoxied section of bulkhead displayed no visible damage, as can be seen in Figure 7-2. This shows the reliability of the adhesive material used to the secure the bulkhead. No changes needed to be made to the final design from these results.

Finally, no damage was seen to either U-Bolt. This shows that there is little risk of U-Bolts yielding or shearing out of the bulkhead.

Figure 7-3 Bolted Bulkhead – Before and After Testing

7.1.4 Shear Pin Loading Test

Per a derived requirement, a minimum factor of safety of at least 1.5 is required. This procedure determines the average shear strength of a sample of shear pins to be used for full-scale flight. This experiment is performed to reaffirm the manufacturer specified strengths. If manufacturer specified strength is incorrect, then the test strength will be used for shear calculations. A failure to pass this test is defined as a failure to meet any of the following passing criteria. A failure to pass this test will lead to deliberation to either change the type of shear pin being used or a possible increase in the number of shear pins. The test sample will consist of two steel plates, a shear pin, and two quick links. The steel plates will have a ¼" hole drilled on one end, and a 3/16" hole drilled on the other. The ¼" hole is designed to allow for a quick link insertion, and the 3/16" hole is designed to allow for shear pin insertion.

Table 7-5 Shear Pin Loading Test Success Criteria

Success Criteria	Met? (Y/N)
Each of the test samples shear at approximately 23 lb.	TBA

7.1.4.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Choice of Shear Pin
- Force Applied

7.1.4.2 Procedure

The test execution procedure is as follows:

- Ensure that all personnel are wearing safety glasses
- Attach a quick link through the 1/4" diameter hole on each steel plate
- Align the 3/16" holes on each plate and insert the desired shear pin/bolt through both
- Align the jaws of the universal testing machine so that the testing article can fit between the jaws while taught
- Insert the quick links into both side of the universal testing machine
- Inspect all connections to make sure that the test sample is properly secured
- Begin to increase force on testing article
- Increase in increments of 5 pounds until 10 lbf. away from the desired force. From there increase in increments of 1 lbf.
- Continue process until the sample breaks

7.1.4.3 Results and Conclusions

The shear pin failed at 27lbs. This is a higher force than expected, but close enough to call the test a success. No design changes were made based on these results. There are still four shear pins per separating section. This value was used to determine the required size of black powder charges in the full-scale launch vehicle. This calculation was then verified using ejection testing described in section 7.1.9.

Figure 7-4 Shear Pin Test Set Up

7.1.5 Fastener Shear Loading Test

Per the associated team derived requirement, a minimum factor of safety of at least 1.5 is required. This procedure determines the average shear strength of a sample of fasteners to be used for full-scale flight. This experiment is performed to reaffirm the manufacturer specified strengths. If manufacturer specified strength is incorrect, then the test strength will be used for shear calculations. A failure to pass this demonstration is defined as a failure to meet any of the following passing criteria. A failure to pass this test will lead to deliberation to either change the type of fastener being used or a possible change in design. The test sample will consist of two steel plates, a shear pin, and two quick links. The steel plates will have a ¼" hole drilled on one end, and a 3/16" hole drilled on the other. The ¼" hole is designed to allow for quick link insertion, and the 3/16" hole is designed to allow for fastener insertion. The sample is designed for both plates to be pulled from their quick links, which would cause shear in the fastener inserted between the plates.

Table 7-6 Fastener Loading Test Success Criteria

Success Criteria	Met? (Y/N)
Each of the test samples shear at approximately 250 lb.	TBA

7.1.5.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Choice of Fastener

- Force Applied

7.1.5.2 Procedure

The test execution procedure is as follows:

- Ensure that all personnel are wearing safety glasses
- Attach a quick link through the 1/4” diameter hole on each steel plate
- Align the 3/16” holes on each plate and insert the desired shear pin/bolt through both
- Align the jaws of the universal testing machine so that the testing article can fit between the jaws while taught
- Insert the quick links into both side of the universal testing machine
- Inspect all connections to make sure that the test sample is properly secured
- Begin to increase force on testing article
- Increase in increments of 5 pounds until 10 lb. away from the desired force. From there increase in increments of 1 lb.
- Continue process until the sample breaks

7.1.5.3 Results and Conclusions

The fastener broke at 1200 lbs. This meets the success criteria. This test data assured that current fastener locations would provide sufficient strength is their designated locations. These locations include payload-parachute bay, payload-Nosecone, and the nose cone bulkhead. The design of the rocket includes four fasteners holding each non-separating section together. This is equivalent to 4800 lbs. of ultimate tensile force. This is enough to overcome flight loads without additional support. The final design for the nosecone bulkhead features six of the tested fasteners. This is equivalent to 7,200 lbs. of ultimate tensile force. Again, this is enough to endure flight loads, and recovery loads. No changes to the design of the rocket were needed once these tests were complete.

Figure 7-5 Fastener Loading Test Set Up

Figure 7-6 Sheared Fastener

7.1.6 Recovery Electronics Battery Life Demonstration

Per requirement NASA 2.7, a demonstration of electronics battery life is required. The Recovery Electronics Battery Life Demonstration is to make sure that the batteries can last more 2 hours once connected to the altimeters. A failure to pass this demonstration is defined as a failure to meet any of the following passing criteria. Failure of this test would lead to a change in the type of battery or type of altimeter until success criteria are met.

Table 7-7 Recovery Electronics Battery Life Demonstration Success Criteria

Success Criteria	Met? (Y/N)
Altimeter 1's battery life lasts longer than two hours.	Y
Altimeter 2's battery life lasts longer than two hours.	Y
Eggfinder GPS tracking system's battery life lasts longer than two hours.	Y

7.1.6.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Choice of 9V Batteries
- Choice of Altimeter
- Choice of Tracking Device

7.1.6.2 Procedure

The test execution procedure is as follows:

- Set up the altimeter apparatus for testing
- Connect a 9V battery to each altimeter
- Connect a 2S LiPo to the tracking device
- Start the stopwatch
- Check to make sure the altimeters and tracking device are still functional every 15 minutes
- At 3 hours, conclude the test

7.1.6.3 Results and Conclusions

All designed criteria for the Recovery Electronics Battery Life Demonstration were met successfully. The primary and secondary altimeter's battery functioned for 3 hours before the test was concluded. The altimeter batteries both started around 9.5 volts and had approximately 9 volts by the conclusion of the test. The Eggfinder GPS functioned properly for three hours before the test was concluded. The GPS battery started at approximately 9.5 volts and had approximately 7.8 volts by the conclusion of the test.

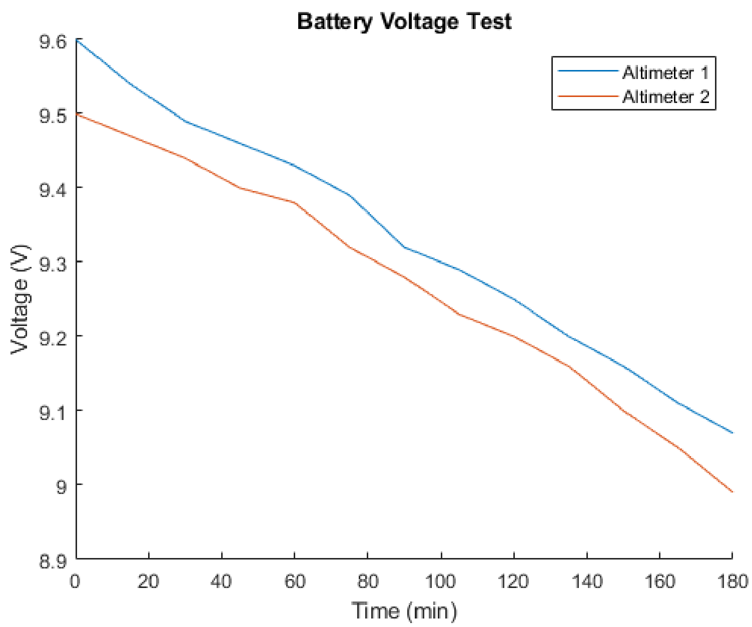


Figure 7-7 Altimeter Battery Voltage Results

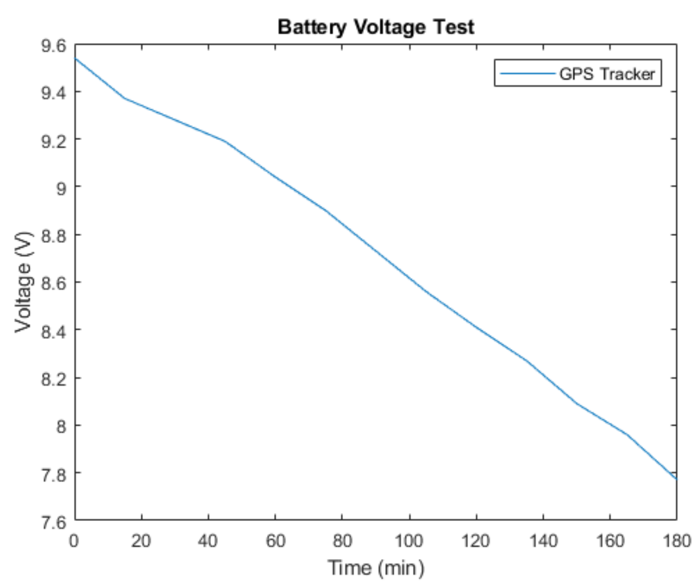


Figure 7-8 GPS Battery Voltage Results

7.1.7 Altimeter Operational Demonstration

Per the associated team derived requirement, a demonstration of altimeter functionality prior to each launch is required. The Altimeter Operational Demonstration test is meant to make sure that the altimeters work properly when going through a simulated launch. A failure to pass this demonstration is defined as a failure to meet any of the following passing criteria. If one or both altimeters fail this test, the altimeters will be fixed or replaced until the success criteria are met.

Table 7-8 Altimeter Operational Demonstration Success Criteria

Success Criteria	Met? (Y/N)
LED #1 lights when the altimeter senses apogee.	Y
LED #2 lights when the altimeter senses the main deployment altitude.	Y
Pre-Flight beeps match what is recorded on the beep sheet. See Appendix A for beep sheets.	Y
Post-Flight beeps do not indicate any errors.	Y

7.1.7.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Pressure
- Choice of Altimeter

7.1.7.2 Procedure

The test execution procedure is as follows:

- Attach the two altimeters to the testing apparatus
- Connect the one 9V battery to each altimeter
- Record the pre-flight beep sheet
- Seal the vacuum chamber making sure the lights are visible through the small window in the top of the chamber
- Pulling the vacuum slowly to simulate a launch
- Once the vacuum is turned off, the first light should turn on
- Shortly afterwards, the second light should turn on
- Open the chamber and record the post-flight beep sheet and confirm the recorded altitudes are the same

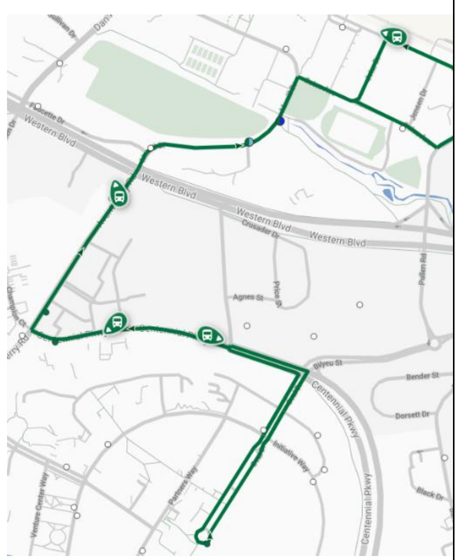
7.1.7.3 Results and Conclusions

Both altimeters tested performed as expected. Pre-flight beeps indicated the correctly programmed settings for each of the altimeters, and both lights lit up in order. After the test the primary altimeter reported an apogee of 792 ft, while the redundant altimeter reported an apogee of 796 ft. The two altimeters reported apogee values only 4 ft apart and experienced no errors, so the demonstration is considered a success.

7.1.8 GPS Tracker Operational Demonstration

Per requirement NASA 3.12, a tracking unit is required. The GPS Tracker Operational Demonstration is meant to confirm the GPS being placed in the rocket works and is accurate in relaying the GPS location data. A failure to pass this demonstration is defined as a failure to meet any of the following passing criteria. If the GPS fails this demonstration, the GPS will be replaced.

Table 7-9 GPS Tracker Operational Demonstration Success Criteria

Success Criteria	Met? (Y/N)
The recorded GPS Tracker path matches that of the NCSU Wolfline #3 bus route, pictured.	Y
	

7.1.8.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Selected Bus Route
- Selected GPS tracker

7.1.8.2 Procedure

The test execution procedure is as follows:

- Power on the ground receiver dongle and transmitter
- Pair the ground receiver dongle to a club member's Android phone with Rocket Locator installed
- Establish connection between the ground receiver and transmitter, and make sure the location is properly displaying to Rocket Locator

- With the transmitter, receiver, and phone, get on the WolfLine #3 bus.
- Compare the results plotted by the GPS on the phone to the current position, estimating delay and positional error.

7.1.8.3 Results and Conclusions

The transmitter's coordinates were more than accurate enough to identify the vehicle's position. The maximum error was estimated to be about 50 ft from the current position. Any delay was a function of the transmission frequency between transmitter and receiver of once per second, each packet received was up to date. Time to first fix took approximately 3 minutes, which while not favorable is perfectly acceptable given the results of the Recovery Electronics Battery Life Test as described in section7.1.6 .

7.1.9 Full-Scale Ejection Demonstration

Per the associated requirement, a demonstration of successful recovery deployment is necessary prior to each launch. A failure to pass this demonstration is defined as a failure to meet any of the following passing criteria. If a failure occurs, ejection charge sizes will be adjusted, and the demonstration repeated until success occurs. The below described procedure is a demonstration of the deployment of recovery devices for the full-scale launch vehicle, to be performed on 2/18/20. A failure to pass this demonstration is defined as a failure to meet any of the following passing criteria.

Table 7-10 Full-Scale Ejection Demonstration Success Criteria

Success Criteria	Met? (Y/N)
Vigorous and complete separation at the main parachute bay.	Yes
Vigorous and complete separation at the drogue parachute bay.	Yes
No damage to recovery devices.	Yes
No damage to launch vehicle.	Yes

7.1.9.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Ejection Charge Size

7.1.9.2 Procedure

See Appendix A for the field assembly checklist used for launch.
In contrast to the launch checklist the following changes are made:

- The e-match wires are not trimmed whatsoever
- The sled and all mounted electronics are not placed in the avionics bay
- The e-match wires are fed through holes in the AV bay to the exterior
- Motor assembly and launch pad procedure is not performed
- Once the rocket is fully assembled, it is placed on top of foam with the motor backing against the wall, with another piece of foam between the wall and the rocket

- With all team members in attendance at a safe distance and out of the path of the nosecone, one designated member approaches the rocket and attaches the launch switch to the drogue e-match wires with alligator clips
- Retreating to a safe distance, the battery is attached to the switch, and the switch is thrown to detonate the drogue charge
- The fin can is placed out of the way and the remaining midsection is placed back up against the wall
- The same wiring and detonation process is repeated with the main charge

7.1.9.3 Results and Conclusions

During the Full-Scale Ejection Demonstration, all success criteria were met. The planned amount of black powder was sufficient to separate both the main and drogue parachute bays without damaging the launch vehicle or the recovery devices.

7.1.10 Full-Scale Demonstration Flight

Per the associated requirements listed in Table 7-1 a successful flight of a full-scale launch vehicle is required prior to the FRR Milestone. A failure to pass this demonstration is defined as a failure to meet any of the following success criteria. If a failure occurs, the failed component will either be redesigned and/or repaired prior to the FRR Addendum Milestone.

Table 7-11 Full-Scale Demonstration Flight Success Criteria

Success Criteria	Met? (Y/N)
Successful motor ignition	Y
Successful drogue parachute deployment at apogee	Y
Successful main parachute deployment at 500 ft	Y
Minimal damage (defined as able to launch again on same day)	Y
Apogee recorded by on-board avionics	Y

7.1.10.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Motor Selection
- Launch Vehicle Weight
- Ejection Charge Size
- Altimeter Selection

7.1.10.2 Procedure

The checklists in Appendix A are used to assemble and launch the full-scale rocket.

7.1.10.3 Results and Conclusions

The Full-Scale Demonstration flight succeeded in meeting all the designated success criteria. Onboard avionics record apogees of 3187 ft AGL. The drogue parachute successfully deployed at apogee and recovery harness placement allowed for ample separation of body sections during drogue descent. At approximately 500 ft AGL, the team observed the main parachute ejection event, followed promptly by main parachute deployment. This was substantiated by data recorded by the onboard avionics. Again, recovery harness locations allowed for ample separation of body tube sections during main descent and no collision between body sections were observed during main parachute deployment. After landing, the main parachute remained inflated, causing the launch vehicle to be dragged across the field. This resulted in the nosecone and payload bay sections falling into an irrigation ditch. With these sections full of water, payload deployment was not attempted. Despite being waterlogged, the payload was successfully retained. The waterlogged electronics were deenergized and left to sit in rice for two days. After drying, these components were inspected, and all were found to be in working order. The body tubes were left to dry in a shaded area to prevent warping of wooden components. All bulkheads were inspected for water damage and none were found to require repair. Further analysis on the demonstration flight can be found in section 5.

7.2 Payload Tests

Table 7-12 Payload Test Suite

Test	Requirement Verified	Required Facilities	Required Personnel	Scheduled Date
BURRITO Nominal Performance Test	NASA 4.3.4; TDR 4.2; TDR 4.11	N/A	Payload Vehicle Lead	01/28/2020
BURRITO Terrain Performance Test	NASA 4.3.4; TDR 4.2; TDR 4.5; TDR 4.11	Dorthea Dix Park	Payload Vehicle Lead	01/28/2020
BURRITO Inclined Performance Test	NASA 4.3.4; TDR 4.2; TDR 4.5; TDR 4.11	Dorthea Dix Park	Payload Vehicle Lead	01/30/2020
BURRITO Declined Performance Test	NASA 4.3.4; TDR 4.2; TDR 4.5; TDR 4.11	Dorthea Dix Park	Payload Vehicle Lead	1/30/2020
BURRITO Orientation Test	NASA 4.3.4; TDR 4.16	N/A	Payload Vehicle Lead	1/30/2020
BURRITO Control Range Test	TDR 4.3	Dorthea Dix Park	Payload Vehicle Lead	2/6/2020
BURRITO Driving Range Test	TDR 4.3	Dorthea Dix Park	Payload Vehicle Lead	2/6/2020
SICCU Operational Test	NASA 4.3.2; NASA 4.3.3; TDR 4.9; TDR 4.10; TDR 4.13	N/A	Sample Acquisition Lead	2/11/2020
Retention System Loading Test	NASA 4.3.7; NASA 4.3.7.2; TDR 4.14	Universal Testing Machine	Payload Integration Lead	2/12/2020
Deployment System Operational Demonstration	NASA 4.2; NASA 4.3.7.1; NASA 4.3.7.3; TDR 4.6; TDR 4.15; TDR 4.16	N/A	Payload Integration Lead	2/17/2020
Payload Electronics Power Consumption Test	NASA 2.7	N/A	Payload Integration Lead	2/17/2020

7.2.1 BURRITO Nominal Performance Test

Per the corresponding requirements listed in Table 7-12, the rover must travel at least 2000 ft. from the payload deployment site to the ice recovery location, while maintaining a speed of at least 3 mph without becoming stuck. It then must travel 10 linear feet. from the recovery site after the SICCU system is deployed. The following test ensures that the rover can complete a drive that incorporates these steps that must be completed during the competition. A failure of any of the following success criteria will result in a failure of the test. Depending on which aspect of the test failed, a change in battery capacity, motor power, transmitter choice, or wheel selection would need to occur.

Table 7-13 Success Criteria

Success Criteria	Met? (Y/N)
The rover travelled from its starting point to a location 2000 ft away over even field terrain.	Y
The rover did not require external tampering to remain upright or avoid obstacles.	Y
The rover did not sustain damage to any parts during the test (including SICCU).	Y
The rover maintained uninterrupted connection with the operator's controller.	Y
The rover maintained an average speed of at least 3 mph.	Y

7.2.1.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Rover Direction
- Rover Speed

7.2.1.2 Procedure

The test execution procedure is as follows:

- Turn on both the BURRITO rover and the Taranis X-Lite remote control
- Ensure that the rover and controller pair with one another
- Place the rover on terrain as similar to the competition field as possible
- Drive the rover to a point 2000 ft. away, changing speed and direction as needed to avoid obstacles or rough terrain; follow the rover with the controller from at least 15 ft
- Drive the rover 10 linear feet with the SICCU deployed

7.2.1.3 Results and Conclusions

The BURRITO successfully demonstrated that it could be driven at walking speed over 2000 ft. without interruptions caused by component damage or disconnections. It should be noted, however, that it would be wise to reinforce some of the BURRITO systems before competition day. With the rapid movements made possible by the torque of the drive motors, as well as the loads withstood during flight, it would be wise to use hot glue on the somewhat fragile connections between components inside the electronics bay. This would always keep jumper wires connected to pins; they otherwise have a tendency to slide out.

Additionally, it is important that bolts and nuts be torqued tightly before launch. Brief indoor drives with the rover during the construction phase sometimes loosened nuts and bolts via vibrations. Special care should be taken to ensure that the bolts holding the caster wheels to their arms do not come loose during operation.

7.2.2 BURRITO Terrain Performance Test

In accordance to the corresponding requirements in Table 7-12, the rover must not become stuck on any terrain during its operation. To ensure that the BURRITO rover can navigate unusual terrain on the competition field, as well as drive on the simulated ice itself, the following terrain test was devised. In the event that the rover must cross a gravel road at the competition field, the rover must be capable of driving through large-grain gravel. Should the competition occur following a recent rainfall, BURRITO must handle slick, wet mud without becoming stuck in it. As the competition will occur in a field with plant matter, the presence of long, potentially entangling stalks or leaves must not impede the rover's movement. Finally, the simulated ice itself must not give way underneath the rover's wheels, allowing it to become stuck. A failure of any of the following success criteria entails a failure of the test. Such a failure would require either an increase in motor power or a change in wheel design to increase traction; it might also require an increase in clearance between the ground and the underside of the chassis.

Table 7-14 Success Criteria

Success Criteria	Met? (Y/N)
The rover maintained forward progress across soil.	Y
The rover maintained forward progress across large-grain gravel.	Y
The rover drove through wet mud (without puddles) without becoming stuck.	Y
The rover drove through tall, thick grass without becoming stuck or entangled.	Y
The rover drove through a pit of simulated ice 2 inches deep without becoming stuck.	Y

7.2.2.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Rover Direction
- Rover Speed
- Terrain Type

7.2.2.2 Procedure

The test execution procedure is as follows:

- Turn on both the BURRITO rover and the Taranis X-Lite remote control
- Ensure that the rover and controller pair with one another
- Place the rover on one of the following terrain types:
    - Compacted soil
    - Large-grain gravel
    - Wet mud (without puddles)
    - Tall/thick grass (similar to usual field terrain)
    - 2-inch deep simulated ice
- Drive the rover forward at 1, 2, 3, and 4 mph without allowing the rover to become stuck. If all four speeds are reached, the rover has successfully overcome the terrain.

7.2.2.3 Results and Conclusions

BURRITO was successfully operated on all terrains stated above. The rover was placed on each terrain type with the power and controller on. It moved forward at all speeds ranging from 1 to 4 mph while avoiding any obstacles. The rover performed better on soil, gravel, and mud than over tall grass. The competition field is expected to mainly consist of soil and rocks, with little plant matter. As for the simulated ice, rice grains poured into an open box had to be used to approximate the terrain of simulated ice. Though the wheels tended to start digging themselves into the rice, the actual simulated ice will have much larger grains than rice, making it possible to drive on it. In addition, the rover will not need to venture far into the simulated ice recovery site to acquire a sample. Figure 7-9 shows the Terrain Performance Test conducted over gravel.

It should be noted that, during operation in mud, the plaction treads on the wheels began to retain clumps of the mud in their diamond-shaped cavities. This resulted in a gradual loss of traction, as the mud clumps would slide against mud already on the ground and little of the actual tread was exposed. However, this drawback did not prevent the rover from mounting a relatively steep (~20°) hump of ground around a tree. Overall, the test results confirm that the rover can navigate over any unusual terrain expected on the competition field.

Figure 7-9 BURRITO traversing simulated lunar terrain

7.2.3 BURRITO Inclined Performance Test

To fulfill the corresponding requirements listed in Table 7-12, the rover must be impeded by an increase in the slope of the terrain; these could appear frequently on the competition field. The following test ensures that the rover can climb an incline of 5°, whether field-like terrain is present or not. A failure of either of the following success criteria entails a failure of the test. Such a failure would require either an increase in motor size and power or a change of wheel design to increase traction.

Table 7-15 Success Criteria

Success Criteria	Met? (Y/N)
The rover maintained forward progress across an inclined slope of 5° on smooth terrain.	Y
The rover maintained forward progress across an inclined slope of 5° on field terrain.	Y

7.2.3.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Rover Direction
- Rover Speed
- Terrain Type

7.2.3.2 Procedure

The test execution procedure is as follows:

- Turn on both the BURRITO rover and the Taranis X-Lite remote control
- Ensure that the rover and controller pair with one another
- Place the rover on the following terrain types:
    - 5-degree incline

- Drive the rover forward such that it climbs a 5-degree slope without slipping or tipping backwards

7.2.3.3 Results and Conclusions

The rover was operational over smooth and field terrain on an inclined surface. A brick pathway was chosen as smooth terrain, while patchy grass was chosen as field terrain. Figure 7-10 displays the rover being driven up the smooth terrain. During testing, the rover did not slip or tip backwards. These test results confirm that surface inclination will not impede the rover's movement.

It should be noted that other short drives were conducted during the construction phase that included short amounts of steep climbing. In one scenario, the rover mounted a very steep hump in the ground surrounding a tree (approximately a 20° slope). This was accomplished by "swinging" the rover chassis back and forth by alternately driving the left and right motors forward. Doing so prevented the rover from tipping backwards; this technique could be used at the competition field to overcome particularly tough patches of terrain.

Figure 7-10 BURRITO Traveling Uphill

7.2.4 BURRITO Declined Performance Test

To fulfill the corresponding requirements in Table 7-12, the rover must not tip forward when encountering a downward slope on the competition field. The following tests determines whether a significant downward slope, which could be prevalent on the competition field, would cause the rover to tip forward irrecoverably. A failure of either of the success criteria listed below would entail a failure of the tests. Such a failure would require either adjustment of the rover's center of mass or the introduction of forward-facing stabilization wheels.

Table 7-16 Success Criteria

Success Criteria	Met? (Y/N)

The rover maintained forward progress across a declined slope of 5° on smooth terrain without flipping forward.	Y
The rover maintained forward progress across a declined slope of 5° on field terrain without flipping forward.	Y

7.2.4.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Rover Direction
- Rover Speed
- Terrain Type

7.2.4.2 Procedure

The test execution procedure is as follows:

- Turn on both the BURRITO rover and the Taranis X-Lite remote control
- Ensure that the rover and controller pair with one another
- Place the rover on the following terrain types:
  - 5-degree decline
- Drive the rover forward such that it descends a 5° slope without slipping or tipping backwards

7.2.4.3 Results and Conclusions

The rover was operational over smooth and field terrain on a declined surface. A brick pathway was chosen as smooth terrain, while patchy grass was chosen as field terrain. During testing, the rover did not slip or tip forwards due to the decline drive. These test results confirm that a declined surface will not impede the rover's movement.

As for slopes steeper than 5°, the BURRITO is capable through the high torque of its motors to flip itself back upright, as demonstrated in the orientation test. As such, steep declines are not a significant concern for BURRITO's performance.

7.2.5 BURRITO Orientation Test

In accordance with to the corresponding requirements listed in Table 7-12, the rover must not become stuck due to entering an orientation that prevents driving or operation of the SICCU system. The following test determines whether the BURRITO rover can maintain an upright position while driving and whether, using the drive motors, an operator can return the rover to an upright orientation if the rover flips. Failure of any of the following success criteria entails a failure of the test. Such a failure would require a change in the chassis design to prevent the rover from becoming stuck in an orientation or the introduction of forward-facing stabilization wheels.

Table 7-17 Success Criteria

Success Criteria	Met? (Y/N)

The rover maintained nominal orientation across smooth terrain.	Y
The rover returned to and maintained nominal orientation from a “nose-down” orientation on field terrain using only its motors.	Y
The rover returned to and maintained nominal orientation from an upside-down orientation on field terrain using only its motors.	Y
The rover returned to and/or maintained nominal orientation after decelerating from maximum velocity to 0 mph.	Y

7.2.5.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Initial Rover Orientation
- Wheel Rotational Speed

7.2.5.2 Procedure

The test execution procedure is as follows:

- Turn on both the BURRITO rover and the Taranis X-Lite remote control
- Ensure that the rover and controller pair with one another
- Place the rover in an upright orientation on field terrain
- Drive the rover forward at 4 mph and ensure the rover remains upright
- Place the rover in the “nose-down” orientation on field terrain (i.e., place the rover on the field with its front plate parallel to the ground)
- Using the remote control, drive the wheels forward in order to rotate the rover chassis into the upright position
- Place the rover in an upside-down orientation on field terrain
- Using the remote control, drive the wheels forward in order to rotate the rover chassis into the upright position
- Place the rover in an upright orientation on field terrain
- Drive the rover forward at 4 mph, then release the controller’s sticks so that the motors on the rover suddenly stop. The rover will have passed this part of the test if the rover returns to the upright orientation after the chassis rotates forward during the stop.

7.2.5.3 Results and Conclusions

The BURRITO was successfully able to right itself from both a nose-down and upside-down orientation. This was possible as long as both drive wheels maintained contact with the ground. BURRITO could even handle cases where the motors were suddenly run in reverse during forward drive; it could quickly recover its normal orientation almost immediately after being turned upside-down by the sudden stop. In certain scenarios, large humps in the terrain could catch the chassis mid-rotation, causing one of the wheels to lift off the ground. In these cases, the rover could still be recovered if the remaining wheel was driven back and forth until the rover was dislodged.

To get the rover to maintain its orientation during a sudden stop, a technique had to be applied where one of the wheels could be stopped while the other was slowly reduced in speed. This prevented the chassis from swinging too far forward and becoming stuck upside-down. This turn technique could be useful in preventing the terrain from trapping the rover with only one wheel on the ground as previously explained.

7.2.6 BURRITO Control Range Test

In accordance with the corresponding requirements listed in Table 7-12, the rover must be controllable from a short range, as the operator will follow the BURRITO rover during its operation. This test confirms that the rover can maintain a continuous short-range connection. Failure of either of the following success criteria entails a failure of the test. Such a failure would likely require the selection of a stronger transmitter on the controller or a more sensitive receiver on the rover.

Table 7-18 Success Criteria

Success Criteria	Met? (Y/N)
The rover maintained connection with the operator’s controller up to 15 ft away.	Y
The operator controlled the wheels and SICCU servos without encountering pauses or stuttering.	Y

7.2.6.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Distance from rover to controller

7.2.6.2 Procedure

The test execution procedure is as follows:

- Turn on both the BURRITO rover and the Taranis X-Lite remote control
- Ensure that the rover and controller pair with one another
- Begin driving the rover away from the controller, ensuring that the connection is sustained from at least 15 ft away
- Continue driving the rover until it loses connection with the controller or connection becomes too intermittent to continue driving

7.2.6.3 Results and Conclusions

The rover was set down in a long hallway and driven away from the controller until it hit 15 ft. At 15 ft, there was confirmation that there was no interrupted control before the rover proceeded. Then the rover was driven beyond the 15 ft to confirm that 15 ft was the minimum and not the maximum. BURRITO was even driven around a corner wall, out of line-of-sight with the remote; it still retained an unbroken connection. The test results confirm that the rover could drive beyond the 15 ft requirement that was set above.

It should be noted that the remote control was operated using its internal antenna, which has less range than its external option. Additionally, it is unlikely that BURRITO will get as far as 15 ft from the operator. As such, the receiver and controller combination for the rover is more than capable of handling operations on competition day.

7.2.7 BURRITO Driving Range Test

In accordance with the requirements listed in Table 7-12, the rover must be capable of driving at least 2000 ft. Some additional buffer range beyond this distance ensures that unexpected obstacles do not cause the rover to deplete its charge before reaching the recovery site, and this test determines how much additional range is available from the battery. Once the range of the battery is determined, the results are used to calibrate the cell voltage indicators connected to the battery. Failure of any of the following success criteria entails a failure of the test. Such a failure would require an increase in battery capacity.

Table 7-19 Success Criteria

Success Criteria	Met? (Y/N)
The rover travelled a linear distance of at least 2000 ft.	Y
The rover exceeded the 2000 ft. requirement by at least 550 ft.	Y
The rover expended all available charge to travel as far as possible.	Y

7.2.7.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Distance between rover and controller

7.2.7.2 Procedure

The test execution procedure is as follows:

- Turn on both the BURRITO rover and the Taranis X-Lite remote control
- Ensure that the rover and controller pair with one another
- Begin driving the rover forward at 4 mph, following it from less than 15 ft away with the controller
- Drive the rover at least 2000 ft and record the battery cells' voltages
- Continue driving the rover until its battery charge is expended and record the maximum distance reached as well as the voltages of the battery cells

7.2.7.3 Results and Conclusions

The rover was driven across campus over a section of known distance. It was repeated until the rover could no longer drive. The rover went well over the required 2550 ft and drove up to 3000 ft. On conclusion of the test, the voltage for the batteries were recorded. The batteries voltages were 3.58 V, 3.54 V and 3.53 V. These batteries had an average percent loss of 5.6% from their charged values of 3.76 V each. These voltages were meant to calibrate a voltage indicator that would have told the operator the remaining charge in BURRITO, but this element has been eliminated from the design as explained in the electronics manufacturing section.

As the rover easily exceeded the maximum required distance, it may be possible to substitute 3000mAh batteries in the event that the rover's original battery is lost or damaged before competition. This means that the team could use batteries it already possesses as backups for BURRITO, and the rover would likely still reach its destination as long as the landing site is not excessively distant from the ice recovery site.

Figure 7-11 Conducting Driving Range Tests

7.2.8 SICCU Operational Test

The success conditions for this operational test that satisfy this criterion are that the SICCU will conduct a series of scoops that must have an average collected volume no less than 15mL. In each of these scoop tests, BURRTIO must be able to move unimpeded by the SICCU before and after each scoop while having the scoops adjacent to the bottom of BURRITO. The SICCU's design implementation must also conform to TDR 4.12 and 4.13 during all phases of operation, in that the SICCU does not have a separate power source and does not self-activate.

Table 7-20 Success Criteria

Success Criteria	Met? (Y/N)
After all trials of scooping the average scoop volume is greater than or equal to 15mL	Y

The scoop tops when stowed are flush with the bottom plate of the BURRITO	Y
When conducting movement during the test the SICCU does not hinder movement when not in operation	Y
Does not require separate power supply	Y
Does not activate until operator elects to	Y

7.2.8.1 Controllable Variables

The controllable variables in this experiment are as follows:

- PVC Size
- SICCU Arm Length

7.2.8.2 Procedure

The test execution procedure is as follows:

- Turn on both the BURRITO rover and the Taranis X-Lite remote control
- Ensure that the rover and controller pair with one another
- Maneuver BURRITO to one of the three test sites
- Attempt to acquire sample, ensure flush orientation, and release a sample
- Move the next test site
- Repeat sample procedure for the following two sites
- Measure the volume of each sample and calculate average scoop volume
- Assess results

7.2.8.3 Results and Conclusions

The SICCU successfully scooped and retained uncooked rice that was used as a simulant for lunar ice. A single scoop held 20mL. This means that there is 300% excess that can be collected.

Figure 7-12 SICCU Test

7.2.9 Retention System Loading Test

In accordance with the requirements listed in Table 7-12, the payload retention system shall withstand all flight forces. The maximum predicted acceleration experienced during flight will be approximately 40 G's, resulting in a maximum of 360 lbf in compression placed on the retention system. A successful test will demonstrate the ability of this retention system to withstand up to 360 lbf with no visible damage to the system. A failure of any of the following success criteria will result in a failure of the test. In case of a failure, the system will need to be structurally reinforced.

Table 7-21 Success Criteria

Success Criteria	Met? (Y/N)
The test sample withstood a load of over 360 lbf.	Y
The test sample had no visible damage after test completion.	Y

7.2.9.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Force applied to the retention system

7.2.9.2 Procedure

The test execution procedure is as follows:

- Secure retention system with the three-point bending configuration of the Universal Testing Machine
- Lower force applicator until contact with the retention system and calibrate the scale
- Apply incremental loads until 360 lbf. is applied to the plate
- Inspect all components within the retention system to ensure no damage has resulted from the test
- Record maximum force applied

7.2.9.3 Results and Conclusions

The setup in Figure 7-13 shows the test stand placed into NCSU's universal testing machine. The force applicator was placed just above the article, the data collection instrument was zeroed out and a continuously increasing load was applied to the article until failure. The PLA performed extremely well during this test and finally met its yielding point at 710 lbf.

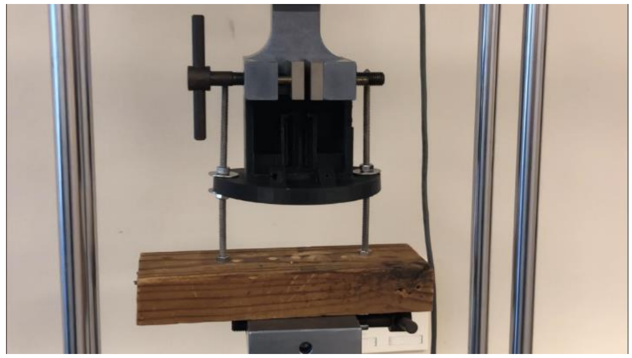


Figure 7-13 PLA test article subjected to compressive loading

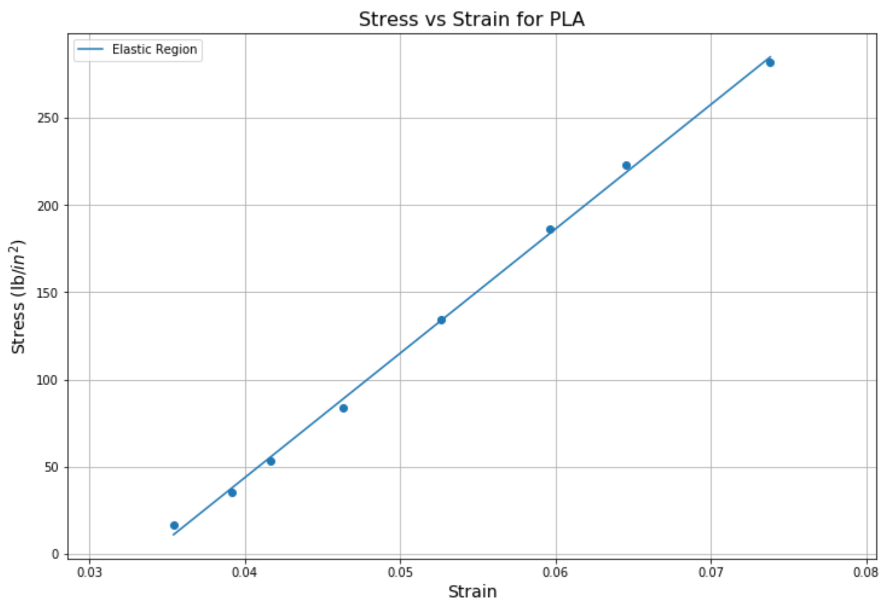


Figure 7-14 PLA test article analysis

The stresses and strain values were plotted from the deformation and force data collected from the PLA test. The material was found to have a modulus of elasticity of 2175 pounds per square inch. This value was obtained as an average of all measurements.

In addition to the test of the PLA material, a test of the entire integration assembly was performed. The test ran up to 360 lbf of compression to meet the requirements listed in Table 7-12. The configuration of the system within the testing apparatus can be viewed in Figure 7-15. The initial force was set to 200 lbf and then increments of 20 pounds were applied until the 360-pound limit was reached. The retention system was able to withstand the desired 360 lbf, but the testing team decided to go up another increment of 20 and the system failed at 380 lbf.

The failure did not cause any damage to the system and ended up being an informative test. The failure was at the interface between the external driving gears and the nut that converts the rotational motion of the gear train to linear motion for deployment. The connection between these two components was a single set screw threaded through the gear into the outer diameter of the nut. An additional set screw was added 90 degrees offset from the initial, to double the frictional load and to secure it in two degrees of freedom.

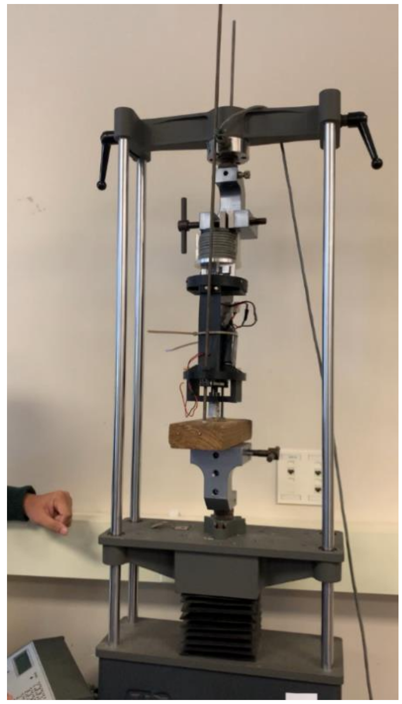


Figure 7-15 Full Assembly Compressive Test

Figure 7-16 shows the failure point as mentioned as well as a newly added set screw to double the holding potential. This failure point had not previously been identified and the team is now aware and have consciously adopted tightening both set screws on each external gear as part of the setup routine before every testing procedure and demonstration.

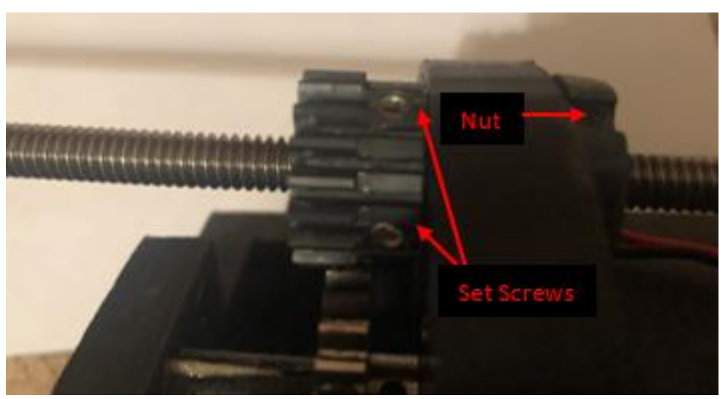


Figure 7-16 Failure Points of compressive test

7.2.10 Deployment System Operational Demonstration

In accordance with the requirements listed in Table 7-12, the payload integration system shall successfully deploy the payload from the rocket upon landing. This test will ensure that the linear actuated system can smoothly move axially within the payload bay, effectively deploying the integration system. This test will also verify that the microcontroller and peripherals have been appropriately connected and the program controlling the communication between the peripherals has no bugs. A successful test will demonstrate that the peripherals are correctly integrated, the preloaded code on the microcontroller is fully functional and that there is no significant resistance upon deployment and unlocking processes. A failure of any of the following success criteria will result in a failure of the test. A failure in the response of the peripherals can easily be fixed by modifying the code. If the system halts during the deployment procedure, methods of reducing friction will be applied and the system will be inspected for any potential obstructions.

Table 7-22 Success Criteria

Success Criteria	Met? (Y/N)
The preprogrammed keyboard controls (0-2) corresponds to the correct motion of the primary motor.	Y
The preprogrammed keyboard controls (3-5) corresponds to the correct motion of the retention motor.	Y
The payload successfully deploys from a loaded state without significant resistance.	Y
The retention system successfully unlocks without significant resistance.	Y

7.2.10.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Direction of rotation of the primary motor
- Direction of rotation of the retention motor

7.2.10.2 Procedure

The test execution procedure is as follows:

- Load the integration system and payload into the payload bay body tube.
- Connect to the onboard Bluetooth module through a smartphone
- Using BLE Terminal and the smartphone’s keyboard (keys 0-2), turn the primary motor on to fully deploy the rover from the body tube. Once completed turn off the motor to save power.
- Using keys 3-5 with BLE Terminal, successfully unlock and release the rover from the integration system.

7.2.10.3 Results and Conclusions

The initial deployment test did encounter resistance from the nuts placed in the nosecone that secures the nosecone to the payload bay. The width of these nuts was minimized, and the path was then cleared for further testing. The second deployment test resulted in major flexing of the lead screws and additional radial supports had to be implemented such that the system was supported every 90 degrees. After addressing both above issues, the deployment system was able to successfully deploy the rover from its locked state.

The unlocking mechanisms also experienced difficulties during the initial phases of testing. It was determined that the cantilever effects from the fully deployed rover were causing a high normal force and subsequently a high frictional force that resisted the retention motor. This issue was addressed in two ways. The first was swapping to a much higher torque motor and the second was to alter the deployment procedure to unlock the rover while it was still supported inside of the body tube. Once these issues were addressed, a successful testing demonstration was accomplished.

7.2.11 Payload Electronics Power Consumption Test

In accordance with the requirements listed in Table 7-12, the launch vehicle and payload shall be capable of remaining in launch-ready configuration on the pad for a minimum of two hours without losing the functionality of any critical on-board components. The voltage applied will remain constant for all systems and the consumption over two hours can be extrapolated from the current draw from all peripherals in each of their operating states. This test will verify that the components are within an appropriate deviation from the factory specified characteristics and are not faulty components. A failure of any of the following success criteria will result in a failure of the test. The selected battery has a capacitance rated for just under three times the power consumption after applying the safety factor. Therefore, these parts should not need to be modified unless the part is defective. In the event of a defective part, the distributor will be contacted for a replacement part.

Table 7-23 Success Criteria

Success Criteria	Met? (Y/N)
The primary motor’s power draw is measured within 10% of its factory specified consumption rate.	Y
The retention motor’s power draw is measured within 10% of its factory specified consumption rate.	Y
The Bluetooth module’s power draw is measured within 10% of its factory specified consumption rate during idle mode.	Y

The Bluetooth module's power draw is measured within 10% of its factory specified consumption rate during operating mode.	Y

7.2.11.1 Controllable Variables

The controllable variables in this experiment are as follows:

- Operational states of peripherals (idle or active)

7.2.11.2 Procedure

The test execution procedure is as follows:

- Connect all peripherals to microcontroller and connect the power source.
- Measure the current draw for all peripherals

7.2.11.3 Results and Conclusions

All components came in under the manufacturer's specifications. Granted, this was to be expected as the specifications did not give normal operating conditions as this varies based on the loading (resistance or additional peripherals) on the system and the max values were used in the preliminary calculations. For example, when determining the battery size, the stall current for the motors was utilized (2A). However, if the motors do not stall, the current will never reach or exceed these values and the measured current for the motor under loading was found to be 0.18A.

Table 7-24 Test Results

Peripheral	Measured Current	Manufacturer Current
Retention Motor	0.36A	2A
Drive Motor	0.18A	2A
HC-06	Pairing: 0.038A Paired: 0.017A	Pairing: 0.04A Paired: 0.02A
Sparkfun Redboard	.927A	Comparable to Arduino Uno: 1A

7.3 NASA Requirement Verification

Table 7-25, below, defines the fields present in Table 7-26, NASA Requirements Verification Matrix.

Table 7-25 Field Definition for Requirements Verification Matrix

Field	Definition
Req No.	Identification number associated with requirement.
Shall Statement	Statement of what the product shall accomplish.
Success Criteria	Description of how the team will define a met requirement.
Verification Method	How the requirement is verified. By Inspection, Demonstration, Test, or Analysis.
Subsystem Allocation	Indicates which subsystems are responsible for meeting the requirement.
Results	Results of the verification.

Table 7-26, below, shows the NASA defined requirements for the NASA Student Launch project.

Table 7-26 NASA Requirements Verification Matrix

Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation	Status	Status Description
NASA 1.1	Students on the team SHALL do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Teams SHALL submit new work. Excessive use of pas work will merit penalties.	The students of the High-Powered Rocketry Club at NC State design and implement a solution to the requirements listed in this table.	Inspection	Project Management	Verified	All documents and analysis has been executed by student team members.

NASA 1.2	The team SHALL provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	The project management team, consisting of the team lead, vice president, treasurer, coordination lead, safety officer, outreach lead, web administrator, and social media lead will manage the project planning tasks listed in this requirement.	Inspection	Project Management	Verified	See section 7 for the project plan.
NASA 1.3	Foreign National (FN) team members SHALL be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during certain activities on site at Marshall Space Flight Center.	The team lead will identify and report Foreign National (FN) team members by November 1, 2019 with the submission of the PDR milestone document.	Inspection	Project Management	Verified	There are no FN team members attending restricted events.

NASA 1.4	The team SHALL identify all team members attending launch week activities by the Critical Design Review (CDR).	The team lead will identify and report team members attending launch week activities by January 10, 2020 with the submission of the CDR milestone document.	Inspection	Project Management	Verified	Competition attending team members have been determined and sent to the appropriate NASA project management team member
NASA 1.4.1	Team members attending competition SHALL include students actively engaged in the project throughout the entire year.	The project management team will identify actively engaged team members to attend launch week activities.	Inspection	Project Management	Verified	Student's participation in the project will determine who attends the competition.
NASA 1.4.2	Team members SHALL include one mentor (see requirement 1.13).	The team lead will invite the mentors listed in section 1.1.2 to attend launch week activities.	Inspection	Project Management	Verified	Alan Whitmore and Jim Livingston will attend launch week activities.
NASA 1.4.3	Team members SHALL include no more than two adult educators.	The team lead will invite the adult educator to attend launch week activities.	Inspection	Project Management	Verified	Dr. Felix Ewere is serving as the team's adult educator.

NASA 1.5	The team SHALL engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the STEM Engagement Activity Report, by FRR.	The outreach lead will identify K-12 student groups to implement STEM engagement plans with throughout the project lifecycle.	Inspection	Project Management	Verified	Outreach forms are sent to the appropriate NASA project management team member. All scored forms will be submitted by March 16th.
NASA 1.6	The team SHALL establish a social media presence to inform the public about team activities.	The web administrator and social media lead will cooperate to develop an engaging and educational social media presence on various platforms including, but not limited to club website, Facebook, Instagram, and Twitter.	Inspection	Project Management	Verified	The team's social media lead maintains the social media accounts.

NASA 1.7	The team SHALL 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 lead will send all completed documents to the NASA project management team prior to each deadline. In the event that the deliverable is too large, the web administrator will post the document on the team's website and the team lead will send the NASA project management team a link to the document.	Inspection	Project Management	Verified	The team lead emails each deliverable to the appropriate NASA project management team member.
NASA 1.8	All deliverables SHALL be in PDF format.	The team lead will convert all deliverables to PDF format prior to submission.	Inspection	Project Management	Verified	This report is submitted in PDF format.
NASA 1.9	In every report, the team SHALL provide a table of contents including major sections and their respective sub-sections.	The team lead will manage the Table of Contents in each milestone report.	Inspection	Project Management	Verified	See the Table of Contents at the start of this document.

NASA 1.10	In every report, the team SHALL include the page number at the bottom of the page.	The team lead will identify the page numbers in each milestone report.	Inspection	Project Management	Verified	Page numbers are included in the bottom right corner of each page.
NASA 1.11	The team SHALL provide any computer equipment necessary to perform a video teleconference with the review panel.	The team lead will acquire the necessary equipment to communicate with the NASA project management team through teleconference.	Inspection	Project Management	Verified	The team lead organizes required equipment for teleconferencing. To date, all necessary equipment has been available.
NASA 1.12	The team SHALL use the launch pads provided by Student Launch's launch services provider.	The aerodynamics lead will design a launch vehicle to be launched from either an 8 foot 1010 rail or a 12 foot 1515 rail. The Structures lead will fabricate said launch vehicle.	Inspection	Aerodynamics; Structures	Verified	The selected rail button is sized for a 1515 rail. Section 7.5.1 shows the line item budget including said rail buttons.
NASA 1.13	The team SHALL identify a "mentor."	The team lead will identify community members qualified to mentor team members through the design process.	Inspection	Project Management	Verified	See section 1.1.2 for mentor listing and contact information.

NASA 2.1	The launch vehicle SHALL deliver the payload to an apogee altitude between 3,500 and 5,500 feet above ground level (AGL).	The aerodynamics subsystem team designs a rocket to launch between 3,500 and 5,500 feet AGL. The team then constructs the vehicle as designed and the launch vehicle flies between 3,500 and 5,500 feet AGL.	Analysis; Demonstration	Aerodynamics		A tolerance study on predicted apogee was performed. All expected conditions resulted in an apogee within these margins. Section 3.6.1 details on this study.
NASA 2.2	The team SHALL identify the target altitude goal at the PDR milestone.	The aerodynamics subsystem team reports the altitude goal in the PDR milestone report and is sent to the NASA project management team by November 1, 2019.	Inspection	Aerodynamics	Verified	The target altitude is 4420 feet.
NASA 2.3	The launch vehicle SHALL carry one commercially available, barometric altimeter for recording the official altitude.	The recovery subsystem team chooses a commercially available, barometric altimeter to be used in the launch vehicle.	Inspection	Recovery	Verified	The team has selected the StratoLogger CF altimeter. Details can be found in section 3.5.5.

NASA 2.4	The launch vehicle SHALL be designed to be recoverable and reusable.	The recovery subsystem team designs a recovery harness system that will allow the launch vehicle to be recovered upon ground impact with minimal damage.	Demonstration	Recovery		The vehicle demonstration flight will demonstrate the recoverable and reusable nature of the launch vehicle.
NASA 2.5	The launch vehicle SHALL have a maximum of four (4) independent sections.	The aerodynamics and recovery subsystem teams design a launch vehicle that has fewer than four (4) independent sections.	Inspection	Aerodynamics; Recovery	Verified	The launch vehicle has one (1) independent section. All components descend under the same recovery harnessing system seen in section 3.5.
NASA 2.5.1	Couplers which are located at in-flight separation points SHALL be at least one (1) body diameter in length.	The aerodynamics subsystem team designs a rocket with couplers at in-flight separation points at least one body diameter in length. The structures subsystem team construct the couplers in the correct lengths.	Inspection	Aerodynamics; Structures	Verified	All in-flight separation points have at least 6 inches of coupler used. Section 3.3 gives a series of dimensioned CAD models of the launch vehicle showing this information.

NASA 2.5.2	Nosecone shoulders which are located at in-flight separation points SHALL be at least 1/2 body diameter in length.	The aerodynamics subsystem team designs a rocket with nosecone shoulders at in-flight separation points at least 1/2 body diameter in length. The structures subsystem team construct the couplers in the correct lengths.	Inspecti on	Aerodynam ics; Structures	Verified	There are no in-flight separation points using nosecone shoulder.
NASA 2.6	The launch vehicle SHALL be capable of being prepared for flight at the launch site within two (2) hours of the time the Federal Aviation Administration flight waiver opens.	The project management and safety teams develop launch day checklists that can be executed in under two (2) hours.	Demons tration	Project Manageme nt; Safety	Verified	Checklists included in Appendix A will be executable within 2 hours. The payload demonstration flight will be timed to verify this.
NASA 2.7	The launch vehicle and payload SHALL be capable of remaining in launch-ready configuration on the pad for a minimum of two (2) hours without losing the functionality of any critical on-board components.	The project management and safety teams monitor the selected power supplies for each on-board component and test to verify functionality after over two (2) hours.	Demons tration	Project Manageme nt; Safety	Verified	Battery life demonstrations on both the avionics equipment section 7

NASA 2.8	The launch vehicle SHALL be capable of being launched by a standard 12-volt direct current firing system.	The project management and safety teams choose the motor ignitor that can be ignited from a 12-volt direct current firing system.	Inspection	Project Management; Safety	Verified	The team uses Aerotech First Fire igniters that are compatible with a 12-volt direct current firing system.
NASA 2.9	The launch vehicle SHALL require no external circuitry or special ground support equipment to initiate launch.	The project management and safety teams limit the launch vehicle such that it has no external circuitry or ground support equipment.	Inspection	Project Management; Safety	Verified	The designed launch vehicle does not include any external circuitry nor ground equipment to initiate launch. Pre-launch procedures and necessary assembly materials can be found in Appendix A.
NASA 2.10	The launch vehicle SHALL 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 aerodynamics team selects a solid motor propulsion system approved and certified by NAR and/or TRA.	Inspection	Aerodynamics	Verified	The Aerotech L1520-T is the selected motor.
NASA 2.10.1	Final motor choices SHALL be declared by the Critical Design Review (CDR).	The aerodynamics team selects and reports the final motor choice by January 10, 2020.	Inspection	Aerodynamics	Verified	The motor has been selected as an Aerotech L-1520T as described in Section 1.2.2

NASA 2.10.2	Any motor change after CDR SHALL be approved by the NASA Range Safety Officer (RSO) and SHALL only be approved if the change is for the sole purpose of increasing the safety margin.	The aerodynamics team selects and reports the final motor choice by January 10, 2020.	Inspecti on	Aerodynam ics	Verified	The motor has been selected as an Aerotech L-1520T as described in Section 1.2.2
NASA 2.11	The launch vehicle SHALL be limited to a single stage.	The aerodynamics team designs a launch vehicle with a single stage.	Inspecti on	Aerodynam ics	Verified	The launch vehicle contains one commercially available motor to be burned in a single stage.
NASA 2.12	The total impulse provided by a College or University launch vehicle SHALL not exceed 5,120 Newton-seconds (L-class).	The aerodynamics team chooses an L-class motor for the full-scale launch vehicle.	Inspecti on	Aerodynam ics	Verified	The selected Aerotech L-1520T has a total impulse that does not exceed 5,120 Newton-seconds as described in Section 3.6.2
NASA 2.13	Pressure vessels on the vehicle SHALL be approved by the RSO.	The structures lead provides the necessary information on any on-board pressure vessels to the NASA RSO and home field RSO.	Inspecti on	Structures	Verified	There are no pressure vessels in this design.

NASA 2.13.1	Pressure vessels on the vehicle SHALL have a minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) of 4:1 with supporting design documentation included in all milestone reviews.	The structures lead provides the necessary information on any on-board pressure vessels to the NASA RSO and home field RSO.	Inspection	Structures	Verified	There are no pressure vessels in this design.
NASA 2.13.2	Pressure vessels on the vehicle SHALL 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 structures lead provides the necessary information on any on-board pressure vessels to the NASA RSO and home field RSO.	Inspection	Structures	Verified	There are no pressure vessels in this design.
NASA 2.13.3	Pressure vessels on the vehicle SHALL be described, including the application for which the tank was designed and the history of the tank.	The structures lead provides the necessary information on any on-board pressure vessels to the NASA RSO and home field RSO.	Inspection	Structures	Verified	There are no pressure vessels in this design.
NASA 2.14	The launch vehicle SHALL have a minimum static stability margin of 2.0 at the point of rail exit.	The aerodynamics team designs a launch vehicle with a minimum static stability margin of 2.0.	Analysis	Aerodynamics	Verified	A tolerance study was performed by the aerodynamics subsystem team to determine the most likely static margin. This study can be found in section 3.6.4

NASA 2.15	Any structural protuberance on the rocket SHALL be located aft of the burnout center of gravity.	The aerodynamics team designs a launch vehicles with all structural protuberances aft of the burnout center of gravity. The structures team verifies that all structural protuberances are aft of the burnout center of gravity upon construction.	Inspection	Aerodynamics; Structures	Verified	There are no structural protuberances forward of the burnout center of gravity.
NASA 2.16	The launch vehicle SHALL accelerate to a minimum velocity of 52 fps at rail exit.	The aerodynamics team designs a launch vehicle with a minimum velocity of 52 fps at rail exit.	Analysis	Aerodynamics	Verified	The rail exit velocity is 83.5 fps as seen on the flysheet. This was determined via RockSim analysis.

NASA 2.17	The team SHALL successfully launch and recover a subscale model of the rocket prior to CDR.	The structures team leads the construction of the subscale model of the launch vehicle. The project management and safety teams lead the launch of the subscale model of the launch vehicle before January 10, 2020.	Demonstration	Project Management; Safety; Structures	Verified	See the CDR Milestone for subscale demonstration flight results.
NASA 2.17.1	A full-scale model SHALL not be used as the subscale model.	The project management team verifies the subscale model is a different size than the full-scale launch vehicle.	Inspection	Project Management; Safety	Verified	The subscale launch vehicle is approximately 2/3 the size of the full-scale launch vehicle. More details are covered in the CDR Milestone.
NASA 2.17.2	The subscale model SHALL carry an altimeter capable of recording the model's apogee altitude.	The recovery team chooses an altimeter to record the subscale model's altitude.	Demonstration	Recovery	Verified	See the CDR Milestone for subscale demonstration flight results.
NASA 2.17.3	The subscale model SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The project management team acquires the materials necessary to construct a new launch vehicle for this year's project.	Inspection	Project Management	Verified	Section 7.5.1 includes the team's line item budget including the ordered subscale parts for this competition year.

NASA 2.17.4	Proof of a successful flight SHALL be supplied in the CDR report.	The recovery team provides altimeter data from the subscale launch in the CDR by January 10, 2020.	Inspecti on	Recovery	Verified	See CDR Milestone for subscale demonstration flight results.
NASA 2.18	The team SHALL execute demonstration flights of the launch vehicle and payload.	The project management team holds to the schedule for the team to be able to launch demonstrations flights for both the vehicle and payload.	Demons tration	Project Manageme nt	Verified	The vehicle demonstration flight was successful. See section 5.1
NASA 2.18.1	The team SHALL successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration.	The project management team holds to the schedule for the team to be able to launch demonstrations flights for both the vehicle and payload.	Demons tration	Project Manageme nt	Verified	The vehicle demonstration flight was successful. See section 5.1

NASA 2.18.1.1	During the Vehicle Demonstration Flight (VDF) the vehicle and recovery system SHALL function as designed.	The launch vehicle specific subsystem teams design and construct the launch vehicle as written and the systems function as designed.	Demonstration	Project Management; Safety; Recovery; Structures; Aerodynamics	Verified	The vehicle demonstration flight was successful. See section 5.1
NASA 2.18.1.2	The full-scale rocket SHALL be a newly constructed rocket, designed and built specifically for this year's project.	The project management team acquires the materials necessary to construct a new launch vehicle for this year's project.	Inspection	Project Management	Verified	Materials used in the full-scale rocket are new and purchased as detailed in the line item budget in section7.5.
NASA 2.18.1.3.1	If the payload is not flown during the VDF, mass simulators SHALL be used to simulate the payload mass.	The payload team chooses mass simulators to fly in the vehicle demonstration flight if the payload is not ready for launch.	Inspection	Payload	Verified	The vehicle demonstration flight was successful. See section 5.1

NASA 2.18.1.3.2	If the payload is not flown during the VDF, mass simulators SHALL be located in the same approximate location on the rocket as the missing payload mass.	The payload team attaches mass simulators in the same approximate location on the launch vehicle as the missing payload mass.	Inspection	Payload	Verified	The vehicle demonstration flight was successful. See section 5.1
NASA 2.18.1.4	If the payload affects the external surfaces of the rocket or manages the total energy of the vehicle, those systems SHALL be active during the full-scale VDF.	The payload team has external components of the payload prepared for the vehicle demonstration flight.	Inspection	Payload; Aerodynamics	Verified	The vehicle demonstration flight was successful. See section 5.1
NASA 2.18.1.5	The team SHALL fly the launch day motor during the VDF.	The safety and aerodynamics teamwork alongside the team's mentors to acquire and use the motor on launch day.	Inspection	Safety; Aerodynamics	Verified	The vehicle demonstration flight was successful. See section 5.1
NASA 2.18.1.6	The vehicle SHALL be flown in its fully ballasted configuration during the full-scale test flight.	The aerodynamics team decides on the final ballasting configuration. The structures team constructs the designed ballasting configuration.	Inspection	Aerodynamics; Structures	Verified	The vehicle demonstration flight was successful. See section 5.1

NASA 2.18.1.7	The launch vehicle or any of its components SHALL not be modified without the concurrence of the NASA RSO.	If any modifications are necessary after the demonstration flights, the safety and structures team communicate with the NASA RSO prior to making modifications.	Inspection	Safety; Structures	Verified	There will be no modifications after the success of the vehicle demonstration flight.
NASA 2.18.1.8	The team SHALL provide proof of a successful flight in the FRR report.	The recovery team reports the altimeter data from the demonstration flights in the FRR by March 02, 2020.	Inspection	Recovery	Verified	The vehicle demonstration flight was successful. See section 5.1
NASA 2.18.1.9	The team SHALL complete the VDF before March 02, 2020.	The project management team holds to the team's schedule and completes the VDF by March 02, 2020.	Inspection	Project Management	Verified	The vehicle demonstration flight was successful. See section 5.1
NASA 2.18.2	The team SHALL successfully launch and recovery the full-scale rocket containing the completed payload prior to March 23, 2020.	The project management team holds to the team's schedule and launches the payload demonstration flight prior to March 23, 2020.	Inspection	Project Management	Verified	The payload demonstration flight was successful. See section 5.2

NASA 2.18.2 .1	During the Payload Demonstration Flight (PDF), the payload SHALL be fully retained until the intended point of deployment.	The payload and safety teams design a fail-safe retention system and demonstrate its performance prior to flight.	Demons tration	Safety; Payload	Verified	The payload demonstration flight was successful. See section 5.2
NASA 2.18.2 .2	The payload flown during the PDF SHALL be the final, active version.	The payload team completes the construction of all payload systems prior to the payload demonstration flight.	Inspecti on	Payload	Verified	The payload demonstration flight was successful. See section 5.2
NASA 2.18.2 .4	The PDF SHALL be completed by March 23, 2020.	The project management team manages the schedule such that the payload demonstration flight is complete prior to March 23, 2020.	Inspecti on	Project Manageme nt	Verified	The payload demonstration flight was successful. See section 5.2
NASA 2.19	If a reflight is necessary, the FRR Addendum SHALL be submitted by March 23, 2020.	The project management team manages the schedule such that any reflight is complete prior to March 23, 2020.	Inspecti on	Project Manageme nt	Verified	No reflight is necessary.

NASA 2.19.1	If a reflight is necessary, the FRR Addendum SHALL be submitted by March 23, 2020.	The project management team manages the schedule such that the FRR Addendum is complete prior to March 23, 2020.	Inspection	Project Management	Verified	No reflight is necessary.
NASA 2.19.2	The team SHALL successfully execute a PDF to be allowed to fly the payload at competition.	The project management team manages the schedule such that the payload demonstration flight is complete prior to March 23, 2020.	Demonstration	Project Management	Verified	The payload demonstration flight was successful. See section 5.2
NASA 2.19.3	The team SHALL not fly the payload at competition if the PDF was unsuccessful.	The project management team manages the schedule such that the payload demonstration flight is complete prior to March 23, 2020.	Demonstration	Project Management	Verified	The payload demonstration flight was successful. See section 5.2
NASA 2.20	The team SHALL mark each independent launch vehicle component with the team's launch day contact information.	The project management team marks each independent section of the rocket with the team’s contact information.	Inspection	Project Management	Verified	The team lead's contact information will be written on each section of the launch vehicle.

NASA 2.21	The team SHALL sufficiently protect all Lithium Polymer batteries from ground impact. The team SHALL mark all Lithium Polymer batteries with brightly colored, clearly marked	The payload team designs a retention system for all LiPo batteries in the payload that protects the battery from impact. The safety team will inspect and test the aforementioned design.	Inspection	Safety; Payload	Verified	All LiPo batteries are protected from ground impact. See section 4 for current payload design.
NASA 2.22.1	The launch vehicle SHALL not utilize forward canards.	The aerodynamics team designs a launch vehicle that does not utilize forward canards.	Inspection	Aerodynamics; Structures	Verified	The design does not utilize forward canards.
NASA 2.22.2	The launch vehicle SHALL not utilize forward firing motors.	The aerodynamics team designs a launch vehicle that does not utilize forward firing motors.	Inspection	Aerodynamics	Verified	The design does not utilize forward firing motors.
NASA 2.22.3	The launch vehicle SHALL not utilize motors that expel titanium sponges.	The aerodynamics team designs a launch vehicle that does not utilize motors that expel titanium sponges.	Inspection	Aerodynamics	Verified	The Aerotech L1520-T is the selected motor and does not utilize titanium sponges.

NASA 2.22.4	The launch vehicle SHALL not utilize hybrid motors.	The aerodynamics team designs a launch vehicle that does not utilize hybrid motors.	Inspecti on	Aerodynam ics	Verified	The Aerotech L1520-T is the selected motor and is not a hybrid motor.
NASA 2.22.5	The launch vehicle SHALL not utilize a cluster of motors.	The aerodynamics team designs a launch vehicle that does not utilize clustered motors.	Inspecti on	Aerodynam ics	Verified	The Aerotech L1520-T is the selected motor and will not have more than one motor.
NASA 2.22.6	The launch vehicle SHALL not utilize friction fitting for motors.	The aerodynamics team designs a launch vehicle that does not utilize friction fitted motors.	Inspecti on	Aerodynam ics	Verified	The 75 mm Aero Pack motor retainer was selected as the motor retention system.
NASA 2.22.7	The launch vehicle SHALL not exceed Mach 1 at any point during flight.	The aerodynamics team designs a launch vehicle that does not exceed Mach 1 during flight.	Analysis	Aerodynam ics	Verified	The full-scale launch vehicle has a maximum Mach number less than1. Altimeter data from the full-scale demonstration flight indicates this.

NASA 2.22.8	Vehicle ballast SHALL not exceed 10% of the total unballasted weight of the launch vehicle.	The aerodynamics team designs the final ballasting configuration such that total ballast does not exceed 10% of the unballasted weight. The structures team implements the designed ballast configuration.	Inspection	Aerodynamics; Structures	Verified	The launch vehicle contains 0% ballast.
NASA 2.22.9	Transmissions from onboard transmitters SHALL not exceed 250 mW of power per transmitter.	The recovery and payload teams choose transmitters that do not exceed 250 mW of power per transmitter.	Analysis	Recovery; Payload	Verified	See flysheet for details on current onboard transmitters. The team's transmitter data sheet has been submitted.
NASA 2.22.10	Transmitters SHALL not create excessive interference.	The recovery and payload teams choose transmitters with minimal interference.	Analysis	Recovery; Payload	Verified	See flysheet for details on current onboard transmitters. The team's transmitter data sheet has been submitted.
NASA 2.22.11	The team SHALL not use excessive and/or dense metal in the construction of the launch vehicle.	The structures and payload teams choose materials that use minimal amounts of dense metal.	Inspection	Structures; Payload	Verified	Minimal metal components have been used in the launch vehicle design. This includes quick links, U-bolts, payload components and small hardware.

NASA 3.1	The launch vehicle SHALL stage the deployment of its recovery devices.	The recovery team designs a dual deployment recovery system.	Demonstration	Recovery	Verified	The full-scale ejection demonstration showed the staged deployment system. Section 7.1 details on the demonstration results.
NASA 3.1.1	The main parachute SHALL be deployed no lower than 500 feet.	The recovery team designs a main parachute deployment event no lower than 500 feet.	Demonstration	Recovery	Verified	Altimeters are programmed to release the main parachute at 500 feet. The vehicle demonstration flight had a main deployment at 500 feet. Section 7.1 details on the demonstration results.
NASA 3.1.2	The apogee event SHALL not have a delay longer than 2 seconds.	The recovery team designs a drogue parachute deployment event with an apogee delay of no more than 2 seconds.	Demonstration	Recovery	Verified	Only the redundant altimeter has an apogee delay. The apogee delay is 1 second. The vehicle demonstration flight results can be found in section 7.1
NASA 3.1.3	The launch vehicle SHALL not utilize motor ejection.	The recovery and aerodynamics teams design an ejection system that does not use motor ejection.	Demonstration	Aerodynamics; Recovery	Verified	The launch vehicle uses a two stage deployment system initiated by altimeters. The full-scale ejection demonstration is described in section 7.1.
NASA 3.2	The team SHALL perform a successful ground ejection test for both the drogue and main parachutes before both the subscale and full-scale launches.	The recovery and safety teams demonstrate the performance of the launch vehicle's ejection system prior to each launch.	Demonstration	Safety; Recovery	Verified	Ground ejection testing was executed on 2/20/20. See Section 7.1 for ejection testing results.

NASA 3.3	Each independent section of the launch vehicle SHALL not exceed a maximum kinetic energy of 75 ft-lbf at landing.	The recovery team designs a launch vehicle that does not exceed a kinetic energy of 75 ft-lbf.	Analysis	Recovery	Verified	Supporting calculations can be found in section 3.6.5.
NASA 3.4	The recovery system SHALL contain redundant, commercially available altimeters.	The recovery team designs a redundant recovery electronic system that utilizes commercially available altimeters.	Inspection	Safety; Recovery	Verified	The recovery system uses two StratoLogger CF altimeters. Section 3.5.5 shows the recovery design.
NASA 3.5	Each altimeter SHALL have a dedicated power supply, and all recovery electronics SHALL be powered by commercially available batteries.	The recovery team designs a redundant recovery electronic system such that both the primary and redundant altimeters are powered by different commercially available batteries.	Inspection	Recovery	Verified	The recovery system uses two StratoLogger CF altimeters with independent power sources. Section 3.5.5 shows the recovery design.
NASA 3.6	Each altimeter SHALL be armed by a dedicated mechanical arming switch that is accessible from the exterior of the launch vehicle airframe when the rocket is in the launch configuration on the launch pad.	The recovery team designs a redundant recovery electronic system such that both the primary and redundant altimeters are turned on by a mechanical arming switch.	Demonstration	Safety; Recovery	Verified	The recovery system uses two StratoLogger CF altimeters. Section 3.5.5 shows the recovery design. The vehicle demonstration flight showed the ability to access the mechanical arming switches from the launch vehicle exterior.

NASA 3.7	Each arming switch SHALL be capable of being locked in the ON position for launch.	The recovery team designs a redundant recovery electronic system such that both the arming switches can be locked in the ON position during launch.	Demonstration	Safety; Recovery	Verified	Screw switches have been selected as the switch type. These rotate until the screw is in the ON position and remain in the ON position until altered. The vehicle demonstration flight showed the locking ability of these switches.
NASA 3.8	The electronic components of the recovery system SHALL be completely independent of any payload electrical circuits.	The recovery team designs a redundant recovery electronic system such that all recovery electronics are independent of other on-board electronics.	Inspection	Safety; Recovery; Payload	Verified	The recovery electronics are independent of any other on-board electronics system. Section 3.5.5 shows the avionics architecture diagram.
NASA 3.9	Removable shear pins SHALL be used for both the main parachute compartment and the drogue parachute compartment.	The recovery team uses removable shear pins at in-flight separation points.	Inspection	Recovery	Verified	Four 4-40 nylon shear pins are used at each separation point.

NASA 3.10	The launch vehicle SHALL not drift more than 2,500 feet radius from the launch pad.	The recovery team designs a recovery system that results in a drift of no more than 2,500 feet from the launch pad. The vehicle demonstration flight results in a drift radius of no more than 2,500 feet.	Analysis; Demonstration	Recovery	Verified	The supporting calculations can be found in section 3.6.7. The vehicle demonstration flight had a drift of approximately 1200 ft.
NASA 3.11	The launch vehicle SHALL make ground impact within 90 seconds after apogee.	The recovery team designs a recovery system that results in ground impact within 90 seconds of apogee.	Analysis	Recovery	Verified	The supporting calculations can be found in section 3.6.7.
NASA 3.12	The team SHALL use an electronic tracking device to transmit the position of the tethered vehicle or any independent section to a ground receiver.	The recovery team chooses an electronic tracking device to transmit the position of the launch vehicle.	Demonstration	Recovery	Verified	The selected electronic tracking device is the EggFinder TX. The tracking device operational demonstration results are found in section 7.1. Details can be found in section 3.5.6.
NASA 3.12.1	Each untethered section of the rocket SHALL have its own electronic tracking device.	The recovery team designs the launch vehicle so that all sections are tethered during descent	Inspection	Recovery	Verified	The EggFinder GPS is mounted in the nose cone.

NASA 3.12.2	The electronic tracking device SHALL be fully functional during the official flight on launch day.	The recovery team chooses an electronic tracking device to transmit the position of the launch vehicle.	Demonstration	Recovery	Verified	The selected electronic tracking device is the EggFinder TX. The tracking device operational demonstration results are found in section 7.1. Details can be found in section 3.5.6.
NASA 3.13	The recovery system electronics SHALL not be adversely affected by other on-board electronic devices.	The recovery team designs a redundant recovery electronic system such that all recovery electronics are independent of other on-board electronics.	Demonstration	Safety; Recovery; Payload	Verified	The recovery electronics are independent of any other on-board electronics system. Section 3.5.5 shows the avionics architecture diagram. The success of the vehicle demonstration flight shows functionality of all active recovery electronics in unison. The flight results can be found in section 5.
NASA 3.13.1	The recovery altimeters SHALL be located in a separate compartments with the vehicle from any other radio frequency transmitting and/or magnetic wave producing device.	The recovery team designs an avionics bay that is separate from other on-board, transmitting electronics.	Demonstration	Safety; Recovery	Verified	The recovery electronics are independent of any other on-board electronics system. Section 3.5.5 shows the avionics architecture diagram. The success of the vehicle demonstration flight shows functionality of all active recovery electronics in unison. The flight results can be found in section 5.

NASA 3.13.2	The recovery system electronics SHALL be shielded from all onboard transmitting devices.	The recovery team designs an avionics bay that is separate from other on-board, transmitting electronics.	Demonstration	Safety; Recovery	Verified	The recovery electronics are independent of any other on-board electronics system. Section 3.5.5 shows the avionics architecture diagram. The success of the vehicle demonstration flight shows functionality of all active recovery electronics in unison. The flight results can be found in section 5.
NASA 3.13.3	The recovery system electronics SHALL be shielded from all onboard devices which may generate magnetic waves.	The recovery team designs an avionics bay that is separate from other on-board, transmitting electronics.	Demonstration	Safety; Recovery	Verified	The recovery electronics are independent of any other on-board electronics system. Section 3.5.5 shows the avionics architecture diagram. The success of the vehicle demonstration flight shows functionality of all active recovery electronics in unison. The flight results can be found in section 5.
NASA 3.13.4	The recovery system electronics SHALL be shielded from any other onboard electronic devices which may adversely affect the proper operation of the recovery system electronics.	The recovery team designs an avionics bay that is separate from other on-board, transmitting electronics.	Demonstration	Safety; Recovery	Verified	The recovery electronics are independent of any other on-board electronics system. Section 3.5.5 shows the avionics architecture diagram. The success of the vehicle demonstration flight shows functionality of all active recovery electronics in unison. The flight results can be found in section 5.

NASA 4.2	The team SHALL design a system capable of being launched in a high power rocket, landing safely, and recovering simulated lunar ice.	The project management team organizes each of the subsystem teams and works to integrate each subsystem with each other.	Demonstration	N/A	Verified	The payload deployment operational demonstration demonstrated the payload's ability to integrate with the launch vehicle. Section 7.2 details on the demonstration results.
NASA 4.3.1	The launch vehicle SHALL be launched from the NASA-designated launch area using the provided Launch pad.	The aerodynamics team will design a launch vehicle to be launched from either an 8 foot 1010 rail or a 12 foot 1515 rail. The structures team will fabricate said launch vehicle.	Inspection	Aerodynamics; Structures	Verified	The selected rail button is sized for a 1515 rail. Section 7.5 shows the line item budget including said rail buttons.
NASA 4.3.2	The team SHALL recover a lunar ice sample from one of five recovery areas.	The payload team designs a lunar ice recovery vehicle that will collect an ice sample from one of the recovery areas.	Demonstration	Payload	Verified	The results of the SICCU Operational Test are included in section 7.2.
NASA 4.3.3	The payload SHALL recover a lunar ice sample of a minimum of 10 milliliters.	The payload team designs a lunar ice recovery vehicle that is capable of storing 10 milliliters of simulated lunar ice.	Test	Payload	Verified	The results of the SICCU Operational Test are included in section 7.2.

NASA 4.3.4	The payload SHALL transport the stored sample 10 linear feet from the recovery site.	The payload team designs a lunar ice recovery vehicle that can travel 10 linear feet after collecting the sample of lunar ice.	Demonstration	Payload	Verified	The results of the BURRITO Performance Tests are included in section 7.2.
NASA 4.3.5	The team SHALL abide by all FAA and NAR rules and regulations.	The payload team designs a lunar ice recovery vehicle alongside the safety team that abides by all FAA and NAR rules.	Demonstration	Safety; Payload	Verified	The design of the payload and launch vehicle abides by all FAA and NAR rules and regulations.
NASA 4.3.6	The team SHALL not deploy the payload via black powder charges after ground impact.	The payload team designs a deployment system that does not utilize black powder charges after ground impact.	Inspection	Safety; Payload	Verified	The payload does not utilize black powder for deployment or any other purpose.
NASA 4.3.7	The payload SHALL be fully retained until it is deployed as designed.	The payload team designs a payload retention system that functions as designed.	Test	Safety; Payload	Verified	The results of the Retention System Loading Test are found in section 7.2.
NASA 4.3.7.1	The team SHALL design a mechanical retention system.	The payload team designs a mechanical payload retention system.	Demonstration	Safety; Payload	Verified	Section 4.5 has a CAD model of the current retention mechanism. The results of the deployment demonstration are in section 7.2.

NASA 4.3.7.2	The retention system SHALL be designed to successfully endure flight forces.	The payload team designs a payload retention system designed to withstand flight forces.	Test; Analysis	Safety; Payload	Verified	Section 4.5 has a CAD model of the current retention mechanism. The results of the deployment demonstration are in section 7.2.
NASA 4.3.7.3	The retention system SHALL be a fail-safe design.	The payload team designs a fail-safe payload retention system.	Demonstration	Safety; Payload	Verified	Section 4.5 has a CAD model of the current retention mechanism. The results of the deployment demonstration are in section 7.2.
NASA 4.3.7.4	The retention system SHALL not exclusively use shear pins as a method of retention.	The payload team designs a payload retention system that does not use shear pins exclusively.	Inspection	Payload	Verified	Shear pins are not used in the retention system.
NASA 4.4.1	If jettisoned during the recovery phase, the payload SHALL receive real-time RSO permission prior to initiating the jettison event.	The safety team does not jettison the payload until real-time RSO permission is granted.	Inspection	Safety; Payload	Verified	The payload is not jettisoned.
NASA 4.4.2	If jettisoned during the recovery phase and if the payload is a UAV, the payload SHALL be tethered to the launch vehicle until the RSO has given permission to release the UAV.	The safety team does not jettison the payload until real-time RSO permission is granted.	Inspection	Safety; Payload	Verified	The payload is not jettisoned.

NASA 4.4.3	If a UAV is chosen as the payload vehicle, the team SHALL abide by all FAA regulations for model aircraft.	The safety team holds the payload design accountable for all FAA rules and regulations if the payload is a UAV.	Inspection	Safety; Payload	Verified	The team has chosen to not pursue a UAV payload.
NASA 4.4.4	If a UAV is chosen as the payload vehicle and weighs more than 0.55 pounds, the UAV SHALL be registered with the FAA.	The safety team holds the payload design accountable for all FAA rules and regulations if the payload is a UAV.	Inspection	Safety; Payload	Verified	The team has chosen to not pursue a UAV payload.
NASA 5.1	The team SHALL use a launch and safety checklist.	The project management and safety teams write a launch and safety checklist. The launch and safety checklist is included in the CDR milestone report.	Inspection	Project Management; Safety	Verified	The launch operations procedure checklist is included in Appendix A.
NASA 5.2	The team SHALL identify a student safety officer.	The student safety officer is identified in each milestone report.	Inspection	Safety	Verified	The team's Safety Officer is Frances McBride. Her duties have been described in previous documentation.
NASA 5.3.1.1	The student safety officer SHALL, monitor team activities with an emphasis on safety during the design of vehicle and payload.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Inspection	Safety; Structures; Payload	Verified	The student safety officer, Frances McBride, monitors team activities.

NASA 5.3.1.2	The student safety officer SHALL, monitor team activities with an emphasis on safety during the construction of vehicle and payload components.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Inspection	Safety; Structures; Payload	Verified	The student safety officer, Frances McBride, monitors team activities.
NASA 5.3.1.3	The student safety officer SHALL, monitor team activities with an emphasis on safety during the assembly of vehicle and payload.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Inspection	Project Management; Safety	Verified	The student safety officer, Frances McBride, monitors team activities.
NASA 5.3.1.4	The student safety officer SHALL, monitor team activities with an emphasis on safety during the ground testing of vehicle and payload.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Inspection	Project Management; Safety	Verified	The student safety officer, Frances McBride, monitor's team activities.
NASA 5.3.1.5	The student safety officer SHALL, monitor team activities with an emphasis on safety during the subscale test launch.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Inspection	Project Management; Safety	Verified	The student safety officer, Frances McBride, monitors team activities.

NASA 5.3.1.6	The student safety officer SHALL, monitor team activities with an emphasis on safety during the Full-scale test launch.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Inspection	Project Management; Safety	Verified	The student safety officer, Frances McBride, monitors team activities.
NASA 5.3.1.7	The student safety officer SHALL, monitor team activities with an emphasis on safety during the competition launch day.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Inspection	Project Management; Safety	Verified	The student safety officer, Frances McBride, monitors team activities.
NASA 5.3.1.8	The student safety officer SHALL, monitor team activities with an emphasis on safety during the recovery activities.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Inspection	Safety; Recovery	Verified	The student safety officer, Frances McBride, monitors team activities.
NASA 5.3.1.9	The student safety officer SHALL, monitor team activities with an emphasis on safety during STEM engagement activities.	The student safety officer monitors team activities and ensures team members are practicing proper safety techniques.	Inspection	Project Management; Safety	Verified	The student safety officer, Frances McBride, monitors team activities.

NASA 5.3.2	The student safety officer SHALL implement procedures developed by the team for construction, assembly, launch and recovery activities.	The project management and safety teams write a launch and safety checklist that encompasses the assembly, launch and recovery of the launch vehicle.	Inspecti on	Project Manageme nt; Safety	Verified	The launch operations procedure checklist is included in Appendix A.
NASA 5.3.3	The student safety officer SHALL manage and maintain current revisions of the team's hazard analyses, failure mode analyses, procedures, and MSDS/chemical inventory data.	The safety team manages all safety documentation for the team.	Inspecti on	Safety	Verified	See section 6 for safety analysis.
NASA 5.3.4	The student safety officer SHALL assist in the writing and development of the team's hazard analyses, failure mode analyses, and procedures.	The safety team manages all safety documentation for the team.	Inspecti on	Safety	Verified	See section 6 for safety analysis.
NASA 5.4	The team SHALL abide by the rules and guidance of the local rocketry club's RSO during test flights.	The safety team ensures all regulations from the local rocketry club are followed.	Demons tration	Safety	Verified	The team will abide by all RSO guidelines at the demonstration flights and competition flights.
NASA 5.5	The team SHALL abide by all rules set forth by the FAA.	The safety team ensures all rules from the FAA are followed.	Demons tration	Safety	Verified	The team will abide by all RSO guidelines at the demonstration flights and competition flights.

7.4 Derived Requirement Verification

Table 7-27, below, defines the fields present in Table 7-27, Team Derived Requirements Verification Matrix.

Table 7-27 Derived Requirements Field Definition

Field	Definition
Req No.	Identification number associated with requirement.
Shall Statement	Statement of what the product shall accomplish.
Justification	Why the requirement is necessary.
Success Criteria	Description of how the team will define a met requirement.
Verification Method	How the requirement is verified. By Inspection, Demonstration, Test, or Analysis.
Subsystem Allocation	Indicates which subsystems are responsible for meeting the requirement.
Status	Results of the verification.

Table 7-28, below, shows the derived requirements for the NASA Student Launch project.

Table 7-28 Derived Requirements Verification Matrix

Req No.	Shall Statement	Justification	Success Criteria	Verification Method	Subsystem Allocation	Status	Results
TDR 1.1	The team SHALL meet weekly to discuss project goals and progress.	Holding weekly general body meetings will allow for better delegation of tasks and educate club members on what is necessary to execute this project.	The project management team hosts weekly meetings to update team members on the project progress and delegate tasks.	Inspection	Project Management	Verified	Weekly team meetings are scheduled for Thursdays at 7:30 pm on NC State's campus.
TDR 1.2	The team SHALL engage over 750 K-12 students before the FRR milestone report.	NASA SL requires an outreach goal of 200 K-12 students. HPRC strives to exceed expectations regarding sharing interest in rocketry.	The project management team organizes enough K-12 outreach events to exceed 750 participants.	Inspection	Project Management	Verified	The team has currently reached approximately 4500 students with more scheduled outreach events to come.

TDR 2.1	The launch vehicle airframe SHALL be water resistant.	The team's home launch field in Bayboro, NC has several large irrigation ditches the launch vehicle is prone to landing in. A water-resistant airframe will reduce the potential damage in this event.	The airframe is not damaged nor deformed by exposure to water.	Analysis; Inspection	Structures	Verified	A fiberglass airframe has been selected for the full-scale launch vehicle.
TDR 2.2	The launch vehicle SHALL not exceed a velocity of Mach 0.7.	At speeds over Mach 0.7, the launch vehicle enters transonic flight. Fin flutter become much more likely with this increase in velocity which increases risk for fin damage.	The launch vehicle does not exceed Mach 0.7 during flight.	Analysis	Aerodynamics	Verified	RockSim analysis indicates a Mach number less than 0.7.
TDR 2.3	The launch vehicle SHALL utilize a motor compatible with a motor casing already in the team's possession.	Not purchasing a motor casing allows the team the budgetary freedom to pursue more innovative payload designs.	A motor casing for the full-scale launch vehicle is not purchased.	Inspection	Project Management; Aerodynamics	Verified	The selected motor, the L1520-T, is compatible with an Aerotech 75/3840 motor casing which is already owned by the team.

TDR 2.4	The launch vehicle SHALL reach an apogee between 4300 ft and 4550 ft.	This range represents the range relative to a target apogee of 4420ft. This target was chosen in the interest of cost and weight-savings and is therefore a conservative apogee.	The apogee falls within 4300 ft and 4550 ft on competition launch day. All analysis reported prior to competition state that apogee is reached between these altitudes.	Analysis	Aerodynamics	Verified	A tolerance study was performed by the aerodynamics subsystem team to determine the most likely apogee window. This study can be found in in previous documentation.
TDR 2.5	The launch vehicle SHALL have a static stability margin between 2.0 and 2.30 upon rail exit.	To meet the stability requirement a stability margin of 2.0 is necessary. The maximum value of 2.3 was selected because excessive stability margin causes undesirable weathervaning in high winds.	The calculated launch vehicle's static stability margin lies within the range of 2.00 and 2.30.	Analysis	Aerodynamics	Verified	The launch vehicle’s as-built static margin was calculated in section 3.6.4
TDR 2.6	The launch vehicle’s blast caps SHALL be exposed and accessible.	Accessible energetics allow for safer and easier installation of black powder charges.	The designed Avionics Bay has easily accessible blast caps.	Inspection	Structures; Recovery	Verified	A modular AV Bay design was selected to expose blast caps for safer assembly of ejection charges. Section 3.4 details on this design.
TDR 2.7	All critical components of the launch vehicle SHALL be designed with a minimum factor of safety of 1.5.	This will ensure that assumptions made in analysis or reasonably higher than expected loading will not cause unpredicted failure during flight.	The factor of safety of each flight critical component is reported in documentation.	Test; Analysis	Structures	Verified	Factor of safety is determined for various load bearing components both experimentally and through simulation. Section 3.3.7.3 details on the simulation results. Section 7.1 details the launch vehicle test plan.

TDR 2.8	The launch vehicle SHALL be no larger than 6 inches in diameter.	Limiting the size of the launch vehicle makes it safer and easier to manipulate the vehicle at the field.	The diameter of the launch vehicle is not larger than 6 inches.	Inspection	Aerodynamics; Structures	Verified	A 6 inch diameter airframe has been selected for the full-scale launch vehicle. Section 7.5 contains the project schedule that shows materials have been purchased.
TDR 2.9	The team SHALL bring more than one igniter to launch days.	If one igniter fails, a redundant igniter takes its place.	For every launch pad, there are at least two usable igniters brought.	Inspection	Safety	Verified	Checklists described in Appendix A require more than one igniter on the materials list.
TDR 3.1	The onboard altimeters SHALL use one 9V battery each.	StratoLogger altimeters use one 9V battery each.	The avionics sled is designed to hold two 9V batteries. One for each altimeter.	Inspection	Recovery	Verified	The current avionics configuration uses 9V batteries. Section 3.5.5 has the avionics design.
TDR 3.2	Drogue descent velocity SHALL be less than 100 fps.	This speed will minimize the deployment shock at main deployment.	Calculations for descent velocity under drogue parachute are less than 100 fps.	Analysis	Recovery	Verified	A 24 inch drogue parachute was selected to keep the drogue descent velocity under 100 fps. Section 3.5.3 has the supporting calculations.
TDR 3.3	The launch vehicle SHALL use recovery devices that the team owns.	This restriction on the recovery section of the launch vehicle enables a better distributed budget for diversified development of flight systems.	The designed recovery system does not require the team to purchase new recovery devices.	Inspection	Recovery	Verified	A 24 inch drogue parachute and 120 inch main parachute have been selected. These parachutes are within the team's recovery inventory.

TDR 3.4	The black powder ejection charges SHALL produce at least a 15 psi pressure.	The 15 psi is a standard for most ejection charges in hobby rocketry.	Ejection charge calculations indicate a pressure of 15 psi is reached.	Analysis	Recovery	Verified	A pressure of 15 psi was used to calculate the ejection charge sizes. Current values and the supporting calculations can be found in section 3.5.7
TDR 3.5	The launch vehicle SHALL use U-Bolts for all shock cord attachments.	U-Bolts reduce the chance of a single point of failure.	The load bearing bulkheads have recovery connection points that use U-bolts.	Inspection	Recovery	Verified	All load bearing bulkheads are designed to incorporated U-Bolts. Section 3.3.7.3 details on bulkhead design.
TDR 4.1	The payload SHALL have a combined weight of no more than 9 lbs.	To maintain kinetic energy requirements the weight of the payload is limited.	The payload weighs less than 9 lbs.	Analysis	Aerodynamics; Payload	Verified	Launch vehicle systems were designed with a maximum payload weight of 9 lbs. Section 3.6.3 shows the launch vehicle stability analysis. Section 3.3 includes component weights for the payload bay.
TDR 4.2	The payload vehicle SHALL have a maximum speed of at least 3 mph.	The average human walking speed is 3 mph. The rover must keep up with the payload operator walking speed.	The payload vehicle consistently drives at a speed of 3 mph.	Analysis; Test	Payload	Verified	Rover motor selection has been based on this requirement. Supporting analysis can be found in section 4.3. Section 7.2 details on the rover performance tests.
TDR 4.3	The payload vehicle SHALL cover a range of at least 2000 feet.	If the launch vehicle were to land at a maximum wind drift distance of 2500, the rover would have to travel at most 2000 feet.	The payload vehicle is capable of driving over 2000 feet at one time.	Test	Payload	Verified	The BURRITO Range Test explores the limits of the BURRITO rover. This test is described in further detail in section 7.2.

TDR 4.4	The payload vehicle SHALL have a diameter of less than 4.25 inches.	The launch vehicle itself is already constrained to a size of 6 inches. Space also needs to be reserved for retention and deployment mechanisms.	The payload vehicle fits within the payload integration system.	Inspection	Payload	Verified	The selected wheels for the BURRITO have a diameter of approximately 4.2 inches. Section 4.3 shows dimensioned CAD models including the payload diameter.
TDR 4.5	The payload vehicle SHALL resist getting stuck on terrain.	The rover is subject to rough terrain at the field in Huntsville, AL. It is important to design a payload that can operate in adverse conditions as well as favorable.	The payload vehicle maintains traveling configuration over rough terrain and inclines. The design team creates a mechanism to maintain this configuration.	Test	Payload	Verified	The results of the BURRITO performance testing is detailed in section 7.2.
TDR 4.6	The payload vehicle SHALL resist getting stuck during deployment.	The rover is subject to rough terrain at the field in Huntsville, AL. It is important to design a payload that can operate in adverse conditions as well as favorable.	The payload vehicle is expelled from the launch vehicle evenly and as designed.	Demonstration	Payload	Verified	The payload deployment demonstration results are detailed in section 7.2.
TDR 4.7	The payload vehicle SHALL be radially supported within the body tube.	The rover is subject to all flight forces. To limit movement during flight, the rover must be radially supported.	The payload integration system radially supports the payload vehicle such that the rover is not a cantilever upon deployment.	Inspection	Payload	Verified	Four radial supports will be implemented in the final design. Section 4.6 shows CAD models including these supports.

TDR 4.8	The payload integration system SHALL be a maximum of 10 inches long.	Limiting the length of the payload integration in turn limits the length of the payload bay itself. This will contribute to a favorable static stability margin.	The payload integration system is less than 10 inches long.	Inspection	Payload	Verified	Section 4.6 shows a dimensioned CAD model with this information.
TDR 4.9	The sample collection system SHALL contain at least 15 mL of simulated lunar ice.	Collecting a larger sample than necessary will ensure that more than 10 mL are collected for competition.	The payload can collect and store 15 mL of simulated ice.	Test	Payload	Verified	The SICCU Operational Test will determine the average amount of material collected by the system. Section 7.2 details on the test.
TDR 4.10	The sample collection system SHALL contain the sample in a closed compartment when stowed for travel.	A closed compartment will reduce the likelihood of the sample spilling during travel.	The payload seals the sample of collected simulated ice.	Demonstration	Payload	Verified	After sample collection, the SICCU is flush with the base of the BURRITO. Section 4.3 includes a CAD model showing this.
TDR 4.11	The sample collection system SHALL not impede rover mobility when stowed.	The sample collection cannot inhibit travel after the sample is collected.	The payload is capable of traveling 10 feet after sample collection.	Demonstration	Payload	Verified	The BURRITO performance testing is detailed in section 7.2.
TDR 4.12	The sample collection system SHALL use the same power source as the rover.	This reduces the weight of the rover itself as only one battery is necessary.	The rover has one battery to drive both the motors and the sample collection system.	Inspection	Payload	Verified	Both systems use the Hyperion G50 50C battery mounted on the rover. Section 4.3 includes an electrical schematic showing this.

TDR 4.13	The sample collection system SHALL deploy only after operator input.	The sample collection system will interface with the ground to collect the simulated ice. If this is deployed too early, it can impact the rover's travel.	The sample collection system is failsafe and is only deployable after user input.	Demonstration	Payload	Verified	Section 4.3.6 details on SICCU operation. Section 7.2 details on the results of the SICCU operational test.
TDR 4.14	The payload retention system SHALL withstand all flight forces.	A retention system failure will result in damage to the payload and/or launch vehicle.	The payload retention system retains the payload as designed during simulated flight loading	Test	Payload	Verified	Section 7.2 details on the results of the payload retention loading test.
TDR 4.15	The payload integration system SHALL deploy the payload from the rocket upon landing.	The deployment system must be functional for the BURRITO and SICCU to complete their mission per the success criteria in section 4.2.	The BURRITO is deployed from the launch vehicle.	Demonstration	Payload	Verified	The deployment demonstration results are detailed in section 7.2.
TDR 4.16	The payload SHALL orient itself in the correct position after deployment	An improperly oriented payload after deployment may limit or inhibit the rover's travel	The payload is designed so that it will orient correctly after deployment	Demonstration	Payload	Verified	The BURRITO orientation results can be found in section 7.2.
TDR 5.1	Team members SHALL be trained on power tools prior to use.	Tool training ensures that each team member is aware of how each tool works and what precautions to take prior to use.	Team members receive tool training prior to power tool use.	Inspection	Safety	Verified	Safety officer, Frances McBride, held a safety seminar and tools workshop at the team's 10/24/19 general body meeting.

TDR 5.2	A designated safety officer SHALL be present at all fabrication activities requiring hazardous materials or power tools.	The safety officer specializes in identifying hazardous situations. Their presence at fabrication events allows them to help prevent these situations from occurring.	The designated safety officer is present and signs in with design lead at each fabrication session.	Inspection	Safety	Verified	Safety officer, Frances McBride, has been present at each fabrication session to date.
TDR 5.3	A designated safety officer SHALL be present at all launch day activities.	The safety officer specializes in identifying hazardous situations. Their presence at launch day events allows them to help prevent these situations from occurring.	The designated safety officer is present and signs in with each required checklist procedure.	Inspection	Safety	Verified	Safety officer identification and check in signatures are to be included at the start of each launch day checklist. Sample Launch day checklists can be seen in Appendix A.
TDR 5.4	Launch vehicle hazards that present risk in the red zone SHALL be mitigated to lower likelihood and/or severity by full-scale launch date.	Fewer launch vehicle hazards in the red zone is desirable for mission success.	There are no launch vehicle hazards in the red zone at the full-scale launch date.	Inspection	Safety	Verified	There are currently 0 hazards in the red zone.

TDR 5.5	A designated safety officer SHALL give a lecture on lab and launch safety for new members before launches and workdays.	The safety officer helps team members become knowledgeable of PPE types and when to use them.	The safety officer has a designated meeting time to present valuable safety information.	Demonstration	Safety	Verified	Safety officer, Frances McBride, held a safety seminar and tools workshop at the team's 10/24/19 general body meeting.
TDR 5.6	Motor assembly SHALL be carried out under the supervision of a Tripoli/NAR official.	As motors present a flame risk when handled improperly, supervision ensures safety throughout assembly.	A Tripoli/NAR official signs in preceding motor assembly.	Demonstration	Safety	Verified	Procedures described in Appendix A show the instructions for motor assembly under mentor supervision.
TDR 5.7	The team SHALL provide adequate sun/heat protection to team members during launches.	Overheating due to excessive sun exposure poses hazards to personnel. Providing shade mitigates this.	A sun protective tent, sunscreen, and water cooler is present and available to all members attending launch.	Inspection	Safety	Verified	The team brings sun protective equipment to each launch.
TDR 5.8	The team SHALL remove any non-biodegradable waste from the launch field.	Producing little to no waste during and after launch ensures a more positive impact on the surrounding environment.	Team members are engaged in cleanup if not participating in recovery or payload efforts; no visible trash remains upon departure	Inspection	Safety	Verified	Safety officer, Frances McBride, discusses clean up procedures at the team meeting prior to each launch.

7.5 Financing

7.5.1 Budget

Table 7-29, below details the year-long budget for the 2019-2020 competition year.

Table 7-29 2019-2020 Competition Budget

	Item	Quantity	Price per Unit	Item Total
Subscale Structure	Aerotech J570W-14A	2	$70.00	$140.00
	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	$14.82	$88.92
	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:			**$993.42**
Full-Scale Structure	6" G12 Airframe, Half Length (30"), 3 Slots	1	$80.00	$80.00
	6" G12 Airframe, Full Length (60")	1	$228.00	$228.00
	3" G12 Airframe, Half Length (30"), Motor Tube	1	$50.00	$50.00
	6" G12 Coupler 12" Length	2	$60.00	$120.00
	6" Fiberglass 5:1 Ogive Fiberglass Nosecone	1	$94.95	$94.95
	Domestic Birch Plywood 1/8"x2x2	8	$14.82	$118.56
	Aerotech 75/3840 Motor Case	1	$360.00	$360.00
	75 mm Motor Retainer	1	$72.00	$72.00

	Rail Buttons	4	$2.50	$10.00
	U-Bolts	4	$1.00	$4.00
	Aerotech L1520T-PS	2	$161.00	$322.00
	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
	Screw Switches	2	$12.00	$24.00
	Poster Printing (ft)	4	$10.00	$40.00
	Subtotal:			**$1,742.01**
Payload	1-inch PVC Pipe	1	$5.98	$5.98
	1 /2-inch PVC pipe	40	$0.49	$19.60
	1-inch PVC cap	8	$0.83	$6.64
	PVC cement	1	$8.98	$8.98
	Drum Motor	2	$19.99	$39.98
	Encoder Connector	2	$0.99	$1.98
	Bore Gear	2	$9.99	$19.98
	StratoLogger CF altimeter	1	$61.06	$61.06
	ADXL 354 multi axis Accelerometer	1	$47.39	$47.39
	Limit Switches	1	$7.99	$7.99
	77 oz-in DC Motor	1	$24.99	$24.99
	ESP32 Feather Board	1	$19.95	$19.95
	3.75 in. Aluminum Spur	1	$39.72	$39.72
	1.25 in. Aluminum Spur	2	$18.49	$36.98
	400mmx8mm Lead Screw	2	$21.55	$ 43.10
	6V Solenoid Lock Latch	1	$12.80	$12.80
	Drive Motor	2	$39.99	$79.98
	Lipo Battery	1	$33.99	$33.99
	4" Traction Wheel	2	$15.99	$31.98
	Wheel Hub	2	$2.99	$5.98

	Master Controller	1	$19.95	$19.95
	Motor Controller	1	$99.99	$99.99
	Arm Servo	1	$69.99	$69.99
	Rover Structure	1	$74.29	$74.29
	Caster Wheel	1	$4.36	$4.36
	Deployment/Suspension Spring	1	$11.27	$11.27
	Radio Receiver	1	$33.99	$33.99
	Servo Controller	1	$19.99	$19.99
	Radio Antenna	1	$54.99	$54.99
	Subtotal:			**$998.23**
Recovery and Avionics	Iris Ultra 96" Compact Parachute	1	$433.89	$433.89
	18" Elliptical Parachute	1	$57.17	$57.17
	Stainless Steel Quick Links	14	$1.97	$27.58
	5/8" Kevlar Shock cord (yard)	20	$4.34	$86.80
	1 /4" Kevlar Shock cord (yard)	15	$3.69	$54.75
	Black Powder	1	$17.95	$17.95
	E-Matches	1	$80.25	$80.25
	Shear Pins	1	$1.00	$1.00
	StratoLogger CF Altimeter	4	$49.46	$197.84
	6" Deployment Bag	1	$49.45	$49.45
	18" Nomex Cloth	1	$24.00	$24.00
	BeeLine Radio Transmitter	1	$59.00	$59.00
	4" Deployment Bag	1	$43.00	$43.00
	13" Nomex Cloth	1	$16.00	$16.00
	Iris Ultra Elliptical 24" Compact Parachute	1	$64.00	$64.00
	Iris Ultra Compact Elliptical 60" Parachute	1	$241.88	$241.88
	Subtotal:			**$1,454.56**
Miscell.	Epoxy Resin	2	$86.71	$173.42
	Epoxy Hardener	2	$45.91	$91.82
	Nuts (box)	1	$5.50	$5.50

	Screws (box)	1	$5.00	$5.00
	Washers	1	$5.00	$5.00
	Wire	1	$13.00	$13.00
	Zip Ties	1	$11.00	$11.00
	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	1	$25.00	$25.00
	Battery Connectors	3	$5.00	$15.00
	Shipping			$1,200.00
	Incidentals (replacement tools, hardware, safety equipment)			$1,500.00
	Subtotal:			**$3,115.74**
Travel	Student Hotel Rooms (# rooms)	4	$791.70	$3,166.80
	Mentor Hotel Rooms (# rooms)	2	$918.80	$1,837.60
	Van Rentals (# cars)	2	$198.00	$396.00
	Gas (Miles)	2304	$0.69	$1,589.76
	Subtotal:			**$6,925.36**
Promotion	T-Shirts	40	$14.00	$560.00
	Polos	35	$20.00	$700.00
	Stickers	500	$0.37	$185.00
	Banner	1	$250.00	$250.00
	Subtotal:			**$1,695.00**
	Total:			**$16,924.32**

7.5.2 Funding Plan

HPRC gets all its funding from multiple NC State University organization and North Carolina Space Grant (NCSG).

The NC State University Student Government Association's Appropriations Committee is responsible for distributing university funds to campus organizations. The application process is similar to the Engineers' Council with a proposal, presentation, and an in-person interview. In the 2018-2019 academic year, HPRC received a total of $2,160: $640 in the fall semester and $1,520 in the spring semester. A request for $2,000 has been placed for the current fall semester and the same amount will be requested in the spring semester, assuming that the Appropriations Committee budget will remain the same.

Engineering and Technology Fee is an NC State University fund that allocates funding for academic enhancement through student organizations. Their funding will primarily pay for the faculty advisor's travel costs.

Student and mentor travel costs will be covered by NC State's College of Engineering Enhancement Funds and Engineering Council. 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 $5,000.

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 2019.

In the past, HPRC has held sponsorships with Collins Aerospace, Jolly Logic, and more. The team is currently seeking out new sponsorships and reaching out to the team's past sponsors. The team hopes to get at least $4,500 more in funding from various companies.

These totals are listed in Table 7-30, below, which compares the projected costs and incoming grants for the 2019-2020 school year.

Table 7-30 2019-2020 Funding Sources

Organization	Fall Semester Amount	Spring Semester Amount	School Year Total
Engineering Technology Fee	-	-	$2,500.00
SGA Appropriations	$1038.00	$1070.00	$2,108.00
Sponsorships	-	-	$3,600.00
NC Space Grant	-	-	$5,000.00
College of Engineering	-	-	$3,000.00
E-Council	-	$750	$750.00
Total Funding:			**$16,958.00**
Total Expenses:			**$16,924.32**
Difference:			**$33.68**

7.6Timeline

Table 7-31, below, shows the development schedule for this year's project. A Gantt chart depicting this information can be found in Appendix C. The build schedules have been removed from the appendix as they have been completed and are no longer necessary.

Table 7-31 2019-2020 NASA Student Launch Schedule

Event/Task	Start Date	End Date/Submission
Request for Proposal Released	8/22/2019	8/22/2019
Proposal	8/22/2019	9/18/2019
Preliminary Design Review (PDR) Q&A	10/9/2019	10/9/2019
PDR	10/9/2019	11/1/2019
Subscale Construction Period	10/15/2019	11/17/2019
PDR Team Teleconference	11/4/2019	11/20/2019
Subscale Launch Opportunity	11/23/2019	11/23/2019
Critical Design Review (CDR) Q&A	11/25/2019	11/25/2019
CDR	11/25/2019	1/10/2020
Component Testing Period	12/3/2019	2/17/2020
Full-Scale Construction Period	1/13/2020	2/7/2020
CDR Team Teleconference	1/13/2020	1/28/2020
Flight Readiness Review (FRR) Q&A	1/31/2020	1/31/2020
Full-Scale Launch Opportunity	2/22/2020	2/22/2020
FRR	1/31/2020	3/2/2020
FRR Team Teleconference	3/6/2020	3/19/2020
Launch Week Q&A	3/26/2020	3/26/2020
Team Travel to Huntsville, AL	4/1/2020	4/1/2020
Launch Readiness Review (LRR)	4/1/2020	4/2/2020
Launch Week Activities	4/2/2020	4/3/2020
Launch Day	4/4/2020	4/4/2020
Backup Launch Day	4/5/2020	4/5/2020
Post-Launch Assessment Review (PLAR)	4/6/2020	4/27/2020

Appendix A

E-Match Install

Required Personnel		
Name	**Role**	**Initial**
Ashby Scruggs	Student Team Leader	
Frances McBride	Safety Officer	
	E-Match Personnel 1	
	E-Match Personnel 2	

Required Materials			
Item	**Number**	**Location**	**Confirm**
Bulkhead #5	1		
Bulkhead #4	1		
E-Match	4		
Scissors	1		
Wire Snips	1		
Wire Strippers	1		
Blue Tape	1		
TB Screwdriver	1		

Procedure		
Task	**Check**	**Confirm**
NOTE: Execute this procedure on both bulkhead #4 and #5 at the same time		
Unscrew all **UNOCCUPIED** terminal blocks on bulkheads #4 and #5		
Primary		
Trim the e-match to approximately 7 in length using wire cutter		
Remove red plastic protective e-match cover from e-match		
Feed the e-match through the **P** wire hole NOTE: the e-match head should be on the side with blast caps		
Separate the two leads		
Strip the wire insulation from end of e-match		
Make a loop with the exposed wire		
Place exposed e-match leads into terminal block labeled **P**		
Tighten down the screws in the **P** terminal block		
Lightly tug on e-match wires coming out of the **P** terminal block		Safety Officer
Place e-match head within the blast cap labeled **P**		

Bend the e-match wire such that it lies flat against the blast cap		
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 the e-match in the **P** blast cap is connected to the terminal block labeled **P**		Safety Officer
Confirm all labels are still visible		Safety Officer
Secondary		
Trim the e-match to approximately 7 in length using wire cutter		
Remove red plastic protective e-match cover from e-match		
Feed the e-match through the **S** wire hole NOTE: the e-match head should be on the side with blast caps		
Separate the two leads		
Strip the wire insulation from end of e-match		
Make a loop with the exposed wire		
Place exposed e-match leads into terminal block labeled **S**		
Tighten down the screws in the **S** terminal block		
Lightly tug on e-match wires coming out of the **S** terminal block		Safety Officer
Place e-match head within the blast cap labeled **S**		
Bend the e-match wire such that it lies flat against the blast cap		
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 the e-match in the **S** blast cap is connected to the terminal block labeled **S**		Safety Officer
Confirm all labels are still visible		Safety Officer
Confirm E-Match		Team Lead
Confirm all steps have been executed		Team Lead

AV Bay Assembly

Required Personnel		
Name	**Role**	**Initial**
Ashby Scruggs	Student Team Leader	
Frances McBride	Safety Officer	
Gabe Buss	Recovery Lead	
Trent Couse	AV Personnel 1	
Alex Thomas	AV Personnel 2	

Required Materials			
Item	**Number**	**Location**	**Confirm**
Bulkhead #5	1	Bulkhead Box	
Bulkhead #4	1	Bulkhead Box	
AV Sled (assembled)	1	Bulkhead Box	
AV Bay	1	-	
9V Battery	2	Avionics HDX	
#4-40 screw	4	Avionics HDX	
#4-40 washer	4	Avionics HDX	
#4-40 nut	4	Avionics HDX	
1/4" Wrench	1	Launch Day Toolbox	
Adjustable Wrench	1	Launch Day Toolbox	
Multimeter	1	Launch Day Toolbox	
Plumber's Putty	1	Launch Day Toolbox	
Ziptie	6	Launch Day Toolbox	
Wire Snips	1	Launch Day Toolbox	
Wire Strippers	1	Launch Day Toolbox	
Needle Nose Pliers	1	Launch Day Toolbox	
#8 screw	4	Recovery Hardware Box	
TB Screwdriver	1	Launch Day Toolbox	

Procedure		
Task	**Check**	**Confirm**
Confirm the primary screw switch is turned to the off position NOTE: the primary screw switch should be silent		
Confirm the secondary screw switch is turned to the off position NOTE: the secondary screw switch should be silent		
Use multimeter to check primary battery voltage – 9V NOTE: Replace if lower than 9V		Record battery voltage

Use multimeter to check secondary battery voltage– 9V NOTE: Replace if lower than 9V		Record battery voltage
Connect batteries to the battery clips		
Place batteries in the battery compartment		
Place battery compartment cover over batteries and secure with four (4) #4-40 machine screws, four (4) #4-40 hex nuts.		Recovery Lead
Confirm the primary screw switch is turned to the off position NOTE: the primary screw switch should be silent		Recovery Lead
Confirm the secondary screw switch is turned to the off position NOTE: the secondary screw switch should be silent		Recovery Lead
DO NOT POWER ON ALTIMETERS UNTIL OTHERWISE DIRECTED BY THE CHECKLIST		
Confirm wires between primary altimeter and **DP** terminal block are still connected		Recovery Lead
Confirm wires between secondary altimeter and **DS** terminal block are still connected		Recovery Lead
Confirm e-match wires are installed on **Bulkhead #5**		
Confirm the AV Sled is ready to be inserted into the AV Bay		Recovery Lead
Slide the AV bay body tube over the AV sled and bulkhead assembly fully down until it is flush along **bulkhead #5**		
Use the arrows on the coupler to align the sled correctly		
Confirm the **end of the AV bay labeled #5** is aligned with the **bulkhead #5**		Recovery Lead
Probe pressure ports with small screwdriver to confirm they are		Recovery Lead
Confirm the screw switches are visible through the screw switch holes		
Label the switches primary and secondary		
Confirm e-match wires are installed on Bulkhead #4		Recovery Lead
Confirm wires leading to quick disconnects are installed on Bulkhead #4		Recovery Lead
Connect the **MP** altimeter wires to the wires attached to the **MP** terminal block on Bulkhead #4 using the quick disconnect		
Lightly tug on the **MP** altimeter wires coming out of the **MP** terminal block		Safety Officer

Lightly tug on the connected **MP** quick disconnects		Safety Officer
Connect the **MS** altimeter wires to the wires attached to the **MS** terminal block on Bulkhead #4 using the quick disconnect		
Lightly tug on the **MS** altimeter wires coming out of the **MS** terminal block		Safety Officer
Lightly tug on the connected **MS** quick disconnects		Safety Officer
Confirm AV Sled alignment		Recovery Lead
Slide bulkhead #4 onto the threaded rods until flush with body tube		
Slide a 1/4 inch washer onto each threaded rod		
Slide a 1/4 inch nut onto each threaded rod		
Slide a 1/4 inch cap nut onto each threaded rod		
Confirm the AV Bay alignment		Recovery Lead
Tighten nuts until snug		
Confirm ALL labels on AV Bay are still visible		Safety Officer
Confirm AV Bay assembly and bulkhead		Recovery Lead
Use plumber's putty to seal any holes in the **#4 bulkhead**		
Use plumber's putty to seal any holes in the **#5 bulkhead**		
Confirm all holes are sealed		Recovery Lead
Clear the table for black powder install		
Confirm AV Bay Assembly		Team Lead
Confirm all steps have been executed		Team Lead

Drogue Black Powder

Required Personnel		
Name	**Role**	**Initial**
Ashby Scruggs	Student Team Leader	
Frances McBride	Safety Officer	
	Black Powder Personnel 1	
	Black Powder Personnel 2	

Required Materials			
Item	**Number**	**Location**	**Confirm**
AV Bay (Assembled)	1	-	
8.5x11, 20lb weight, 30% post-consumer recycled material copy paper	2	Launch Day Toolbox	
Paper Towel Roll	1	-	
Blue Tape	1	Launch Day Toolbox	
Plumbers Putty	1	Launch Day Toolbox	
Scissors	1	Launch Day Toolbox	
Safety Glasses	4	PPE Box	
Nitrile Gloves	4	PPE Box	
Heavy Duty Gloves	1	PPE Box	
Drogue Primary Charge	2	Avionics HDX	
Drogue Secondary Charge	2	Avionics HDX	

Procedure		
Task	**Check**	**Confirm**
ALL PARTICIPATING PERSONNEL MUST WEAR SAFETY GLASSES		
ALL PARTICIPATING PERSONNEL MUST WEAR NITRILE GLOVES		
Confirm that all members around the launch vehicle are wearing safety glasses		Safety Officer
Confirm the members handling black powder are wearing nitrile gloves		Safety Officer
Turn AV Bay so that the blast caps on Bulkhead #5 are facing		
Create a paper funnel using 1 sheet of copy paper and 1 piece of blue tape		
Confirm the inside of paper funnel is smooth		

Carefully pour the **Drogue Primary Charge** 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 fingertip sized pieces of paper NOTE: 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 NOTE: Do NOT have any major overlaps but leave no gaps with the blue tape		
Confirm all edges are covered		Safety Officer
Wrap blue tape all the way around the outside of the blast cap to keep the top layers tight		
Secondary		
Carefully pour the **Drogue Secondary Charge** 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 NOTE: 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 **DS** blast cap to cover the blast cap completely NOTE: Do NOT have any major overlaps but leave no gaps with the blue tape		
Confirm all edges are covered		Safety Officer
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		Safety Officer
Turn the AV Bay over onto a sheet of white copy		
Turn the AV Bay back over		
Confirm that no black powder has leaked onto the copy paper		
IF BLACK POWDER HAS LEAKED, EMPTY THE CONTENTS OF THE BLAST CAPS AND REPEAT THE STEPS		

Main Black Powder

Required Personnel		
Name	**Role**	**Initial**
Ashby Scruggs	Student Team Leader	
Frances McBride	Safety Officer	
	Black Powder Personnel 1	
	Black Powder Personnel 2	

Required Materials			
Item	**Number**	**Location**	**Confirm**
AV Bay (Assembled)	1		
8.5x11, 20lb weight, 30% post-consumer recycled material copy paper	2		
Paper Towel Roll	1		
Blue Tape	1		
Plumbers Putty	1		
Scissors	1		
Safety Glasses	4		
Nitrile Gloves	4		
Heavy Duty Gloves	1		
Main Primary Charge	2		
Main Secondary Charge	2		

Procedure		
Task	**Check**	**Confirm**
ALL PARTICIPATING PERSONNEL MUST WEAR SAFETY GLASSES		
ALL PARTICIPATING PERSONNEL MUST WEAR NITRILE GLOVES		
Confirm that all members around the launch vehicle are wearing safety glasses		Safety Officer
Confirm the members handling black powder are wearing nitrile gloves		Safety Officer
Turn AV Bay so that the blast caps on Bulkhead #4 are facing		
Create a paper funnel using 1 sheet of copy paper and 1 piece of blue tape		
Confirm the inside of paper funnel is smooth		

Carefully pour the **Main Primary Charge** into the **MP** 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 sized pieces of paper NOTE: 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 NOTE: Do NOT have any major overlaps but leave no gaps with the blue tape		
Confirm all edges are covered		Safety Officer
Wrap blue tape all the way around the outside of the blast cap to keep the top layers tight		
Secondary		
Carefully pour the **Main Secondary Charge** 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 fingertip size pieces of paper towel NOTE: 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 **DS** blast cap to cover the blast cap completely NOTE: Do NOT have any major overlaps but leave no gaps with the blue tape		
Confirm all edges are covered		Safety Officer
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		Safety Officer
Turn the AV Bay over onto a sheet of white copy		
Turn the AV Bay back over		
Confirm that no black powder has leaked onto the copy paper		
IF BLACK POWDER HAS LEAKED, EMPTY THE CONTENTS OF THE BLAST CAPS AND REPEAT THE STEPS		

Slide the Main Parachute Bay onto the AV Bay coupler using the stars to align the holes		
Secure with four (4) #8 screws		
Use plumber's putty to seal the seam between the **#4 bulkhead** and the body tube		
Confirm all holes are sealed		Safety Officer

Drogue Recovery Assembly

Required Personnel		
Name	**Role**	**Initial**
Ashby Scruggs	Student Team Leader	
Frances McBride	Safety Officer	
Gabe Buss	Recovery Lead	
Robert Kempin	Drogue Personnel 1	
Shiv Oza	Drogue Personnel 2	

Required Materials			
Item	**Number**	**Location**	**Confirm**
AV Bay (assembled)	1	-	
Fin Can	1	-	
Safety Glasses	4	PPE Box	
Drogue Parachute	1	Recovery Tupperware	
Nomex Sheet	1	Recovery Tupperware	
Drogue Shock Cord	1	Recovery Tupperware	
Quick links (#5-#7)	3	Recovery Hardware Box	
Shear Pins	4	Recovery Hardware Box	
Electrical Tape	1	Launch Day Toolbox	
Scissors	1	Launch Day Toolbox	
Plumber's Putty	1	Launch Day Toolbox	

Procedure		
Task	**Check**	**Confirm**
ALL PARTICIPATING PERSONNEL MUST WEAR SAFETY GLASSES		
Confirm that all members near the launch vehicle are wearing safety glasses		Safety Officer
Use **quick link 6** to attach nomex cloth to shock cord parachute **loop 6**		
Do NOT tighten		
Use **quick link 6** to attach drogue parachute eye-bolt **6** to **loop**		
Tighten by hand		
Z fold length of shock cord **between loops 5 and 6** accordion-style in 8 inch folds		

Secure the length of shock cord **between loops 5 and 6** with a single rubber band		
Confirm two fingers fit snugly under the rubber band		Recovery Lead
Confirm the rubber band does NOT cover any part of the parachute		Recovery Lead
Confirm the shock cord is still folded accordion style within the rubber band NOTE: if not, repeat the above steps		Recovery Lead
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 two fingers fit snugly under the rubber band		Recovery Lead
Confirm the rubber band does NOT cover any part of the parachute		Recovery Lead
Confirm the shock cord is still folded accordion style within the rubber band NOTE: if not, repeat the above steps		Recovery Lead
Confirm the drogue parachute is properly folded NOTE: refold according to ECL Handbook if necessary		Recovery Lead
Attach **quick link 5** to **loop 5**		
Do NOT tighten		
Attach **quick link 5** to **bulkhead 5**		
Tighten by hand		
Confirm **loop 5** is attached to **quick link 5** and is attached to **bulkhead 5**		Recovery Lead
Confirm the quick link is secured to the Bulkhead 5 U-bolt by visual inspection and pulling on shock cord		Recovery Lead
Attach **quick link 7** to **loop 7**		
Do NOT tighten		
Attach **quick link 7** to fin can **bulkhead 7**		
Tighten by hand		
Confirm **loop 7** is attached to **quick link 7** and is attached to **bulkhead 7**		Recovery Lead
Confirm the quick link is secured to the fin can bulkhead 7 U-bolt by visual inspection and pulling on shock cord		Recovery Lead
Remove the rubber band securing the drogue parachute		
Firmly grasp the folded drogue parachute		

Confirm all rubber bands are removed from parachute and shroud lines		Recovery Lead
Wrap nomex cloth around the drogue parachute		
Firmly grasp the folded drogue parachute and nomex sheet assembly		
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 NOTE: The yellow fruity chutes label is pointed toward 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 markings 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 NOTE: if shear pins are loose, place a small piece of electrical tape over the shear pin head		
Hold AV Bay and let fin can hang		
Confirm the launch vehicle can hold its own weight from shear pins alone		Recovery Lead
Confirm Fin Can Assembly		Team Lead
Confirm all steps have been executed		Team Lead

Payload Assembly

Required Personnel		
Name	**Role**	**Initial**
Ashby Scruggs	Student Team Leader	
Sean Clark	Payload Integration Lead	
Michael Barton	BURRITO Lead	
Erik Benson	SICCU Lead	
Mike Pudlo	Payload Personnel 1	

Required Materials			
Item	**Number**	**Location**	**Confirm**
BURRITO	1	Payload Box	
Main Parachute Shock Cord	1	Nosecone Assembly	
Quick link K	1	Recovery Hardware Box	
Payload Plug	1	Bulkhead Box	
Plumber's Putty	1	Launch Day Toolbox	
Phone	1	-	

Shear Pin	4	Recovery Hardware Box	
Main Parachute Bay	1	Nosecone Assembly	
Retention Electronics Lid	1	Payload Tupperware	
Taranis X-Lite	1	-	
Zip Ties	1	Launch Day Toolbox	
Nosecone Assembly	1	-	

Procedure		
Task	**Check**	**Confirm**
Connect the payload retention battery to the battery connector		
Insert the retention electronics lid on the retention electronics bay		
Secure with a zip tie		
Confirm the retention electronics lid is secure		Payload Integration Lead
Confirm the payload retention battery is secure		Payload Integration Lead
Open the BLE terminal application on the cell phone		
Connect to ID: HC06		
Enter Password: 1234		
Confirm the application connects to the Bluetooth device		
On the BLE Terminal app, type in 4		
Confirm the retention system moves to the locked position NOTE: reference image attached		Payload Integration Lead
On the BLE Terminal app, type in 3		
On the BLE Terminal app, type in 5		
Confirm the retention system moves to the unlocked position NOTE: reference image attached		Payload Integration Lead
On the BLE Terminal app, type in 3		
Manually latch the BURRITO into the retention mechanism		
Lightly tug on the aft wheel of the BURRITO		
Confirm the BURRITO is latched		Payload Integration Lead
Use a screwdriver to turn the BURRITO power switch		
Confirm the BURRITO is powered ON		BURRITO Lead
Confirm the SICCU is attached to the BURRITO		SICCU Lead
On the BLE Terminal app, enter 2		
Confirm the BURRITO begins to retract into the payload bay		Payload Integration Lead
Support the BURRITO as it retracts		

Confirm the BURRITO passes the RED line in the payload bay		Payload Integration Lead
On the BLE Terminal app, enter 0		
Confirm the BURRITO stops moving		Payload Integration Lead
Slide the main parachute bay into the payload bay, using the silver line to align the holes		
Insert the plug through the main parachute bay until flush with the payload centering ring NOTE: it may be necessary to use the mallet to secure		
Use quick link K to attach the plug to loop K on the main parachute shock cord		
Insert (4) 4-40 nylon shear pins into the shear pin holes		
Use plumber's putty to seal all holes in the plug		
Use plumber's putty to seal the seam between the plug and the body tube		
Confirm the plug is sealed		Recovery Lead
Confirm Payload Assembly		Team Lead
Confirm all steps have been executed		Team Lead

Main Recovery Assembly

Required Personnel		
Name	**Role**	**Initial**
Ashby Scruggs	Student Team Leader	
Frances McBride	Safety Officer	
Gabe Buss	Recovery Lead	
Evan Waldron	Recovery Personnel 1	
Trent Couse	Recovery Personnel 2	

Required Materials			
Item	**Number**	**Location**	**Confirm**
Fin Can Assembly	1	-	
Nosecone Assembly	1	-	
Safety Glasses	6	PPE Box	
Main Parachute	1	Recovery Tupperware	
Deployment Bag	1	Recovery Tupperware	
Main Shock Cord	1	Recovery Tupperware	
Nomex Sheet	1	Recovery Tupperware	
Quick links (#2-4)	3	Recovery Hardware box	
#8 screws	4	Recover Hardware Box	
#8 screwdriver	1	Launch Day Toolbox	

Plumber's Putty	1	Launch Day Toolbox	
Scissors	1	Launch Day Toolbox	

Procedure		
Task	**Check**	**Confirm**
ALL PARTICIPATING PERSONNEL MUST WEAR SAFETY GLASSES		
Confirm that all members near the launch vehicle are wearing safety glasses		Safety Officer
Confirm the holes in the payload plug are sealed		Recovery Lead
Confirm the seam between the payload plug and body tube is sealed		Recovery Lead
Attach quick link 2 to deployment bag loop 2		
Tighten by hand		
Z-fold length of shock cord between loops 2 and 3 in 8 inch folds		
Secure with a single rubber band		
Confirm 2 fingers fit snugly under the rubber band		Recovery Lead
Confirm the rubber band does NOT cover any part of the parachute		Recovery Lead
Confirm the shock cord is still folded accordion style within the rubber band NOTE: if not, repeat the above steps		Recovery Lead
Z fold the length of shock cord between loops 3 and 4 in 8 inch folds		
Secure with a single rubber band		
Confirm 2 fingers fit snugly under the rubber band		Recovery Lead
Confirm the rubber band does NOT cover any part of the parachute		Recovery Lead
Confirm the shock cord is still folded accordion style within the rubber band NOTE: if not, repeat the above steps		Recovery Lead
Confirm that ALL rubber bands are removed from the main parachute		Recovery Lead
Confirm that ALL rubber bands are removed from the deployment bag		Recovery Lead
Attach **quick link 2 to loop 2**		
Attach quick link 2 to deployment bag loop 2		
Tighten by hand		
Attach quick link 3 to loop 3		
Do NOT tighten		
Attach quick link 3 to nomex sheet 3		
Do NOT tighten		
Attach quick link 3 to parachute loop 3		

Tighten by hand		
Wrap the deployment bag and parachute assembly in large nomex sheet		
Carefully insert the length of shock cord between loops 2 and 3 into the main parachute bay		
Carefully insert the wrapped parachute deployment bag into the main parachute bay		
Confirm the open end of the deployment bag is facing the payload plug		Recovery Lead
Carefully insert the length of shock cord between loops 3 and 4 into the main parachute bay		
Do NOT tighten		
Attach quick link 4 to bulkhead 4		
Tighten by hand		
Confirm the **quick link 4** is secured to the **bulkhead 4** by visual inspection and pulling on shock cord		Recovery Lead
Slide the AV bay into the Main Parachute bay using the stars to align the holes		
Secure with four #8 screws		
Hold the launch vehicle by the nosecone and let the rocket hang		
Confirm the launch vehicle can hold its own weight from shear pins alone		Recovery Lead
Confirm Launch Vehicle assembly		Team Lead
Confirm all steps have been executed		Team Lead

Motor Assembly

Required Personnel		
Name	**Role**	**Initial**
Alan Whitmore	L3 Mentor	
Ethan Johnson	Aerodynamics Lead	
Abhi Kondagunta	Motor Personnel 1	
Meredith Patterson	Motor Personnel 2	

Required Materials			
Item	**Number**	**Location**	**Confirm**
Aerotech L1520T Reload Kit	1	Motor Box	
Aerotech RMS 75/3840 motor casing	1	Motor Box	
Vaseline	1	Launch Day Toolbox	
Needle nose pliers	1	Launch Day Toolbox	
Baby Wipes	1	Launch Day Toolbox	
Sharpie Marker	1	Launch Day Toolbox	
Blue Tape	1	Launch day Toolbox	

Nitrile Gloves	2	PPE Box	
Paper Towels	1	-	

Procedure		
Task	**Check**	**Confirm**
Follow the included manufacturer's instructions for motor assembly with L3 Mentor		
Use Vaseline to lightly grease all three (3) included O-rings		
Use Vaseline to lightly grease case threads		
Install smoke grain into smoke insulator until snug		
Install FWD seal disk O-ring in FWD seal disk		
Install FWD seal disk and installed O-ring into one end of the liner until snug		
Install 3 propellant motor grains into liner		
Install liner into motor casing		
Hold liner centered within motor casing		
Install FWD O-ring into FWD end of case		
Confirm the FWD O-ring is seated on top of the FWD seal disk assembly		Aerodynamics Lead
Install Forward Closure with smoke assembly in FWD end of motor casing on top of FWD O-ring until finger tight		
Install AFT nozzle on AFT (opposite) end of case		
Install AFT O-ring onto AFT nozzle		
Install AFT closure onto AFT O-ring		
Install aft closure into casing		
Tighten the aft closure until finger tight NOTE: there will be exposed threads when the aft closure is snug		
Install nozzle cap		
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		
Confirm motor assembly		Aerodynamics Lead
Confirm all steps have been executed		Aerodynamics Lead

Stability Verification

Required Personnel		
Name	**Role**	**Initial**
Ashby Scruggs	Student Team Leader	
Ethan Johnson	Aerodynamics Lead	
Daniel Jaramillo	Personnel 1	
Mike Pudlo	Personnel 2	

Required Materials			
Item	**Number**	**Location**	**Confirm**
Launch Vehicle (assembled)	1	-	
Luggage Scale	1	Launch Day Toolbox	
Rope	1	Launch Day Toolbox	
Circle Sticker	2	Launch Day Toolbox	
Motor (assembled)	1	-	
Sharpie	1	Launch Day Toolbox	

Procedure		
Task	**Check**	**Confirm**
Unscrew the motor retainer		
Slide motor casing into the motor tube		
Secure motor casing using the retainer screw		
Confirm the retainer screw is tight		Aerodynamics Lead
Measure the center of pressure of the launch vehicle (________ inch from nosecone)		
Confirm the center of pressure is correctly marked		Aerodynamics Lead
Use a circular sticker to mark the center of pressure of the launch vehicle		
Tie the rope around the center of the launch vehicle		
Slide the rope around until the launch vehicle balances		
Mark the balance point with a circular sticker, this is the center of gravity		
Record the weight of the launch vehicle NOTE: should be approximately _______		Record weight:
Record the CG location NOTE: should be approximately _______		CG Location: Aerodynamics Lead
Confirm the CG and CP are approximately 12 inches apart		Aerodynamics Lead
Calculate the stability margin of the launch vehicle (CP-CG)/D		Record:

		Aerodynamics Lead
Confirm the stability margin is above 2.0		Team Lead
Confirm the launch vehicle is prepared for launch		Team Lead
Confirm all steps have been executed		Team Lead
Pack the Field Recovery Toolbox		

Launch Pad Procedure

Required Personnel		
Name	**Role**	**Initial**
Ashby Scruggs	Student Team Leader	
Gabe Buss	Recovery Lead	
Alan Whitmore	L3 Mentor	
Jim Livingston	L3 Mentor	

Required Materials			
Item	**Number**	**Location**	**Confirm**
Launch Vehicle	1	-	
Motor ignitor	1	Field Recovery Box	
Launch Rail Lubricant	1	Field Recovery Box	
Nitrile Gloves	5	Field Recovery Box	
Heavy Duty Gloves	1	Field Recovery Box	
Safety Glasses	5	Field Recovery Box	
Switch Screwdriver	1	Field Recovery Box	
TB Screwdriver	1	Field Recovery Box	
Adjustable Wrench	1	Field Recovery Box	
Rubber Band	5	Field Recovery Box	
Phone	1	Field Recovery Box	
Wire Snips	1	Field Recovery Box	
Wire Strippers	1	Field Recovery Box	
Blue Tape	1	Field Recovery Box	
Plastic Bag	1	Field Recovery Box	
12 inch ruler	1	Field Recovery Box	
Measuring tape	1	Field Recovery Box	
Fire Extinguisher	1	Field Recovery Box	
Plumber’s putty	1	Launch Day Toolbox	

Procedure		
Task	**Check**	**Confirm**
Confirm with RSO that field conditions are safe for launch		Team Lead
Confirm with RSO that launch rail is 1515		Team Lead

Submit launch vehicle and flight card to RSO for review		Team Lead
Record location of launch pad		
Confirm the blast deflector is mounted on the launch rail		Team Lead
Grease launch vehicle rail buttons and launch rail track		
Carefully slide the launch vehicle onto the launch rail		
Visually confirm the launch vehicle slides smoothly		Team Lead
Turn the GPS screw switch until tight		
Confirm the GPS is powered on		Recovery Lead
Plug Gabe's Hole with plumber's putty		
Rotate launch rail into upright position		
Lock launch rail in place		
Confirm the launch rail is rotated 5 degrees from vertical		
Confirm the launch rail is locked		Team Lead L3 Mentor
Take a team picture in front of the rocket		
Take a senior design team picture in front of the rocket		
All non-essential personnel are directed to leave the launch pad		
Confirm all individuals remaining at the launch pad are wearing safety glasses		Team Lead
Arm both altimeters		
Turn the primary screw switch until tight		
Fill out the attached PRIMARY ALTIMETER beep sheet		
Confirm the PRIMARY altimeter is beeping correctly		Recovery Lead L3 Mentor
Turn the secondary screw switch until tight		
Fill out the attached SECONDARY ALTIMETER beep sheet		
Confirm the SECONDARY altimeter is beeping correctly		Recovery Lead L3 Mentor
Confirm both altimeters are powered on and beeping correctly before proceeding		Team Lead
Attach igniter to wooden dowel		
Insert igniter assembly into motor tube		
Tape igniter in place at the bottom of the launch vehicle		
Reinstall the red cap to the base of the motor		

Confirm the launch pad power is OFF		Team Lead
Connect the igniter to launch pad power		
Confirm pad continuity		Team Lead
Confirm the readout is between 1.5 and 3.5		Record
ALL personnel navigate behind the RSO launch table		
Pass the primary checklist and field recovery toolbox to the Recovery Lead		
LAUNCH!		

Primary 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.		Should be 2
A two second pause, and then a three- or four-digit number corresponding to the main deploy altitude setting.		IMPORTANT: Should be 500
(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).		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

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.		Should be 1
A two second pause, and then a three- or four-digit number corresponding to the main deploy altitude setting.		IMPORTANT: Should be 450
*(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).		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

Field Recovery

Required Personnel		
Name	**Role**	**Initial**
Gabe Buss	Recovery Lead	
Frances McBride	Safety Officer	
Jennifer Wolfe	Recovery Personnel 1	
Daniel Benitez	Recovery Personnel 2	

Required Materials			
Item	**Number**	**Location**	**Confirm**
Nitrile Gloves	5	Field Recovery Box	
Heavy Duty Gloves	1	Field Recovery Box	
Safety Glasses	6	Field Recovery Box	
Switch Screwdriver	1	Field Recovery Box	
TB Screwdriver	1	Field Recovery Box	
Adjustable Wrench	1	Field Recovery Box	
Rubber Bands	5	Field Recovery Box	
Phone	1	Field Recovery Box	
Wire Snips	1	Field Recovery Box	
Wire Strippers	1	Field Recovery Box	
Blue Tape	1	Field Recovery Box	
Plastic Bag	1	Field Recovery Box	
12 inch ruler	1	Field Recovery Box	
Measuring tape	1	Field Recovery Box	
Fire Extinguisher	1	Field Recovery Box	
GPS Receiver	1	Field Recovery Box	

Procedure		
Task	**Check**	**Confirm**
Upon launch, watch the launch vehicle descend		
Observe where the launch vehicle lands		
Approach the launch vehicle on foot		
Once near the launch vehicle		
ALL PARTICIPATING PERSONNEL MUST WEAR SAFETY GLASSES		
Confirm all participating personnel are wearing safety glasses		Safety Officer
Photograph the entire extents of the launch vehicle from each cardinal compass direction		
Take note of whether all sections of the launch vehicle are present		
Take note of and photograph 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 PARTICIPATING PERSONNEL MUST WEAR NITRILE GLOVES		
Confirm all participating personnel are wearing nitrile gloves		Safety Officer
Secure the main parachutes		
Confirm that the personnel executing this step have practiced prior to launch		Safety Officer
DO NOT grab the shroud lines of the parachute		
Approach the parachute from the billowed side		
Used hands and body to pull down the parachute by the canopy		
Secure with a rubber band		
Secure the drogue parachutes		
Confirm that the personnel executing this step have practiced prior to launch		Safety Officer
DO NOT grab the shroud lines of the parachute		
Approach the parachute from the billowed side		
Used hands and body to pull down the parachute by the canopy		
Secure with a rubber band		
Record Flight data		
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		
If a black powder charge did NOT go off, refer to the appropriate emergency checklist		
Carefully pick up the FWD end of the main parachute bay		
Inspect bulkhead #4 for unblown black powder charges		
Record location of final resting position of launch vehicle		Record GPS Coordinates
Pick up any non-biodegradable waste		
Pack up the launch vehicle and return to launch site		

Primary 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		Should be approximately 4420 ft Record
A long separator tone followed by a two to five-digit number representing the maximum velocity during the flight in miles per hour		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

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
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		Should be approximately 4420 ft Record
A long separator tone followed by a two to five digit number representing the maximum velocity during the flight in miles per hour		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

Payload Operation

Required Personnel		
Name	**Role**	**Initial**
Sean Clark	Payload Integration Lead	
Michael Barton	BURRITO Lead	
Erik Benson	SICCU Lead	
Sadie McCarthy	Payload Personnel 1	
Dana Lamberton	Payload Personnel 2	

Required Materials			
Item	**Number**	**Location**	**Confirm**
Phone	1	Field Recovery Box	
Post-Launch Nosecone Assembly	1	Ground	
Taranis X-Lite	1	Michael's Hand	

Procedure		
Task	**Check**	**Confirm**
On the BLE Terminal app, enter 1		
Confirm the BURRITO begins to deploy		Payload Integration Lead
Wait for the back wheel of the BURRITO to reach the inside of the payload centering ring		
On the BLE Terminal app, enter 0		
Confirm the BURRITO stops		
On the BLE terminal app, enter 5		
Wait for the retention mechanism to de-latch		
On the BLE terminal app, enter 3		
On the BLE terminal app, enter 1		
Confirm the BURRITO continues to deploy		Payload Integration Lead
Wait for the BURRITO to finish deployment		
Use the Taranis X-Lite to deploy the BURRITO's caster wheels		
Use the Taranis X-Lite to control BURRITO operations		
Navigate the BURRITO to the simulated Ice collection area		
Use the Taranis X-Lite to operate the SICCU		
Navigate 10 feet away from the ice collection area		
Collect the BURRITO		
Return to the assembly area to measure the collected ice		

Appendix B

PREMATURE MOTOR IGNITION

1. EXIT LAUNCH AREA
2. IF VISUAL CONTACT OBTAINED, POINT AT LAUNCH VEHICLE TO ALERT OTHER PERSONS AWAY FROM VEHICLE TRAJECTORY
3. WAIT FOR LANDING AND/OR MOTOR EXHAUSTION
4. FOLLOW RECOVERY CHECKLIST

If Personnel are Injured:

1. APPLY EMERGENCY FIRST AID
2. CALL 911 IF NECESSARY

BLACK POWDER FAILS TO DETONATE

1. CLEAR AREA NEAR EXPECTED LAUNCH VEHICLE LANDING SITE
2. MEMBERS AROUND LAUNCH VEHICLE PUT ON PPE:
    a. Nitrile gloves, protective eyewear

Once Launch Vehicle Has Landed:

1. TURN OFF ALTIMETERS BY ROTATING SCREW SWITCHES TO OFF POSITION
2. PERFORM RECOVERY ACTIVITIES; BRING LAUNCH VEHICLE TO ASSEMBLY TENT
3. USING ONE PIECE OF COPY PAPER AND TAPE, MAKE BP CONTAINER-SIZED FUNNEL
4. WITH MAIN BULKHEAD FACING TOWARDS THE SKY, LOCATE THE BLAST CAP LABELED “MP” AND CAREFULLY REMOVE BLUE TAPE
5. POUR UNDETONATED BLACK POWDER INTO GOEX BLACK POWDER CONTAINER
6. REPEAT FOR ALL REMAINING BLAST CAPS

PREMATURE BLACK POWDER DETONATION

1. ALL PERSONNEL CLEAR THE ARE
2. CLEAR FLAMMABLE OBJECTS FROM THE AREA
3. USE FIRE EXTINGUISHER TO EXTINGUISH FIRE

Once Hazard is Clear:

- PERFORM HEAD COUNT OF ALL LAUNCH DAY PERSONNEL

If Personnel are Injured:

1. APPLY EMERGENCY FIRST AID
2. CALL 911 IF NECESSARY

CATOSTROPHIC FAILURE

1. ALL NON-ESSENTIAL PERSONNEL CLEAR THE AREA
2. LISTEN TO RSO’S IMMEDIATE INSTRUCTIONS
3. WHEN AREA CLEAR OF IMMEDIATE HAZARDS, RECOVER THE LAUNCH VEHICLE

If Personnel are Injured:

1. APPLY EMERGENCY FIRST AID
2. CALL 911 IF NECESSARY

LAUNCH RAIL TIPS DURING LAUNCH

1. TAKE COVER
2. CLEAR THE AREA IN THE DIRECTION OF THE TIP
3. LISTEN TO RSO INSTRUCTIONS

If Persons are Injured:

1. APPLY EMERGENCY FIRST AID
2. CALL 911 IF NECESSARY

Once Hazard is Clear:

1. PERFORM HEAD COUNT OF ALL LAUNCH DAY PERSONNEL
2. FOLLOW FIELD RECOVERY CHECKLIST

BALLISTIC DESCENT

1. LISTEN TO RSO INSTRUCTIONS
2. DETERMINE LOCATION OF BALLISTIC DESCENT AND IMPACT
3. MOVE ALL PERSONNEL AWAY FROM DESCENT PATH
4. MAINTAIN VISUAL CONTACT WITH LAUNCH VEHICLE
5. IF VISUAL CONTACT OBTAINED, POINT AT LAUNCH VEHICLE TO ALERT OTHER PERSONNEL

If Persons are Injured

1. APPLY EMERGENCY FIRST AID
2. CALL 911 IF NECESSARY

Once Hazard is Clear

1. PERFORM HEAD COUNT OF ALL LAUNCH DAY PERSONNEL
2. FOLLOW FIELD RECOVERY CHECKLIST
3. INVESTIGATE CAUSE OF BALLISTIC DESCENT

BLACK POWDER SPILL

1. ALL NON-DESIGNATED PERSONNEL CLEAR THE AREA
    a. This includes anyone whose name is not on the current task's checklist
2. EQUIP PPE FOR HANDLING BLACK POWDER
    a. Nitrile gloves, safety glasses
3. CREATE A PAPER FUNNEL USING ONE PIECE OF COPY PAPER AND TAPE
4. BRUSH THE SPILLED POWDER INTO CONTAINER USING FUNNEL
5. DISPOSE OF FUNNEL
6. USE WET WIPES TO CLEAN REMAINING BLACK POWDER
7. DISPOSE OF WET WIPES

RAPID WEATHER CHANGE IMMEDIATELY PRIOR TO LAUNCH

1. LISTEN TO RSO INSTRUCTIONS
2. REMOVE LAUNCH VEHICLE FROM LAUNCH PAD
3. FOLLOW FIELD RECOVERY CHECKLIST

FIRE ON LAUNCHPAD

1. CHECK SOURCE OF FIRE
    a. ELECTRICAL
        i. EXTINGUISH FIRE
        ii. ONCE FIRE IS 100% EXTINGUISHED, ASSESS DAMAGE
        iii. BODY TUBE – SEE *BODY TUBE DAMAGED*
        iv. PAYLOAD – SEE *PAYLOAD STRUCTURAL DAMAGE*
        v. ELECTRONICS – SEE *ALTIMETER INOPERATIVE*
    b. ENERGETICS FIRE
        i. CLEAR AREA OF NON-ESSENTIAL PERSONNEL
        ii. AWAIT INSTRUCTIONS FROM RSO
        iii. ATTEMPT TO EXTINGUISH FIRE WHEN CLEARED
        iv. ASSESS DAMAGE – SEE ABOVE

PARACHUTE UNFOLDS DURING PACKING

1. DISCONNECT PARACHUTE FROM QUICKLINK
2. RE-FOLD PARACHUTE ACCORDING TO LAUNCH DAY CHECKLIST
3. RE-ATTACH PARACHUTE TO QUICKLINK
4. HOLD PARACHUTE IN SHAPE DURING FURTHER ASSEMBLY

SHEAR PINS DO NOT FIT INTO SHEAR PIN HOLES

1. TRY OTHER BODY TUBE ORIENTATIONS
2. ATTEMPT TO LOCATE SMALLER/LARGER SHEAR PINS
3. PERFORM STRENGTH TEST ON NEW SHEAR PINS IF FOUND

If Unable to Resolve:

1. DRILL NEW SHEAR PIN HOLES
2. PLUG UNUSED HOLES WITH PLUMBER'S PUTTY AS NECESSARY

MISSING REQUIRED TOOL

1. ASK TEAM MEMBERS FOR PERSONAL TOOLS
2. ASK OTHER LAUNCH PATRONS
3. ACQUIRE NEW TOOL FROM HARDWARE STORE

PARACHUTES RIPPED DURING FOLDING AND PACKING

1. REMOVE APPROPRIATELY SIZED PATCH TAPE FROM ROLL
    - Note: Patch material should completely cover the hole and any surrounding, smaller holes
2. PEEL OFF PROTECTIVE BACKING
3. PLACE TWO EQUALLY SIZED PATCHES ON EITHER SIDE OF HOLE
4. REPEAT FOR REMAINING HOLES/RIPS

If Unable to Locate Replacement

- DO NOT LAUNCH, VEHICLE IS UNSAFE

BODY TUBE DAMAGED

1. PERFORM NOSECONE TO FIN-CAN VISUAL SWEEP
    a. TAKE NOTE HERE OF DAMAGE TYPE AND SEVERITY
2. CONSULT STRUCTURES LEAD

If Damage is Minor:

- ATTEMPT REPAIRS
- CONTINUE WITH APPROVAL OF STRUCTURES LEAD AND RSO

If Damage is Major:

- VEHICLE UNSAFE FOR LAUNCH

PERMANENT SIGNIFICANT HARDWARE DAMAGE AFTER LANDING

1. REPLACE HARDWARE FOR FUTURE LAUNCHES
2. IF FLIGHT DATA LOST, RELAUNCH VEHICLE

ALTIMETER INOPERATIVE ON LAUNCH PAD

1. REMOVE LAUNCH VEHICLE FROM LAUNCH RAIL
2. DISASSEMBLE VEHICLE TO ACCESS AV BAY
3. DISCONNECT QUICK CONNECTS BETWEEN E-MATCHES AND ALTIMETERS
4. CHECK BATTERIES FOR PROPER POWER LEVEL (9VOLTS) USING MULTIMETER
5. CHECK FOR CONTINUITY BETWEEN TERMINALS OF ALTIMETER
6. REPLACE ALTIMETER

If Altimeter Remains Inoperative:

- REPLACE ALTIMETER WITH BACKUP (if applicable)
- CONFIRM BOTH ALTIMETERS FUNCTION AS DESIRED
- RE-ASSEMBLE LAUNCH VEHICLE
- RETURN TO SAFETY TENT FOR RE-INSPECTION

EXCESS SCREW OR BOLT

1. REPEAT CHECKLIST STEPS TO DETERMINE CAUSE
2. CONSULT APPLICIPABLE SUBSYSTEM LEAD
3. DISMANTLE AND REINSTALL HARDWARE

SIMULTANEOUS DROGUE AND MAIN PARACHUTE DEPLOYMENT

1. LISTEN TO RSO INSTRUCTIONS
2. DETERMINE DESCENT PATH
3. REMAIN CLEAR OF DESCENT PATH
4. FOLLOW FIELD RECOVERY CHECKLIST

If Launch Vehicle Beyond Line of Sight:

- DETERMINE VEHICLE LANDING LOCATION USING ONBOARD TRACKING SYSTEM

FAILED MOTOR IGNITION

- LISTEN TO RSO INSTRUCTIONS
- WAIT UNTIL RSO APPROVES APPROACH
- EXPECT A POSSIBLE MOTOR IGNITION
- DESIGNATED PERSONNEL APPROACH THE LAUNCH PAD AFTER AN RSO DESIGNATED TIME HAS PASSED
- INSPECT LAUNCH PAD WIRING
- CONSULT RSO FOR FURTHER ACTION

If RSO disapproves launch

1. EXPECT IGNITION
1. DESIGNATED PERSONNEL APPROACH THE LAUNCH PAD AFTER AN RSO DESIGNATED TIME HAS PASSED
2. REMOVE VEHICLE FROM LAUNCH PAD
3. DISASSEMBLE VEHICLE A SAFE DISTANCE FROM EVERYONE ELSE

NO IGNITOR CONTINUITY

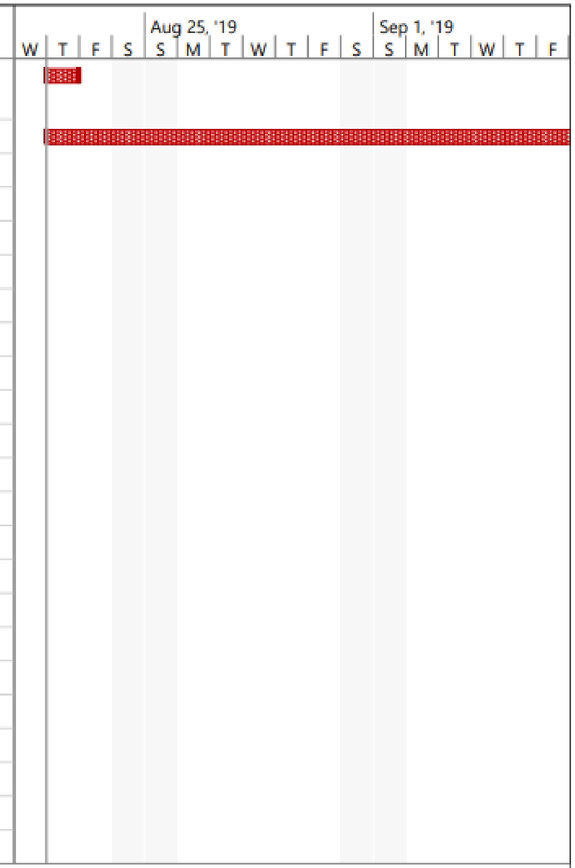
2. LISTEN TO RSO INSTRUCTIONS
3. DESIGNATED PERSONNEL APPROACH THE LAUNCH PAD AFTER AN RSO DESIGNATED TIME HAS PASSED
4. CHECK IF IGNITOR IS PROPERLY INSERTED IN THE MOTOR
5. CHECK IF ALLIGATOR CLIPS ARE PROPERLY ATTACHED TO IGNITOR

If Discontinuity Persists:

1. SEEK RSO DIRECTION
2. CHANGE LAUNCH PAD

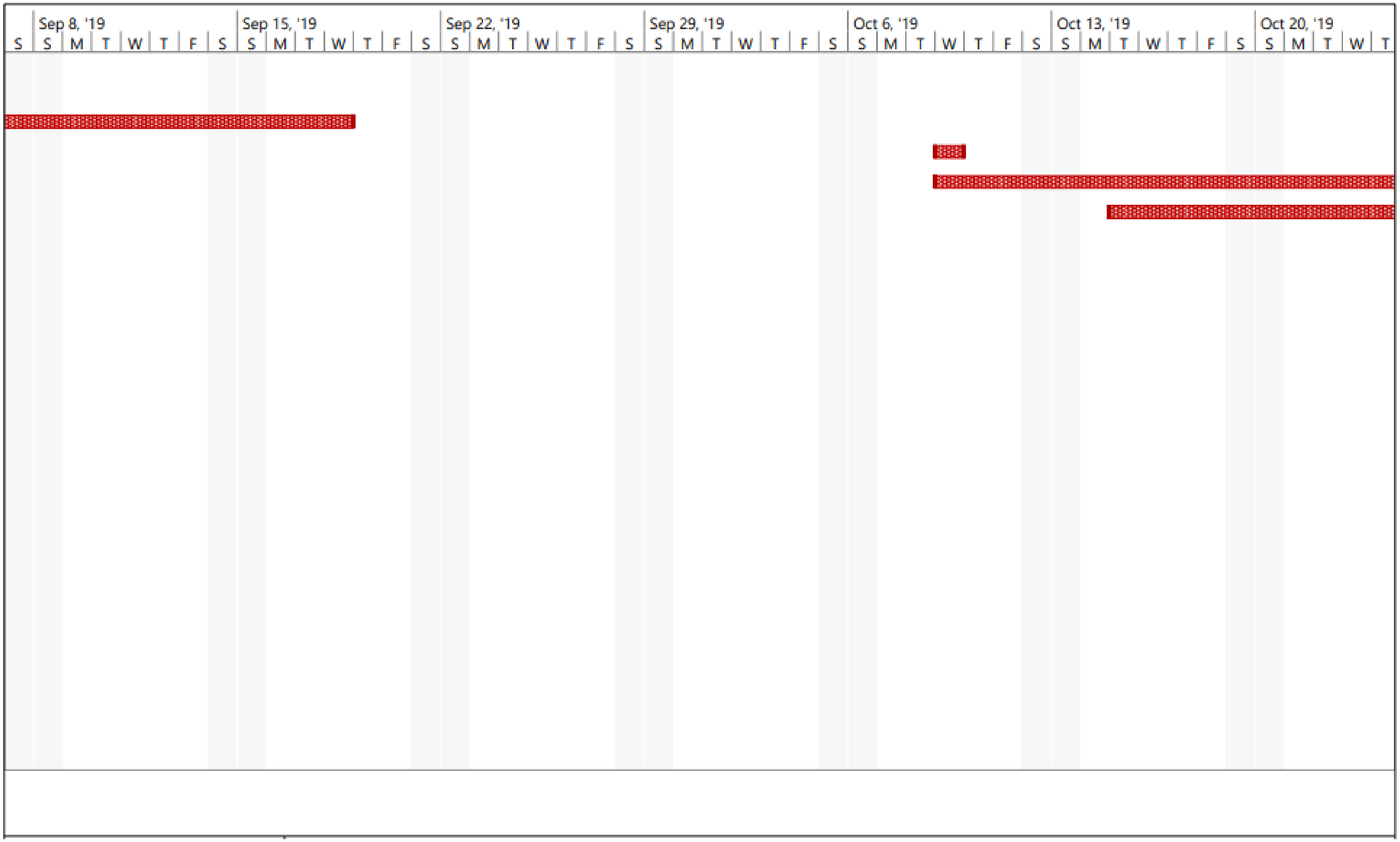
Appendix C

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
1			Request for Proposal Released	1 day	Thu 8/22/19	Thu 8/22/19	
2			Proposal	20 days	Thu 8/22/19	Wed 9/18/19	
3			Preliminary Design Re	1 day	Wed 10/9/19	Wed 10/9/19	
4			PDR	18 days	Wed 10/9/19	Fri 11/1/19	
5			Subscale Constructior	25 days	Tue 10/15/1§	Sun 11/17/1§	
6			PDR Team Teleconfer	13 days	Mon 11/4/19	Wed 11/20/1	
7			Subscale Launch Opp	1 day	Sat 11/23/19	Sat 11/23/19	
8			Critical Design Review	1 day	Mon 11/25/1	Mon 11/25/1	
9			CDR	29 days	Tue 12/3/19	Fri 1/10/20	
10			Component Testing P	26 days	Mon 1/13/20	Mon 2/17/20	
11			Full-Scale Constructio	20 days	Mon 1/13/20	Fri 2/7/20	
12			CDR Team Teleconfer	1 day	Tue 1/28/20	Tue 1/28/20	
13			Flight Readiness Revi	1 day	Fri 1/31/20	Fri 1/31/20	
14			Full-Scale Launch Opp	17 days	Fri 1/31/20	Sat 2/22/20	
15			FRR	1 day	Mon 3/2/20	Mon 3/2/20	
16			FRR Team Teleconfer	1 day	Thu 3/19/20	Thu 3/19/20	
17			Launch Week Q&A	1 day	Thu 3/26/20	Thu 3/26/20	
18			Team Travel to Hunts	1 day	Wed 4/1/20	Wed 4/1/20	
19			Launch Readiness Rev	1 day	Thu 4/2/20	Thu 4/2/20	
20			Launch Week Activiti	1 day	Fri 4/3/20	Fri 4/3/20	
21			Launch Day	1 day	Sat 4/4/20	Sat 4/4/20	
22			Backup Launch Day	1 day	Sun 4/5/20	Sun 4/5/20	
23			Post-Launch Assessm			Mon 4/27/20	



Project: Project Schedule
Date: Tue 1/7/20

Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only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Sep 22, '19
Sep 29, '19
Oct 6, '19
Oct 13, '19
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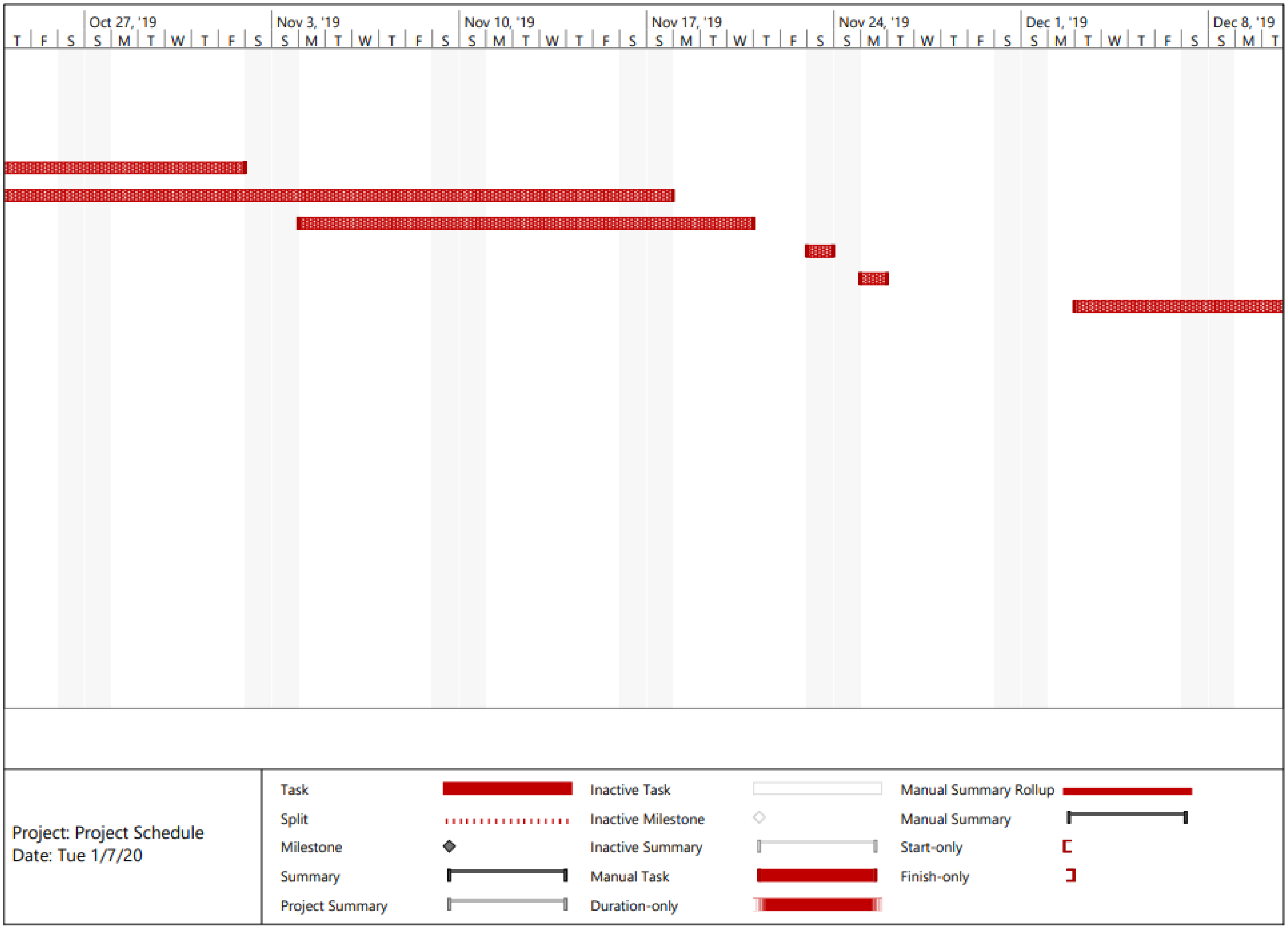
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Nov 10, '19
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Nov 24, '19
Dec 1, '19
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Project: Project Schedule
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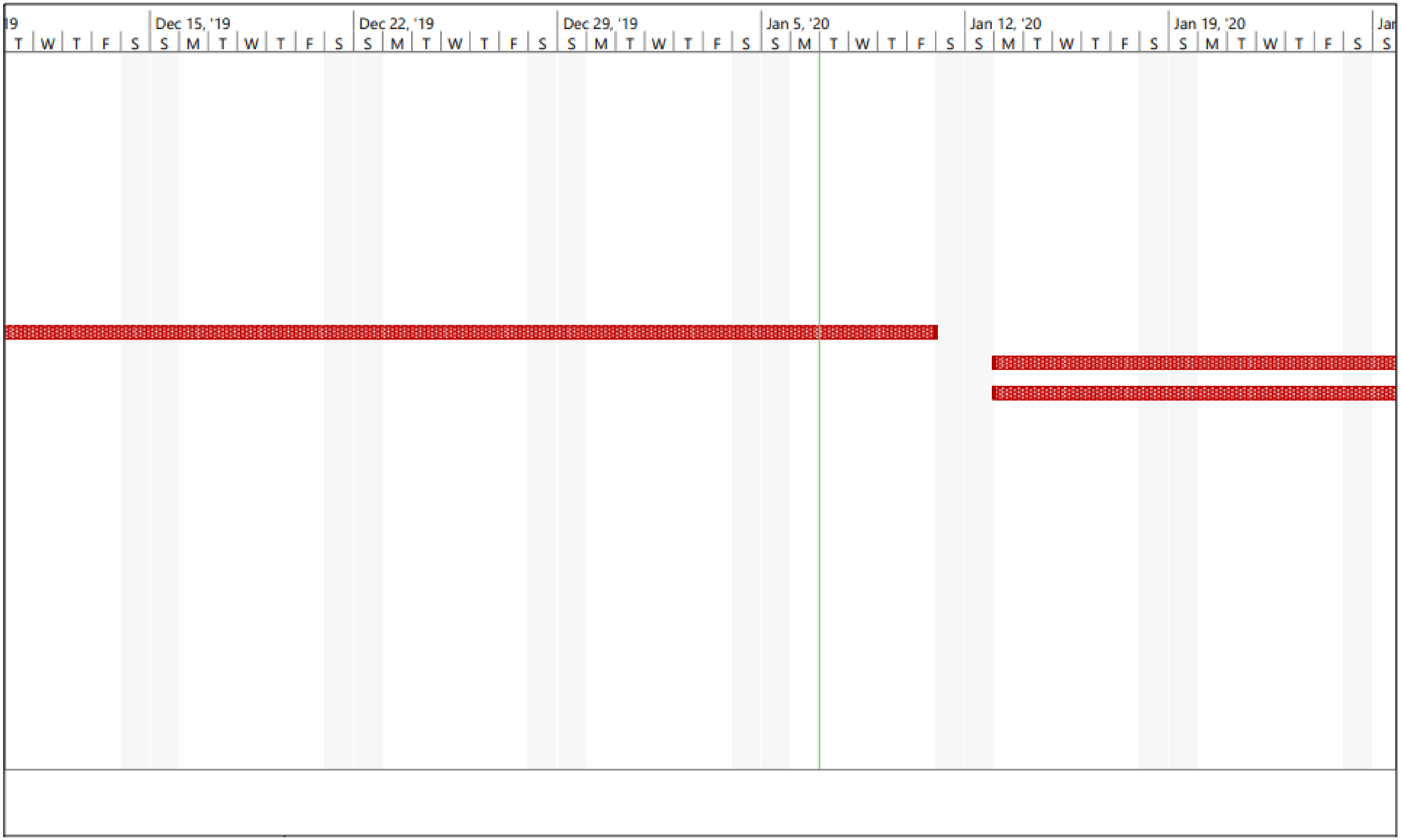

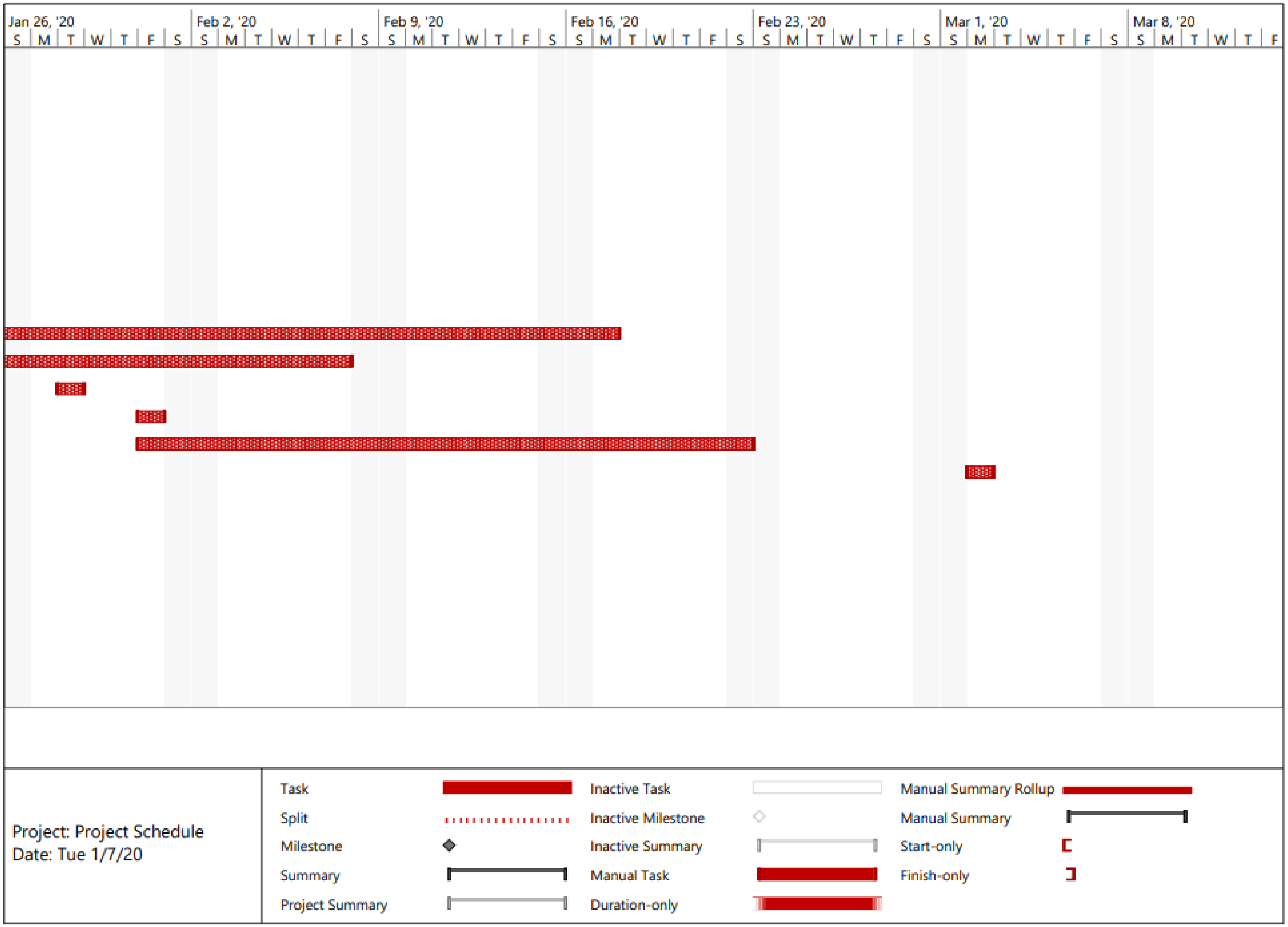
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Feb 9, '20
Feb 16, '20
Feb 23, '20
Mar 1, '20
Mar 8, '20
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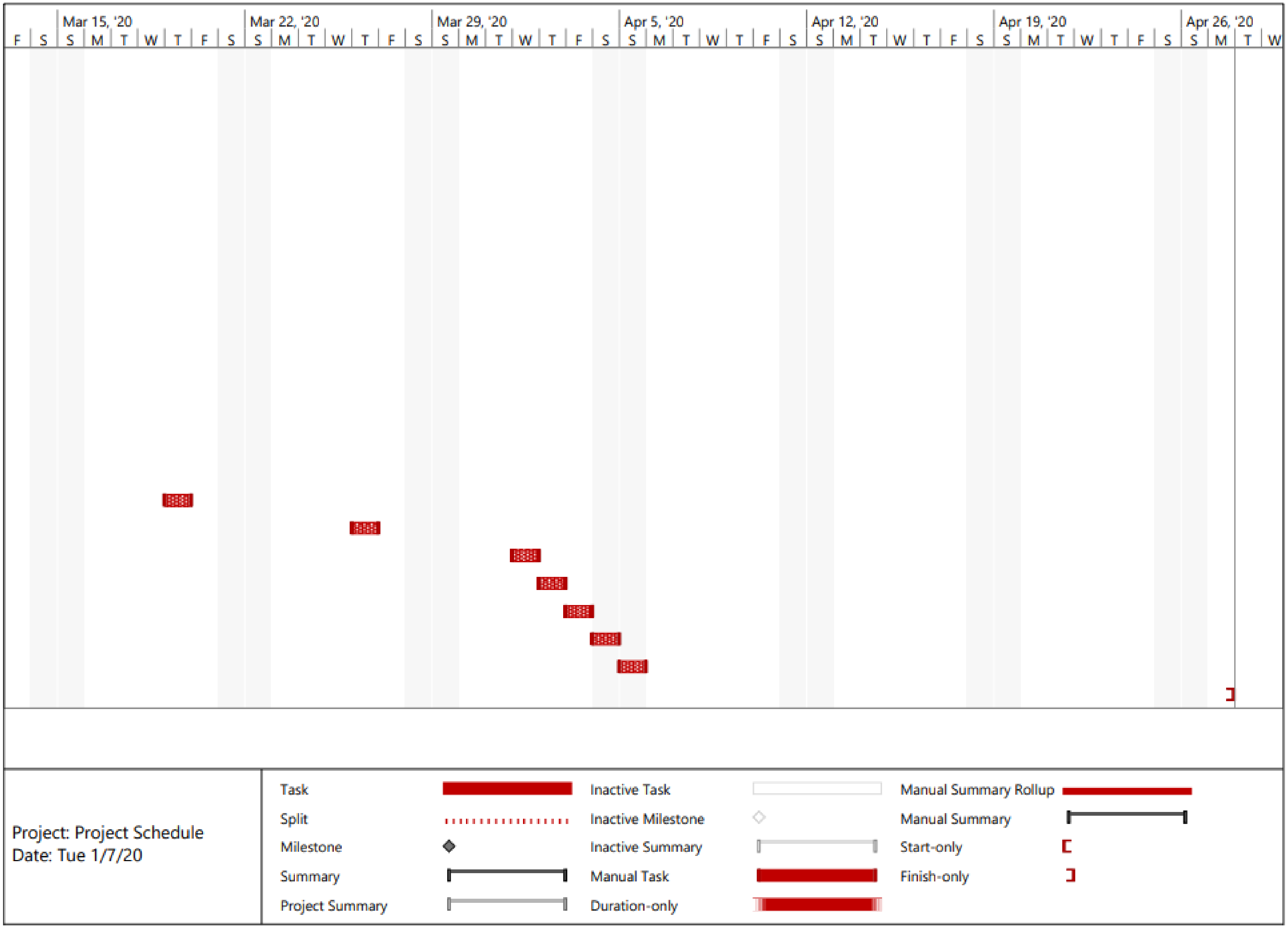
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Apr 12, '20
Apr 19, '20
Apr 26, '20
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