NC STATE UNIVERSITY

Tacho Lycos
2020 NASA Student Launch
Critical Design Review

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

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Common Abbreviations & Nomenclature

AGL	=	above ground level
APCP	=	ammonium perchlorate composite propellant
AV	=	Avionics
BP	=	black powder
CDR	=	Critical Design Review
CG	=	center of gravity
CP	=	center of pressure
FAA	=	Federal Aviation Administration
FMEA	=	failure modes and effects analysis
FN	=	foreign national
FRR	=	Flight Readiness Review
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
NASA	=	National Aeronautics and Space Administration
NCSU	=	North Carolina State University
NFPA	=	National Fire Protection Association
PDR	=	Preliminary Design Review
PLAR	=	Post-Launch Assessment Review
PPE	=	personal protective equipment
RSO	=	Range Safety Officer
SL	=	Student Launch
SLI	=	Student Launch Initiative
SICCU	=	Simulated Ice Collection and Containment Unit
STEM	=	Science, Technology, Engineering, and Mathematics
TAP	=	Technical Advisory Panel (TRA)
TBD	=	To Be Determined
TDR	=	Team Derived Requirement
TRA	=	Tripoli Rocketry Association
UAV	=	Unmanned Aerial Vehicle

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1.1 Team Summary

1.1.1 Team Name and Mailing Address

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1.2 Launch Vehicle Summary

1.2.1 Size and Mass

The current leading launch vehicle design is 107.5 inches long with a diameter of 6 inches. The mass of the leading launch vehicle design with the leading motor option is 43.5 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 Since PDR

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

Table 2-1 Launch Vehicle Changes Since PDR

Description of Change	Reason for Change
Changed the vehicle tracking device from the QRP Labs LightAPRS+WSPR to the Eggfinder GPS tracking system.	APRS transmission modes required at least 500 mW of transmission power, violating requirement NASA 2.22.9, while the WSPR transmission mode did not offer any more precision than a fox-hunting beacon would. After performing a trade study of possible alternatives, found in section 3.4.1.7, the Eggfinder GPS tracking system was determined as the new tracking system for the flight vehicle.
Changed the drogue parachute from a FruityChutes 24" Compact Elliptical to a 24" Classic Elliptical.	After verifying the team's current inventory of parachutes, it was determined that the team possessed a Classic Elliptical in this size but did not possess a Compact Elliptical. Descent time calculations determined the difference in performance between these parachutes was negligible and thus the substitution was made in order to conserve team funds.
Increased Fin Planform Area by 33%	The subscale launch vehicle experienced coning during its initial ascent. After talking with the team's advisors, it was determined that the fin size should be increased to mitigate this issue in the future. Thus, the entire chord component of the full-scale fin was increase by 2 inches, and the semi-span was increased by 0.25 inches.
Decreased Payload Mass by 1 lb.	While the final working payload is not yet finished, early prototypes indicate that the total mass of the payload and its retention/deployment system will be less than the originally estimated 8 lbs. A more reasonable estimate indicates that the final mass of these components will be closer to 7 lbs. This change in payload mass increased the apogee of the launch vehicle. However, due to the increase in fin planform area and the added surface roughness in RockSim, the apogee ended up staying within the same range as the PDR.
Increased Drogue Chute Bay Length	The drogue chute bay was increased to 11.5 inches to allow more room for the drogue chute. The original drogue chute bay presented in the PDR was just barely large enough to pack the parachute chosen to be the drogue. The team decided that the original design should allow for more room to ensure that the folded drogue chute will be able to comfortably fit within the bay.
Decreased AV Mass by 0.5 lb.	The original mass estimate for the avionics bay was 3.5 lbs. After the assembly of the avionics bay for subscale was complete it was realized that this bay was 0.5 lbs lighter than expected. This caused the team to then reduce the avionics bay by 0.5 lbs as well.

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

Table 2-2 Payload Changes Since PDR

Description of Change	Reason for Change
The payload integration controls system has been modified from an accelerometer based autonomous design to functioning strictly off user input via Bluetooth communication with the hardware.	To increase reliability of the system and ensure deployment during full-scale and competition launches.
Added front and back plates to rover chassis.	It was determined that the chassis structure would need to be reinforced in the front and back to prevent the rectangular prism structure from collapsing.
BURRITO drive motor selection changed from 313 RPM HD Premium Planetary Gear Motor to 350 RPM Premium Planetary Gear Motor.	The change of motors decreased the weight of the rover and permitted more space for other components inside the rover chassis.
BURRITO battery selection changed from Tenergy NiMH Battery to Hyperion G5 50C LiPo Battery.	LiPo batteries do not suffer from "memory" effects during charging, and the dimensions suited the rover better and have a higher energy density.[1]
Number of deployable caster wheels increased from 1 to 2	More space was needed in the center of the rover chassis. By having two caster wheels, the caster wheels could be placed near the right and left sides of the rover.

Table 2-3, below lists all changes made to the payload since PDR submission.

Table 2-3 Project Plan Changes Since PDR

Description of Change	Reason for Change
TDR 4.1.1 and TDR 4.1.2 removed.	Redundant with TDR 4.1 and deemed unnecessary
Additional team derived safety requirements added	Further safety analysis warranted the need for more requirements

[1] "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].

3. Vehicle Criteria

3.1 Design and Verification of Launch Vehicle

3.1.1 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.

3.1.2 Launch Vehicle Mission Success Criteria

Mission success is first defined as compliance with both the NASA SL requirements in Table 6-28 and the team derived requirements in Table 6-29. 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

3.1.3 Overall Design

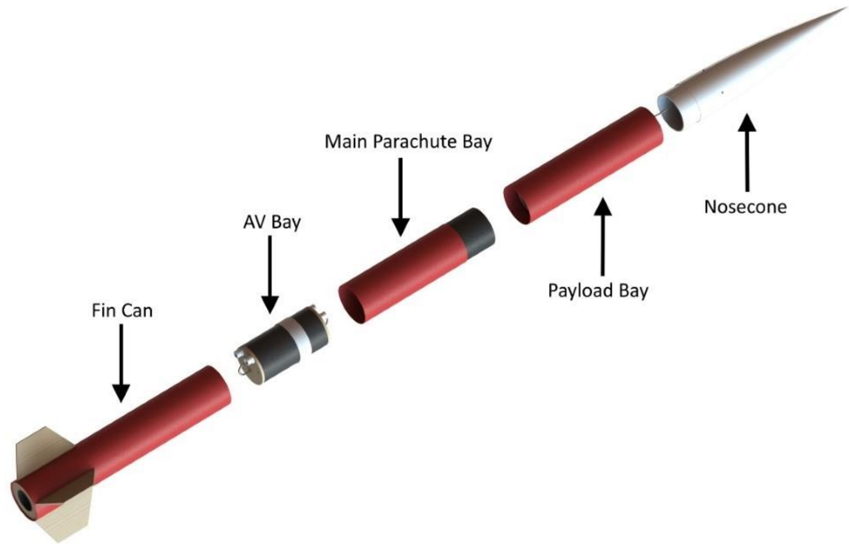


Figure 3-1 Exploded View of Launch Vehicle

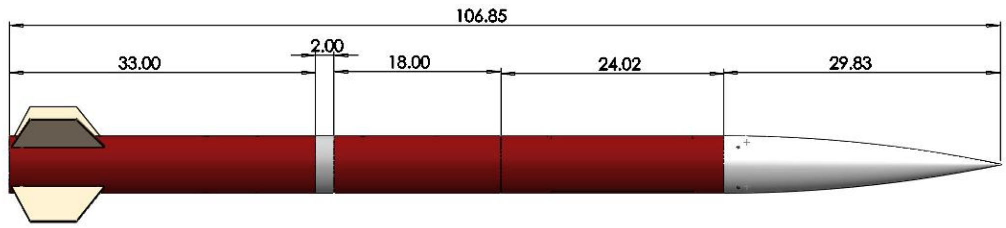


Figure 3-2 Dimensioned Drawing of Launch Vehicle

The launch vehicle layout is show in Figure 3-1. A forward payload bay is implemented to assist with rocket stability as this moves the CG forward. Each component, expect for the payload bay, will be described in the following section.

3.1.4 Material Selection

The airframe of the rocket will be made of G12 Fiberglass. This includes the body tube, motor tube, and nosecone. G12 Fiberglass is a strong material that can withstand significant compressive and tensile loads. Additionally, it is resistant to non-conventional forces that would come from unexpected impacts. The material is also water-resistant, which will eliminate the risk of the rocket being crippled by water damage. These factors will help to ensure the reusability of the rocket. G12 Fiberglass body tubes are commercially available and will be able to be easily purchased.

All bulkheads and fins will be made of 1/8" aircraft grade plywood. This is a light material that has proven to be strong enough to undergo flight loads. Bulkheads will range from 1/4" to 1 inch thick by layering the plywood.

U-Bolts and fasteners will be made out of stainless steel. While this material is heavy, it is only being used for a small volume of material on the rocket. U-Bolts and fasteners need to be a sturdy material, as their failure could potentially lead to the loss of the launch vehicle during flight.

3.1.5 Nosecone Bulkhead

The team has decided to use a removable nosecone bulkhead, as shown in Figure 3-3. The bulkhead will be supported by four steel L brackets, of which each will have bolts running through the nosecone. This design choice is the most beneficial to the team for a few main reasons. Most prominently, this allows for the addition and removal of ballast as needed. This sort of flexibility is needed, as the predicted CG will never hold true as the construction process will not be perfect. There will be variance in the CG location. Being able to easily correct this variance will reduce pressure on the fabrication team and will allow the team to keep an accurate stability margin.

Additionally, having a removable bulkhead allows for easy maintenance of the bulkhead itself. For example, if the U-Bolt were to be damaged, it would be an extraordinarily difficult process to remove or replace the U-Bolt from a non-removable bulkhead as there would be no access to the forward side of the bulkhead. The bulkhead would need to be removed. If the bulkhead were removable, then this process would be quite simple as there is easy access to both sides of the bulkhead.

The potential downside of using a removable bulkhead is the loss of strength from not using an epoxied joint. However, the tests described later in this section will prove that this loss in strength is not significant enough to warrant worry.

The total weight of the nosecone with the bulkhead is 5.7 lbf.

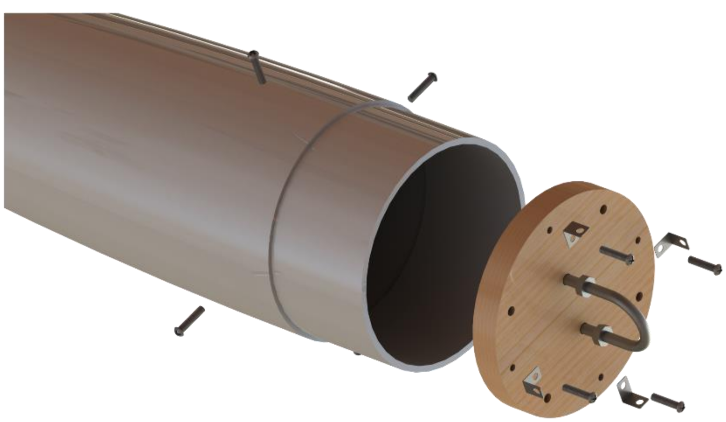


Figure 3-3 Exploded View of Nose Cone Bulkhead

3.1.6 Main Parachute Bay

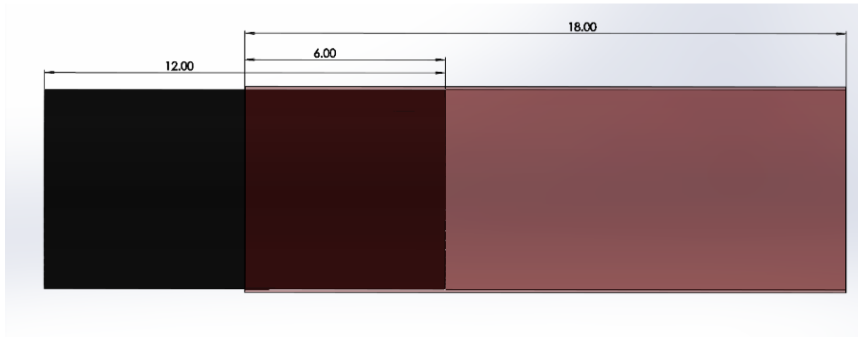


Figure 3-4 Main Parachute Bay

The main parachute bay will connect the AV bay midsection to the forward payload section. A 12-inch coupler section will be attached to the forward end of main chute bay, permanently epoxied in place with half of the coupler length extending outwards. The payload bay will be attached to this coupler by shear pins during launch assembly. The body tube composing the parachute bay is itself 18 inches long, and the aft end of it will have 3.5 inches of overlap with the AV bay when assembled. The main parachute selected, the Fruity Chutes Iris UltraCompact 120", has a packing volume of 4.9 x 10.6 inches (diameter x length) per the manufacturer's website. Excluding the space taken by the AV bay, there is 14.5 inches of body tube in which to fit the parachute if the coupler area in the payload bay is excluded. This is enough space to fit the parachute, with a remaining 4 inches in which to fit the recovery harness with additional space available if the payload bay length of the coupler is utilized. The aft end of the main parachute bay will be attached to the AV bay with 4 screws. Screws are utilized so that the AV bay can be fully assembled including ejection charges without having to reach into the main parachute bay. After the AV bay has been sealed and prepped, the main parachute bay may be attached without hassle. Without any recovery hardware inside, the main parachute bay is estimated to weigh 3.3 lb.

3.1.7 Modular AV Bay

The team will be using a modular AV bay. A modular AV bay, displayed below, consists of a piece of coupler tube with a thin band of body tube near the forward end of the coupler tube. There are bulkheads on either side of the coupler tube. The bulkheads consist of two different diameter pieces, one that matches the outer diameter of the coupler and one that matches the inner diameter of the coupler. Attached to each bulkhead are a U-Bolt and two blast caps. This design is the best choice for this year's rockets. The main advantage of using a modular AV bay is that it allows for the parallel construction of the main launch vehicle and the AV bay. During the fabrication of the subscale, the AV bay can be removed for the recovery team, while the main structural team works on the main body of the rocket. Most importantly, this will allow for parallel preparation of the main launch vehicle and AV bay on launch day. This will reduce the launch vehicle preparation time.

Another key feature of the modular AV bay is its easy access to energetics. Rather than having to reach into the rocket to place energetics, like in an integrated AV bay set up, the bay can be removed, and the energetics can be placed into the blast caps in an easy and safe manner. This reduces the chances of injury and the mishandling of dangerous materials. Additionally, the inside of the AV bay is protected from black powder charges due to the way the bulkheads are inserted. The mixture of larger and smaller diameter bulkheads creates a plug on either side of the AV bay, stopping any black power from reaching the electronics inside.

Without the avionics sled and black powder charges, the AV bay is estimated to weigh 2.5 lbf.

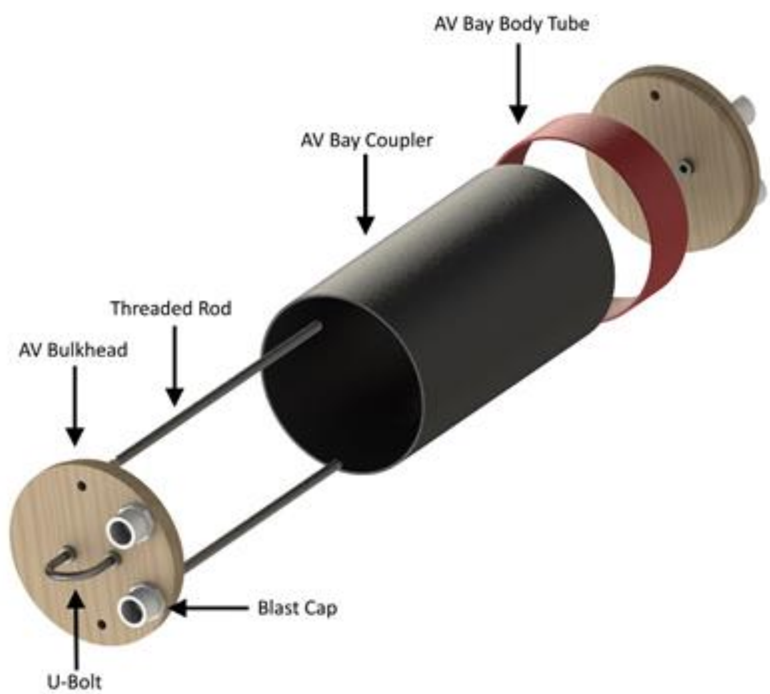


Figure 3-5 Exploded View of AV Bay

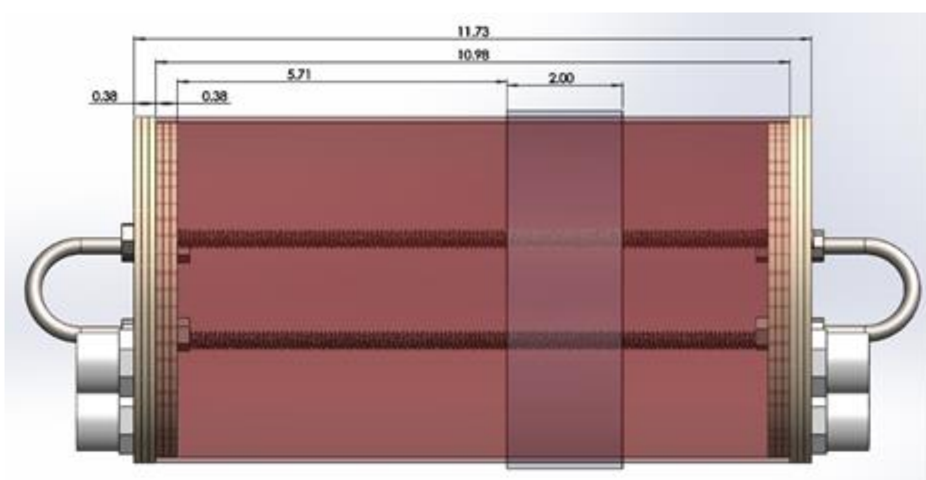


Figure 3-6 Dimensioned AV Bay

3.1.8 Fin Can

The length of the drogue chute bay has been increased to 11.5 inches from PDR. This is because the original design would not be able to fit a drogue parachute. The new dimension alleviates this problem.

The fin can is designed to hold the motor tube during flight. Most of the forces will be withstood by the aft centering ring, with the rest being held by the forward bulkhead. The middle centering ring is designed to align the motor tube.

The validity of this design has been verified using FEA, as shown in section 3.3.7, and will be verified with tensile testing.

Without the motor tube, the estimated mass of this assembly is 7.5 lbs.

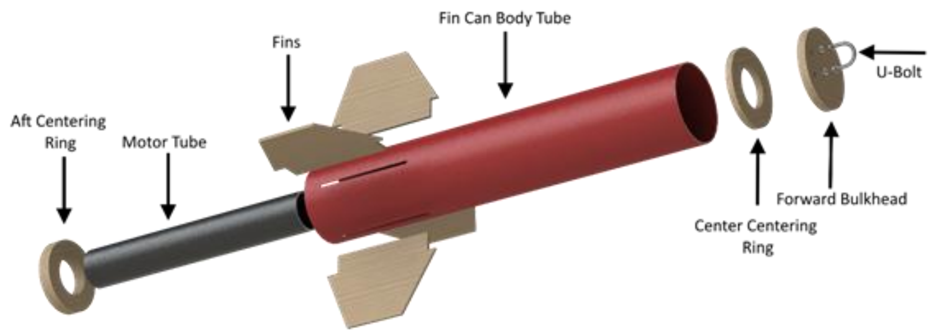


Figure 3-7 Exploded View of Fin Can

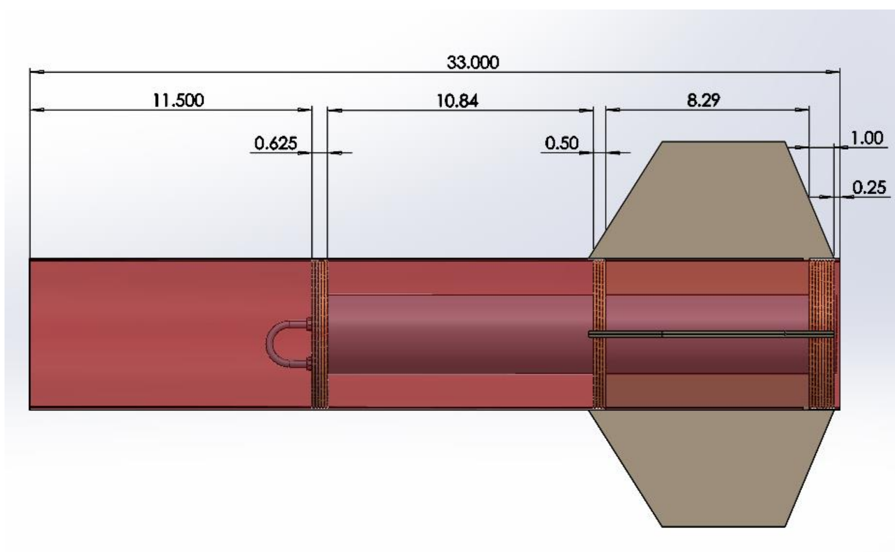


Figure 3-8 Dimensioned Fin Can

3.1.8.1 Fin Can Configuration

The fin can will incorporate a four-fin configuration. This was chosen to create two axes of symmetry for the aerodynamic loads as well as to place the center of pressure in a location that will result in a stability margin that exceeds 2.0 at rail exit. These fins will have a large trailing edge sweep and be placed 1 inch from the aft-end of the vehicle. This was done to mitigate the risk of damage to the fins in the event the launch vehicle landed aft-end first. The fin area was increased by 33% compared to the Preliminary Design Review, and this adjustment is discussed further in section 3.2.

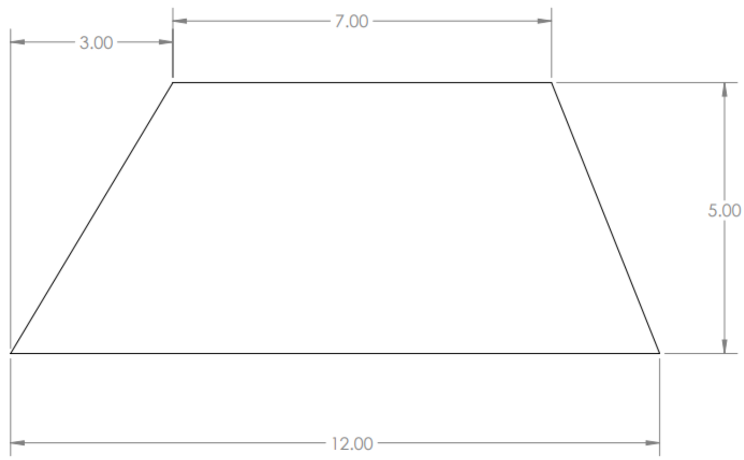


Figure 3-9 Updated Fin Planform Area

3.1.9 Nose Cone

The launch vehicle will use a 5:1 fiberglass ogive as the nosecone. This decision was made due to commercial availability, price, and popularity. This nosecone easily allows for a stability margin in excess of 2.0 at rail exit and brings the vehicle to an apogee within the 3,500 – 5,500 ft apogee envelope. Additionally, these nosecones are readily available on the commercial market and are reasonably priced.

The nose cone is predicted to weigh 5.7 lbf.

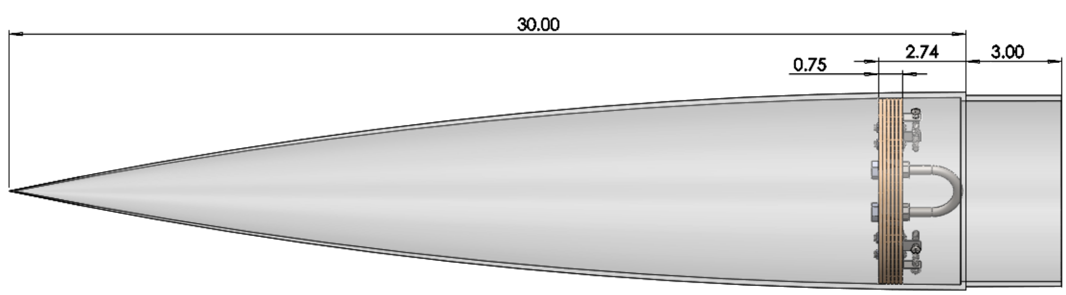


Figure 3-10 Nosecone Dimensions

3.2 Subscale Flight Performance

3.2.1 Flight Analysis

3.2.1.1 Flight Predictions

Wind conditions at the launch site, Bayboro, North Carolina, on November 23rd were 8 mph on the ground. Based on the simulations conducted at those conditions, the expected apogee was 4,000 ft. A plot of the simulation data is provided below in Figure 3-11. It should be noted that the parachutes were not included in the apogee simulations in RockSim.

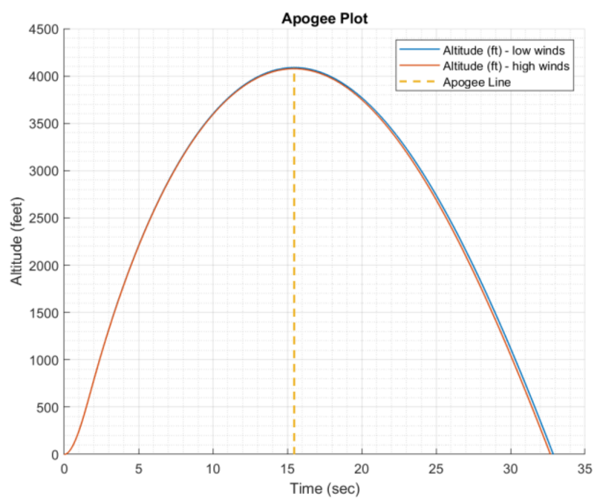


Figure 3-11 Simulated Apogee of Subscale Launch Vehicle

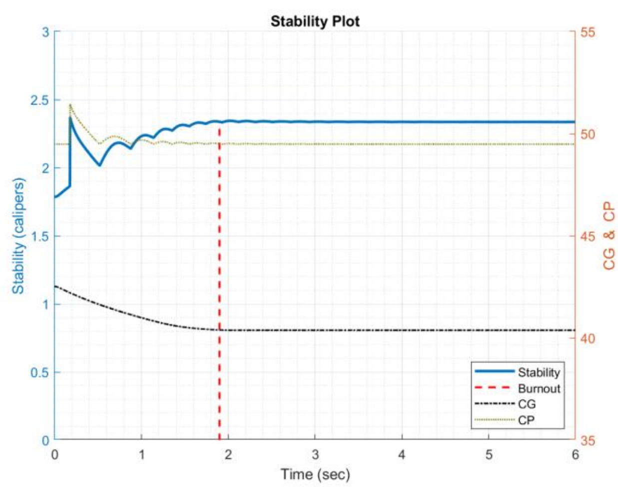


Figure 3-12 Simulated Stability Data of Subscale Launch Vehicle

Tabulated data of the stability margin at critical phases during the flight is provided in Table 3-2.

Table 3-2 Simulated Stability Data at Critical Flight Phases

Vehicle State	Stability Margin
On Rail	1.78
Rail Exit	2.05
Motor Burnout	2.34

Table 3-2 shows that the subscale was designed to have a rail exit stability greater than 2.0. Spikes in the center of pressure data influenced the stability margin calculation. These spikes were ignored as they were considered outliers. Instead, the overall trend of the curve was used to obtain the data points listed in Table 3-2. Additionally, the simulations gave a drag coefficient of 0.38.

3.2.1.2 True Flight Data

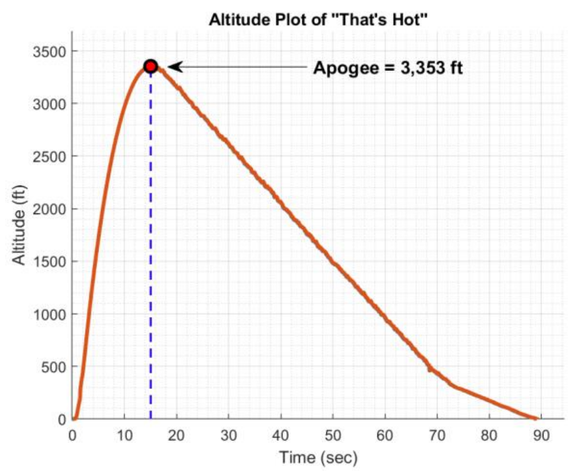


Figure 3-13 True Apogee of Subscale Launch Vehicle

The true apogee experienced by the subscale launch vehicle was only about 84% of the original apogee predicted from RockSim. This significant reduction in the apogee was attributed to two main factors. As Bayboro North Carolina is near the coast, atmospheric conditions above 500 ft can vary wildly and are extremely difficult to capture in a simple software such as RockSim. The potential of large gusts of wind affecting the vehicle's ascent is simply a reality of launching by the coast. Additionally, the subscale experienced a phenomenon known as coning during the beginning of its ascent. This occurrence is known to dramatically reduce the apogee of launch vehicles. This phenomenon is discussed further in section 3.2.3.

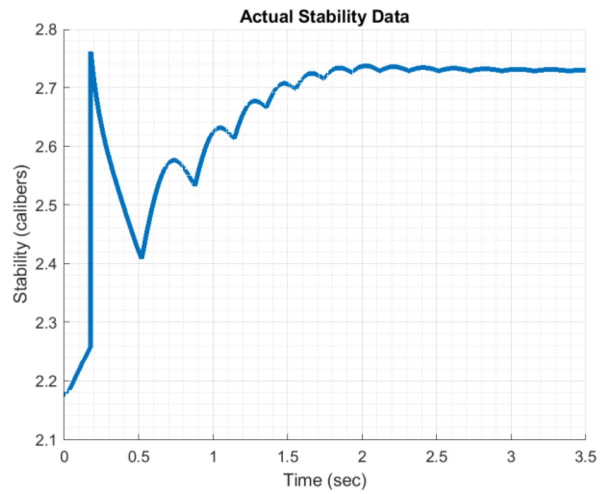


Figure 3-14 True Stability Margin of Subscale Launch Vehicle

Table 3-3 True Stability Data at Critical Flight Phases

Vehicle State	Stability Margin
On Rail	2.17
Rail Exit	2.26
Motor Burnout	2.72

It should be noted that the primary reason between the differences in the stability margin was due to an error with the simulations done in RockSim. A setting was incorrectly applied that caused the motor propellant grains to extend out beyond the end of the motor case by 0.5 inches. This issue was not realized until the post-flight analysis took place. As this is physically impossible, the actual vehicle had the motor grains positioned half of an inch closer to the nose of the launch vehicle than what the simulations showed. Since the motor was the heaviest component of the vehicle, this shift in position caused the center of gravity to be farther away from the center of pressure, and thus the stability margin was increased greatly.

3.2.2 Scaling Factors

When designing the subscale launch vehicle, the team chose to implement a scaling factor of 2/3 or 66%. This scaling factor was chosen as the team was already in possession of 4 inch blue tube for the airframe. The rest of the vehicle was then scaled by 2/3 so that this airframe tubing may be utilized. Applying this scaling factor resulted in many dimensions having a large number of decimal places. To make the schematic easier to read and thus simpler to manufacture, these values were rounded to the nearest tenth of an inch. A table of these measurements is provided below in Table 3-4. Lastly, the full-scale dimensions that were used to determine the scaling factor that are presented in the table below have since been changed due to subscale influence on the full-scale design.

Therefore, values for the center of gravity, center of pressure, stability, and span do not reflect the final dimensions chosen for the full-scale launch vehicle.

Table 3-4 True Stability Data at Critical Flight Phases

	Full-scale	Subscale	Scaling Factor
ℓ (in)	106.8	69.8	65.4 %
CG (in)	64.3	41.4	64.3 %
CP (in)	77.6	49.5	63.8 %
d (in)	6.2	3.9	62.9 %
span (in)	15.7	9.4	60.0 %
Stability	2.16	2.09	

3.2.3 Subscale Influence on Full-scale Design

As mentioned in section 2, the subscale launch vehicle experienced coning shortly after leaving the launch rail. This phenomenon occurs when the fins are not large enough to provide an adequate corrective force to the vehicle and can greatly reduce the apogee of the vehicle. Thus, a small disturbance causes the vehicles body to slightly rotate around the center of gravity location. This behavior continues until the vehicle's velocity increases to a point where the fins can provide a large enough corrective force to overcome these disturbances. An optimal solution to this issue is to increase the chord wise component of the fin area. After some consideration the team has decided to increase both edges of the chord, the chord root, and the chord tip by 2 inches. Additionally, the team's advisors indicated that the subscale's fin span wise component was not large enough either and this length should be increased for future designs. Since the subscales fin span length is directly proportional to the full-scale vehicle, the team opted to increase the span wise component of the full-scale vehicles fins as well by 0.25 inches. Figure 3-15 depicts the new design for the fin planform area. Overall, the team managed to increase the fin area by 33%. To maintain the same overall stability of the launch vehicle, the fins were also moved 0.5 inches further from the aft end. The aft most corner of the fin now measures one 1 inch from the aft end of the vehicle.

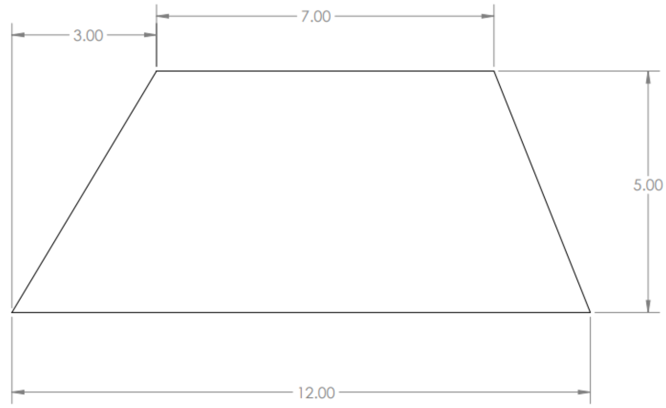


Figure 3-15 Updated Fin Planform Area

3.3 Construction Methods

3.3.1 Cutting Body Tubes

The team has access to the University's machine shop. Body tubes will be cut using the shop's industrial band saw and it will be operated by the shop's qualified personnel. Body tubes will be pre-measured by team members. Slots for fin cans will be precut by airframe's manufacturer.

3.3.2 Fin Can

The current fin can design, which is seen in Figure 3-7, is complete and ready to manufacture. The design has been proven to be structurally sound through FEA analysis found in section 3.3.7. This has shown that the bulkheads will not break under the force of the motor's ignition. Additionally, the current fin can design has been used in the past, and no structural issues have been observed from the use of this design.

Through observations made during the fabrication process of the subscale, it follows that the full-scale will be easily fabricated. The main complications that arose during the subscale fin can construction were issues due to the small diameter of the fin can. It was difficult to manipulate bulkheads once inserted into the fin can. With the larger diameter presented by the full-scale this should be a lesser issue and will allow for more versatility during the fabrication process. Other issues arose due to the delamination of the blue tube, but this will be a non-issue during the full-scale. Blue tube delaminates when taking damage because it is a paper rolled materials. The full-scale airframe will be G12 fiberglass, which is a composite material. The layers are held together by resin and has little chance to delaminate.

The general construction process for the fin can is as follows. This list starts after all bulkheads and fins have been assembled. The time between all steps is assumed to be long enough for any epoxy to fully cure

- The forward bulkhead (1) is inserted and epoxied into the body tube at a premeasured point.

- Fillets consisting of Silica filled epoxy are added to where the bulkhead contacts the body tube. These are added to the forward and aft side of the body tube.
- With the motor tube still outside of the fin can, the center-centering ring is epoxied to the motor tube at a premeasured point.
- The center-centering ring is filleted where the centering ring contacts the motor tube.
- Epoxy is added the aft most side of the forward bulkhead. The motor tube is inserted into the fin can and fitted into the forward bulkhead. The aft side of the center-centering ring is filleted where the centering ring contacts the fin can.
- The four fins are inserted into the body tube through slots that were pre-milled. Epoxy is added to where the fins meet the motor tube and to where the fins meet the aft side of the center-centering ring.
- The fins are filleted where they meet the outside of the fin can, and the outside of the motor tube.
- The aft-most centering ring is inserted. Epoxy is added where the centering ring meets the fins, and where the centering ring meets the body tube.
- Fillets are added on the aft side of the centering ring, where it meets the body tube and where it meets the motor tube.
- The motor retainer is then added to the end of the motor tube using epoxy.

3.3.3 Nosecone W/ Removable Bulkhead

The current nosecone bulkhead design is complete and ready to manufacture. A similar designed was used in the team's subscale launch vehicle. No issues were encountered during the fabrication of the subscale iteration of the removable bulkhead. Additionally, the strength of the design was successfully tested at forces up to 1040lbs, with plans to test further. These tests are shown in section 6.1.

Steps to manufacture:

- Bulkhead is assembled as per bulkhead fabrication process seen section 3.3.6
- Hard points for U-Bolt, and 4 L-Brackets are drilled into the bulkhead
- L-Brackets are secured using #6 bolts
- Bulkhead is fit into the nose cone, and locations where L-Brackets are located, are marked onto the nose
- Holes are drilled out where the previous marks were made
- Bulkhead can then be mounted using #6 bolts

3.3.4 Main Parachute Bay

The main parachute bay consists of a length of airframe and a length of coupler. Holes for fasteners will be drilled on the aft end of the body tube, and holes for shear pins will be drilled into the forward end of the body tube.

Steps to Manufacture

- Measure the location where the coupler will rest inside the body tube
- Apply two-part epoxy in the contact region between the coupler and the body tube
- Insert the coupler into the body tube
- Wipe off excess epoxy and allow the article 24 hours to dry

3.3.5 AV Bay

The AV bay will have to endure a large amount of force during recovery. Tests will be done to ensure its ability to endure recovery forces, but past uses of this design have shown its passable integrity. Additionally, the design of the AV Bay allows for a quick and simple manufacturing process.

Steps to Manufacture:

- Bulkheads are assembled as per bulkhead fabrication process seen in section 3.3.6.
- Hard points for U-Bolt and threaded rods are added
- Strip of body tube is attached to the AV coupler using two-part epoxy
- Threaded rods are run through the AV bay and attached to both bulkheads at either end of the coupler.

3.3.6 Bulkhead Fabrication Process

Bulkhead fabrication is an integral part of the launch vehicle fabrication process. All bulkheads are made with layers of 1/8” aircraft grade plywood and held to together with two-part epoxy.

Steps to Manufacture:

- Layers are cut from 1’x2’ sheets using a laser cutter. Layer designs vary, but all bulkheads feature two 1/16” holes. These exist to allow for 1/16” dowel rods to be inserted into them. This will help to align layers during the vacuum bagging process.
- The faces of all layers are prepped by sanding by them with low grit sandpaper
- Dowel rods are cut down to match the thickness of the bulkhead
- Bulkheads are dry fit together using dowel rods to ensure that they properly line up

- Vacuum bagging area is prepared. Vinyl is laid out over the area that will be used. Peel ply is laid over the vinyl
- Two-part epoxy is mixed
- Liberal amounts of two-part epoxy are applied to each layer's contact face(s).
- Layers are stacked using dowel rods for alignment
- Peel-ply is placed on top of the bulkhead, with breather following
- A final layer of vinyl is placed on top of the entire set up, with a seal being created between the top and bottom layers using plumbers' putty
- A vacuum tube is inserted into the system creating a vacuum under the vinyl
- The system is left alone for 24 hours

3.3.7 FEA Analysis

FEA, Finite Element Analysis, is a useful tool to get estimates of material behavior without needing any physical testing. While not completely accurate, it is still good to check the initial validity of a design.

3.3.7.1 Forward Fin Can Bulkhead

The following test is for the forward fin can bulkhead. The assembly includes the following parts:

- U-Bolt
- 4 Nuts
- 4 Layers of 1/8" birch plywood

To simulate the model being epoxied to the fin can, the outer diameters of the plywood layers are treated as a fixed support. The U-Bolt is supported by nuts on the top and bottom of the bulkhead. The predicted loads on the U-Bolt for this bulkhead is 352 lbs. This load was applied to the top of the U-Bolt into the positive Z axis.

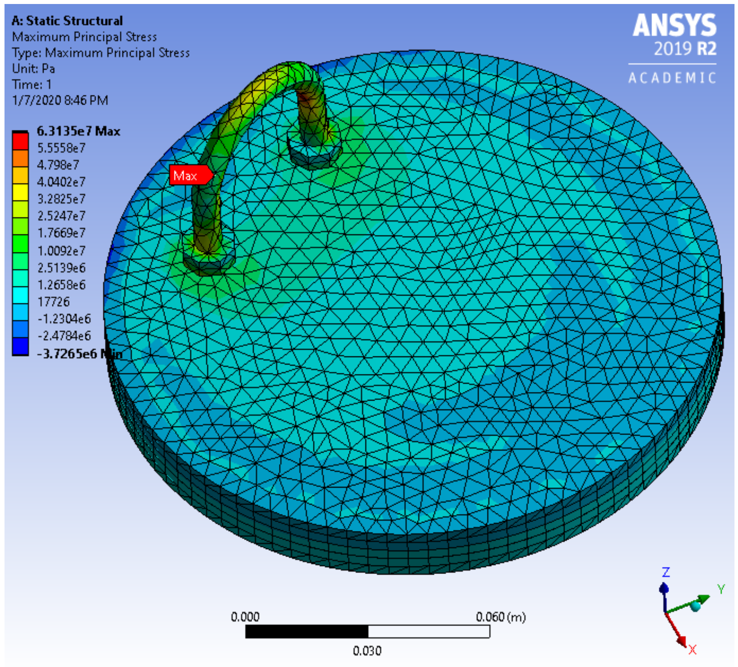


Figure 3-16 FEA of Forward Fin Can Bulkhead

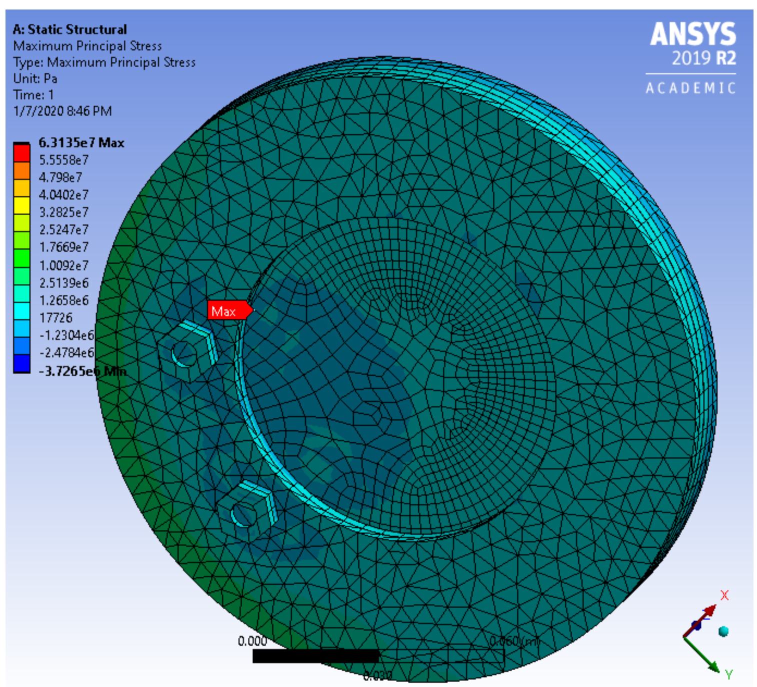


Figure 3-17 Test of Forward Fin Can Bulkhead – Aft Side

The results of this simulation show that the stress concentrations lie around the U-Bolt. The high stresses do not perpetuate far into the bulkhead. The simulation shows stresses that reach up 63 MPa, but these are found on the U-Bolt, not the bulkhead itself. A steel U-Bolt is more than capable of handling these stresses. The max stresses on the bulkhead lie between 10 and 17 MPa. The ultimate stress of plywood lies around 30 MPa. Still, these concentrations show the importance of using washers on high strain areas to prevent high stress areas.

3.3.7.2 Nose Cone Bulkhead

The following test is for the nose cone bulkhead. The assembly includes the following parts:

- U Bolt
- 4 Steel Brackets
- 8 Stainless Steel #6 Bolts
- 4 Nuts
- 4 Layers of 1/2" Birch Plywood

The predicted load on the nosecone bulkhead is 570 lbf during deployment. This force was applied to the U-Bolt. The outward facing bolts were treated as fixed supports.

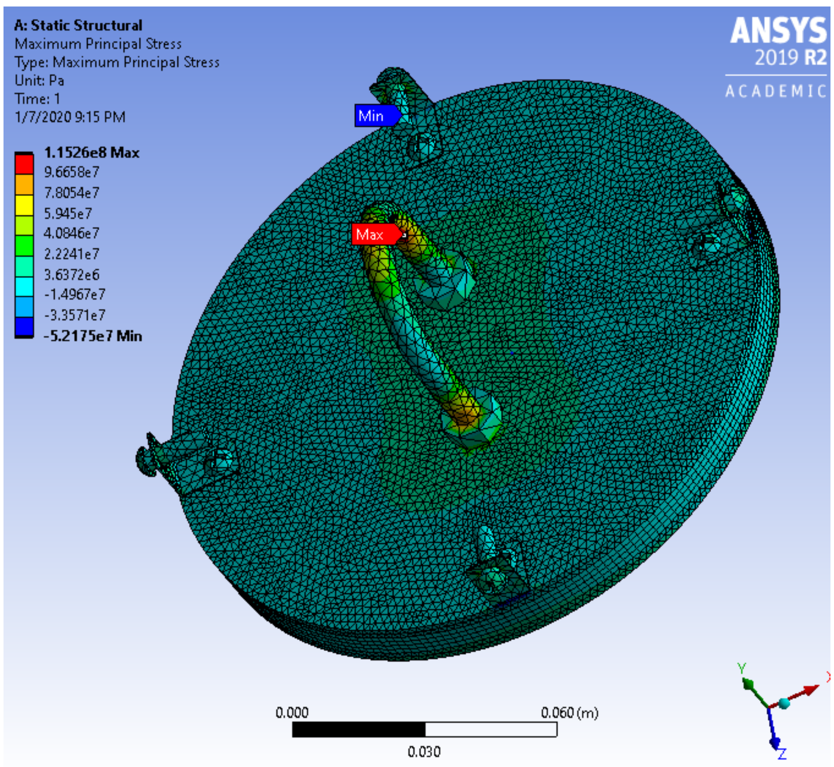


Figure 3-18 FEA of Nose Cone Bulkhead – ½"

With a ½" nosecone bulkhead there are stresses in the bulkhead ranging from 22 to 40 MPa. This is undesirable as the max stress for birch plywood is around 30 MPa. At the current thickness, this design would most likely fracture during recovery. A thicker bulkhead will need to be used to ensure the safety of the launch vehicle.

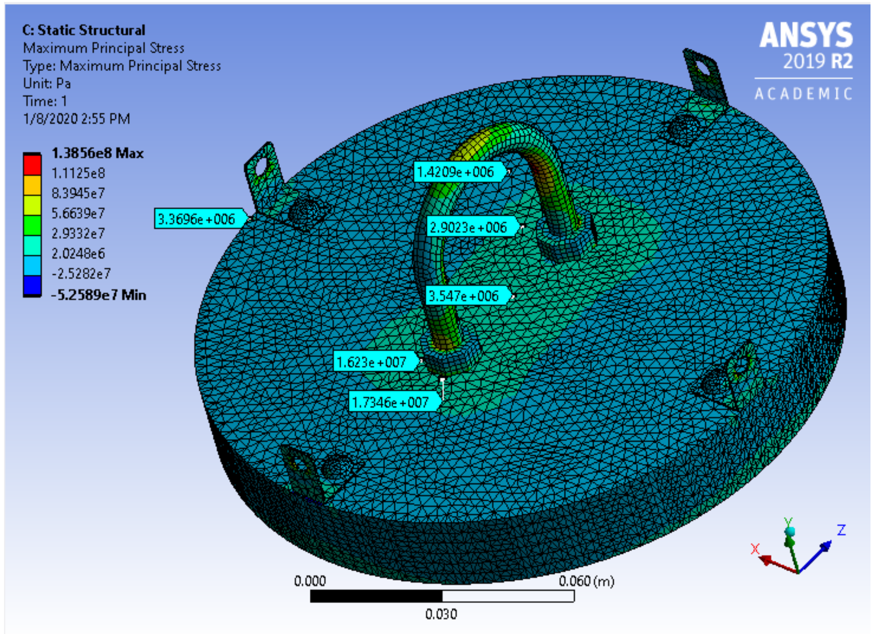


Figure 3-19 FEA of Nose Cone Bulkhead – ¾”

With an updated thickness of ¾”, the maximum stresses are more desirable. While the stresses on the U-Bolt are just as high, there is a significant reduction in the stresses found on the bulkhead. At its maximum, the stresses reach a maximum of around 16 MPa. This is half as much as the maximum stress of plywood, and thus proves the integrity of this design. There is no need to use a 1” bulkhead.

3.3.7.3 Motor Retention

The following test is for the fin can motor retention. This was done to test the forces undergone by the fin can bulkheads during initial flight.

The assembly includes the following parts:

- Forward fin can bulkhead
- Middle Centering ring
- Aft Centering Ring
- Motor Tube

The predicted maximum force caused by the motor is 396.9 lbf. This force was applied at the base of the motor tube to simulate the motor’s attachment to the motor retainer. Connections between the bulkheads and motor tubes were treated as bonded connections.

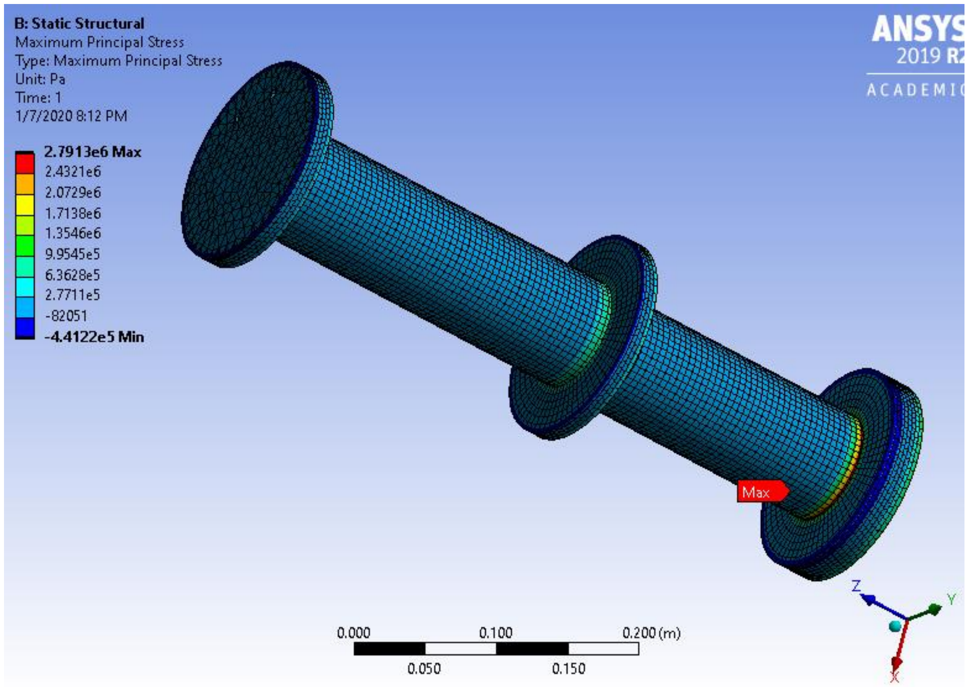


Figure 3-20 FEA of Motor Retention

As predicted, the most stress is found around the aft centering ring, however the FEA predicts that the maximum forces will be found on the motor tube itself, rather than the centering ring. There is still a significant amount of force on the centering ring. However, the maximum predicted stress on the system is about 2.7 MPa and the average ultimate stress (for both compressive and tensile) for plywood is around 30 MPa. This number will be even higher for the G12 fiberglass that the motor tube is made from. This shows that the present design is more than sturdy enough to support loads during launch.

3.3.8 Bulkhead Testing

A shear test was run to test the integrity of both a removable bulkhead and an epoxied bulkhead. The test sample was created using a sample piece of 5.5 inch fiberglass airframe. A 1/2” bulkhead was epoxied to one end of the test piece, and a ½” removable bulkhead was added to the other end of the test piece using the same methods described in section 3.3.6. With this set up, two type of bulkheads could be tested with a single test but pulling on both ends simultaneously.

Holes were added in both bulkheads to simulate the holes that would be added if anything were to be attached to the bulkheads.

Figure 3-21 Epoxied Bulkhead

Figure 3-22 Removable Bulkhead

The bulkhead was tested on a tensile tester that was rated to pull up to 1000 Ibs of force. The test sample was help in place by quick links which were attached to the tensile tester.

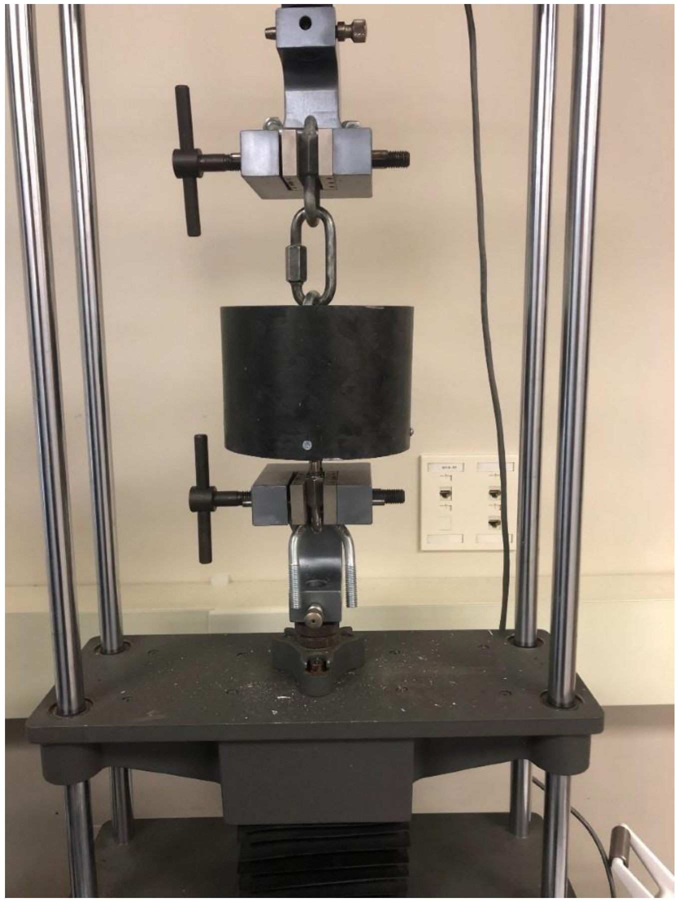


Figure 3-23 Test Set Up

The piece was slowly brought up to a load of 1000 lb. in 30 lb. increments. It was able to reach the max force without any visible buckling or deformation. Three fatigue tests were then carried out by rapidly taking the same from 0 to 1000 Ib. None of these tests caused any damage to either bulkhead. There will be additionally testing done of this sample on a machine that can reach higher loads to find the yield stress of the bulkhead. This will be done to ensure a factor of safety, but at the moment the bulkheads can withstand forces above the predicted.

3.3.9 Planned Testing

3.3.9.1 Testing of Bulkheads with varying thickness

A test of the bulkheads will determine their integrity as their thickness ranges from 1/8" to 3/8". For consistency, these bulkheads will all be epoxied in place. The idea of this test is to test the strength of the bulkhead material, not the connection strength. This test will be done on a universal testing machine. This will be done to simply have a reference of what forces difference bulkheads can undergo.

3.3.9.2 Testing of AV bulkhead

Since the AV bay will undergo heavy loads during recovery, we will need to test the integrity of the structure. A mock AV bay will be created and run through the universal testing machine. The connection points will be the U-Bolts on both bulkheads. A body tube may not be necessary to correctly run this test, as the AV Bay's threaded rods are holding the bulkheads together, not the AV bay coupler piece. Results from this test will tell if the system needs to be bolstered. This test is described in section 6.1.

3.3.9.3 Shear Testing of Shear Pins

Will test the ultimate shearing value of the team's shear pins. This is to ensure that shear calculations are using the correct values and that the manufacturer's values are correct. The test data will be used to for shear calculations rather than the manufacturer data. This test is described in section 6.1.

3.3.9.4 Shear Testing of Bolts

Will test the ultimate shearing value of #8 bolts. This is to ensure that these will not shear out of the launch vehicle while undertaking flight loads. These tests will determine how many fasteners will be required to hold sections of the launch vehicle together. This test is described in section 6.1.

3.3.10 Motor Selection

The team currently possesses several RMS-75/3840 motor casings that can house the 850W, 1150R, 1390G, and 1520T motors from AeroTech. As the team did not want to purchase additional motor casings, it was decided that one of these motors would be the primary choice for the launch vehicle propulsion. Historically, the team has used the 1150R and has experienced unreliable performance characteristics from it. Last year, the team determined that this motor would no longer be used in the team's launch vehicle. The team has decided to uphold this decision to not use the 1150R. Thus, the 850W, 1390G, and 1520T are the primary motors that were considered for the launch vehicle.

One of the largest difficulties the team experienced last year was severe weathercocking of the vehicle immediately upon rail exit. This was believed to be caused by two primary reasons: inadequate fin sizing and the 1150R not accelerating the launch vehicle to a large enough velocity upon launch rail exit. Due to the latter reason, the team has chosen a motor that provides a high initial thrust and maintain this large output through the duration of the motor burn. Additionally, the team has selected a powerful motor but with a short burn time. The purpose of this decision is to ensure that the launch vehicle achieves a large velocity quickly, bringing the center of pressure further aft and ensuring the vehicle maintains a stability margin of at least 2.0 calipers. The thrust curves, shown below, were examined to identify which of the three potential motors satisfy these requirements.

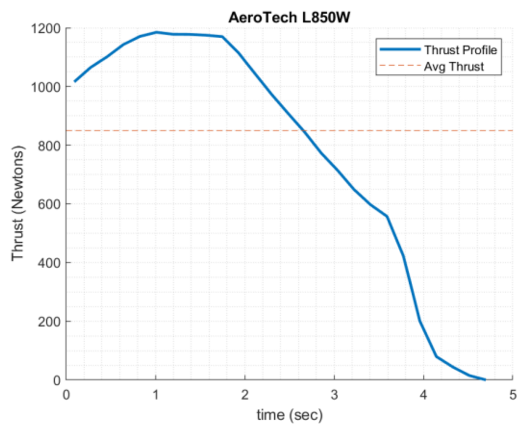


Figure 3-24 L850 Thrust Curve

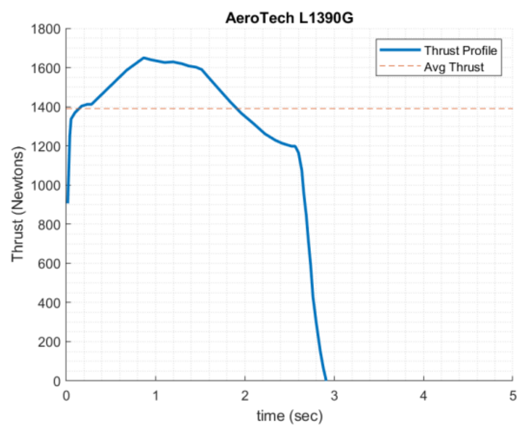


Figure 3-25 L1390 Thrust Curve

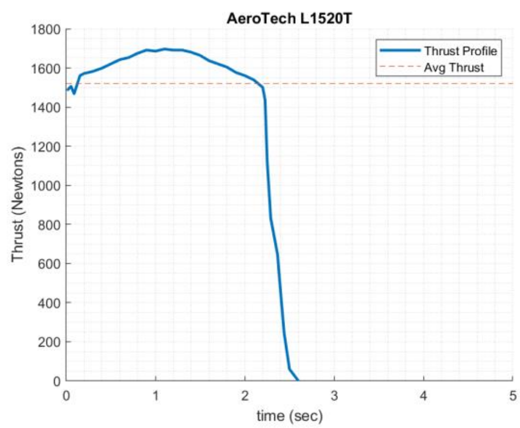


Figure 3-26 L1520 Thrust Curve

Additional performance specifications of the motors are provided below in Table 3-5.

Table 3-5 Motor Data

Motor	Total Weight (g)	Total Impulse (Ns)	Burn Time (s)
L 850W	3,742.0	3,646.2	4.4
L 1390G	3,879.0	3,949.0	2.6
L 1520T	3,651.4	3,715.9	2.4

Upon quick inspection of the thrust curves above, it became obvious that the 850W is not an optimal design choice for the requirements listed above. Namely, this motor has much longer burn time compared to the other two motors, and thus, the launch vehicle would achieve its maximum stability much later in the flight trajectory.

The 1390G appeared to be a worthwhile candidate because it adequately satisfies the requirements listed previously. However, these curves showed the 1520T to be the winning choice as it fits these requirements more closely than the 1390G.

Simulations conducted in RockSim indicated that all three of these motors resulted in apogees within the 3,500 – 5,500 ft apogee envelope. These simulations showed that the 1390G resulted in the highest apogee which caused issues for the descent time of the rocket. Most of the calculations showed that the descent time from apogee would be greater than 90 seconds which is in excess of the limit. The 850W and 1520T gave apogees significantly lower than 1390G, and the recovery team found that because of this lower apogee the descent time would fall beneath the 90 second requirement.

From the analysis presented above the team has decided to select the AeroTech L1520T as the motor for the full-scale launch vehicle. This motor will give the vehicle a thrust to weight ratio of 8.1

3.4 Recovery Subsystem

3.4.1 Final Recovery Design Components

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, their respective batteries and switches, and a tracking device will be mounted on an avionics sled created out of laser cut 1/8" birch plywood and supported by two parallel threaded rods. The altimeters systems will be housed on one side of the sled while the tracking device and its battery will be mounted on the opposite side of the sled. After the vehicle is mounted on the launch rail, the altimeters will be armed using two independent screw switches, accessible from the outside through holes in the airframe large enough to fit a screwdriver. At apogee, the primary altimeter will detonate a black powder charge separating the fin can and midsection. The redundant altimeter will detonate another charge to achieve the same goal 1 second later in case of failure in the primary system. The two sections will 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. Loops at the end of the shock cord will be connected to U-bolts on bulkheads in the airframe by ¼” quick links. The fin can will be tethered by a permanent bulkhead, while the midsection will be tethered by a bulkhead that is part of the AV Bay assembly. This bulkhead will be 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 altimeters, tracking device, and ejection charges, and can be prepared separate from the rest of the vehicle during launch procedures. At 500 ft, the primary altimeter will detonate a black powder charge separating the nosecone and midsection. At 450 ft, the redundant altimeter will do the same. 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 will be tethered to the AV bay bulkhead on this side, described earlier, while the nosecone will be tethered by a removable bulkhead in the nosecone. This removable bulkhead is beyond the payload section, and as such a length of shock cord will be routed through holes in the payload bay bulkheads and centering rings until reaching the bulkhead in the nose. Supporting this recovery harness will be a Fruity Chutes 120” Iris UltraCompact parachute. The parachute will be deployed and protected by a piston ejection system, attached to the shock cord at a fixed distance.

3.4.1.1 Altimeters

The vehicle’s recovery events will be controlled by two PerfectFlite StratoLoggerCF altimeters, one primary altimeter and one redundant altimeter. The StratoLoggerCF was chosen due to its precision, programmability, availability, and wiring layout. 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 – as well as ensuring that the wiring, setup, and data collection of both altimeters is identical, requiring team members to only learn these processes once. 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, as the redundant altimeter needs to be capable of a 1 second apogee delay and a 450 ft main deployment. Finally, the StratoLoggerCF has a favorable wiring setup, with two terminals each for battery power, switch, drogue e-match, and main e-match. A number of alternatives explored did not have an integrated switch circuit or used a shared ground pin that required inserting two wires into a single terminal. The StratoLoggerCF’s wiring layout does not run into these problems and is clearly labeled on the board to avoid confusion. For these reasons, the PerfectFlite StratoLoggerCF shall be used as both the primary and redundant altimeters in the rocket.

3.4.1.2 Avionics Sled

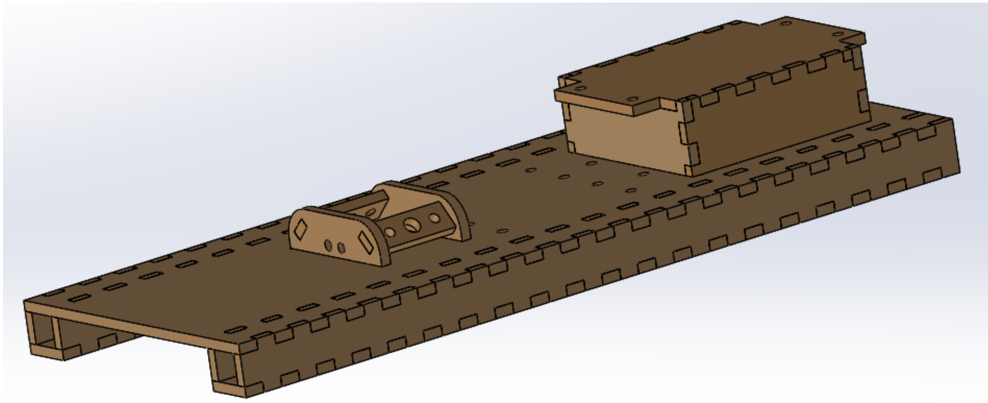


Figure 3-27 AV Sled Render

Pictured above is the fully assembled AV sled, without any electronics or hardware mounted. The sled will be constructed out of laser cut 1/8" birch plywood and held in place within the AV bay by the threaded rods running through the length of the bay. The square holes on either side of the sled will slide over the threaded rods, holding it in place laterally, while nuts on the threaded rods will hold it in place axially. The tilted pieces to the left with three holes will have screw switches mounted to them via standoffs, ensuring they are radially aligned at a 90° angle to each other. The arced pieces holding these in place are held in place by two pairs of screws, one on either side of the base, which hold the two plates in tension and help prevent bowing. The eight circular holes to the right of the screw switches, better visualized in the dimensioned sled base below, will mount the two StratoLoggerCF Altimeters. The box to the right will house the two batteries for the altimeters. The top piece of this box will be 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. Except for the top battery cover and the already mentioned switch holder pieces, all pieces of the sled will be wood glued together along the jigsaw. The team has used this construction method for AV sleds in the past, which have proven reliable.

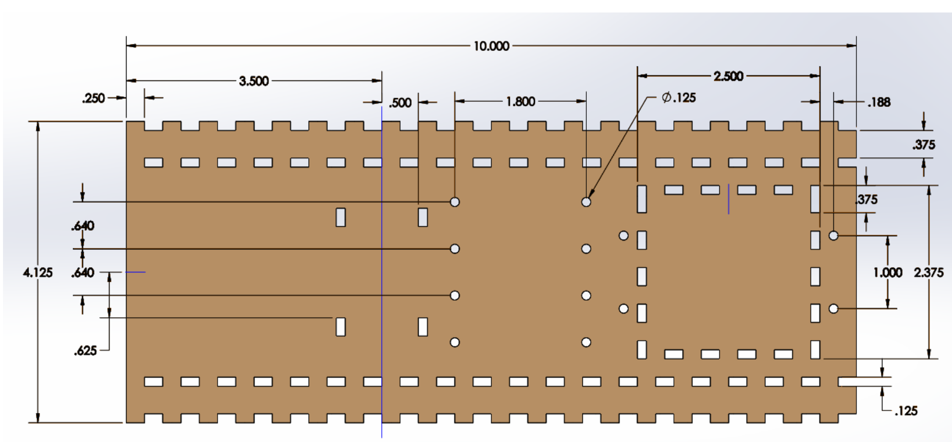


Figure 3-28 Dimensioned AV Sled Base

3.4.1.3 Avionics Electrical Schematic

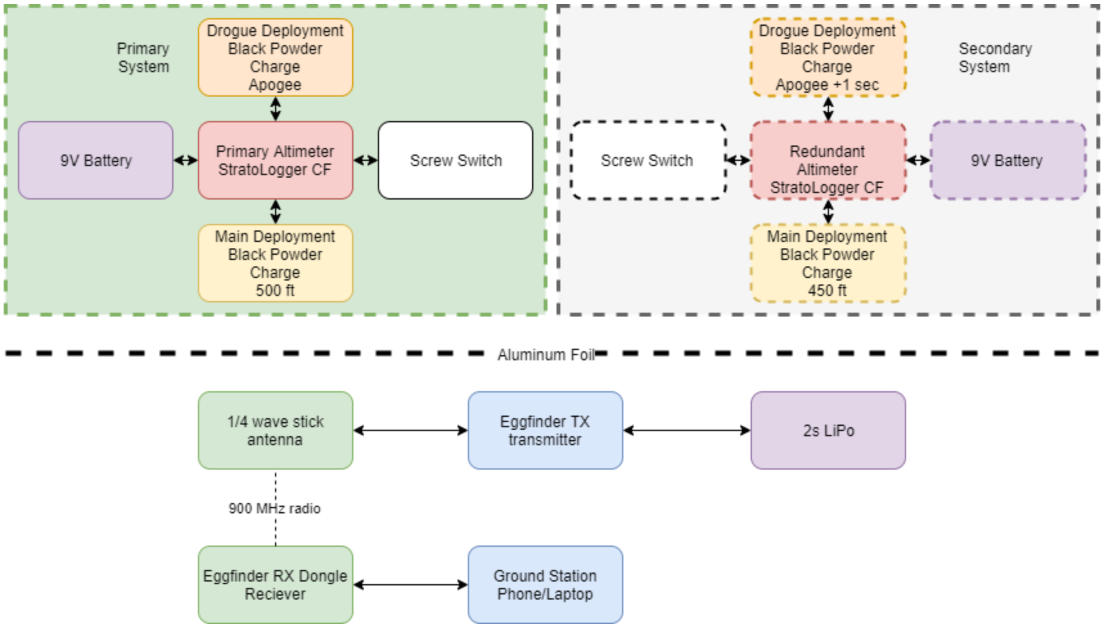


Figure 3-29 Recovery Electronics Diagram

The diagram above illustrates the components housed within the AV bay and how all of them are wired. 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.

Housed on the other side of the avionics sled is the Eggfinder TX transmitter, a 2S LiPo, and a 1/4 wave stick antenna. These components are located on the opposite side of sled and have a piece of aluminum foil installed between them and sled in order to shield the recovery electronics from radio interference. The Eggfinder system transmits GPS coordinates in real time on the commercial 900 MHz band to the receiver dongle, which communicates with a ground station device via USB or

Bluetooth. This allows the team to plot the vehicle's location on a phone even while walking towards the rocket to recover it.

3.4.1.4 Parachutes

The vehicle will use 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, and packing size. The 24" Classic Elliptical was chosen as the drogue parachute for its high descent speed and team ownership. 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. Current model mass predictions suggest a burnout mass of 1.267 slugs. 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 86.1 fps. The 24" Compact Elliptical also from Fruity Chutes is the only comparable drogue the team could find with a predicted descent rate less than 100 fps per requirement TDR 3.2; the Compact Elliptical has a predicted descent rate of 88.1 fps. Assuming the vehicle descends at this speed from apogee to main deployment altitude, this results in a difference of only a second between the descent time under drogue for both parachutes. With the current wind drift and descent time calculations, this extra second is allowable, and will allow the team to use a parachute already in its ownership to conserve funds. This complies with TDR 3.3, the team shall use recovery devices that the team owns, which is implemented for this exact reason.

The Fruity Chutes 120" Iris UltraCompact has been chosen for the main parachute primarily for its wind drift, descent time, and kinetic energy performance. Of the parachutes evaluated by the team, only three met the descent time, kinetic energy, and 20 mph wind drift requirements using the selected drogue parachute. Of these three parachutes, the UltraCompact had the highest descent rate at 14.4 fps, resulting in the highest kinetic energy, but also the lowest descent time and wind drift. Descent rate is calculated using the same terminal velocity equation used for the drogue, with a reference area of 78.4 ft^2 and a C_D of 2.11 for the 120" Iris UltraCompact. The team chose to favor a "weaker" parachute in this regard, as

[2] *Fluid Friction*. http://hyperphysics.phy-astr.gsu.edu/hbase/airfri2.html. Accessed 7 Nov. 2019.

current payload experiments and predictions suggest that the payload may be lighter than currently modeled. This will reduce the descent speed of the vehicle, as well as lowering the mass and thus kinetic energy of the nosecone section, currently the heaviest body section. As a result, a “stronger” parachute is more likely to exceed the wind drift or descent time restrictions based on payload mass than a “weaker” parachute is to exceed the kinetic energy restriction. In addition, the team already possesses a Fruity Chutes 120” Iris UltraCompact parachute, conserving funds as with the drogue parachute. The team also possesses a Sky Angle CERT-3 XXL, the “strongest” of the three tested parachutes to meet both requirements. If the vehicle does come in heavier than expected, the team would be able to switch to using the Sky Angle.

3.4.1.5 Recovery Harness

The recovery harness will be 40’ x 5/8” Kevlar shock cord. This shock cord is rated for loads upward of 2000 lbf, and current mass and acceleration predictions suggest a maximum load of 655 lbf. The drogue shock cord will have two loops tied within 1 ft of each other approximately 1/3 down the length of the shock cord. The shorter end will be attached to the midsection, while the longer end will be attached to the fin can. The drogue parachute will be attached to one of the loops, while a Nomex sheet while be attached to the other. The main shock cord will also have a loop tied 1/3 down the length of the shock cord. The main parachute will be attached to this loop, with the shorter end attached to the nosecone, and the longer end attached to the midsection. Along the length of shock cord between the midsection and parachute loop, the ejection piston is attached to a fixed point on the shock cord. This ejection piston protects both the recovery hardware and payload section from the hot flames and ejection gases.

3.4.1.6 Ejection Charge Sizing

Black powder sizing is determined by finding the force or pressure necessary to separate body sections, and then calculating the mass of black powder necessary to achieve this. Ejection tests of the subscale vehicle suggest a pressure of up to 25 psi may be required if the recovery hardware is a particularly tight fit in the body tube of the rocket, with 15 psi being generally acceptable for looser fits. Assuming a moderately tight fit until manufacturing for both the main and drogue sections, a desired pressure of 20 psi will be used in the calculations. The main parachute bay has a cavity 21 inches in length, while the drogue parachute cavity is 7 inches in length. With a 6 inch inner diameter, these sections have a volume of 593.8 and 197.9 in^3 respectively. Using the Ideal Gas equation below, the required mass of black to bring this volume to the desired pressure can be calculated.

$$PV = mRT$$

Here R is the gas constant of black powder gas, and T is the combustion temperature of black powder. These are known quantities for the 4F black powder used in the ejection charge[3]. Rearranging the equation to solve for m gives the mass of black powder necessary. Using the previously stated volumes, the main charge will be 6.1 grams, and the drogue charge will be 2 grams.

In order to provide redundancy in the recovery system, a secondary charge will be activated after the primary charge for each event. This charge will be 0.2 grams larger, to force separation if the first charge was detonated but did not fully separate the body sections. Separation may also fail to occur if the first charge does not detonate; in this case 0.2 grams is small enough of a difference that over pressurization is unlikely to occur if the primary charge would not also cause it. As a result, a total of 4 black powder charges will be installed in the rocket for each flight: A 2 g primary drogue charge, a 2.2 g redundant drogue charge, a 6.1 g primary main charge, and a 6.3 g redundant main charge.

3.4.1.7 Tracking Device Trade Study

Seven different tracking devices were evaluated for consideration in the rocket. A trade study has been conducted in order to select the new leading candidate, through use of a Decision Matrix. All considered devices were rated based on six criteria, the difficulty of tracking using the device, range of the device, precision of the device, cost, requiring a HAM license, and transmitter output power. Range and Output Power have mandatory requirements, any transmitter considered must have a range greater than 5000 ft and a transmitter output power less than 250 mW. The range requirement is to ensure than the transmitter receiver pair maintains a proper connection throughout the flight. The transmitter output power is mandatory in order to meet requirement NASA 2.22.9. Requiring an amateur radio license has the lowest weight at 5%, as members of the team already plan on acquiring an amateur radio license. Precision has a lower weight at 10% because a few other tools can help locate the rocket once the field recovery team is closer to the rocket, such as the locator siren and parachute. Range and Output Power were given a weight of 20% due to being mandatory requirements, with increased range generally translating to better reception and lower output power correlating to longer battery life and reduced risk of RF interference. Tracking difficulty was also given a weight of 20% because user error may make recovery of the vehicle take longer, which limits the team’s time to perform the payload experiment before the next volley begins. As a result, more difficult tracking may affect not only the vehicle’s performance, but the payload’s performance as well. Finally, cost was given a weight of 25% due to the relative expense between the systems. For example, the Simple GPS costs $415 compared to the 70 cm BeeLine which costs $59, with some non-considered systems costing upwards of $800.

[3] *Aerocon Systems Hot Tips*. http://aeroconsystems.com/tips/. Accessed 7 Nov. 2019.

Table 3-6 Tracking Device Trade Study

Criteria	Mandatory	Weight	Scale	Simple GPS	TeleGPS	Micro Hunt	Eggfinder	70 cm RF BRB	70 cm GPS	BRB900
Tracking Difficulty	No	20	3 = Easiest to use 1 = Most Difficult to use	3	2	1	3	1	2	3
Range	Yes (>5000 ft)	20	3 = Longest Range 1 = Shortest Range	2	2	3	1	2	3	2
Precision	No	10	3 = Best Precision 1 = Worst Precision	3	3	1	3	1	3	3
Cost	No	25	3 = Most Expensive 1 = Least Expensive	1	2	3	3	3	2	1
HAM License	No	5	3 = No license 1 = Requires license	3	1	1	3	1	1	3
Output Power	Yes (<250 mW)	20	3 = Lowest Power 1 = Highest Power	2	3	2	2	3	2	1
Weighted Totals in %		100	3	70	75	70	80	70	75	63.33

Ratings for tracking difficulty are primarily based on the method of locating using the device. The easiest devices have integrated or provided systems which directly map or point to the rocket's location. The most difficult devices require "fox hunting," which require user skill and practice for effective locating. Precision is similarly quantified, with fox hunting methods being the least precise due to radio reflections, and GPS methods all having similar levels of precision. Given the selection of options studied, the Eggfinder GPS Tracking System has the greatest weighted value at 80%. The BRB900, if given a score of 3 in the cost category due to the team already owning one, also has a score of 80%. Comparing the two devices to each other given these scores, the Eggfinder has a lower range of about 3 mi, while the BRB900 has a range of about 6 mi. The only other category for which the two differ is output power. The BRB900 has an output power of 250 mW, while Eggfinder has an output power of 100 mW. Comparing the value of these two devices comes down to the uncertainty in some events. While the Eggfinder has a lower range, 3 mi should still be more than sufficient for the rocket, given an apogee of 4420 ft and a maximum wind drift of 2500 ft. This provides a 3 times margin to ensure the vehicle remains within range for the Eggfinder. Transmission power is more of a concern between the two devices. Increased transmission power increases the chances of RF interference with other devices such as altimeters and accelerometers. Weighing these concerns against each other, the new leading alternative for the tracking device in the vehicle is the Eggfinder GPS. The Eggfinder GPS is inexpensive, costing less than $100, does not require a HAM license, and has adequate, if low, range for the application. It has a relatively low transmission power and provides accurate data to an Android phone via Bluetooth that can be used to map the vehicle's location.

3.4.1.8 Tracking Device

The launch vehicle will be located using an Eggfinder GPS. The system will consist of a standard Eggfinder Transmitter TX with the included antenna and a 2S (7.4 V) LiPo battery, transmitting to a Bluetooth Eggfinder RX dongle. The transmitter will be attached to the sled via standoffs, while the 2S LiPo battery will be secured with a strap. The transmitter will be paired with a receiver, transmitting on the same frequency. The receiver will also be connected to a 2S LiPo, held in a plastic case. The receiver will be paired to the phone of a team member on the field recovery team via Bluetooth. The GPS data will then be plotted using a program such as GPS Rocket Locator or Rocket Tracker on the phone.

3.5 Mission Performance Predictions

3.5.1 Launch Day Target Altitude

Based on RockSim data, the team has determined that the target altitude for the full-scale launch vehicle will be 4,420 ft.

3.5.2 Flight Profile Simulations

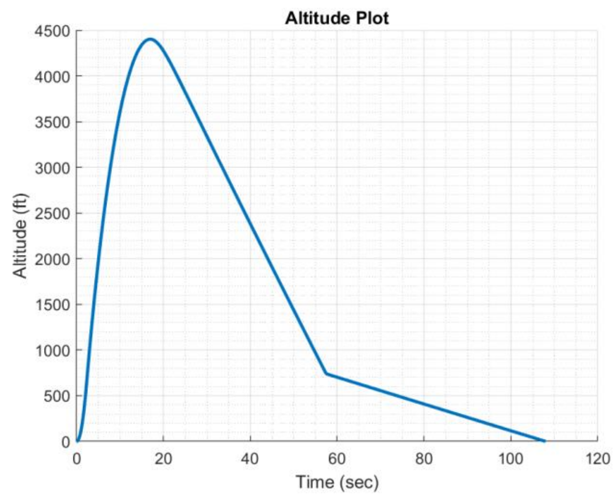


Figure 3-30 Altitude Plot of Full-scale Vehicle

Using the launch conditions described in Table 3-7 for the full-scale launch vehicle.

Table 3-7 Launch Simulation Parameters

Parameter	Assumption	Justification
Launch Rail Angle	5°	Handbook 1.12
Launch Rail Length	96 in.	Handbook 1.12
Wind Speed	8.4 mph	Mean at launch site
Launch Direction	Into wind	Prevailing wind at launch site

3.5.3 Altitude Verification

A secondary method to calculate the altitude was performed to verify that an altitude of 4,420 ft was reasonable. A simple set of algebraic expressions were evaluated and can be seen below:

First, preliminary values are needed to begin these calculations:

Table 3-8 Variables for Apogee Calculation

Quantity	Variable	Value	Units
Mass	M	19.73	kg
Frontal Area	A	0.018	m^2
Gravitational Accel.	g	9.81	$\mathrm{m/s}^2$
Total Impulse	I	3769	$\mathrm{N\cdot s}$
Avg Thrust	T	1513	N
Burn time	t	2.4	s
Air density	ρ	1.225	$\mathrm{kg/m}^3$
Drag coefficient	C_D	0.33	n/a

Using these values, this first calculation solved for the wind resistance:

$$K = \frac{1}{2} * \rho * C_D * A = 0.0037\ \mathrm{kg/m}$$

Next, the maximum velocity was calculated:

$$v_{max} = \sqrt{\frac{T - M * g}{k}} * \frac{1 - \exp(-xt)}{1 + \exp(-xt)} = 162\ \mathrm{m/s}$$

From this, the altitude of the rocket once the motor has burned out was calculated:

$$h_{boost} = -\frac{M}{2k} * \ln\left(\frac{T - Mg - kv^2}{T - Mg}\right) = 205 \text{ m}$$

Next, the altitude that the rocket will achieve from coast was calculated:

$$h_{coast} = \frac{M}{2k} * \ln\left(\frac{Mg + kv^2}{Mg}\right) = 1089 \text{ m}$$

Finally, from summing the altitudes calculated, the total altitude (or apogee) was calculated:

$$h_{total} = h_{boost} + h_{coast} = 1294 \text{ m} \quad \Rightarrow \quad 4245 \text{ ft}$$

This apogee is now compared to the altitude given by RockSim:

Table 3-9 Apogee Verification Table

Method	Apogee (ft)	Comparison
RockSim	4,420	$\%_{\text{diff}} = 4.04\ \%$
Algebraic	4,245	

3.5.4 Stability Margin Simulation

Simulations in RockSim indicated that the stability margin of the launch vehicle at rail exit will be 2.26 calipers. However, the simulation is designed for an operating Mach number of 0.3, the average Mach number that the launch vehicle will experience during its ascent. For this Mach number, the simulation resulted in a stability margin of 2.18 calipers. In order to verify the accuracy of this result, a validation method utilizing separate calculations was required. One of the most popular sets of equations in rocketry is known as Barrowman's method. This method involves a series of simple algebraic equations that identify the center of pressure of the rocket. This result can then be used to calculate the stability margin of the launch vehicle.

Firstly, the arm length for any ogive nose,X_N, is a linear function of the length of the nose cone L_N. For the current leading launch vehicle design, this length is 30 inches, thus:

$$X_N = 0.466 * L_N = 13.38$$

Next, the sweep angle of the fins was calculated. For this calculation, the fin semi-span length, S, was needed along with the fin sweep length measured parallel to the rocket body, X_R. For the current leading vehicle design, these values are $S = 5.0$ inches and $X_R = 3.0$ inches.

$$\theta = 90° - \tan^{-1}\left(\frac{S}{X_R}\right) = 30.96°$$

This angle value then allowed for the computation of the fin mid-chord line length. The important values in this equation were the chord root length, C_R, and the chord tip length,

C_T. For the current leading vehicle design, these values are $C_R = 12$ inches and $C_T = 7$ inches.

$$L_F = \sqrt{S^2 + \left(\frac{1}{2}C_T - \frac{1}{2}C_R + \frac{S}{\tan\theta}\right)^2} = 7.68 \text{ inches}$$

Once this value is calculated, the coefficient for the fins was then R, and the number of fins, N. For the current leading vehicle design, these values are $R = 3$ inches and $N = 4$.

$$C_F = \left(1 + \frac{R}{S+R}\right)\left(\frac{4N\left(\frac{S}{R*2}\right)^2}{1 + \sqrt{1 + \left(\frac{2L_F}{C_R + C_T}\right)^2}}\right) = 6.68$$

The arm length of the fins was also computed. This calculation was dependent on the distance from the nose cone tip to the root chord leading edge, X_B. For the current leading vehicle design, this value is $X_B = 94.5$ inches.

$$X_F = X_B + \frac{X_R}{3}\frac{C_R + 2C_T}{(C_R + C_T)} + \frac{1}{6}\left[(C_R + C_T) - \frac{C_R C_T}{(C_R + C_T)}\right] = 98.30 \text{ inches}$$

Finally, from these values the center of pressure was calculated:

$$X_{CP} = \frac{(C_N X_N + C_F X_F)}{C_N + C_F} = 78.74 \text{ inches}$$

The center of gravity location was obtained from RockSim:

$$X_{CG} = 65.30 \text{ inches}$$

With this information, the stability margin of the launch vehicle was then calculated and compared to the stability margin given by RockSim:

Table 3-10 Stability Margin Verification Table

Computation Method	Result	Comparison
Barrowman	$S_{M_1} = \frac{X_{CP} - X_{CG}}{2*R} = 2.24$	$\%_{\text{diff}} = \frac{\lvert S_{M_1} - S_{M_2}\rvert}{\left(\frac{S_{M_1} + S_{M_2}}{2}\right)} \times 100 = 2.71\%$
RockSim	$S_{M_2} = 2.18$	

Table 3-10 shows that Barrowman's equations provided a remarkably similar stability margin compared to RockSim's calculations. With a percentage difference of less than 3%, it was concluded that the result for the stability margin was precise. A summary of the input and output values from these equations along with a variable definition list and a sketch showing variable locations is provided in Figure 3-31.

For further clarity of the stability margin, data was obtained from RockSim for the center of pressure, center of gravity, and resulting stability margin starting from motor ignition to apogee. This data was then plotted using MATLAB and can be seen in Figure 3-31 below:

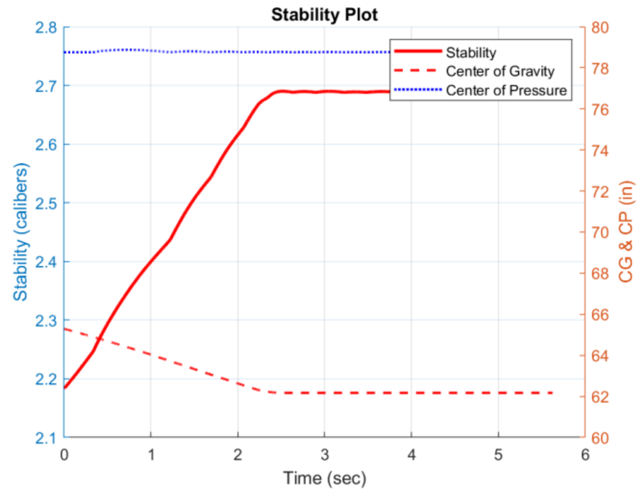


Figure 3-31 Simulated Stability Data of Full-scale Launch Vehicle

Table 3-11 Simulated Stability Data at Critical Flight Phases of Full-scale

Vehicle State	Stability	Total Velocity (ft/s)
On Rail	2.18	0.0
Rail Exit	2.26	83.5
Motor Burnout	2.69	556.4

The table above shows that the full-scale launch vehicle meets several requirements set in place by the NASA Handbook. Namely, that the stability margin at rail exit is at least 2.0, the minimum velocity at rail exit exceeds 52 ft/s, and the flight remains entirely subsonic as the highest Mach number experienced by the vehicle is 0.5.

Variable Definitions

L_N – Length of nose cone

R – Radius of rocket body

S – Fin semi-span length

N – Number of fins

L_F – Fin mid-chord line length

C_R – Root chord length

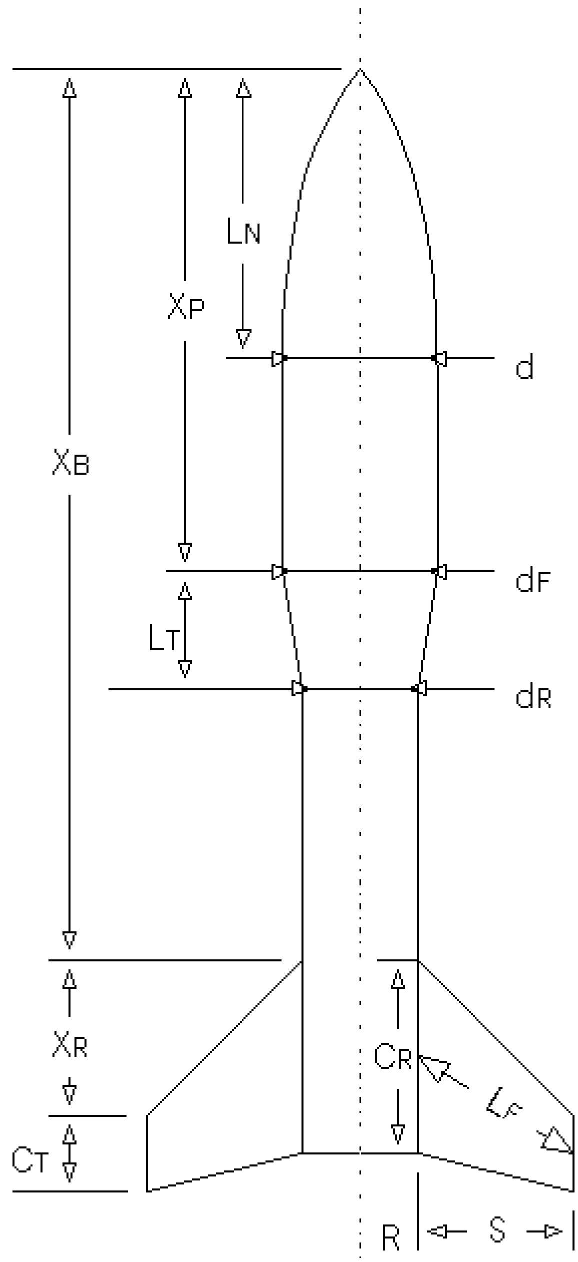
C_T – Tip chord length

θ – Sweep angle of the fin leading edge

X_B – Distance from nose cone's tip to fin root chord leading edge

X_R – Fin sweep length measured parallel to the rocket body

Variable	Input Value	Units
C_N	2	n/a
L_N	30	inches
R	3	Inches
S	5	inches
N	4	n/a
C_R	12	inches
C_T	7	inches
X_B	94.5	inches
X_R	3	inches
CG	65.3	inches
Variable	**Output Value**	**Units**
X_N	13.38	inches
θ	30.96 °	degrees
L_F	7.68	inches
C_F	6.68	n/a
X_F	98.3	Inches
X_{CP}	78.74	Inches
$\boldsymbol{S_{M_1}}$	**2.24**	**Calipers**



3.5.5 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[4]:

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

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 calculated using the "Parts list" feature on RockSim to predict the mass of airframe components and then summing the mass of all the parts attributed to each tethered section.

Table 3-12 Kinetic Energy at Landing

Section	Mass	Main Velocity	Kinetic Energy at Landing
Nosecone	.5897 slugs	14.19 ft/s	51.5 ft-lbs
Midsection	.3137 slugs	14.19 ft/s	34.8 ft-lbs
Fin can	.3641 slugs	14.19 ft/s	37.6 ft-lbs

With the heaviest section of the launch vehicle descending with a kinetic energy of 51.5 ft-lbs, the vehicle has a large margin between this value and the maximum as given by requirement NASA 3.3.

3.5.5.1 Alternative Calculation Method

Kinetic energy at landing was also calculated using RockSim as a method of verifying the results of hand calculations. While RockSim does not consider how the vehicle descends in pieces and thus does not calculate the mass of each section, the velocity at which the parts descend is a function of the total mass of the rocket. As such, the mass of each section is calculated the same as for the hand method, but the descent velocity should remain valid. Simulating a launch in RockSim with no wind, the velocity of the vehicle at landing can be found in the details of the flight. With this, the Kinetic Energy of each section can be calculated.

Table 3-13 RockSim Kinetic Energy at Landing

Section	Mass	Main Velocity	Kinetic Energy at Landing
Nosecone	.5115 slugs	14.56 ft/s	54.2 ft-lbs
Midsection	.3453 slugs	14.56 ft/s	36.6 ft-lbs
Fin can	.3737 slugs	14.56 ft/s	39.6 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 2 ft-lb difference between

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

the RockSim and hand calculations due to the method by which RockSim determines the descent velocity of parachutes. RockSim accounts for the spill hole of the parachute uses an assigned C_D rather than determining it based on manufacturer ratings. However, this difference remains negligible with a margin of over 20 ft-lb.

3.5.6 Descent Time Calculations

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

3.5.7 Wind Drift Calculations

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[5]:

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

The selected parachutes along with an apogee of 4425 and main deploy altitude of 500 give a descent time of 81 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.

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

Table 3-14 Descent Time and Drift Distance

Wind Speed	Apogee	Descent Time	Drift Distance
0 mph	4425 ft AGL	81 s	0 ft
5 mph	4425 ft AGL	81 s	598 ft
10 mph	4425 ft AGL	81 s	1195 ft
15 mph	4425 ft AGL	81 s	1793 ft
20 mph	4425 ft AGL	81 s	2390 ft

In 20 mph winds, the worst-case scenario considered, the vehicle is projected to descend in 81 seconds, 9 seconds less than the required maximum, and cover 2390 ft, approximately 100 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.

3.5.7.1 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 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 3-15 RockSim Descent Time and Drift Distance

Wind Speed	Apogee	Descent Time	Drift Distance
0 mph	4445 ft AGL	77 s	0 ft
5 mph	4435 ft AGL	77 s	562 ft
10 mph	4405 ft AGL	77 s	1125 ft
15 mph	4353 ft AGL	77 s	1695 ft
20 mph	4277 ft AGL	74 s	2157 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 reduced altitude as wind increases. As RockSim does not allow for controlled variable wind speed, the wind is affecting the ascent of the rocket and reducing apogee. This is more realistic, but fails to capture the worst case scenario considered by the hand calculations. As such, RockSim calculations provide a large margin of error, with at least 13 seconds of leeway in descent time and over 300 ft of space in drift distance at the highest considered winds.

4. Payload Final Design

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 6.2 as well as the team derived requirements set forth by the team derived requirements defined in section 6.3. 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

4.3 BURRITO Rover Final Design

4.3.1 Overall Design

The selected 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 was 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 communicating between a radio receiver and 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, two spring-loaded arms with caster wheels attached 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 can be seen below. The first image shows the stowed configuration of the rover, viewed from the front. The second image is an exploded view of the BURRITO that shows the subsystems of the rover. The third image shows the major dimensions of BURRITO, in inches.

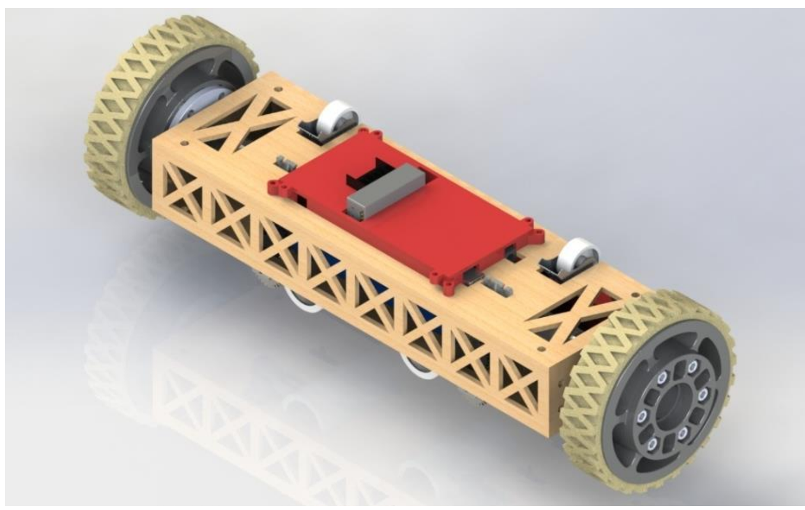


Figure 4-1 BURRITO Front View, Spring-Loaded Caster Wheels Stowed[6]

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[6] "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].

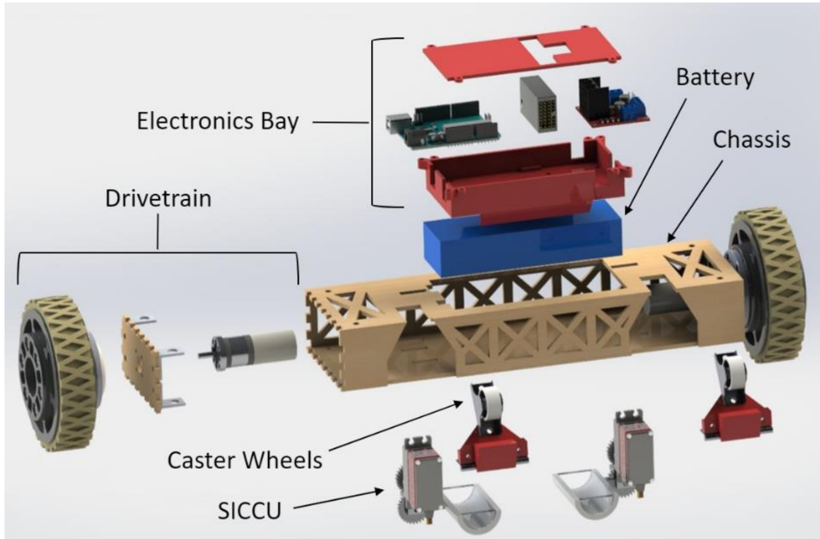

Figure 4-2 BURRITO Exploded View with Labelled Subsystems

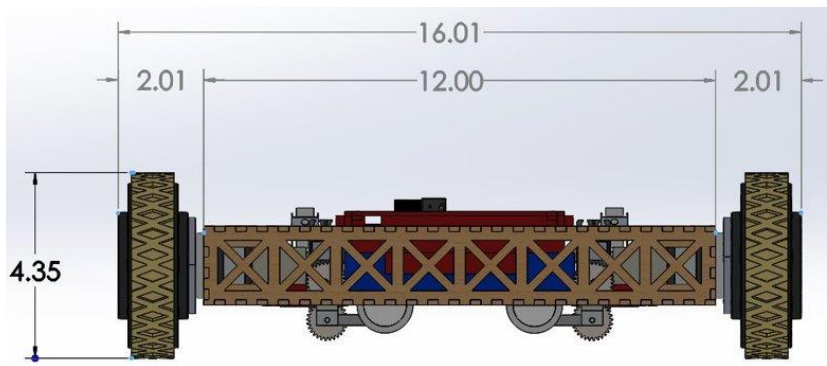

Figure 4-3 BURRITO Front View with Dimensions in Inches

The two-wheeled design was selected over other alternatives, since the righting systems needed in the payload bay for a four-wheeled or tank-treaded rover would have been more complex to build. Orienting the chassis would be necessary to deploy such rover types, and these mechanisms would need sensors to determine how far to rotate the chassis. Failure of any part of such a righting mechanism would prevent the rover from

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"Files – Resources – AndyMark Inc." [Online]. Available: https://www.andymark.com/pages/resources-files?prefix=STEP%20Files/. [Accessed: Dec-2019].

"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].

driving. By contrast, the two-wheeled design can deploy in any rotation and correct its orientation outside the payload bay by rotating the chassis about the wheels' axis. Such simplicity was the primary reason for selecting the two-wheeled design; other reasons included a greater volume available for components on the rover and greater ground clearance. Due to the low stability of the two-wheeled coaxial design, two caster wheels on spring-deployed arms were incorporated into the design to counteract this disadvantage of the selected chassis.

Plywood was selected as the chassis material, since the team already possesses a successfully flown avionics bay similar in size and appearance to the rover that is constructed out of plywood pieces. This existing example demonstrates that a plywood rover chassis could withstand launch loads equal to those experienced by the avionics bay. Additionally, the benefits of an easily cut and modified material factored into the selection of plywood. Construction of the rover could be done rapidly, and necessary modifications could be incorporated quickly.

The standard wheels were selected for the traction system, since tank treads would not be compatible with the selected chassis, and Mecanum wheels lack traction. The standard wheels were also the simplest of the traction choices and thus were considered unlikely to fail.

It was decided that the wheels would be independently powered by their own motors, since implementing a single motor and steering with a two-wheeled design would be very challenging. Using two motors allows for a simple drive system where spinning one motor faster than the other can produce turning motion. The selection of a lithium-polymer battery was due its widespread presence in RC applications, as well as its energy density.[7]

As for the control systems, the radio system will operate on a 2.4 GHz frequency so that commercially bought components can be easily found. The central control will be via a microcontroller, since the rover is a very simple system that does not require the processing power of a microprocessor.

4.3.2 Chassis Structure

BURRITO will use a chassis constructed out of birch plywood plates, which will be laser cut to shape and adhered together using epoxy. This kind of plywood structure has been used in previous years in the avionics bays of rockets and is thus capable of sustaining the high accelerations of launch while remaining lightweight. Additionally, the team has access to large supplies of birch plywood, as well as a laser cutter to create the structural pieces. The structure features holes cut to shape 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

[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].

amounts of strength. To allow access to the internals of the rover, specifically the motors, the two side plates of the chassis will be bolted on, rather than epoxied in place. The bolts will attach adjacent plates together via L-brackets at the corners of the side plates. This will be helpful during construction, as it would otherwise be impossible for the motors to be attached and wired into place. If a disconnection of the wires inside the rover occurs, the side plates can be removed again to allow straightforward repairs. The structure consists of a total of 8 separate plate pieces; the rendering below shows the plates assembled into the chassis.

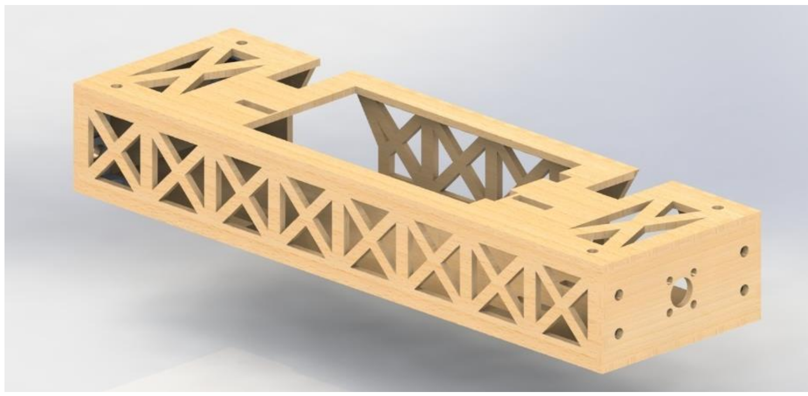

Figure 4-4 BURRITO Chassis Assembled

4.3.3 Drivetrain

The drivetrain of BURRITO will consist 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 rational 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 will be nylon-covered rings. Because BURRITO will be 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 will provide a buffer for the rover's weight to rest on; they will serve to take compressive loads off the motors' axles. At the same time, because they will be covered in nylon, the rings will 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.[8]

Both motors will be connected to the same battery, a Hyperion G5 50C 3S LiPo battery with a capacity of 4000 mAh. It was calculated that this capacity would be enough to carry

[8] "Material Contact Properties Table." [Online]. Available: http://atc.sjf.stuba.sk/files/mechanika_vms_ADAMS/Contact_Table.pdf. [Accessed: Jan-9-2020].

the rover the maximum possible distance to the ice recovery site, with some leftover capacity. The same battery will also supply power to the control electronics of BURRITO. The sizing and selection of the battery is detailed in the powertrain selection calculations in section 4.1.4. The figure below shows BURRITO with only its powertrain and some structure to illustrate the arrangement of these parts.

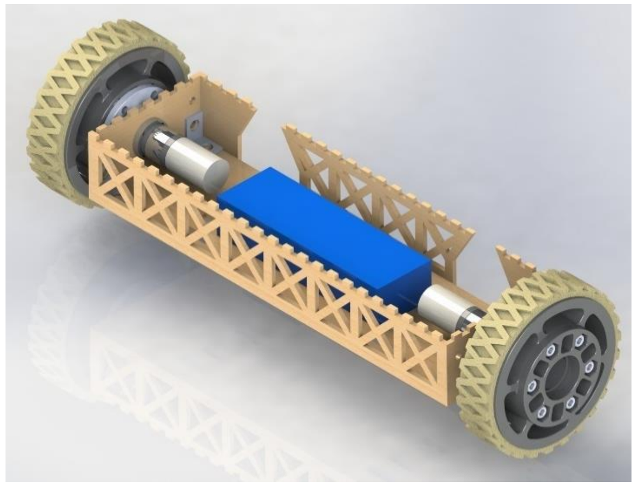

Figure 4-5 BURRITO Powertrain

On the backside of the rover will be 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 will be connected to spring-loaded hinges, such that, once BURRITO deploys from the payload bay, they will extend instantly. The arms themselves will be 3D-printed such that, when the rover is stowed, the deployment system will hold the arms in a closed position. This will be done so that, as the spring-loaded hinges force the arms outward, the caster wheels will not contact the wall of the payload bay. If the caster wheels did contact the wall, they could cause BURRITO to become stuck during deployment. Additionally, the caster wheels would be experiencing the high load applied by the (almost fully compressed) spring hinges, potentially damaging them. When the caster wheel arms deploy, a tab on the arms will prevent them from extending too far; the arms will hold the caster wheels such that their swivels will turn as the rover turns. The arms will be 3D-printed so that the deployment of the arms will reach the correct angle for the caster wheels to swivel left and right. The team owns its own printer that uses ABS plastic and will use it to print the arms. The caster wheels are available as a standard part from McMaster. The image below shows the deployed configuration of the caster wheel arms.

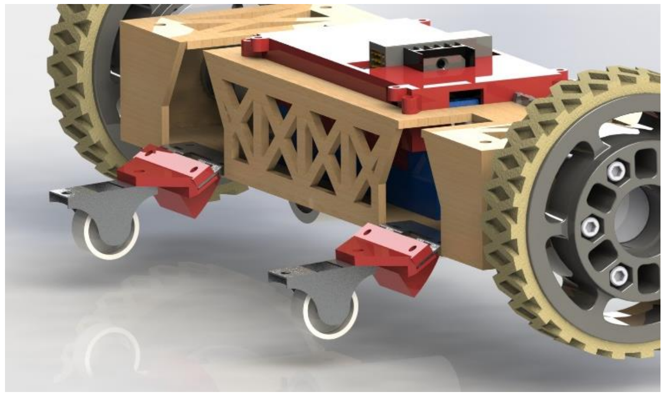

Figure 4-6 BURRITO Caster Wheel Arms Deployed

Compared to their state in PDR, the number of caster wheels has increased from 1 to 2. This is because using only one caster wheel left little space in the center of the chassis for other components, namely the battery. By placing two caster wheels on the rover, the space between them could be used by the battery and electronics bay seen in the final design.

4.3.4 Powertrain Selection Calculations

An online sizing tool was used to determine the motor and battery specifications required for BURRITO.[9] 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.[10]

Though BURRITO is intended to operate on a relatively flat competition field, it is unknown exactly how much resistance the rover will encounter to its forward movement. The online motor sizing tool suggests that an approximation of the resistance from driving can be obtained by modelling the rover as accelerating on an incline of a specified angle, assuming that the traction between the wheels and the surface is perfect. The following equation can then be used to produce a worst-case estimate for the required stall torque (e.g. maximum torque) of the drive motors.

$$T = \frac{100}{e}\frac{RM\left(a + g\sin(\theta)\right)}{N}$$

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.

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

As the motors need to run for a specified time, the power they consume must be estimated to determine the capacity of the required battery. The first property to determine is how fast the motors will need to spin to maintain the desired speed. The following equation determines the rpm of the motor that will 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 does the rotational velocity of the motors need to be known, but the time the battery needs to operate for must be determined. The following equation determines the time of operation based on the rover's speed and the distance it must travel.

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

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 are obtained, the following equation can be 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.[11]

The amount of current the battery will need to supply to each motor can also be 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,

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

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. They were also much smaller and lighter than the Heavy Duty Premium Planetary Gear Motor from PDR; these motors were deemed too large and heavy, especially as they seemed intended for competitive robots weighing around 30 lbf.

With the preselected components in place, the following table adds up the weights of the components for BURRITO; the total mass from this is then used with the aforementioned equations in the online tool to determine if the batteries and motors are of the correct specification.

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
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. The table below outlines the inputs that were used for the final design. Some of the inputs were left to their default values in the tools; 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 is higher than in the requirements established for the rover; the higher estimate is more accurate and will result in additional range buffer that will help offset 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 following table.

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 are well within the capabilities of the 350 RPM Premium Planetary Gear Motor from Actobotics, whose stall torque is 79.2 oz-in[12]. The preselected Hyperion battery also exceeds the required specifications by a large margin, with a maximum current of 100 A and a capacity of 4000 mAh.[13] With large margins in both motor specifications and battery specifications, the final design for BURRITO should easily traverse even the maximum distance possible from the ice recovery sites.

[12] "350 RPM Premium Planetary Gear Motor." ServoCity, 2019. [Online]. Available: https://www.servocity.com/350-rpm-premium-planetary-gear-motor. [Accessed: Dec-2019].
[13] "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].

4.3.5 Electronics

The electronics of BURRITO will consist of a microcontroller connecting a radio receiver to a motor speed controller and two servos. The microcontroller, receiver, and motor controller will all be housed in a protective casing to shield the exposed circuitry from dirt and moisture that could be encountered at the competition field. This casing, known as the electronics bay, will be 3D printed out of ABS using the team's 3D printer; this will ensure a perfect fit with the plywood chassis of the rover and the electronic parts inside. The bay will have a removable lid such that the electronics are easily accessible; this lid will be bolted into place to prevent accidental opening during driving. The electronics bay will also feature holes that allow power wires to be connected from the battery and to the motors and servos. Additionally, the underside of the electronics bay will hold the LiPo battery in place within the chassis of the rover. The bay itself will be bolted to the chassis' upper plywood plate and will be removable to allow access to the battery. The figure below shows, from left to right, the motor controller, the radio receiver, and the microcontroller housed in the electronics bay (lid removed for visibility).

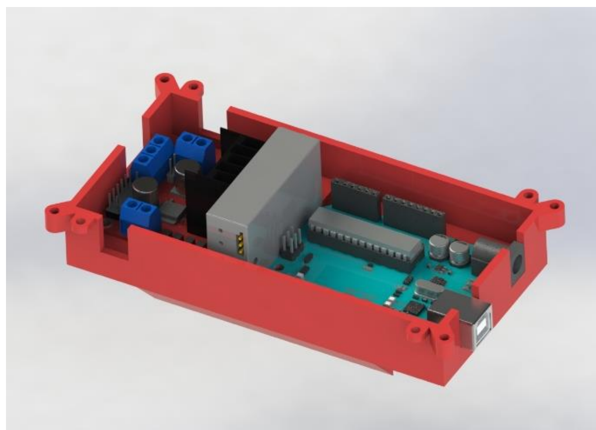

Figure 4-7 BURRITO Electronics Bay Interior

The microcontroller selected was 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 selected motor controller was 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.[14] The radio receiver selected was an FrSky X8R, which operates on the same band (2.4 GHz) as a compatible radio transmitter the team already owns. The X8R features 8 PWM channels, more than enough to control two motors and two servos.

The Arduino Uno will be 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

[14] 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].

send motor signals. The connections between the Arduino Uno, X8R, servos, and L298N Motor Driver will be transmitting PWM (Pulse-Width-Modulation) signals. As for power transmission, the Hyperion G5 battery will be directly connected to the L298N Motor Driver, and Arduino Uno. The L298N will transfer this power to the drive motors on command, while the Arduino will regulate the voltage down and send power to the servos in the SICCU ice collection unit underneath the rover. The figure below illustrates this setup in the form of a flow chart.

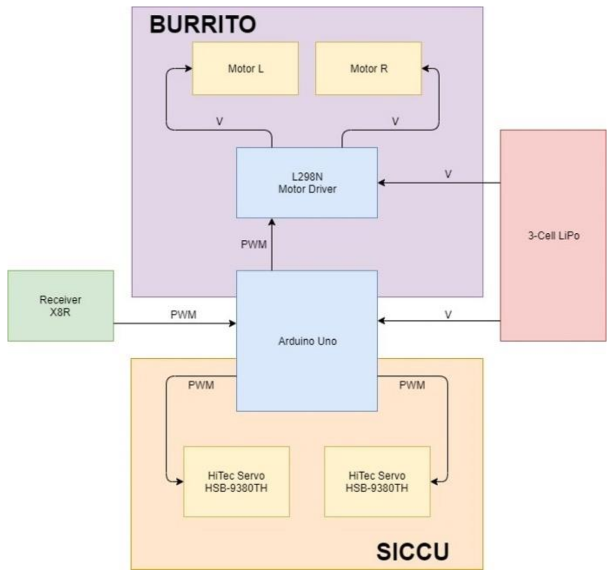

Figure 4-8 BURRITO Electronics Flow Chart

The following scenario illustrates exactly how data will flow 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 to the L298N Motor Driver. Upon receiving the signal, the L298N translates the PWM input to a voltage output; because the signal was received on the left side of the L298N's inputs, the voltage output is applied to the left motor. The PWM signal carried information on which direction the motor should rotate; as the operator moved 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 but does not require the medium of a motor driver.

The figure below is a schematic showing the actual connection layout of the BURRITO systems. The four 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 those components to move. It should be noted that a switch controls power flow from the battery; this must be flipped to the "on" position prior to launch. Additionally, two Yueton Voltage Checkers are attached to a port on the battery; these indicators emit a beeping noise when any of the cells drop below a certain voltage.[15] One indicator will beep when the rover has expended enough battery capacity to reach 2000 ft, and the other will beep when the battery has 10% of its charge remaining.

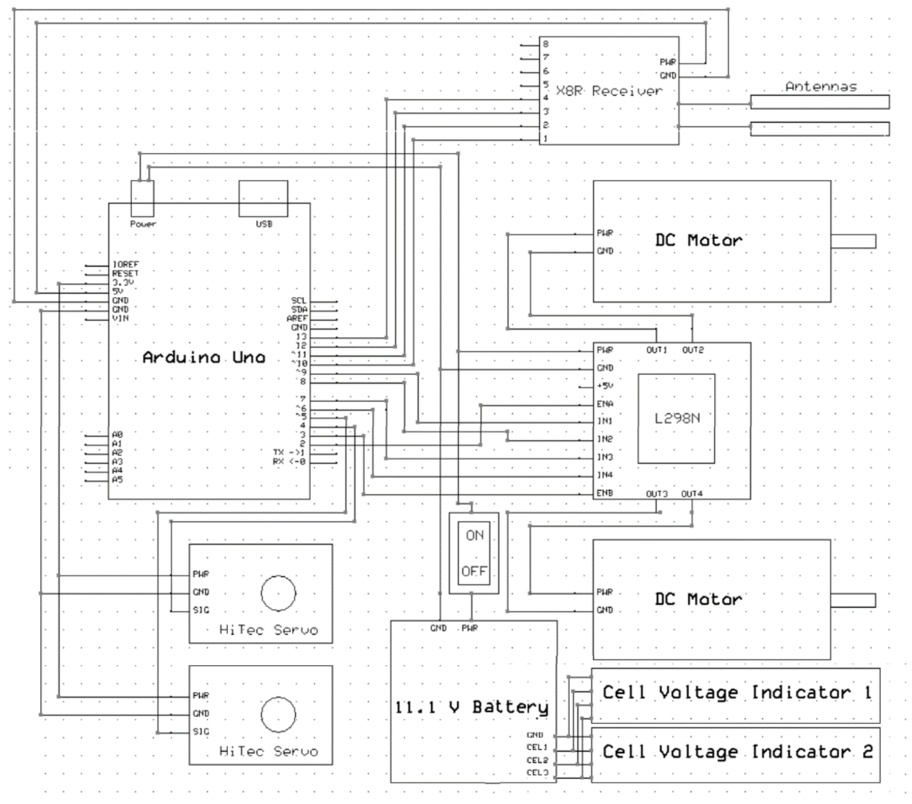

Figure 4-9 BURRITO Electronics Schematic

4.3.6 SICCU Mounting

In order to maintain BURRITO's clearance off the ground, a large portion of the SICCU system will be mounted inside the chassis of the rover. The servos selected for SICCU are just thin enough to fit between the drive motors and the battery and will be bolted to the plywood chassis on the top and bottom plates. The bottom plywood plate will feature cutouts such that the servos can slide into place and have enough room for their signal and power wires to loop back to the electronics bay. Additional cutouts will be made such that the gears used to transmit rotation from the servos to the scoops below will be able to interface. The rendering below shows how the SICCU system will interface with the structure of the BURRITO chassis; the front chassis plate has been removed for visibility.

[15] "yueton Rc 1-8s Lipo Battery Tester Monitor Low Voltage Buzzer Alarm Voltage Checker with LED Indicator for Lipo LiFe LiMn Li-ion Battery." Amazon, 2019. [Online]. Available: https://www.amazon.com/Battery-Monitor-Voltage-Checker-Indicator/dp/B013U1CP08. [Accessed: Jan-9-2019].

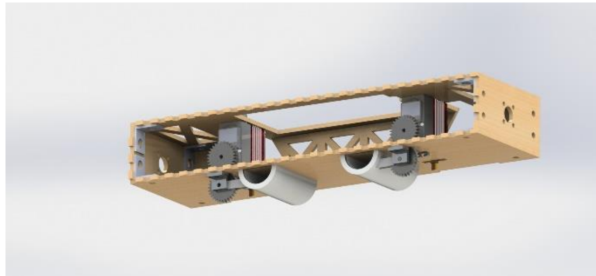

Figure 4-10 BURRITO Interface with SICCU

4.4 BURRITO Rover Manufacturing

4.4.1 Chassis Structure

As stated in the design of BURRITO, the chassis is constructed of birch plywood panels laser cut to shape. The panels that are not intended to be removable will be glued together with wood glue; the toothed edges of the panels will ensure that they are positioned correctly. The removable panels on the left and right sides on the rover will attach to the rest of the structure with bolts. The team has a great deal of experience building plywood structures, and is familiar with the operation of the Dremel Laser Cutter; as such, the process of cutting and gluing will occur quickly and with little difficulty.

Steps for Manufacturing:

- Using Adobe Acrobat Pro, prepare the 2-D sketches of the plates for laser cutting by setting the sketch lines to be 0.01 pt in size and red in color.
- Put on a pair of safety glasses.
- Place a board of 1/8th inch birch plywood into the Dremel Laser Cutter.
- Increase the laser power level to be 10% higher than default, set the movement speed to 10% lower than default, and set the number of passes to be 2.
- Upload the Acrobat Pro file to the laser cutter and ensure that the plates are the correct scale and position relative to the board being cut.
- Start the laser cutter and supervise it; stop the laser cutter if board catches fire.
- After the cut is complete, wait for the vacuum system to remove the fumes for 1 to 2 minutes.
- Remove the cut parts from the laser cutter and discard unwanted fragments.
- Using wood glue, glue the permanent parts of the rover chassis together and wait until dry. Ensure that the servos for the SICCU system are in place before gluing all plates together.

4.4.2 Drivetrain

The manufacturing of the drivetrain consists of connecting the motors to the drive wheels, printing and assembling the two caster wheel systems, and connecting these systems to the chassis, control systems, and battery as needed.

Steps for Manufacturing:

- Cut a keyed hole of the same diameter as the motor axle into the drive wheel hubs and bolt the drive wheel hubs to the drive wheels.
- Bolt the drive motors onto their respective plywood plates.
- Attach the nylon rings to the plywood plates.
- Attach the drive wheels to the drive motors using the drive wheel hubs.
- Connect the plates with the drive motors to the chassis using nuts, bolts, and the L-brackets.
- Export the CAD model of the caster wheel arms to the Rostock Max V2 3D printer and run the printer.
- Bolt the spring hinges, caster wheel arms, and caster wheels together, then bolt the assemblies to the rover chassis.

4.4.3 Electronics

The only physical manufacturing that must occur for the electronics is the 3D printing of the electronics bay that will house the control systems, as well as the wiring together of the electronic components. The controller, radio receiver, and motor driver will need to be programmed and configured to correctly control the rover.

Steps for Manufacturing:

- Export the CAD models for the electronics bay and its lid to the Rostock Max V2 3D printer and run the printer.
- Place the Arduino Uno, the L298N motor driver, and the X8R receiver into the corresponding slots in the electronics bay.
- Place the power switch in its location inside the rover chassis.
- Wire together all electronic components according to the diagram seen in the electronics section.
- Place the battery into its location inside the rover chassis, then place the electronics bay with its lid on top of it and bolt it in place.

4.4.4 System Integration

BURRITO will need to interface with both SICCU and the payload deployment system. For the former, parts of SICCU will need to be integrated before the gluing of the chassis plates. For the latter, the payload deployment system merely attaches to the side of one of BURRITO’s wheels, meaning that integration is straightforward.

4.5 Sample Collection

The Sample Ice Collection and Containment Unit (SICCU) is the principle system the BURRITO will utilize to acquire the ice on the launch field. Its current design consists of two scoops that will sit beneath the rover that, through gears, will be powered by two servos. Below are several views of the rendered and dimensioned view of the SICCU.

Figure 4-11 Isometric View of SICCU

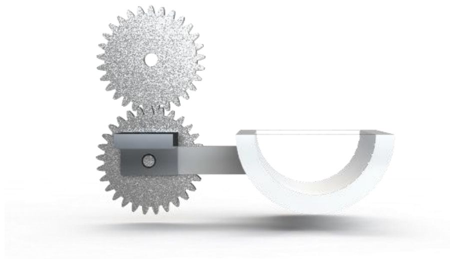

Figure 4-12 Rendered Front View of SICCU

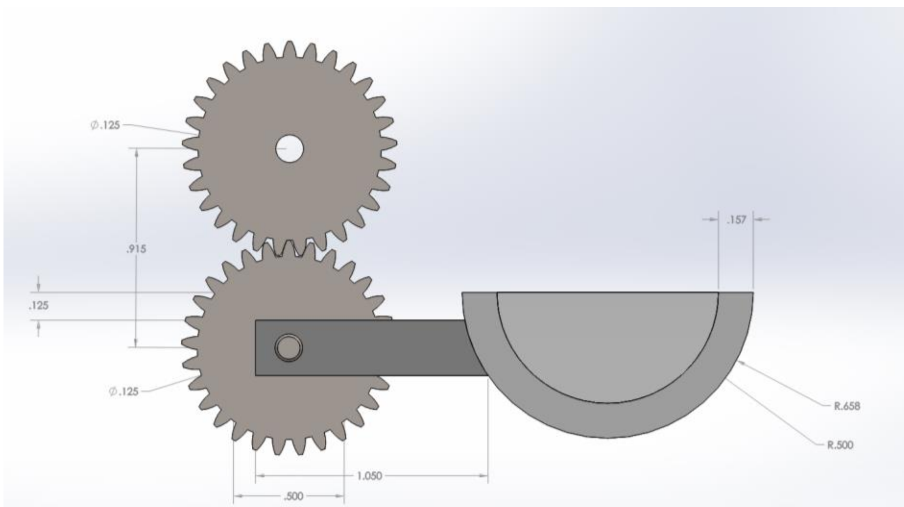

Figure 4-13 Dimensioned Front View of SICCU

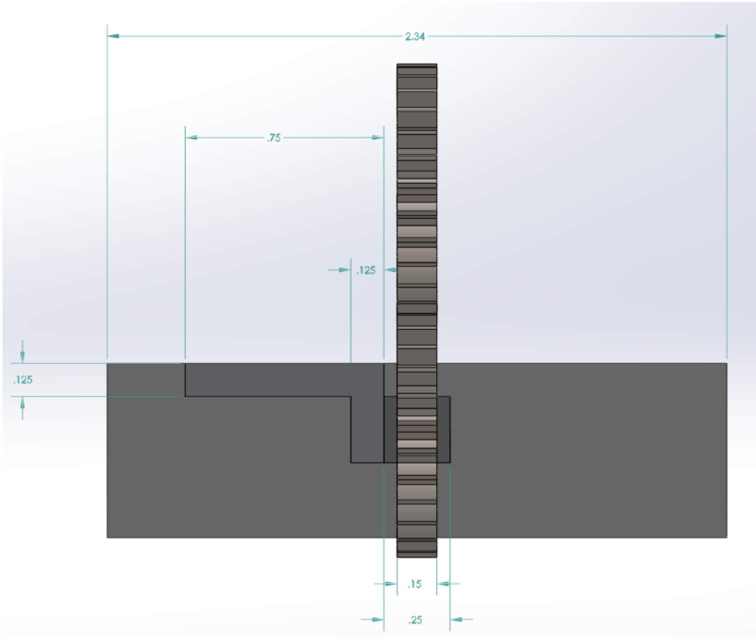

Figure 4-14 Dimensioned Side View of SICCU

Figure 4-15 Rendered Top View of SICCU

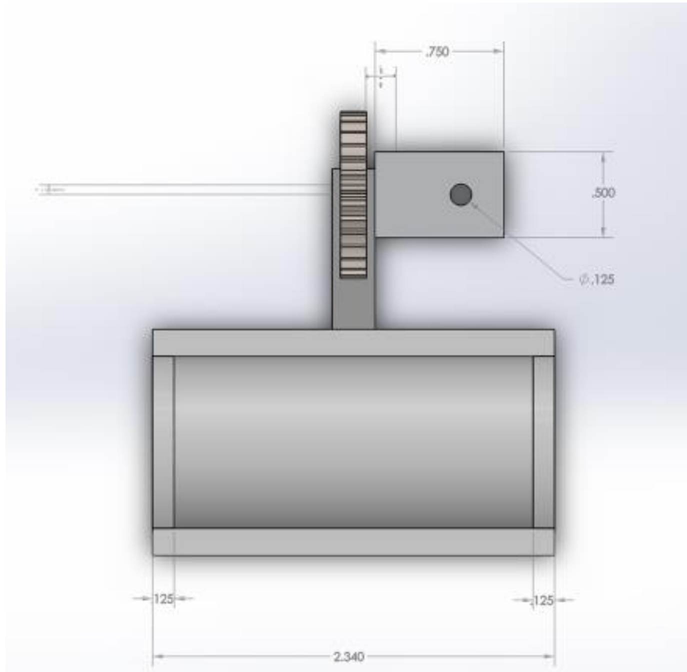

Figure 4-16 Dimensioned Top View of SICCU

The set of gears, seen best in Figure 4-13, shows the power delivery solution. This solution is necessary due to clearance issues with the D951TW Servos constraining them to be mounted within the BURRITO's chassis. Because the axis of the servo and the axis of rotation of the scoop are not colinear two gears with a 1:1 ratio will deliver the power the scoop arm. The lower gear is fixed to the aluminum arm while the upper gear is fixed to the servo. The aluminum arm is fixed to the PVC scoop. The aluminum will be contoured to mate with the side of the PVC. On either end of the PVC an acrylic insert will be placed to fit within the inner radius of the PVC Pipe seen in Figure 4-11 and Figure 4-13. The Acrylic inserts will be attached using PVC Cement which has been verified to withstand reasonable loads. With that consideration made, the primary force experienced during sample collection would cause the acrylic to press against the PVC, therefore it is unlikely to cause an issue. In the final iteration of design, a modest housing of 3D-Printed PLA Plastic will be included to protect the gears from being exposed.

4.5.1 Alternative Selections

For the overall Sample Collection method, the Two Scoop was chosen. The primary factors that informed this decision are volume and complexity. The small volume necessary to facilitate scoops is valuable since the space underneath the BURRITO is very limited. The complexity of the scoops is also very limited in that it functions congruent to a rotating arm.

For the Scoop Material the selection was made for PVC. PVC's primary advantages are that its light weight, high strength, and convenient geometry integrate well into the intended manufacturing scheme.

For the Power Delivery method, Servos were selected. The servos have the advantages of small size and low weight. The small size is important because the internal capacity of the

BURRITO is limited even excluding the other critical components to its own operation. The low weight serves to keep the chassis from being stressed unduly.

For further detail review alternative analysis tables in PDR Sections 5.3.2.1 and 5.3.2.2

4.5.2 SICCU Manufacturing

Steps for Manufacturing:

- 1" PVC and cut it in half axially using the band saw
- Trim the PVC to have two lengths of 2.34 Inches
- Each PVC Length will be slotted and adhered with epoxy
- The aluminum arms will be trimmed and slotted to a gear each
- Each gear-arm assembly will be pinned to an L-Bracket
- The L-Bracket will be screwed into the bottom panel of the BURRITO and the teeth of the gears will be properly meshed

4.5.3 SICCU Integration

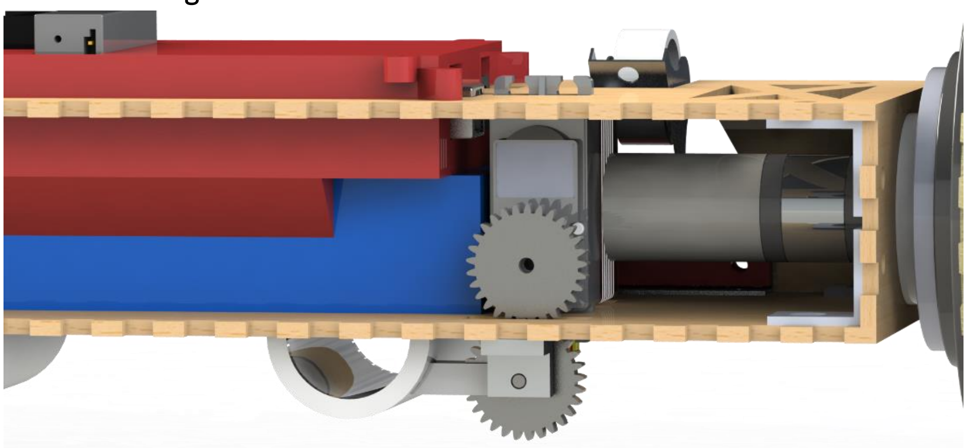

Figure 4-17 SICCU Integration

The SICCU is fixed to the bottom panel of the BURRITO by an L-Bracket for each scoop. The gears will transfer the power from the servos mounted within the body of the BURRITO to the axis of rotation to each of the scoops. The orientation displayed in Figure 4-17 shows the post-sample stowed position.

4.6 Payload Integration

4.6.1 Background

As defined by the NASA SL handbook, the main requirement of the payload integration system is to retain the payload during flight. As this retention of the payload is a safety concern, it is prioritized higher than the actual functioning requirement of the integration system. The payload and aerodynamics team have decided that to obtain the required 2.0 stability margin, the payload and deployment components of this challenge should cumulatively weigh no more than eight lbs. The payload team has divided this weight by allotting 4.5 lbs to the rover and 3.5 lbs to the integration system. The specifics for how the payload weight effect the stability is covered in the Stability Margin Study section

(4.3.1). The following sections will describe the final deployment mechanism, controls and retention system selected for the 2020 NASA Student Launch event.

4.6.2 Integration System Overview

All alternative designs for payload deployment were centered on the same base design of a linear actuated system. The base system is comprised of a main plate, electronics bay, and pushing plate. The final design includes all three of these subsystems. The main plate which contains the power transmission, actuation motor, and interfaces with the lead screws. The electronics bay acts as an extrusion to clear a six-inch coupler section at the aft end of the payload bay. The electronics bay will contain the power supply for the entire system as well as the microcontroller, communication module, and retention motor. The pushing plate houses a retention mechanism that interfaces with the rover. Finally, radial supports are placed between the minor axis of the main plate and the payload body tube to minimize forces on the retention mechanism as well as restrain the payload during flight. The following figure shows an exploded view of all main subsystems of the payload integration system.

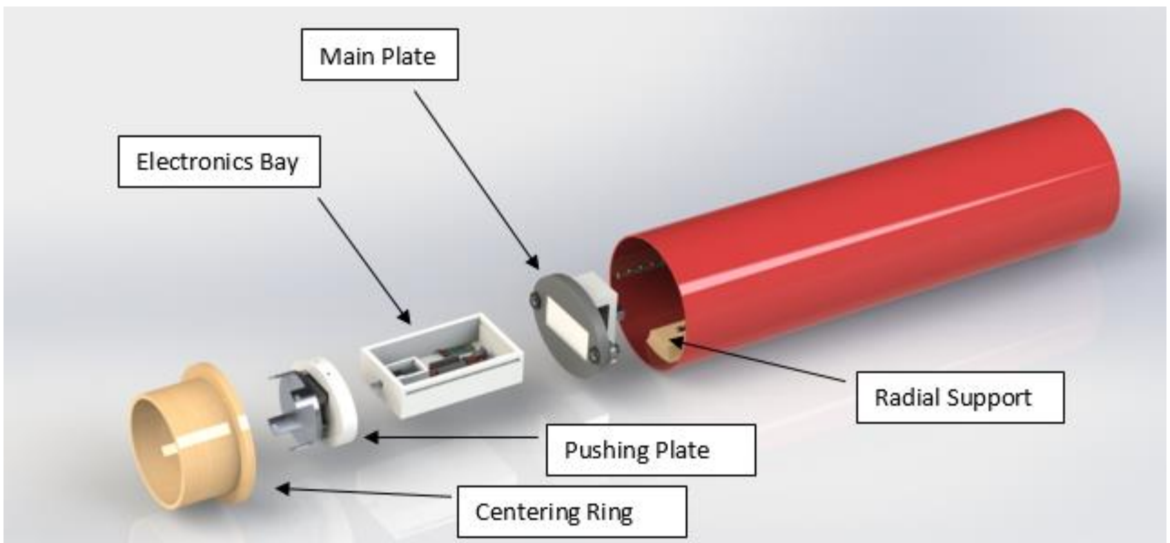

Figure 4-18 System Overview

The axial dimensions of the payload deployment system are displayed in Figure 4-19. From forward to aft end, the integration system measures approximately 9.9 inches in length. A desired 15-inch rover would make the full payload assembly 24.9 inches in length, which is longer than the payload bay section.

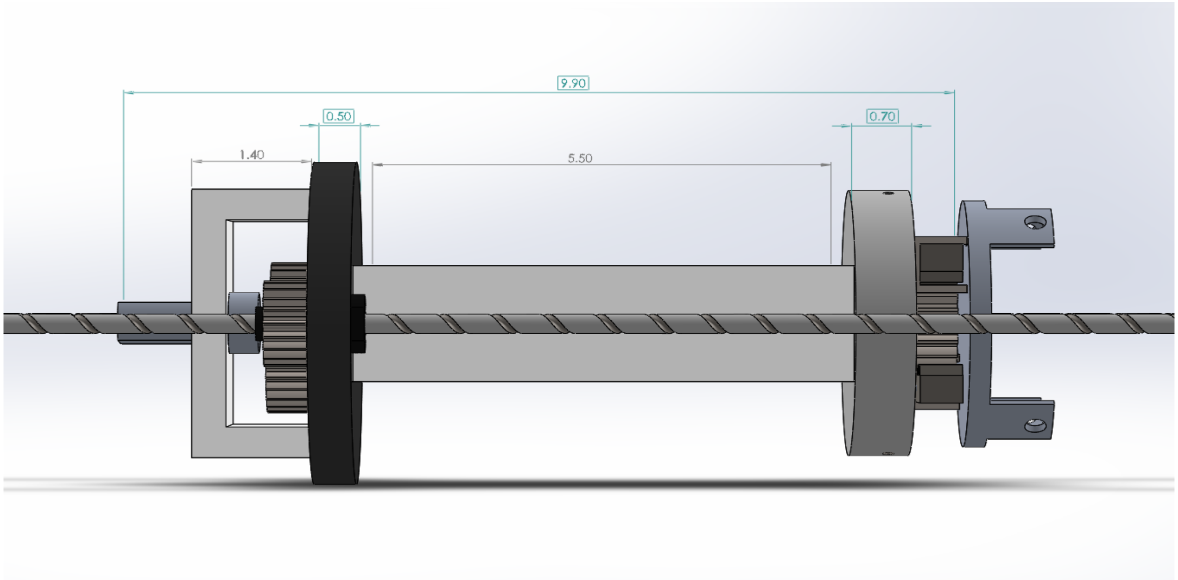

Figure 4-19 Axial Dimensions of Payload Deployment System

In order to accommodate the length of the rover, two actions will be taken to maximize the available space. The first of these actions is to implement an extrusion off the aft centering ring as depicted in Figure 4-20. This extrusion will support the rover's aft wheel and will help to mitigate the space that is lost due to the coupler that will be removed during the coupler procedure. The second action will utilize the nosecone bulkhead to secure the lead screws. This will provide several additional inches forward of the payload bay to meet the space requirements given by the rover team lead.

Before building the integration system up by its respective components, the entirety of the system and how it interfaces with the actual payload is displayed in Figure 4-20.

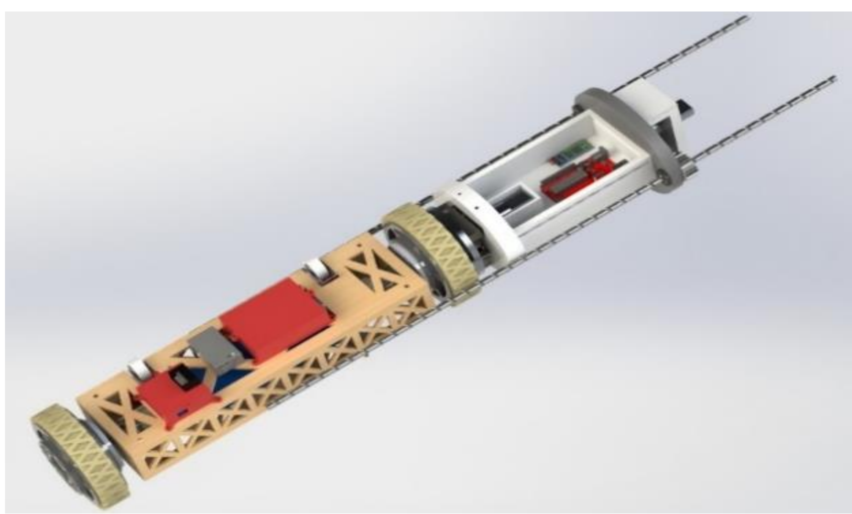

Figure 4-20 Rendered model of the rover interfacing with the integration system

4.6.3 Power Transmission

The considerations for power transmission included a belt driven system, a three-gear system, and a five-gear system. The belt driven system has potential to slip and while this could be mitigated, the team erred on the side of caution and eliminated this consideration for a more reliable system. The three-gear system required a large drive gear, which introduced two problems. The main plate was forced to take on a circular geometry in order to accommodate the 3.75-inch diameter gear. Second, and more importantly, the gear ratio reduced the output torque of the motor by a factor of 3.5. A larger motor would have been required, which introduced issues with the available axial space, would add more weight and potentially increase deployment time as the speed of a DC motor tends to decrease with higher torques.

The five-gear system reduces the drive gear (largest gear) from approximately 3.75 inches in diameter to 1.6 inches in diameter by utilizing two additional gears.

The resizing of the gears results in the torque reduction constant dropping from an initial value of 3.5 in the three-gear system to 1.5 in the five-gear system. The reduction of the drive gear also allows for the main plate's geometry to take on an ovular shape. With an oval shaped main plate, the minor axis provides enough room to place radial supports. These radial supports will be discussed in greater detail in section 4.6.6.4.

As seen in Figure 4-21, there are three sized gears, the drive gear (diameter = 1.6 inches), the middle gears (diameter = 1.4 inches) and the exterior gears (diameter = 1.1 inches). As discussed in the PDR, the team has eliminated any plastic (i.e. acetal) gears.

The ideal material for these gears was to be aluminum, which offered the necessary strength at a low density. However, due to the restricted commercial availability of aluminum gears with the necessary dimensions, these gears will be of a steel alloy. Two flange nuts will act to convert the rotational motion of the gears to linear motion down the screw. The flange of each flange nut will be located on the underside of the main plate, and the extruded hub will run through the main plate and be friction fitted as well as bonded to the inner bore of each of the external gears. The two mid gears are mounted via greased, aluminum pegs that are bonded into the half-inch thick main plate. Both the mid gears and external gears will generate friction from contact with the main plate. To minimize this friction, spacers will be placed between the gear and the plate. The motor is secured by a table extruding above the main plate and the drive gear is fitted to the drive shaft of the motor. Both the motor table and main plate will be 3-D printed with ABS to conserve weight. The main plate or any of its components will not be subjected to extreme stresses therefore a stronger material is not warranted. Verification for this assumption is provided by a FEA analysis discussed in section 4.6.6.4

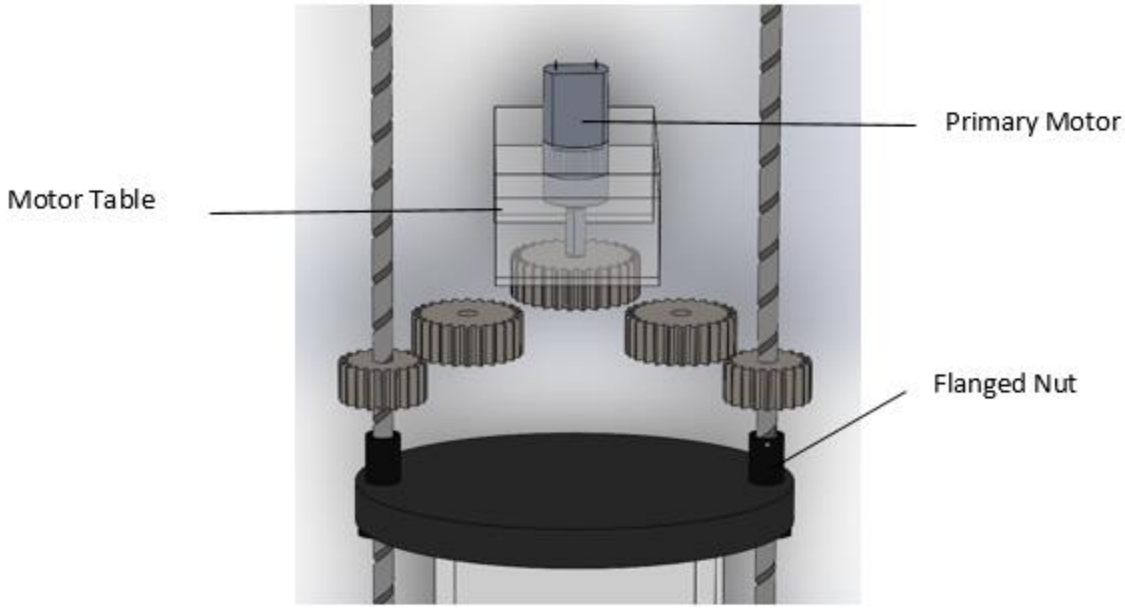

Figure 4-21 Gear assembly and Motor Table

4.6.4 Actuator Components

The two considerations for actuation were the type of screw used (lead vs ball screw) and whether to use two screws or a screw and guide rod combination. The ball screw provided benefits in reducing the friction during the deployment phase. However, this advantage was heavily outweighed by the cost of commercially available ball screws. Therefore, the team has opted to minimize the overall budget and incorporate lead screws into the final design. The design will also incorporate two lead screws in order to provide a balanced axial force distribution, minimizing the potential for unnecessary resistance. Initially, when the integration weight was only 2 lbs, there was a concern that two screws would add too much weight to the system. However, as the rover's weight estimate fell, the additional weight of a second screw was able to be justified.

This actuated system requires all three components of the integration system to move together along the axial axis of the payload bay. As discussed in the power transmission section, for the entire system to move as one body, the actuating nuts must be fixed to the main plate. This is done by bonding the external diameter of the nut's hub to the inner diameter of the gear's bore hole. The flange of the nuts will be placed beneath the main plate, so it is able to pull the plate up when the motor reverses (necessary for loading the rover into the rocket).

As the only rotating components in this design are the gears and nuts, the lead screws can be completely fixed within the structure of the rocket. The forward end of the screws will be fixed within the nosecone bulkhead and the aft end fixed into a centering ring just forward of the coupler section. To allow for the desired 15-inch rover, each of these screws will need to be approximately 24 inches in length. Lastly, the lead screws will be of 303 stainless steel due to price and commercial availability.

4.6.5 Motor Selection

The motor comparison was straight forward as the motor selection was primarily based off its ability to provide the minimum torque requirements. Using the following two equations for required torque which were obtained from amesweb[16], a torque analysis was conducted and a minimum torque requirement of 68.8 oz-in was determined. This analysis was performed using the highest friction coefficients for leadscrew-nut interfaces to overestimate the required torque.

$$T_R = \frac{F d_m}{2}\left(\frac{l + \pi f d_m \sec(\alpha)}{\pi d_m + f l sec(\alpha)}\right) + T_c$$

Where T_R = required torque, F = load, d_m = mean thread diameter, f = coefficient of thread friction, α = half thread angle, and T_c = frictional torque of thrust collar.

$$T_C = \frac{F f_c d_c}{2}$$

Where f_c = collar friction coefficient, d_c = mean collar diameter.

Stepper motors provide an irregular torque profile[17], which creates more of a potential for the deployment system to get hung up relative to a constant torque profile that is offered by a DC motor. Due to this small potential, a stepper motor was eliminated from further consideration for motor types. As both brushless and brushed DC motors offered the desired constant torque profile at the specified requirements, the consideration came down to mass and volume. A RobotZone mini econ DC motor was selected due to its small dimensions, weight (1.5 ounces), and its ability to provide the minimum torque requirements by offering up to 104 oz-in of torque.

As discussed in the power transmission section, this actuation motor will be fixed into an extruded table off the main plate. This design also calls for a second motor for the retention mechanism. While the torque requirements for the retention system are not nearly as high, due to the lightweight and compact nature of this motor, a second mini econ motor will be housed within the electronics bay.

4.6.6 Controls Overview

The initial deployment system was one that would demonstrate autonomous capability. The procedure was that an accelerometer would detect the various flight stages the rocket experiences through changes in acceleration felt during launch, recovery deployment, and landing. Once landing was detected, the system would request approval to deploy with the team through use of transceivers. The first step in this process was recovering acceleration data from the subscale flight. However, complications arose with this subsystem during flight and the data was not obtained through the subscale flight. In

[16] (*Leadscrew Torque Calculations for Acme Thread*)
[17] (*Speed - Torque Curves for Stepper Motors*)

order to ensure that the full-scale system operates on launch day, the system has been modified to increase the overall reliability of the system.

The final design will operate solely on user input. The team will connect to the controller and payload integration system via a Bluetooth module and a smart phone. Once connected, a user can use their smart phone's keyboard to initiate the loading or deploying procedures. This is a significant, but necessary simplification to ensure that all processes that occur post landing can be carried out as intended.

4.6.6.1 Software

The new control system has been designed around feasibility and reliability. BlueTerm is an android application that utilizes Bluetooth to send serial data to and from a microcontroller. This application will be utilized in tandem with a Bluetooth module connected to the microcontroller within the electronics bay. When the team approaches the landing sight, a mobile device with BlueTerm can connect to the microcontroller communication module and send signals to initiate both the deployment sequence and the unlocking sequence. By eliminating dependence on multiple integrated electronic systems, the potential for failure dramatically reduces. Another advantage this new system holds over the autonomous system is that the Bluetooth network can be secured, only allowing the one specific mobile phone to connect to the system. This secured network would block out any potential interference from the onboard altimeters as well as other SLI teams that could cause the system to deploy prematurely. One final benefit of this system is that it eliminates the need for a second microcontroller-transceiver device as all smart phones have Bluetooth modules integrated into them.

4.6.6.2 Hardware

Peripherals are external input and output devices that add functionality to a control system. This system requires connection to three peripherals. Two of these peripherals are independent motors and the third peripheral is the Bluetooth module.

In order to allow the two motors to operate both forwards and backwards, an H-bridge is required to reverse the polarity of an applied voltage. This can be accomplished by building an H-bridge circuit, or by purchasing a motor shield with a built in H-bridge, as well as voltage and current regulators. Many common microcontrollers such as the Arduino Uno and Sparkfun Redboard have an abundance of motor shields that can interface with DC motors. The Sparkfun Ardumoto motor shield can run two independent motors at up to 2 Amperes per channel, which is more than enough to cover the needs of this project. The Ardumoto and its corresponding microcontroller, the Redboard, have been selected to control the different subsystems within the payload integration system.

The third peripheral, the Bluetooth module, was selected based on power draw. Common modules such as the HC series (HC-05 or HC-06) operate on minimal power and are capable of being switched to power saving modes of operation when they are not in use. This means that the time between loading the payload into the rocket and deployment the payload, the HC module will be placed in an idle mode and draw minimal power until the SLI team connects to the module for the deployment sequence.

The most restrictive parameter on the initial controls design was the range of the transceiver modules. However, as the SLI teams can walk up to their landed rocket, these range factors are no longer required when selecting a communication module. The HC modules are operable up to 30 ft which is well within the new range requirements for this system.

A summary of each component of the controls system and their respective characteristics can be seen in Table 4-5. In this table, the extreme ranges of current draw have been utilized. For example, the stall current for the mini econ motor is 0.3A. While this is not the actual operating current, it was used to overestimate the power needs of the project. Finally, a safety factor of 3 was applied to the overall power budget. This safety factor was set in place if the SLI team misses the initial launch window and must utilize a later volley to launch the rocket. By selecting a power supply based on this safety factor, the system is designed to be fully operational on one power supply for the entirety of the launch day. The battery selected to perform this job is an ADMIRAL 1000mAh 11.1V battery. The voltage given by this battery is comfortable within the allowable ranges for both the motors and the microcontroller, while offering well over the required capacitance.

Table 4-5 Power Consumption per Launch Window

Power Budget Per launch				
	Operating Current (A)	**Idle Current**	**Time Active (hrs)**	**Consumption (mAh)**
Redboard	5.00E-02	-	2	100.00
Actuator Motor	0.3	-	0.06	16.67
Retention Motor	0.3	-	0.01	1.67
HC-06	2.00E-02	2.00E-03	2	0.006
			Total	**118.34**
			3x Safety Factor	**355.02**

A schematic showing the configuration between the motors, power supply and communication module are shown in Figure 4-22.

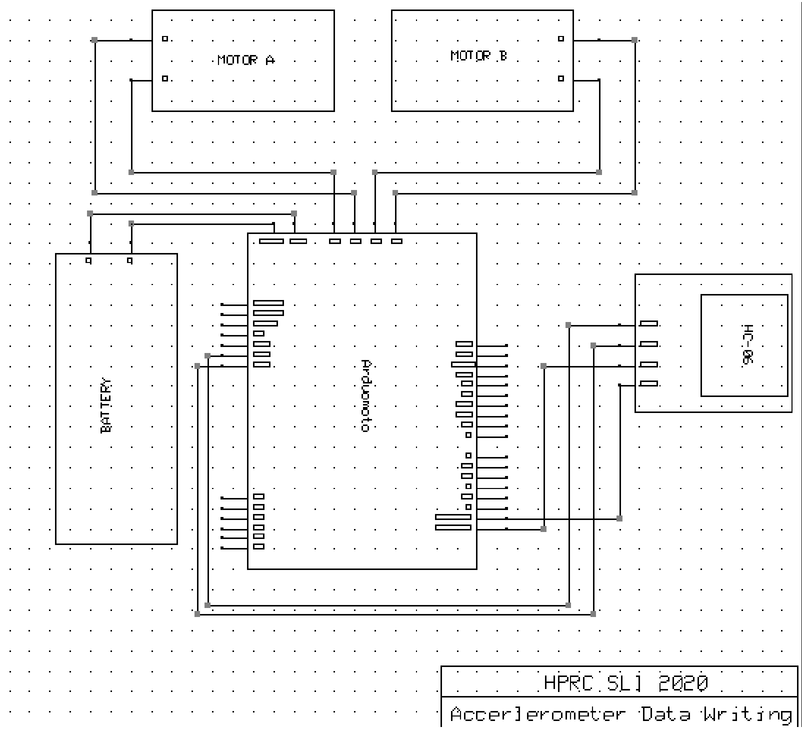

Figure 4-22 ExpressSCH schematic showing the configuration of the micro controller; peripherals and the power supply

4.6.6.3 Electronics Housing

All components of the payload integration system are housed on or within the main plate and pushing plate so that the entire system moves as one rigid body through the payload bay. Due to the system acting as one body, the most efficient use of space would be to house the electronics within the six-inch extrusion from the main plate to the pushing plate that interfaces with the rover. The electronics bay will be lined with foam padding to reduce any perturbations or vibrations that may be placed on the integration system during the launching and recovery sequence. Due to the housing section (electronics bay) needing to be 6 inches in length to clear the coupler section, this housing section has ample room to store all electronics, aside from the primary driving motor, within the electronics bay. The power source is not shown in Figure 4-23 but will be secured to the bottom side of the electronics bay. A hole will be drilled through this section allowing the power to be supplied to both motors and micro controller.

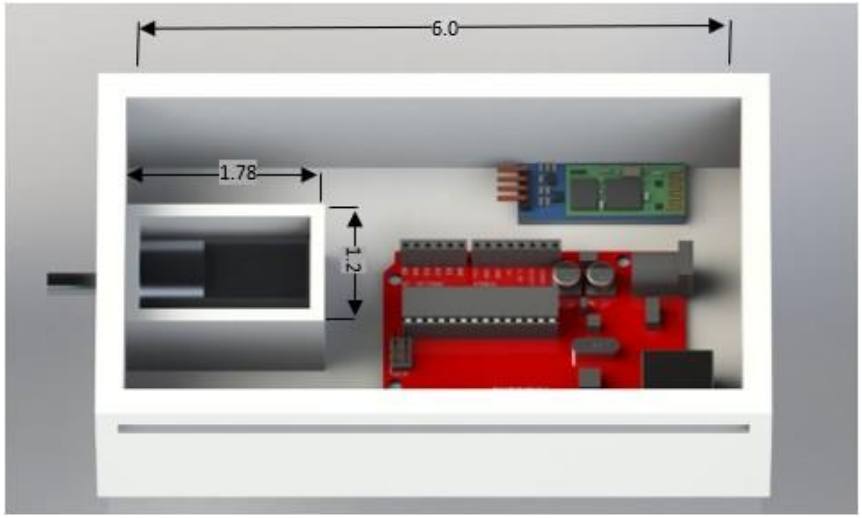

Figure 4-23 Electronics Housing design (credit for microcontroller[18] , HC-06[19])

4.6.6.4 Retention

The retention of the payload is the most important aspect of this design. As the RockSim dynamic analysis shown in section 3.5.2 shows a maximum acceleration change of ~40 g's, the retention mechanism needs to be rated to withstand peak forces up to 240 lbf, at an initial rover weight of 6 lbs. For the rocket to experience the predicted 40g in the RockSim analysis, the recovery team calculated that the parachute would have to open in approximately 1/20th of a second. Therefore, the rocket will most likely not experience the drastic change in acceleration, but a safety factor of 1.5 was still applied to this extreme case. With a 1.5 safety factor, the retention system was initially designed to withstand peak forces of 60 g's (360 lbf). However, as the weight of the rover has changed since the PDR and is now estimated at 4.5 lbs, a 40g acceleration results in approximately 180 lbs applied to the retention system, resulting in the safety factor increasing to 2 as the design will still be rated for 360 lbs.

In the unlikely event that the retention mechanism breaks during flight, there is no potential for the payload to become ballistic. The rocket has been designed such that the nosecone and payload bay stay coupled during flight and that the nosecone will point towards the Earth through the entirety of the recovery process. The only exception to the previous statement is if recovery systems fail and the rocket itself becomes ballistic. However, even in that event, the center of mass of these two sections are further forwards than the geometrical center. This provides a large

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[18] "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].
[19] "HC-06 bluetooth module | 3D CAD Model Library | GrabCAD." [Online]. Available: https://grabcad.com/library/hc-06-bluetooth-module-1#. [Accessed: 11-Dec-2019].

resistance to rotation and will not allow the section to flip its orientation allowing the payload to become a second ballistic.

However, the deployment sequence relies on the rover staying latched and, in the circumstance that the parachute becomes tangled and the rocket's orientation is flipped during descent, the latch shall be selected to withstand the forces felt within flight and a factor of safety.

To implement the Southco latch, it would have had to be placed within the electronics bay. This itself is not a concern, but the size of the latch took up more surface area than was available in the electronics bay. The Southco latch was also heavier than our alternative by a factor of 1.5. In order to keep the size of the electronics bay and weight of the retention system at a minimum, the alternative retention method has been selected. Therefore, the rest of the section will focus on the alternative "vault door" design.

The retention mechanism is modeled after a vault door. As shown in Figure 4-24 it is comprised of a central gear that's teeth are interlaced with two gear racks mounted to a guiding track. As the motor driven gear rotates, the gear racks can move within their respective guiding tracks. The motion of the locking bars is tangent to the rotation of the gear at the interface between the gear and the locking bar.

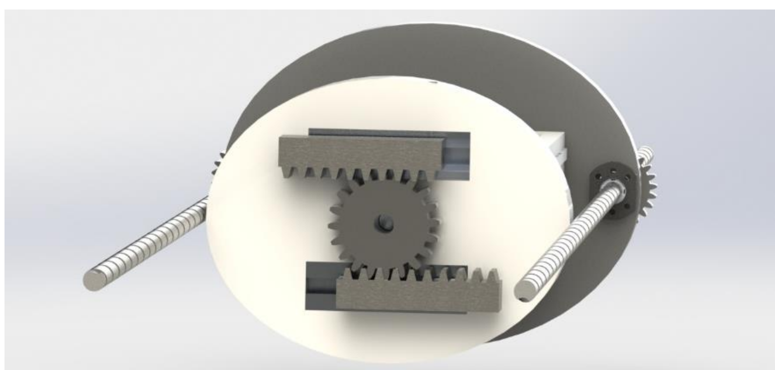


Figure 4-24Payload Retention Mechanism in the Locked State

Upon pre-launch assembly, the rover will be secured to the deployment mechanism by interfacing with a metal plate secured onto from the forward wheel of the rover as seen in Figure 4-25. The gear will be driven until the locking bars are fully extended through the plates U-brackets, effectively securing the rover to the deployment mechanism. After the deployment sequence has completed, the motor will rotate opposite of the assembly procedure. The gear racks will be pulled back in their tracks to a central position and free of their connection to the wheel, as shown in Figure 4-25.

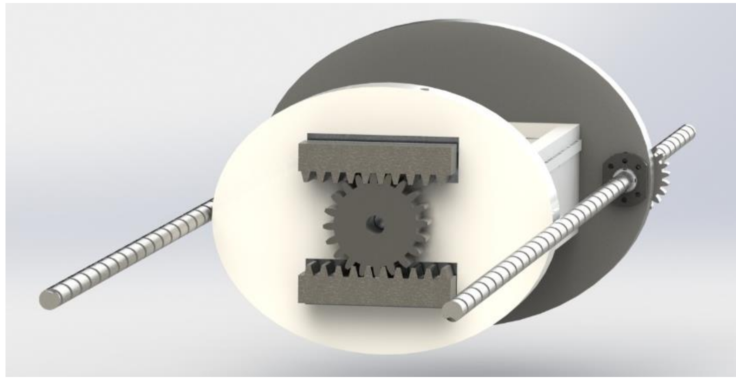


Figure 4-25Payload Retention Mechanism in the Unlocked State

The guiding tracks will be embedded and screwed into the aft pushing plate, securing the locking bars to the deployment mechanism. The main failure point of this design is if the guiding tracks are pushed through the pushing plate, or if the U-brackets buckle.

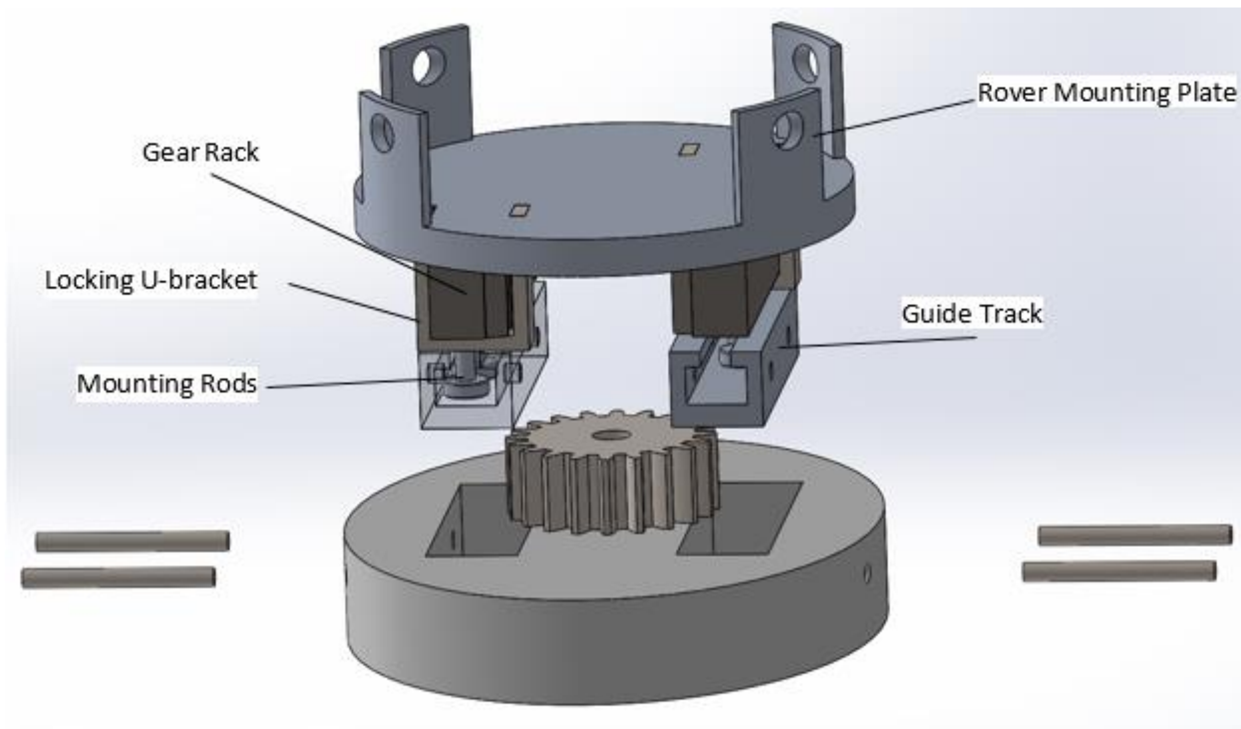


Figure 4-26 Exploded and labeled view of the retention mechanism

The initial FEA analysis conducted on the system was with the lightest weight components. The pusher plate used ABS, the U-brackets, rover mounting plate, and guide tracks were made of aluminum, mounting rods were of stainless steel, and the gear racks and gear were made of carbon steel. The following table displays each of these materials with their corresponding strengths.

Table 4-6 Material properties[20] of retention system components

Retention System Material Properties			
Component	**Material**	**Yield Strength (ksi)**	**Ultimate Shear Strength (ksi)**
Shell	ABS	6.2	-
Gear Rack	Carbon Steel	76.9	~30
Gear	Carbon Steel	76.9	~30
Mounting Rod	Stainless Steel	97.2	33
Guide Track	Aluminum	21	17
Mounting Plate	Aluminum	21	17
U-brackets	Aluminum	21	17

These material characteristics can now be applied to the following images of the ANSYS analysis to determine whether the system's components need to be modified or if the structure can withstand the predicted stresses.

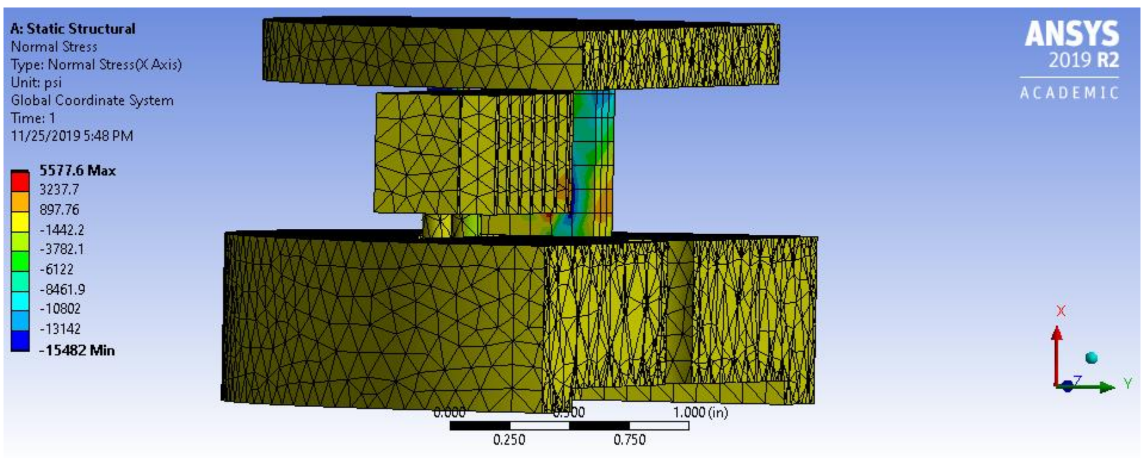


Figure 4-27 Normal Stress analysis of retention system

[20] (*Online Materials Information Resource - MatWeb*)

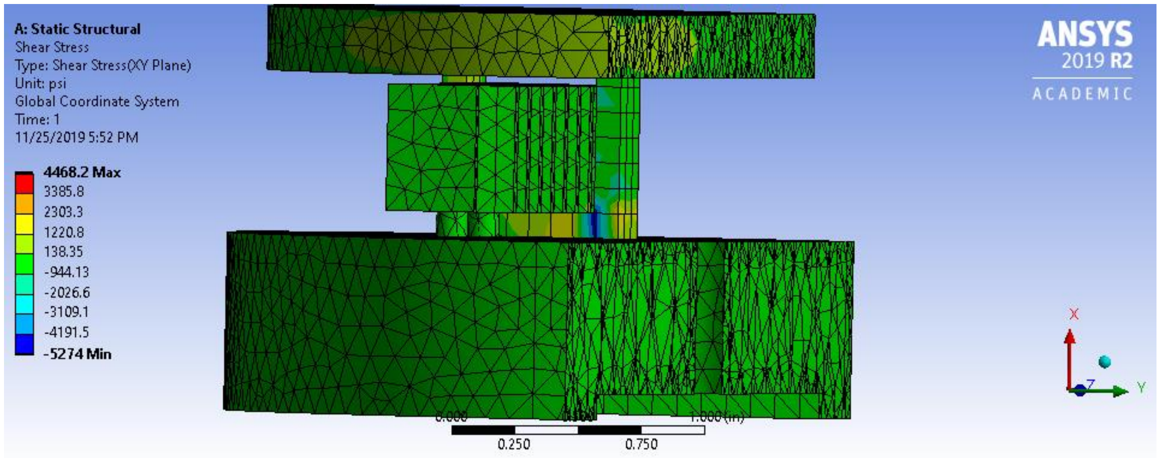


Figure 4-28 Shear Stress analysis of retention system

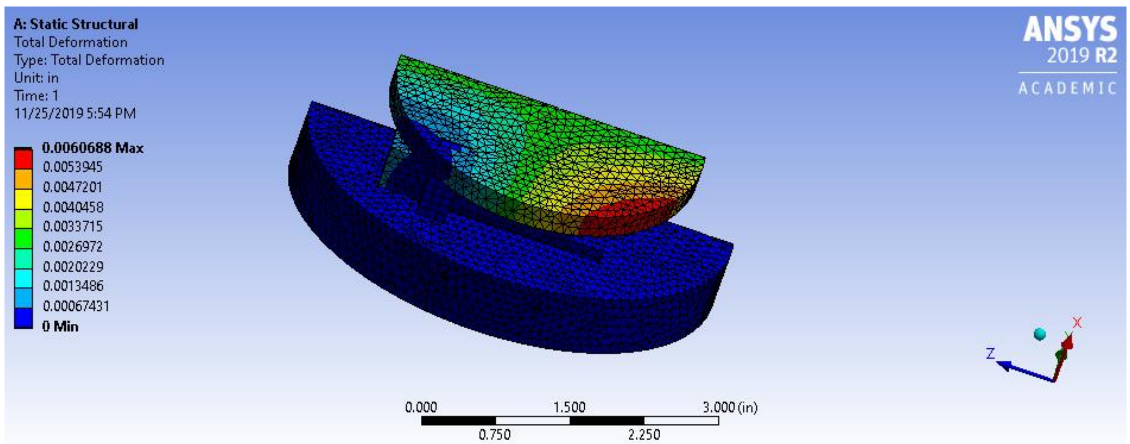


Figure 4-29 Deformation analysis of retention system

From the initial analysis, with a 360-pound force applied to the mounting plate, the maximum normal and shear stress occur on the U-brackets. As seen in the U-brackets are rated up to 17 ksi in shear and 21 ksi in tensile or compressive loading. The FEA analysis shows that a maximum normal stress of 15.48 ksi will be exerted on the U-brackets as well as 5.2 ksi in shear. The total deformation of all parts remained within a safe margin. As seen in the critical areas are on the aluminum plate, which experiences up to 0.006 inches of deformation. It is important to note the above analysis is specifically in the x direction or xy plane. Each plane was analyzed, and the highest stress values and corresponding planes were selected to present. Lastly, the analysis shows that no significant stress transfers to the pushing plate, therefore any component forward of the pushing plate was not analyzed.--

As stated, the results of the above analysis focused on how the lightest weight materials performed when 360 lbf was placed on the rover mounting plate. As shown by the analysis, all components were able to withstand the maximum forces therefore stronger components and a second analysis was not required. It is again worth noting that this design was centered on the assumption of a six-pound rover. As the rover's weight has decreased since this analysis, it only provides to increase the factory of safety and further verify that the materials will be able to withstand the stress. From the results, a prototype of the retention system will be constructed with these materials and subjected to compressive testing via the 1KM-T force applicator in NCSU's structures lab. This prototype will be tested until failure to verify that this system can hold a minimum of 360lbf and is indeed flight ready.

4.6.6.4(a) Weight Budget

The integration overview discussed the modification to the initial weight constraints placed on this design. The Payload Integration System now has approximately 3.5 lbs as the upper limit for allowable weight. A table has been constructed utilizing the materials analyzed through the ANSYS analysis.

Table 4-7 breaks down the weight of each individual subsystem (main plate, electronics bay, pushing plate) by their own respective components.

Table 4-7 Weight Breakdown of the Integration System

Weight Budget			
	Component	Material	Weight (lbf)
Main Plate			
	Shell	ABS	0.192
	Motor	-	0.094
	Motor Table	ABS	0.150
	Gears	Aluminum	0.250
	Mounting Rod	steel	0.140
	Lead Screw	Stainless Steel	0.600
	Flange Nut	Acetal	0.007
	Total		**1.432**
Electronics Bay			
	Shell	ABS	0.420
	Battery	-	0.413
	Motor	-	0.094
	MicroController	-	0.050
	Total		**0.976**
Pushing Plate			
	Shell	ABS	0.250
	Gear Rack	Carbon Steel	0.240
	Gear	Carbon Steel	0.100
	Mounting Rod	Stainless Steel	0.005
	Guide Track	Aluminum	0.060
	Total		**0.655**

4.6.6.4(b) Additional Supports

Aside from the locking mechanism, the rover will also need to be supported radially within the payload bay. As the team has opted for a power transmission design that allows for an oval shaped main plate, radial supports be aligned with the minor axis of the main plate and will placed between the main plate and the body tube as shown in Figure 6-29. These radial supports will restrict the rover in one degree of freedom, reduce movement in a second degree of freedom, reduce the stress placed upon the latch and help to guide the rover out of the payload bay during deployment.

The rover's aft wheel will also be placed within an extrusion from the aft centering ring. This extrusion will add additional support for the latch, keep the rover centered within the payload bay, and allow for use of the space that the coupler section occupies before ejecting. Figure 6-29 also depicts how the entire payload deployment system will be situated within the body tube as well as the aft centering ring extrusion which will support the rover's wheel.

As a last note, on additional supports, the interface between the rover wheels and the radial supports (and centering ring extrusion) will generate unnecessary friction. The team will loosely wrap the wheels in a fabric. The fabric needs to be loosely connected to the wheels so that upon deployment, the rover can easily roll out of fabric coverings to prevent any traction issues during the sample collection process.

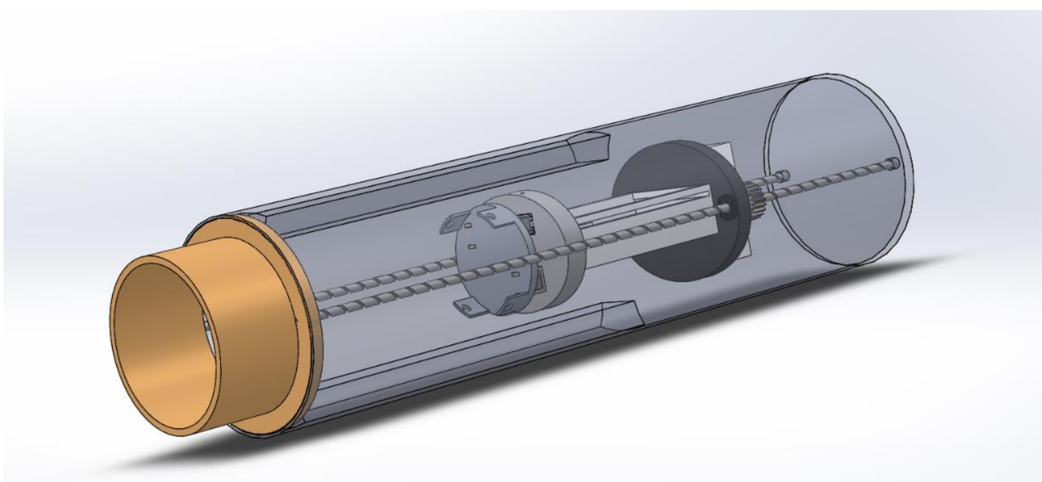


Figure 4-30 Payload Integration System with Radial Supports

5. Safety

Safety engineering is an essential part of Tacho Lycos' team structure, and as such, the team takes active steps, detailed below, to minimize personnel injury and maximize mission success. Using FMEA tables, fault tree analysis, personnel safety training, and a newly created lab handbook, the team seeks to create an environment with no worry of personnel injury or partial/total mission failure.

5.1 Safety Officer

Frances McBride is the safety officer for the 2019-2020 competition. Frances' responsibilities include collaborating with design teams to ensure mission success and personnel safety, educating the team on safe lab and launch practices, and optimizing lab design for increased safety. Frances or an individual trained by Frances as a stand-in safety officer is present for all team meetings, launches, and fabrication sessions for NASA Student Launch.

Responsibilities:

- Establish safety culture in club
  - Via frequent discussions on safety, training days, and weekly safety meetings.
- Provide redundant safety and checklist approval during launches
  - Every checklist item past 1A hazard level has a signed safety officer confirmation.
- Be present for all build days
  - Frances or another highly trained stand-in safety officer will monitor all build activities.
- Develop verifiable strategies to minimize personnel and mission damage
  - Including, but not limited to creation of lab handbook of condensed MSDS and how-to-use for all tools, labels on all power tools, and safety training for every lab space user.
- Collaborate with design teams to prevent failure through improving designs
  - Designs analyzed for redundancy and likelihood to succeed.

The safety officer is responsible for maintaining and enforcing the contents of the club safety handbook. This handbook includes condensed safety data sheets, instructional guides for tool usage, instructions for safe handling of hazardous materials, and guidelines for hazardous manufacturing procedures.

Additionally, the safety officer is responsible for creating supplemental failure mode and hazard analysis using Fault Tree Analysis (FTA). FTA helps the team deductively determine mitigations for hazards encountered during the project. FTA for various subsystems of payload, recovery, structures, environmental hazards, and personnel hazards are detailed below:

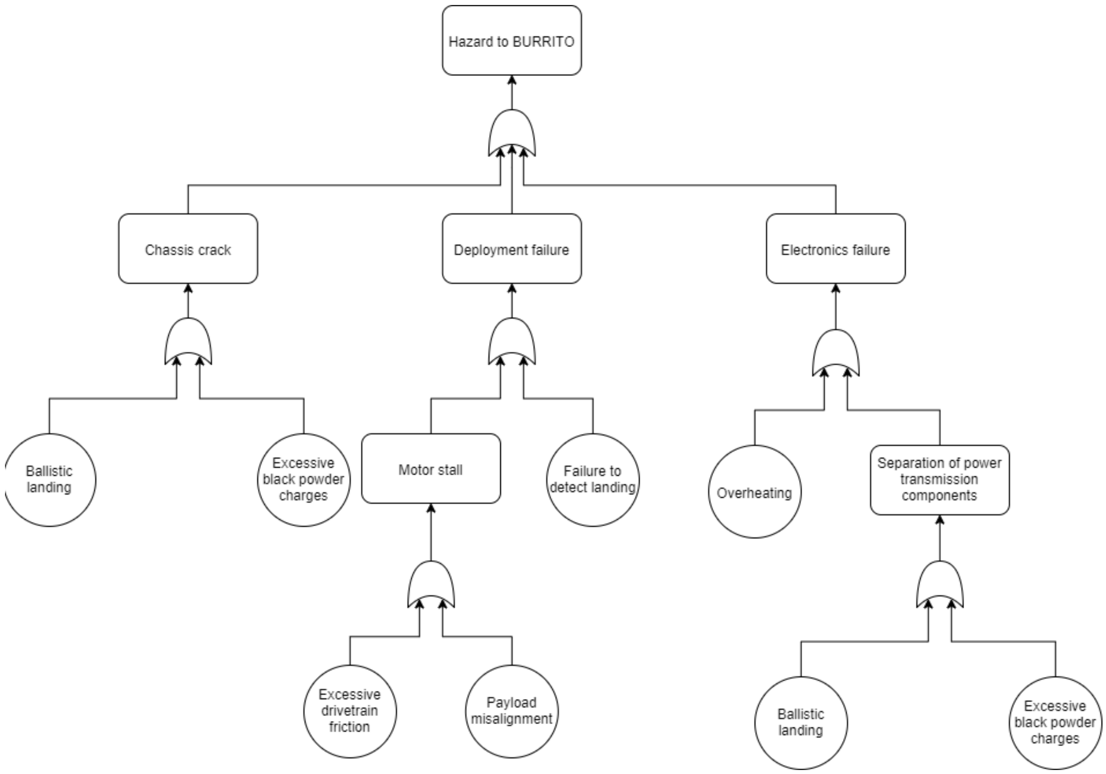


Figure 5-1 BURRITO Fault Tree Analysis

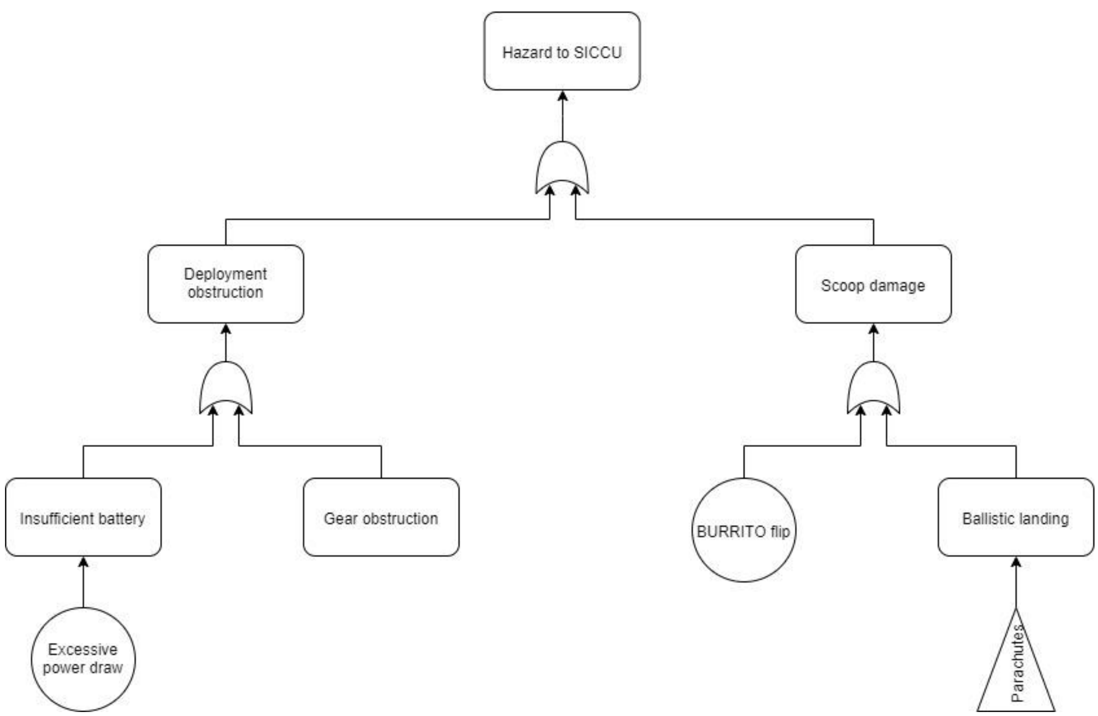


Figure 5-2 SICCU Fault Tree Analysis

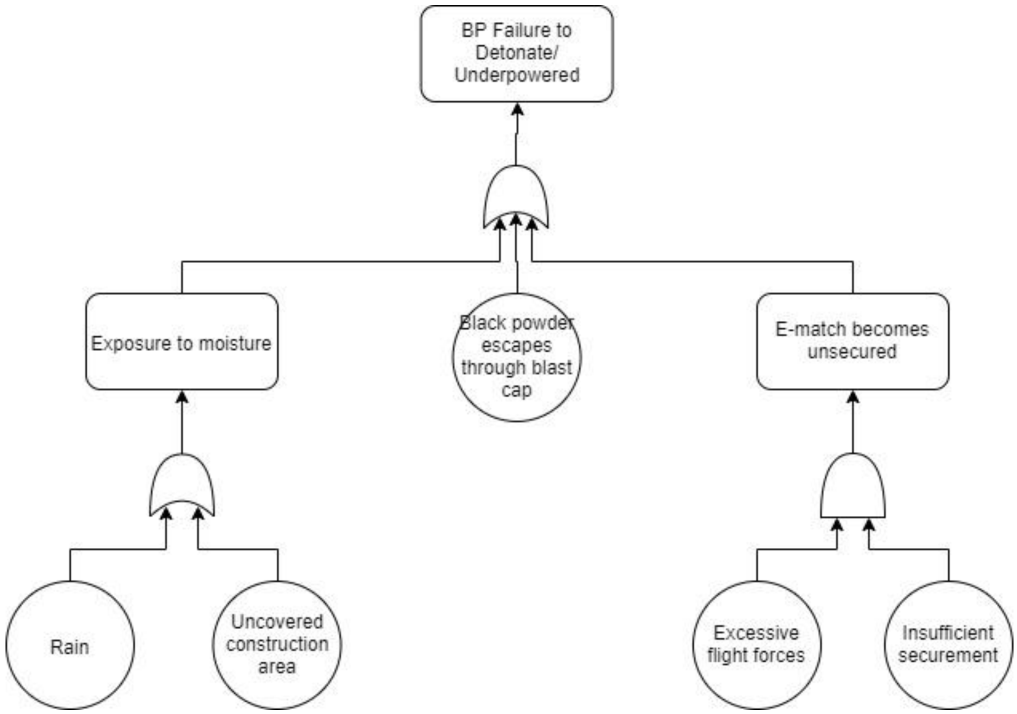


Figure 5-3 Black Powder Failure to Detonate Fault Tree Analysis

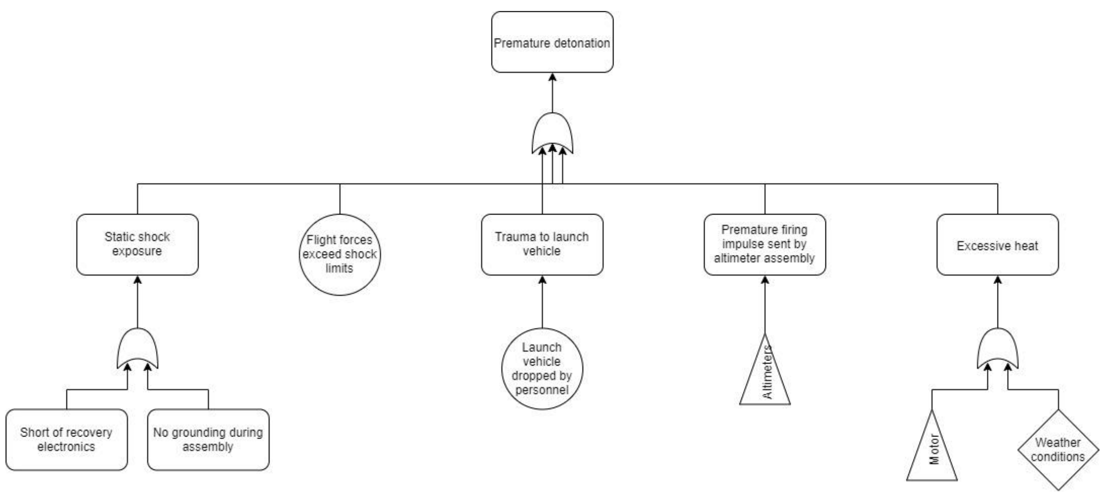


Figure 5-4 Black Powder Fault Tree Analysis

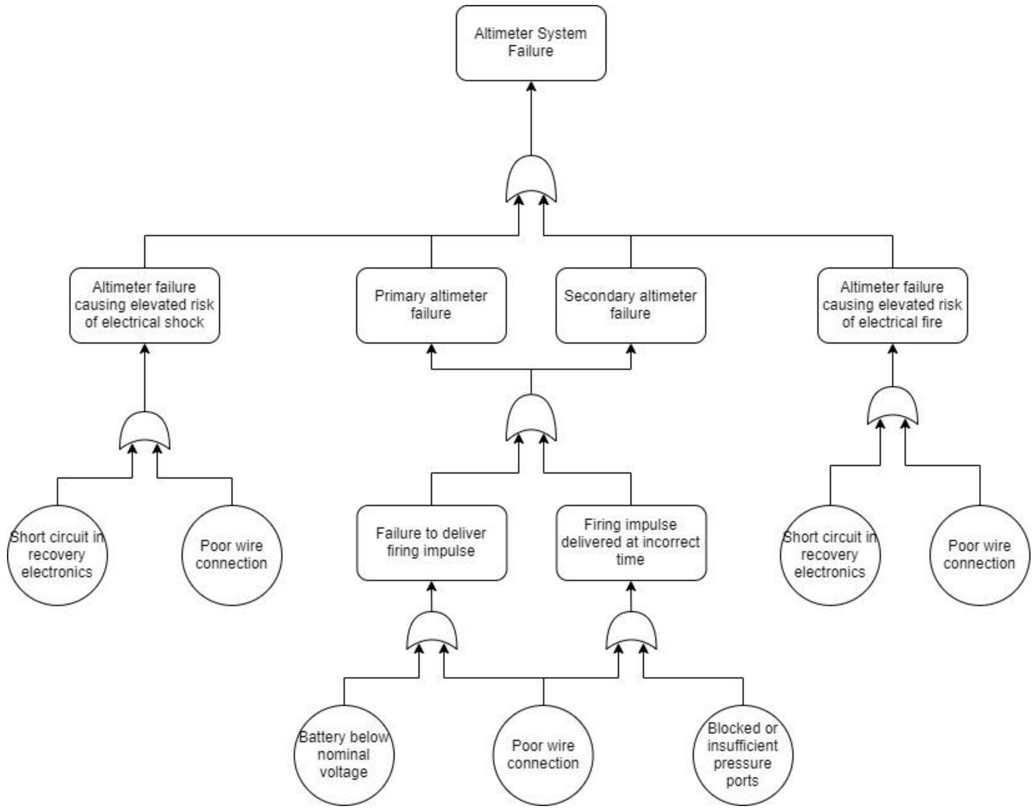


Figure 5-5 Altimeter Fault Tree Analysis

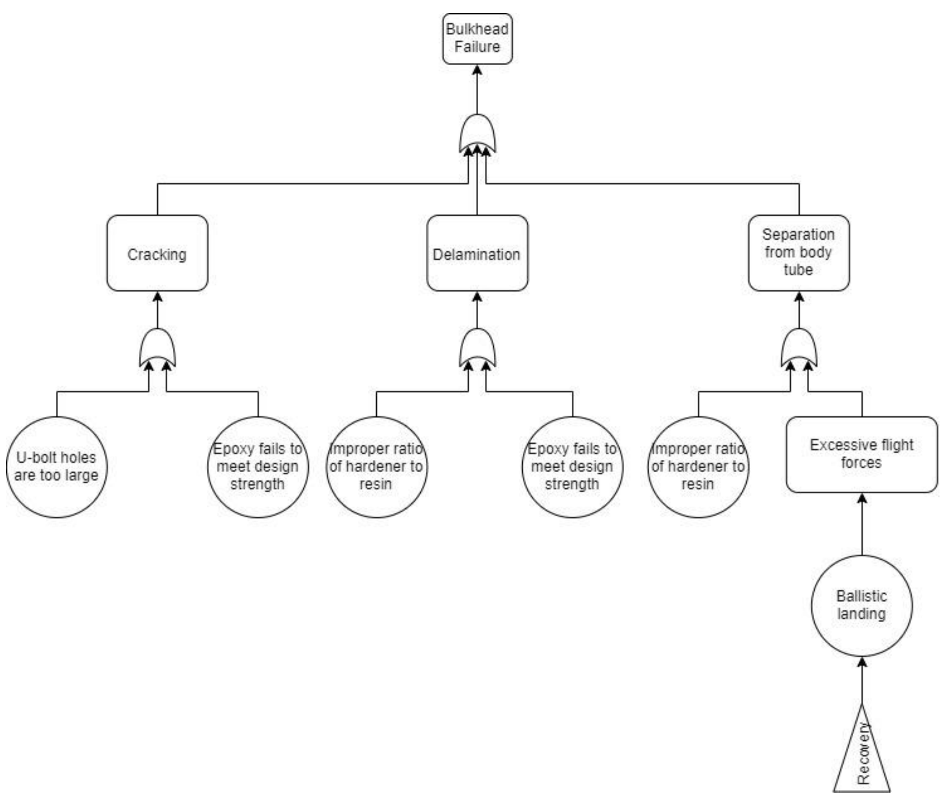


Figure 5-6 Bulkhead Failure Fault Tree Analysis

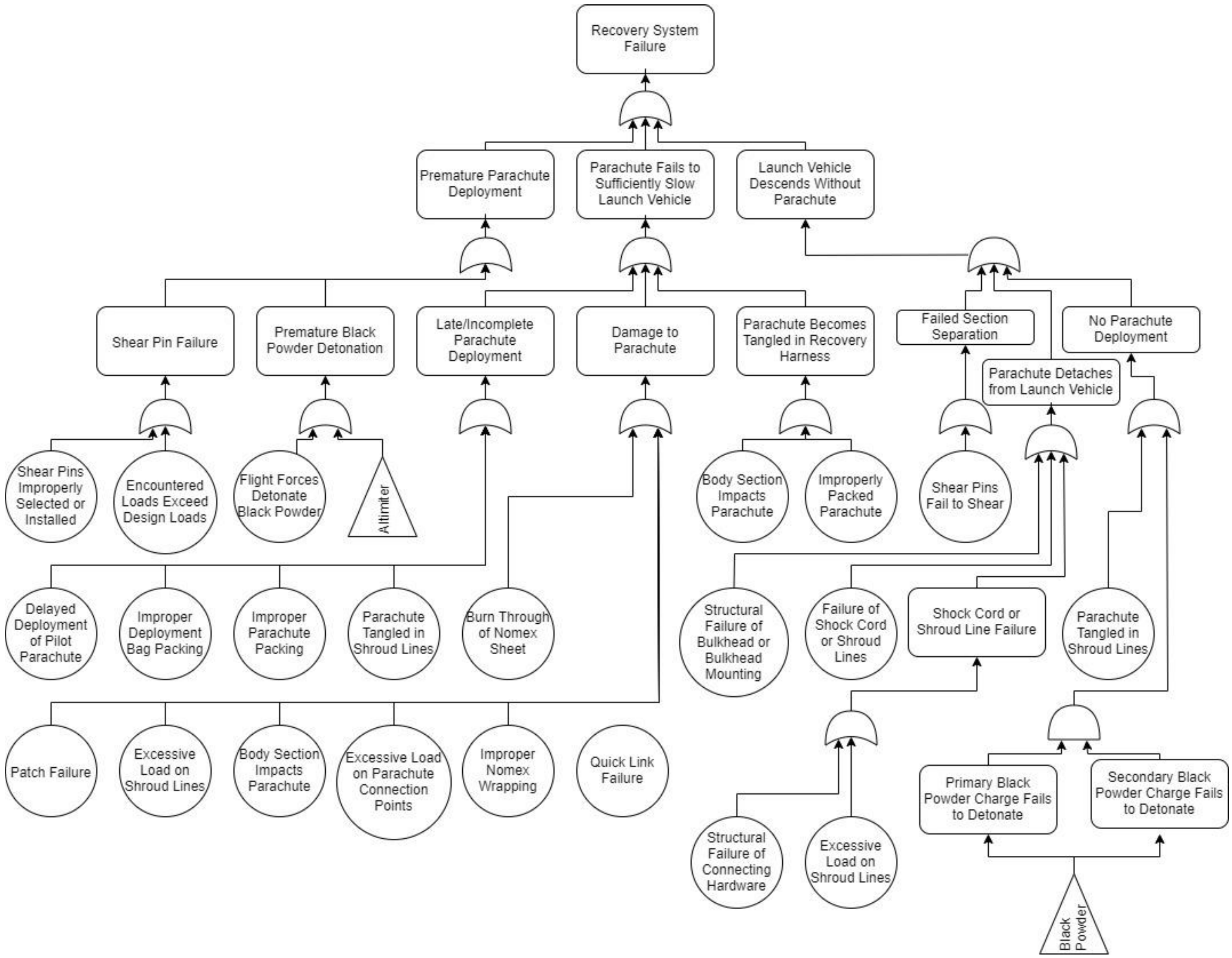


Figure 5-7 Recovery Fault Tree Analysis

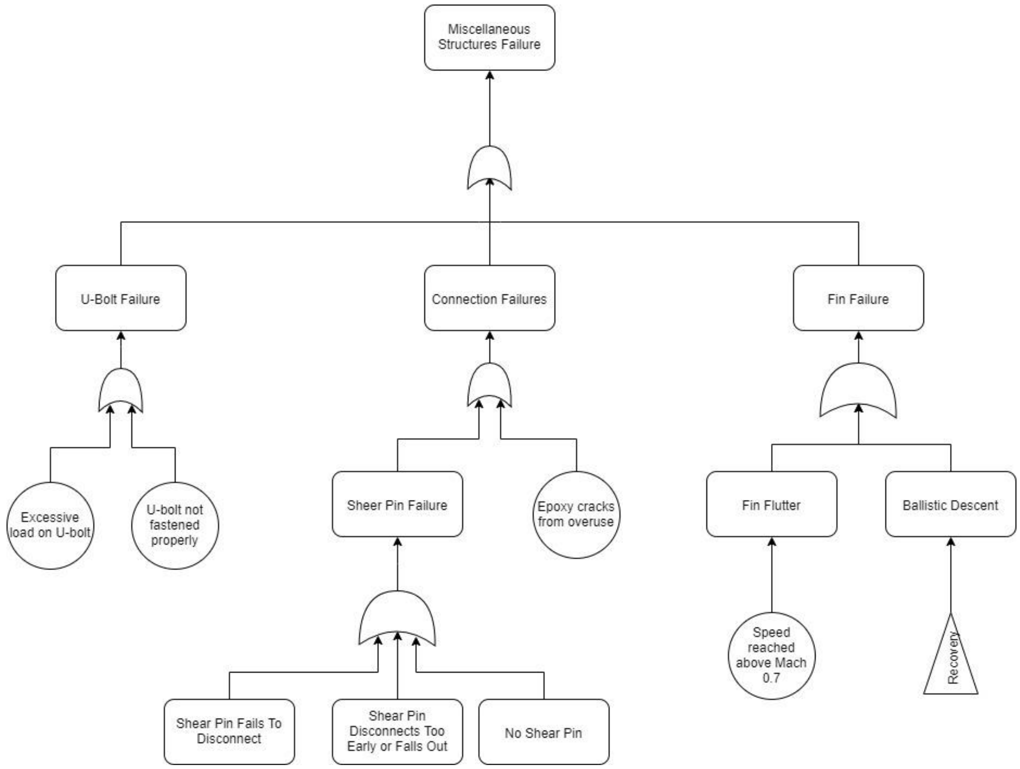


Figure 5-8 Structures Fault Tree Analysis

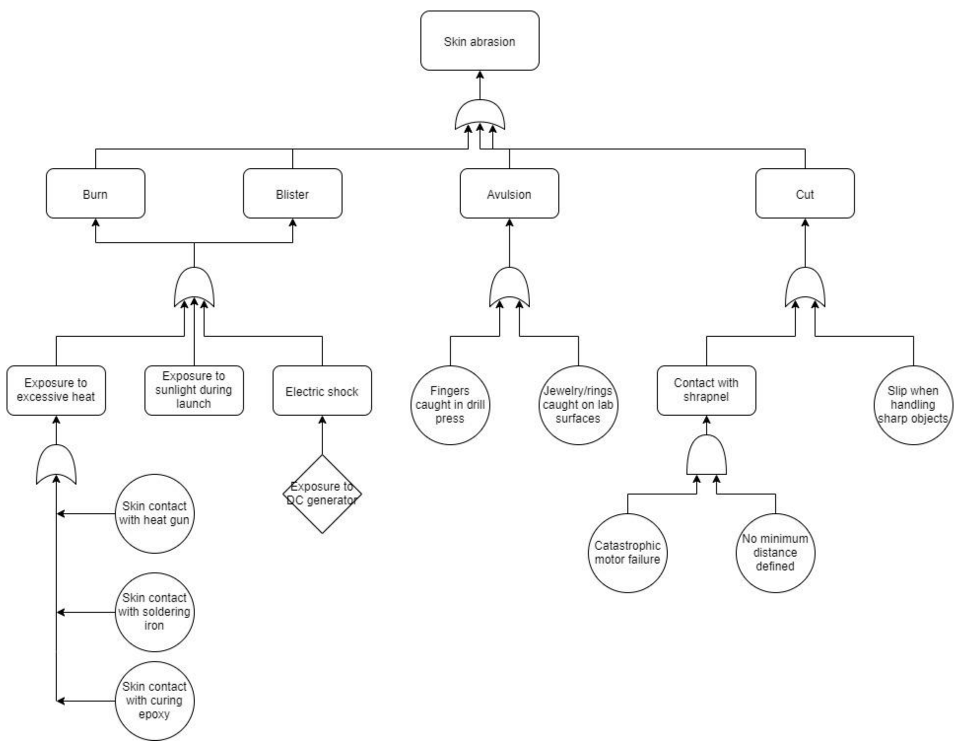


Figure 5-9 Skin Abrasion Fault Tree Analysis

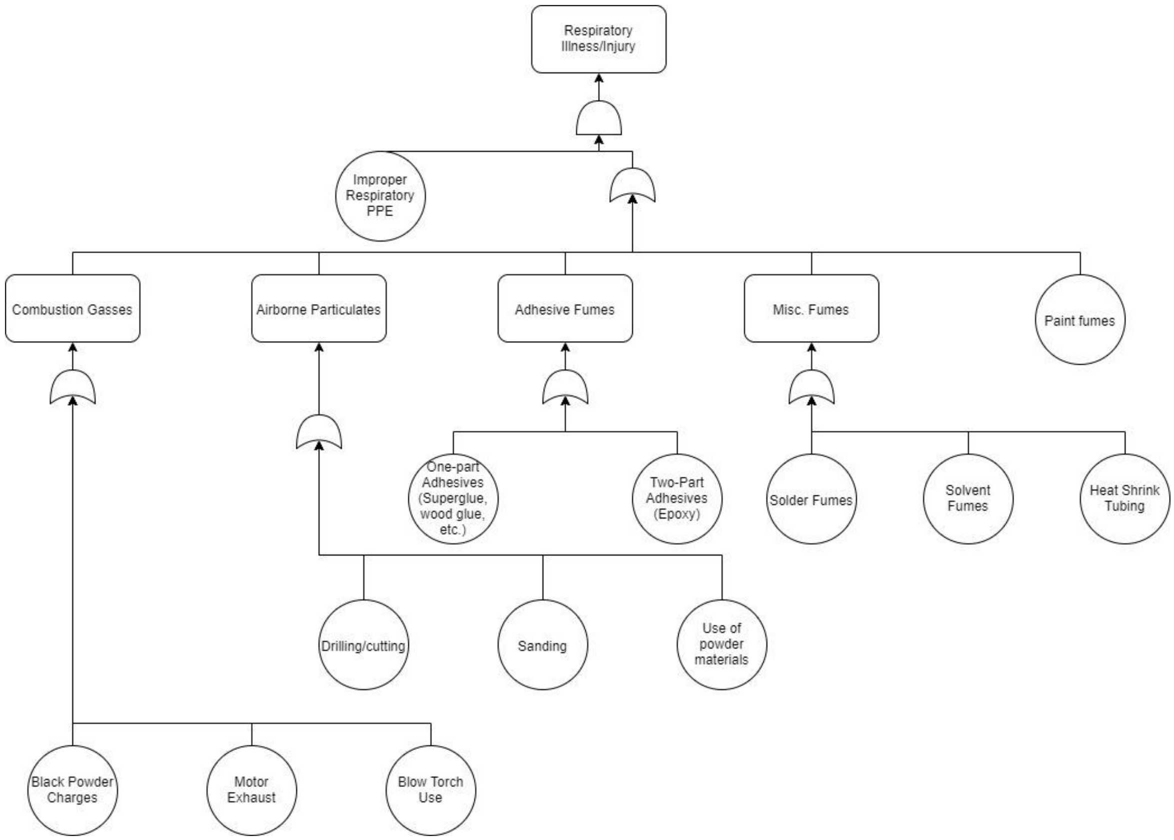


Figure 5-10 Respiratory Hazard Fault Tree Analysis

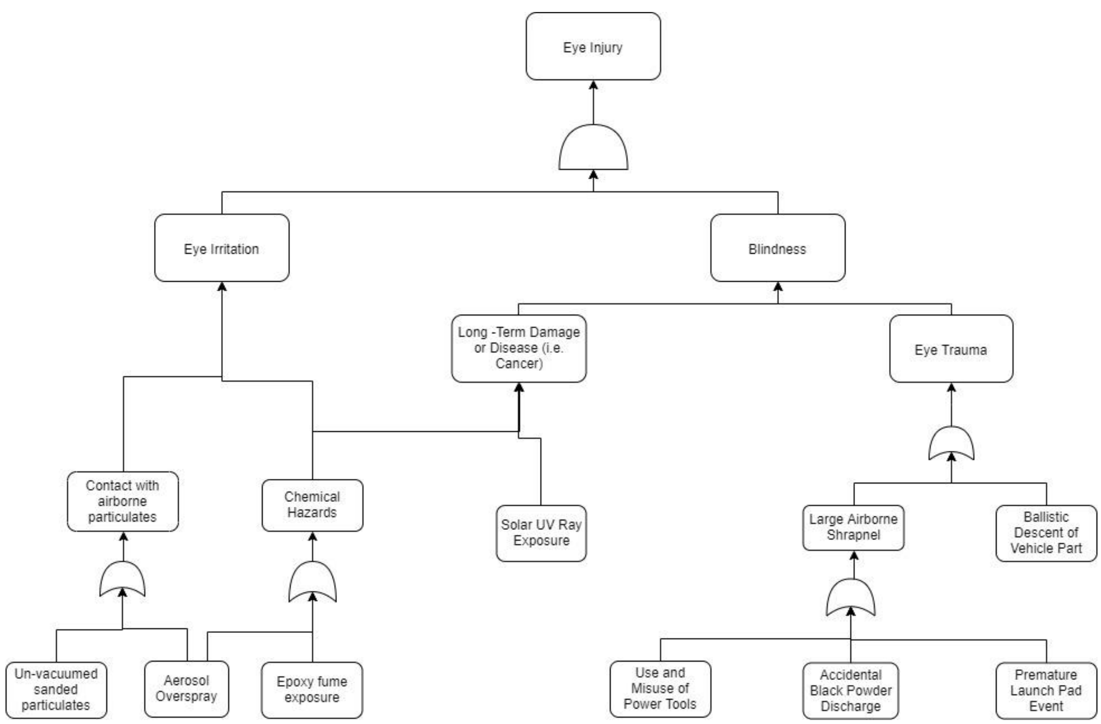


Figure 5-11 Eye Injury Fault Tree Analysis

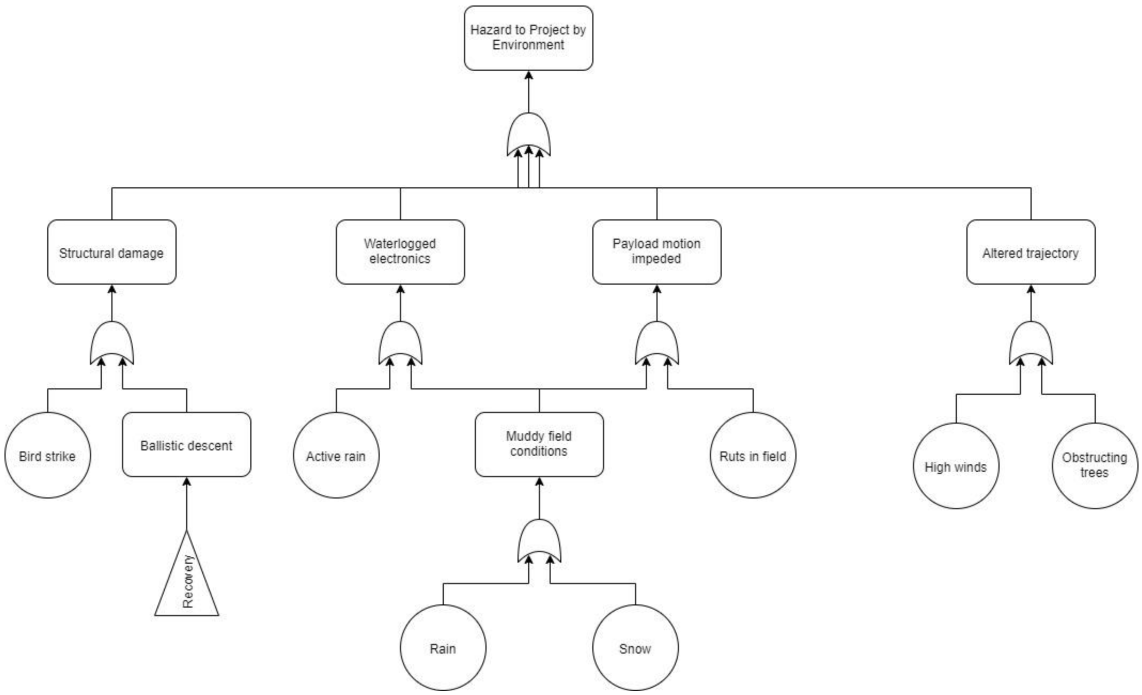


Figure 5-12 Environmental Hazard by Environment Fault Tree Analysis

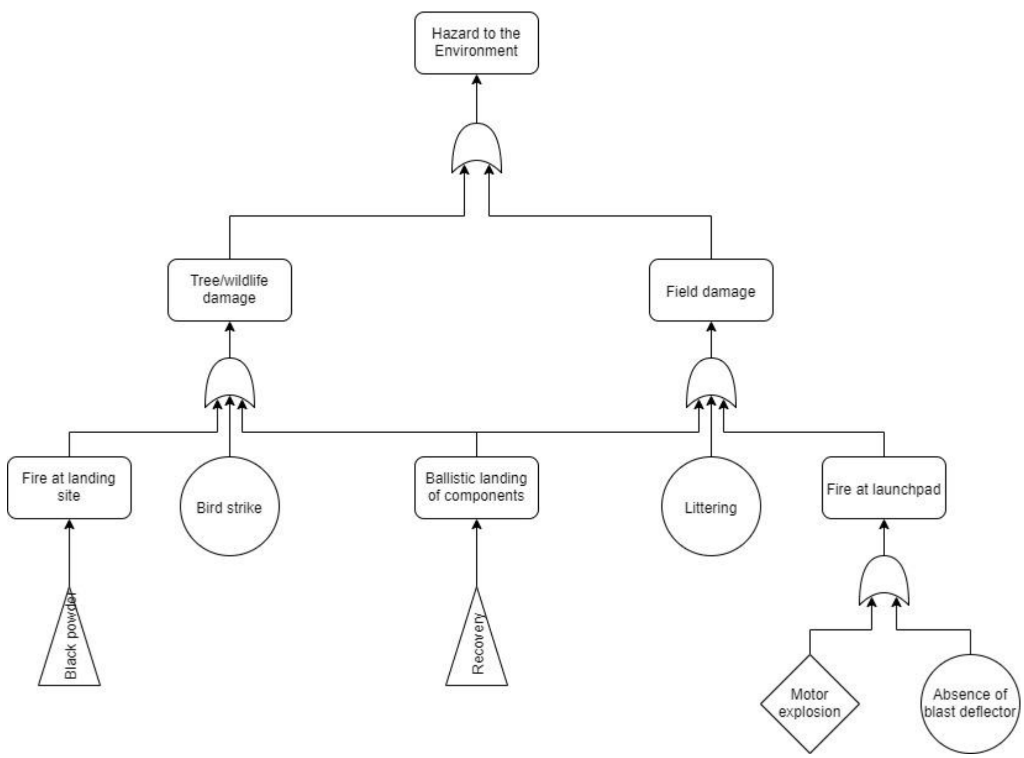


Figure 5-13 Environmental Hazard to Environment Fault Tree Analysis

5.2 Risk Analysis

Table 5-1, below, defines levels of severity as associated with likeliness of occurrence.

Table 5-1 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

5.3 Personnel Hazard Analysis

Table 5-2 details hazards to personnel and their mitigations by injury type.

Table 5-2 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 cords 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.
Eye Injury						

Eye contact with airborne particulates	Residual material particulates from sanding, drilling, or 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.
	Aerosol product use (i.e. spray paint)				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, drilling, or sanding				All personnel working on and around power tools with potential to create airborne particulates wear protective eyewear. 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.
Head Injury						
Collision of personnel with ballistic launch vehicle component	Improper parachute deployment	Concussion	3B	3A	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
Contact with large airborne shrapnel	Premature black powder detonation				Black powder charges are the final components in assembling the launch vehicle. Once black powder charges are installed, no personnel are permitted in the potential blast area.	NASA 2.3; NASA 3.4
	Black powder detonation during recovery				Redundant altimeters will be used to ensure all charges detonate. Members will avoid generation of static and will wear PPE to protect against flames.	
	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	NAR Safety Code #6, NASA 5.4

					and propulsion FMEA for catastrophic motor failure mitigations.	
Loss of Limb						
Motor ignition among personnel	Premature motor ignition (see motor FMEA)	Limb loss or severe injury that warrants amputation	4B	4A	Motor will be handled carefully: avoiding possible ignition sources like sparks and excessive heat.	NAR Safety Code #6, NASA 5.4
	No minimum distance defined				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.	
Black powder ignition among personnel	Premature black powder ignition (see recovery FMEA)				Black powder charges are the final components in assembling the launch vehicle. Once black powder charges are installed, no personnel are permitted in the potential blast area.	Checklist section: Main/Drogue Black Powder Installation
	Live black powder charges remaining in launch vehicle upon recovery				Recovery personnel wear Nomex gloves when approaching the launch vehicle and disarm altimeters before handling the launch vehicle.	Checklist section: Main/Drogue Black Powder Installation
Collision of personnel with	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	NAR Safety Code #9

ballistic launch vehicle component					horn when launch vehicle components are overhead.	
Soft Tissue Injury						
Slips, trips, and falls	Uneven or wet ground surfaces during launch	Bruising	1D	1A	Recovery personnel collecting 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 cords 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 surroundin g 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 wear particulate masks.	An oxygen monitor will be located on the center table during fabrication using epoxy.
	Exposure to airborne				All personnel working on and around power tools with potential to create	TDR 5.8; The shop

	particulates from drilling, cutting, or sanding				airborne particulates wear protective eyewear. A Shop Vac is used while drilling, sanding, and cutting to reduce risk of particles becoming airborne.	vac is located next to all major desktop lab power tools.
	Exposure to fumes from aerosol products (i.e. 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	3C	3A	Solder temperature is restricted. Those working with solder are trained by experienced team members.	TDR 5.1
	Skin contact with curing epoxy				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				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				Tools and machinery with exposed wiring will be replaced.	
Fingers caught in blade or bit of band saw or drill press	Jewelry or gloves worn while working with power tools	Avulsion and degloving of fingers' skin		2A	A jewelry and glove box will be 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	Cuts in skin	2D		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
	Uneven or wet ground surfaces				Launches will not occur during or following adverse weather or field conditions. The RSO has the final say on	NAR Safety Code #6

Slipping or tripping when handling sharp objects					the status of launches and the team will follow the guidelines set by the RSO.	
	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 cords 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.

5.4 Failure Modes and Effects Analysis (FMEA)

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.

5.4.1 Recovery

Table 5-3 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.	CDR 2.3.9.3 CDR 5.1.1.5: Shear pin shear loading test scheduled for 01/15/2020 NASA 3.9
	Insufficient black powder charges		4B	4A	Proper black powder charge will be calculated mathematically and will be demonstrated via ejection testing well before launch.	CDR 5.1.1.1: Full-scale Ejection Test scheduled for 02/18/2020 CDR 2.4.1.6

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.	CDR 2.3.9.3 CDR 5.1.1.5: Shear pin shear loading test scheduled for 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.	CDR 5.1.1.8: Altimeter operational test will be performed on 01/20/2020
Chute 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.	CDR 2.3.8 CDR 5.1.1.3: Bulkhead tensile loading test was performed 12/03/2019. Bulkhead did not fail at 1.5x anticipated load. CDR 5.1.1.4: AV Bay bulkhead tensile loading test is scheduled for 01/15/2020

Limited parachute deployment	Shock cord tangling	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
	Parachute collapse					TDR 5.2, 5.3
Late parachute deployment	Delayed E-match burning	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.	CDR 5.1.1.8: Altimeter operational test will be performed on 01/20/2020
	Defective altimeter					
	Delayed black powder detonation					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					CDR 5.1.1.7: Recovery electronics battery life demonstration will be performed 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.	CDR 5.1.1.8: Altimeter operational test will be performed on 01/20/2020
	Defective altimeter					
Altimeters						
Excessive pressure in parachute bay	Detonation of primary charge	Airframe and recovery harness damage	3C	3A	Black powder charges will be placed on opposite sides of the bulkhead to	Checklist section: Avionics bay assembly

	causing detonation of secondary charge				reduce the chance of sympathetic detonation.	
	Altimeter error			3A	Altimeters will be tested for functionality using pressure vessel prior to installation on the launch vehicle.	CDR 5.1.1.8: Altimeter operational test will be performed 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.	CDR 5.1.1.9: GPS Operation test will be performed on 01/25/2020
	Insufficient range capabilities of GPS					Checklist section: Launchpad procedure

5.4.2 Structures

Table 5-4 Structures FMEA Tables

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

AV bay bulkhead failure	Excessive loading during recovery events	Ballistic descent of all body section not attached to main parachute shock cord				maximum force of 1000 lb on 12/06/2019.
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	CDR 3.2.2.5: 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.	CDR 3.1.4.1: 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.	CDR 3.2.2.8: Optimal shock cord length is in between 27 and 45 ft. The team owns 40 ft shock chord.

5.4.3 Payload

Table 5-5 Payload FMEA Tables

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.	CDR 3.1.2
	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.	CDR 3.1.5
					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.	CDR 3.1.5
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.	CDR 3.1.3: 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.	CDR 3.1.2
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.	CDR 3.1.2
	Motor stall torque reached during driving		2B	2A	The motor will have a higher stall torque than peak operating torque during driving.	CDR 3.1.3; Table 3-3
Separation of rover power transmission components (wheels, stabilizing arm, etc.)	Terrain impacts exceeding maximum design loading criteria	Rover damaged; unable to continue mission	2A	2A	During rover assembly, multiple team members will confirm securement of rover components.	Checklist section: Payload
	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 scheduled for 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 g's in RockSim in tests conducted on 11/12/2019
Failure to initiate deployment operation	Payload deployment system wiring 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 scheduled for 01/28/2020
	Programming fault					
Deployment motor stall	Payload misalignment	Damage to or overheating of deployment motor; inability to complete payload deployment	2C	2A	Radial supports in payload bay will guide the rover.	CDR 3.5.6.3(b); Figure 3-30
	Excessive drivetrain friction					
In-flight failure of payload retention latch	In-flight loads exceed expected design loads	Payload unsecured within rocket; potential for damage to airframe and	4B	4A	The payload retention latch will be built to withstand 60 g's of force with a factor of safety of 1.5.	CDR 3.5.6.3; CDR 3.5

		payload, potential for payload separation leading to ballistic payload descent				
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.	CDR 3.5.4
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 scheduled for 02/17/2020
	Binding or debris in latch mechanism				Latch will be sufficiently powerful to dislodge any debris.	CDR 3.5.3
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 scheduled for 01/28/2020
	Unanticipated current draw				Components will utilize standby mode when not in operation to conserve battery capacity.	CDR 3.1.5
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.	CDR 3.4
	Unexpected ground resistance				Scoop prototypes will be tested in sample site analog prior to launch.	SICCU Operational Test scheduled for 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.	CDR 3.4
	Incorrect design volume				The scoop will have more than 10 mL internal volume for required sample size.	CDR 3.4
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.	CDR 3.4
	Misalignment of gears				The addition of a cover will maintain that the gears are coplanar.	CDR 3.4

5.4.4 Aerodynamics and Propulsion

Table 5-6 Aerodynamics and Propulsion FMEA Tables

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 propellant 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.	CDR 1.2.2; NASA 2.10
	Incorrect motor assembly				Motor assembly is carried out under supervision of experienced Tripoli L3 mentors. Motor will be examined beforehand for external flaws.	NASA 1.1
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
	Improper fin installation					

5.1 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 5-7 Risk 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.	CDR 6.3.1 Budget; Table 6-5
		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.	CDR 6.3.1 Budget; Table 6-5
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.	CDR 3.1.3
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 5-8 Risk 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.	CDR 4.3.4(b): 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	
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 5.3	
	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.	CDR 3.1.4.7: An avionics sled is contained within a sealed avionics bay.
High kinetic energy impact of launch vehicle on ground	Late or no parachute deployment Insufficiently sized parachutes Parachute damage (rips/tears to parachute, shock cord, or shroud lines)	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 is scheduled to take place on 02/18/2020

Appendix B contains brief reactionary procedures to launch field failures to be referenced if the designated safety controls measures fail to prevent them. These procedures, termed out-of-process events, are designed to deescalate undesirable situations that deviate from the plan and provide a clear path forward. While there is no singular, correct reaction to a given system failure, developing a strategy helps to prepare team members in case of a failure.

6. Project Plan

6.1 Testing

6.1.1 Launch Vehicle Test Suite

Table 6-1 Launch Vehicle Test Suite

Test	Requirement Verified	Required Facilities	Required Personnel	Scheduled Date
Subscale Ejection Test	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 Shear Loading Test	TDR 2.7	Universal Testing Machine	Structures Lead	01/15/2020
Fastener Shear Loading Test	TDR 2.7	Universal Testing Machine	Structures Lead	01/15/2020
Altimeter Operational Test	NASA 3.4	Vacuum Container	Recovery Lead	01/20/2020
Recovery Electronic Battery Life Test	NASA 2.7	N/A	Recovery Lead	01/20/2020
Tracking Device Operational Test	NASA 3.12; NASA 3.12.2	Wolfline Bus	Recovery Lead	01/25/2020
Piston Ejection Test	NASA 3.2	N/A	Recovery Lead	01/15/2020
Full-Scale Ejection Test	NASA 3.1; NASA 3.1.3; NASA 3.2	N/A	Recovery Lead	02/18/2020
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	02/22/2020

6.1.1.1 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 in Table 6-2. 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 6-2 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

6.1.1.1(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Ejection Charge Size

6.1.1.1(b) 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

6.1.1.2 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 in Table 6-3. If the demonstration flight were to fail, any alterations necessary to the launch vehicle would be made and the procedure repeated. As shown in section 3.2, the team successfully launched the subscale launch vehicle on 11/23/2019.

Table 6-3 Subscale Demonstration Flight Success Criteria

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

6.1.1.2(a) Controllable Variables

The controllable variables in this experiment are as follows:

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

6.1.1.2(b) Procedure

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

6.1.1.3 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 in Table 6-4. 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. The results of this procedure can be found in section 3.3.8.

Table 6-4 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

6.1.1.3(a) Controllable Variables

The controllable variables in this experiment are as follows:

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

6.1.1.3(b) 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

6.1.1.4 **AV 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 in this test will result in the bolstering the of the current AV bay recovery system. A failure to pass this demonstration is defined as a failure to meet any of the following passing criteria in Table 6-5. Failing this test means the AV bulkhead would have to be redesigned and tested again until it met the minimum factor of safety stated in TDR 2.7. The test samples are two 1/4" thick plywood bulkheads, held at 10.22" apart by two threaded rods and fasteners.

Table 6-5 AV Bulkhead Tensile Loading Test Success Criteria

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

6.1.1.4(a) Controllable Variables

The controllable variables in this experiment are as follows:

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

6.1.1.4(b) 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

6.1.1.5 Shear Pin Shear Loading Test

Per the associated requirements in Table 6-1, 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 in Table 6-6. 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 6-6 Shear Pin Loading Test Success Criteria

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

6.1.1.5(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Choice of Shear Pin
- Force Applied

6.1.1.5(b) 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

6.1.1.6 Fastener Shear Loading Test

Per the associated requirements in Table 6-1, 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 in Table 6-7. 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 6-7 Fastener Loading Test Success Criteria

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

6.1.1.6(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Choice of Fastener
- Force Applied

6.1.1.6(b) 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

6.1.1.7 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 in Table 6-8. Failure of this test would lead to a change in the type of battery or type of altimeter until success criteria are met.

Table 6-8 Recovery Electronics Battery Life Demonstration Success Criteria

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

6.1.1.7(a) Controllable Variables

The controllable variables in this experiment are as follows:

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

6.1.1.7(b) 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

6.1.1.8 Altimeter Operational Demonstration

Per the associated requirements in Table 6-1, 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 in Table 6-9. If one or both altimeters fail this test, the altimeters will be fixed or replaced until the success criteria are met.

Table 6-9 Altimeter Operational Demonstration Success Criteria

Success Criteria	Met? (Y/N)
LED #1 lights when the altimeter senses apogee.	TBA
LED #2 lights when the altimeter senses the main deployment altitude.	TBA
Pre-Flight beeps match what is recorded on the beep sheet.	TBA

See Appendix A for beep sheets.	
Post-Flight beeps do not indicate any errors.	TBA

6.1.1.8(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Pressure
- Choice of Altimeter

6.1.1.8(b) Procedure

The test execution procedure is as follows:

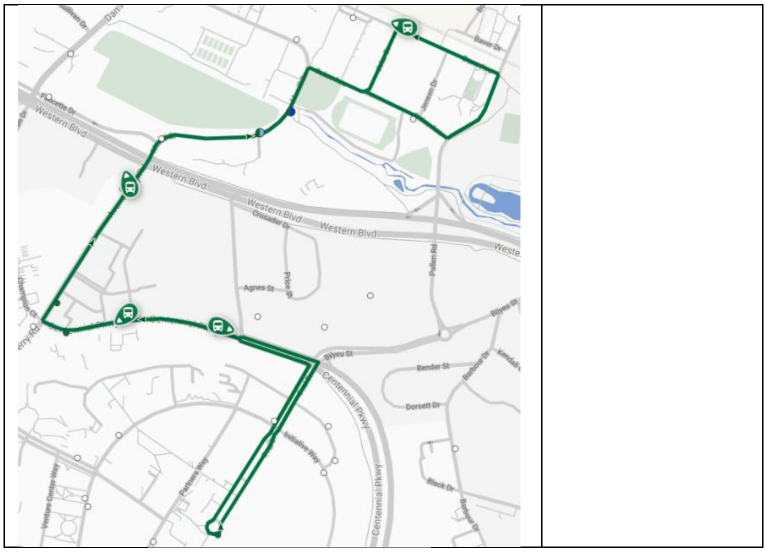
- Attach the two altimeters to the testing apparatus
- Connect the one 9V battery to each altimeter
- Record the pre-flight beep sheet
- Seal the vacuum chamber making sure the lights are visible through the small window in the top of the chamber
- Pulling the vacuum slowly to simulate a launch
- Once 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

6.1.1.9 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 in Table 6-10. If the GPS fails this demonstration, the GPS will be replaced.

Table 6-10 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.	TBA



6.1.1.9(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Selected Bus Route
- Selected GPS tracker

6.1.1.9(b) 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
- Have one team member carry the transmitter onto the Wolfline #3 bus
- Have another team member hold the receiver dongle and the Rocket Locator phone, while displaying the TransLoc website on the laptop
- While the team member with the transmitter is riding the bus, the receiver member is comparing the track plotted on Rocket Locator to the path of the bus provided by the TransLoc website.
- Comparing the two paths, estimate the delay of the location provided by the tracking system with respect to the bus, if any. Delays will not cause failure of the test, but are useful data for application in the field.

6.1.1.10 Piston Ejection Test

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 passing criteria in Table 6-11. If a failure occurs, the ejection charge sizes may be adjusted, or changes to the shape/design of the piston may be made to ensure proper separation.

Table 6-11 Piston Ejection Test Success Criteria

Success Criteria	Met? (Y/N)
The subscale launch vehicle separates as expected at the main parachute bay.	TBA
The piston and launch vehicle do not require significant repair between launches.	TBA
Paper placed in the parachute section is deemed to have acceptable residue.	TBA

6.1.1.10(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Ejection Charge Size
- Piston Shape/Design

6.1.1.10(b) Procedure

The test execution procedure is as follows:

- Attach sheets of paper to the payload bulkhead facing aft using blue tape. Additionally, attach copy paper to the inner wall of the body tube in this body section
- Construct main parachute black powder charge according to the launch checklist
- Tether the inner end of the piston shock cord to the forward AV bay bulkhead, and slide the piston into the attached body section
- Tether the outer end of the piston shock cord to the nosecone bulkhead, fed through the payload bay
- Place some paper towels on top of the piston
- Combine the body sections together and insert two shear pins to hold it together
- At a safe distance and out of the path of the nosecone, detonate the charge
- Wearing heavy leather gloves, inspect the interior of the parachute bay. Remove the paper taped to the interior and inspect for residue

- Check for any burnt paper towels in the nosecone side of the rocket
- Clean out the piston and interior body tube, then repeat the test 4 more times.

6.1.1.11 Full-Scale Ejection Demonstration

Per the associated requirements in Table 6-1, 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 in Table 6-12. 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 in Table 6-12.

Table 6-12 Full-Scale Ejection Demonstration Success Criteria

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

6.1.1.11(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Ejection Charge Size

6.1.1.11(b) 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

6.1.1.12 Full-Scale Demonstration Flight

Per the associated requirements in Table 6-1, 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 in Table 6-13. If a failure occurs, the failed component will either be redesigned and/or repaired prior to the FRR Addendum Milestone.

Table 6-13 Full-Scale Demonstration Flight Success Criteria

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

6.1.1.12(a) Controllable Variables

The controllable variables in this experiment are as follows:

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

6.1.1.12(b) Procedure

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

6.1.2 Payload Test Suite

Table 6-14 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 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
Payload Electronics Battery Life Test	NASA 2.7	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 Integration Power Draw Test	NASA 2.7	N/A	Payload Integration Lead	2/17/2020

6.1.2.1 BURRITO Nominal Performance Test

Per the corresponding requirements listed in Table 6-14, 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 6-15 BURRITO Nominal Performance Success Criteria

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

6.1.2.1(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Rover Direction
- Rover Speed

6.1.2.1(b) 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.

6.1.2.2 BURRITO Terrain Performance Test

Per the corresponding requirements listed in Table 6-14, 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 6-16 BURRITO Terrain Performance Success Criteria

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

6.1.2.2(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Rover Direction
- Rover Speed
- Terrain Type

6.1.2.2(b) 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.

6.1.2.3 BURRITO Inclined Performance Test

Per the corresponding requirements listed in Table 6-14, 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 6-17 BURRITO Inclined Performance Success Criteria

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

6.1.2.3(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Rover Direction
- Rover Speed
- Terrain Type

6.1.2.3(b) 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:
    - Perfectly even surface (e.g. plastic or metal ramp)
    - Tall/thick grass (similar to usual field terrain)

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

6.1.2.4 BURRITO Declined Performance Test

Per the corresponding requirements listed in Table 6-14, 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 6-18 BURRITO Declined Performance Success Criteria

Success Criteria	Met? (Y/N)
The rover maintained forward progress across a declined slope of 5° on smooth terrain without flipping forward.	TBA
The rover maintained forward progress across a declined slope of 5° on field terrain without flipping forward.	TBA

6.1.2.4(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Rover Direction
- Rover Speed
- Terrain Type

6.1.2.4(b) 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:
  - Perfectly even surface (e.g. plastic or metal ramp)
  - Tall/thick grass (similar to usual field terrain)
- Drive the rover forward such that it descends a 5° slope without slipping or tipping backwards.

6.1.2.5 BURRITO Orientation Test

Per the corresponding requirements listed in Table 6-14, 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 6-19 BURRITO Orientation Success Criteria

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

6.1.2.5(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Initial Rover Orientation
- Wheel Rotational Speed

6.1.2.5(b) 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.

6.1.2.6 BURRITO Control Range Test

Per the corresponding requirements listed in Table 6-14, 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 6-20 BURRITO Control Range Success Criteria

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

6.1.2.6(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Distance from rover to controller

6.1.2.6(b) 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.

6.1.2.7 BURRITO Driving Range Test

Per the corresponding requirements listed in Table 6-14, 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 6-21 BURRITO Driving Range Success Criteria

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

6.1.2.7(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Distance between rover and controller

6.1.2.7(b) 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.

6.1.2.8 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 6-22 SICCU Operation Success Criteria

Success Criteria	Met? (Y/N)
After all trials of scooping the average scoop volume is greater than or equal to 15mL	TBA
The scoop tops when stowed are flush with the bottom plate of the BURRITO	TBA
When conducting movement during the test the SICCU does not hinder movement when not in operation.	TBA
Does not require separate power supply	TBA
Does not activate until operator elects to	TBA

6.1.2.8(a) Controllable Variables

The controllable variables in this experiment are as follows:

- PVC Size
- SICCU Arm Length

6.1.2.8(b) 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

6.1.2.9 Payload Electronics Battery Life Demonstration

Per Requirement NASA 2.7 the payload and all related electronics shall have a pad stay time of at least two hours. The Payload Electronics Battery Life Demonstration will verify compliance with this requirement for the BURRITO and the payload deployment electronics. A failure to pass this demonstration is defined as a failure to meet any of the following passing criteria in Table 6-23. Failure of this test would lead to a change in the type of batteries or power settings used by the BURRITO and deployment electronics

Table 6-23 Payload Electronics Battery Life Success Criteria

Success Criteria	Met? (Y/N)
BURRITO's battery life last longer than two hours in low power mode.	TBA
Payload deployment electronics' battery life lasts more than two hours.	TBA
Payload completes the deployment process after two hours on standby.	TBA
BURRITO completes terrain traversal and ice collection procedures after two hours on standby.	TBA

6.1.2.9(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Choice of batteries
- Low Power Configuration
- Choice of onboard electronics

6.1.2.9(b) Procedure

The test execution procedure is as follows:

- Assemble Payload Bay in accordance with relevant checklists
- Assemble BURRITO in accordance with relevant checklists
- Connect BURRITO to battery
- Connect Payload deployment electronics to battery
- Begin timer
- Check electronics for functionality every 15 minutes
- After 3 hours, perform payload deployment sequence in accordance with Deployment System Operational Test
- Proceeding a successful deployment, perform BURRITO terrain traversal and ice collection procedures in accordance with BURRITO Terrain Performance Test and SICCU Operational Test
- Assess Results

6.1.2.10 Retention System Loading Test

Per the corresponding requirements listed in Table 6-14, 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 6-24 Retention System Loading Success Criteria

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

6.1.2.10(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Force applied to the retention system

6.1.2.10(b) 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

6.1.2.11 Deployment System Operational Demonstration

Per the corresponding requirements listed in Table 6-14, 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 6-25 Payload Deployment Success Criteria

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

6.1.2.11(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Motor direction

6.1.2.11(b) 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 Blueterm 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 Blueterm, successfully unlock and release the rover from the integration system.

6.1.2.12 Payload Integration Power Draw Test

Per the corresponding requirements listed in Table 6-14, 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 6-26 Payload Integration Power Draw Success Criteria

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

6.1.2.12(a) Controllable Variables

The controllable variables in this experiment are as follows:

- Operational State of Peripherals (idle or active)

6.1.2.12(b) Procedure

The test execution procedure is as follows:

- Connect all peripherals to microcontroller and connect the power source.
- Measure current draw from microcontroller, primary and retention motor, and the Bluetooth module in an idle state.
- Switch each peripheral to an active operating state and remeasure the current draw for all peripherals

6.2 NASA Requirements Verification Matrix

Table 6-27, below, defines the fields present in Table 6-28, NASA Requirements Verification Matrix.

Table 6-27 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 6-28, below, shows the NASA defined requirements for the NASA Student Launch project.

Table 6-28 NASA Requirements Verification Matrix

Req No.	Shall Statement	Success Criteria	Verification Method	Subsystem Allocation	Status
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).	The students of the High-Powered Rocketry Club at NC State design and implement a solution to the requirements listed in this section.	Inspection	Project Management	Verified. All documents and analysis have been executed by student team members.

	Teams SHALL submit new work. Excessive use of past work will merit penalties.				
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 6 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 foreign national team members.
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	Inspection	Project Management	Verified. Competition attending team members have been determined and sent to the appropriate NASA project

		the CDR milestone document.			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 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.
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	Inspection	Project Management	Verified. The team's social media lead maintains the social media accounts.

		website, Facebook, Instagram, and Twitter.			
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	The team lead will acquire the necessary equipment to communicate with the NASA	Inspection	Project Management	Verified. The team lead organizes required

	teleconference with the review panel.	project management team through teleconference.			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 6.4.1 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 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 ft above ground level (AGL).	The aerodynamics subsystem team designs a rocket to launch between 3,500 and 5,500 ft AGL. The team then constructs the vehicle as designed and the launch vehicle flies between 3,500 and 5,500 ft AGL.	Analysis; Demonstration	Aerodynamics	Incomplete. A tolerance study on predicted apogee was performed. All expected conditions resulted in an apogee within these margins. Section 3.5.1 details on this study. The vehicle demonstration flight will provide further verification as described in section 6.1.1.

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 ft as seen in section 3.5.1.
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 3.4.1.1.
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	Incomplete. The vehicle demonstration flight will demonstrate the recoverable and reusable nature of the launch vehicle. Details can be found in section 6.1.1.
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 3.4.1.

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 3.1 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.	Inspection	Aerodynamics; 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.	Demonstration	Project Management; Safety	Incomplete. 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	The project management and safety teams monitor the selected power supplies for each on-board component and test to verify	Demonstration	Project Management; Safety	Incomplete. Battery life demonstrations on both the avionics equipment and

	without losing the functionality of any critical on-board components.	functionality after over two (2) hours.			payload will be performed as detailed in section 6.1.
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	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. More details on how this was selected can be found in section 3.3.10.

	Canadian Association of Rocketry (CAR).				
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 3.3.10.
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.	Inspection	Aerodynamics	Verified. The motor has been selected as an AeroTech L-1520T as described in Section 3.3.10.
NASA 2.11	The launch vehicle SHALL be limited to a single stage.	The aerodynamics team designs a launch vehicle with a single stage.	Inspection	Aerodynamics	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.	Inspection	Aerodynamics	Verified. The selected AeroTech L-1520T has a total impulse that does not exceed 5,120 Newton-seconds as described in Section 3.3.10
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	Inspection	Structures	Verified. There are no pressure vessels in this design.

		vessels to the NASA RSO and home field RSO.			
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 3.5.4
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 aft 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 section 3.2 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 section 3.2.
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.	Demonstr ation	Recovery	Verified. See section 3.2 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 6.4.1 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.	Inspection	Recovery	Verified. See section 3.2 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.	Demonstr ation	Project Management	Incomplete. The vehicle demonstration flight is scheduled for February 22, 2020.
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	Demonstr ation	Project Management	Incomplete. The vehicle demonstration flight is

		flights for both the vehicle and payload.			scheduled for February 22, 2020.
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	Incomplete. The vehicle demonstration flight is scheduled for February 22, 2020.
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 section 6.4.1.
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	Incomplete. The vehicle demonstration flight is scheduled for February 22, 2020.
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	Incomplete. The vehicle demonstration flight is scheduled for February 22, 2020.
NASA 2.18.1.4	If the payload affects the external surfaces of the rocket or manages the total energy of the vehicle, those	The payload team has external components of the payload prepared for the vehicle demonstration flight.	Inspection	Payload; Aerodynamics	Incomplete. The vehicle demonstration flight is scheduled for February 22, 2020.

	systems SHALL be active during the full-scale VDF.				
NASA 2.18.1.5	The team SHALL fly the launch day motor during the VDF.	The safety and aerodynamics teams work alongside the team's mentors to acquire and use the motor on launch day.	Inspection	Safety; Aerodynamics	Incomplete. The vehicle demonstration flight is scheduled for February 22, 2020.
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	Incomplete. The vehicle demonstration flight is scheduled for February 22, 2020.
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	Incomplete. 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	Incomplete. Altimeter data from the vehicle demonstration flight will be included in the FRR milestone.
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	Incomplete. The vehicle demonstration flight is scheduled for February 22, 2020.

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	Incomplete. The payload demonstration flight is scheduled for February 22, 2020.
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.	Demonstr ation	Safety; Payload	Incomplete. The payload demonstration flight is scheduled for February 22, 2020.
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.	Inspection	Payload	Incomplete. The payload demonstration flight is scheduled for February 22, 2020.
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.	Inspection	Project Management	Incomplete. The payload demonstration flight is scheduled for February 22, 2020.
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.	Inspection	Project Management	Incomplete. No reflight is currently 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	Incomplete. No reflight is currently 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.	Demonstr ation	Project Management	Incomplete. The payload demonstration flight is scheduled for February 22, 2020.
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.	Demonstr ation	Project Management	Incomplete. The payload will be replaced with a mass simulator if the payload demonstration flight is unsuccessful.
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	Incomplete. 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	Inspection	Aerodynamics	Verified.

		does not utilize forward firing motors.			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.	Inspection	Aerodynamics	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.	Inspection	Aerodynamics	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.	Inspection	Aerodynamics	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	Aerodynamics	Verified. The full-scale launch vehicle has a maximum Mach number of 0.5. Section 3 has details on how this analysis was performed.

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	Incomplete. There is no plan to include ballast currently, leaving the ballast budget at the full 10% of the total weight.
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. The maximum power per transmitter used is in the flysheet. See section 4.6.3 for details on current onboard transmitters.
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 section 4.6.3 for details on current onboard transmitters
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	Incomplete. The full-scale ejection demonstration will

					show the staged deployment system. Section 6.1.1 details on the demonstration procedure.
NASA 3.1.1	The main parachute SHALL be deployed no lower than 500 ft.	The recovery team designs a main parachute deployment event no lower than 500 ft.	Demonstration	Recovery	Incomplete. Altimeters are programmed to release the main parachute at 500 ft. The vehicle demonstration flight will have main deployment at 500 ft. Section 6.1.1 details on the demonstration.
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	Incomplete. Only the redundant altimeter has an apogee delay. The apogee delay is 1 second. The vehicle demonstration flight that will demonstrate this is detailed in section 6.1.1
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	Incomplete. The launch vehicle uses a two stage deployment system initiated by altimeters. The full-scale ejection

					demonstration. In section 6.1.1, will demonstrate this.
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	Incomplete. Ground ejection testing will occur prior to each launch. See Section 6.1.1 for ejection demonstration procedure.
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 kinetic energy calculations can be found in section 3.5.5.
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 3.4.1.1 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 3.4.1.1 shows the recovery design.
NASA 3.6	Each altimeter SHALL be armed by a dedicated	The recovery team designs a redundant recovery	Demonstration	Safety; Recovery	Incomplete.

	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.	electronic system such that both the primary and redundant altimeters are turned on by a mechanical arming switch.			The recovery system uses two StratoLogger CF altimeters. Section 3.4.1.1 shows the recovery design. The vehicle demonstration flight will show the ability to access the mechanical arming switches from the launch vehicle exterior. Section 6.1.1 shows demonstration flight procedure.
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	Incomplete. 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 will show the locking ability of these switches. Section 6.1.1 shows demonstration flight procedure.

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 3.4.1.3 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 ft radius from the launch pad.	The recovery team designs a recovery system that results in a drift of no more than 2,500 ft from the launch pad. The vehicle demonstration flight results in a drift radius of no more than 2,500 ft.	Analysis; Demonstration	Recovery	Incomplete. The supporting drift calculations can be found in section 3.5.7. The vehicle demonstration flight will have a drift less than 2500 ft. Section 6.1.1 shows demonstration flight procedure.
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; Demonstration	Recovery	Incomplete. The supporting descent time calculations can be found in section 3.5.6. The vehicle demonstration flight

					will have a descent time less than 90 seconds. Section 6.1.1 shows demonstration flight procedure.
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	Incomplete. The tracking device operational demonstration will show the functionality of said tracking device. Details can be found in section 3.4.1.8 and section 6.1.1.
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. There is one tracking device for the one independent section of the launch vehicle.
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	Incomplete. The tracking device operational demonstration will show the functionality of said tracking device. Details can be found in section 3.4.1.8 and section 6.1.1.
NASA 3.13	The recovery system electronics SHALL not be	The recovery team designs a redundant recovery electronic system such that	Demonstration	Safety; Recovery; Payload	Incomplete. The recovery electronics are

	adversely affected by other on-board electronic devices.	all recovery electronics are independent of other on-board electronics.			independent of any other on-board electronics system. Section 3.4.1.3 shows the avionics architecture diagram. The vehicle demonstration flight will show functionality of all active recovery electronics in unison. The procedure can be found in section 6.1.1.
NASA 3.13.1	The recovery altimeters SHALL be located in a separate compartment 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	Incomplete. The recovery electronics are independent of any other on-board electronics system. Section 3.4.1.3 shows the avionics architecture diagram. The vehicle demonstration flight will show functionality of all active recovery electronics in unison. The procedure can be found in section 6.1.1.
NASA 3.13.2	The recovery system electronics SHALL be shielded	The recovery team designs an avionics bay that is	Demonstration	Safety; Recovery	Incomplete.

	from all onboard transmitting devices.	separate from other on-board, transmitting electronics.			The recovery electronics are independent of any other on-board electronics system. Section 3.4.1.3 shows the avionics architecture diagram. The vehicle demonstration flight will show functionality of all active recovery electronics in unison. The procedure can be found in section 6.1.1.
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	Incomplete. The recovery electronics are independent of any other on-board electronics system. Section 3.4.1.3 shows the avionics architecture diagram. The vehicle demonstration flight will show functionality of all active recovery electronics in unison. The procedure can be found in section 6.1.1.

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	Incomplete. The recovery electronics are independent of any other on-board electronics system. Section 3.4.1.3 shows the avionics architecture diagram. The vehicle demonstration flight will show functionality of all active recovery electronics in unison. The procedure can be found in section 6.1.1.
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	Incomplete. The payload deployment operational demonstration will demonstrate the payload's ability to integrate with the launch vehicle. Section 6.1.1 details on the demonstration procedure.
NASA 4.3.1	The launch vehicle SHALL be launched from the NASA-	The aerodynamics team will design a launch vehicle to be launched from either an 8-	Inspection	Aerodynamics; Structures	Verified. The selected rail button is sized for a

	designated launch area using the provided Launch pad.	foot 1010 rail or a 12-foot 1515 rail. The structures team will fabricate said launch vehicle.			1515 rail. Section 6.4.1 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	Incomplete. The SICCU Operational test will demonstrate the system's ability to collect a sample. See section 6.1.2 for further detail on test.
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	Incomplete. The SICCU Operational test will record the size of sample collected on each run. See section 6.1.2 for further detail on test.
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	Incomplete. The BURRITO performance tests will determine the rover's ability to travel in various conditions. Section 6.1.2 details on this test.
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.	Inspection	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	Incomplete. The Retention System Loading Test will determine when the payload retention system will fail. Section 6.1.2 details on this test.
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	Incomplete. Section 4.6 has a CAD model of the current retention mechanism. The deployment demonstration, detailed in section 6.1.2, will show the operation of the retention system.
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	Incomplete. The Retention System Loading Test will determine when the payload retention system will fail. Section

					6.1.2 details on this test. Section 4.6.6.4 shows the supporting ANSYS analysis.
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	Incomplete. The deployment demonstration will demonstrate the fail-safe qualities of the system. Section 6.1.2 provides details on this procedure.
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	The safety team holds the payload design accountable for all FAA rules and	Inspection	Safety; Payload	Verified.

	regulations for model aircraft.	regulations if the payload is a UAV.			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 and safety checklist will be included in CDR and FRR documentation. Appendix X contains said procedure.
NASA 5.2	The team SHALL identify a student safety officer.	The student safety officer is identified in each milestone report.	Inspection	Safety	Verified. See section 5.1 with safety officer information.
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, monitors 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	The student safety officer monitors team activities and ensures team members are	Inspection	Safety; Recovery	Verified. The student safety officer, Frances

	on safety during the recovery activities.	practicing proper safety techniques.			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.	Inspection	Project Management; Safety	Verified. The launch and safety checklist will be included in CDR and FRR documentation. Appendix X contains said procedure.
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.	Inspection	Safety	Verified. See section 5 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.	Inspection	Safety	Verified. See section 5 for safety analysis.
NASA 5.4	The team SHALL abide by the rules and guidance of the	The safety team ensures all regulations from the local rocketry club are followed.	Demonstration	Safety	Incomplete. The team will abide by all RSO guidelines at

	local rocketry club's RSO during test flights.				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.	Demonstration	Safety	Incomplete. The team will abide by all RSO guidelines at the demonstration flights and competition flights.

6.3 Team Derived Requirements Verification Matrix

Table 6-29, below, defines the fields present in Table 6-29, Team Derived Requirements Verification Matrix.

Table 6-29 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 6-30, below, shows the derived requirements for the NASA Student Launch project.

Table 6-30 Derived Requirements Verification Matrix

Req No.	Shall Statement	Justification	Success Criteria	Verification Method	Subsystem Allocation	Status
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	Incomplete. The team has currently reached approximately 270 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. Section 6contains the project schedule that shows materials have been purchased.
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. The full-scale launch vehicle has a maximum Mach number of 0.5. Section 3.5.2 has details on how this analysis was performed.
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 the PDR document

TDR 2.5	The launch vehicle SHALL have a static stability margin between 2.0 and 2.30 upon rail exit.	To meet the associated NASA 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. A tolerance study was performed by the aerodynamics subsystem team to determine the most likely static margin. This study can be found in the PDR document
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 3.1.7 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	Incomplete. Factor of safety is determined for various load bearing components both experimentally and through simulation. Section 3.5.2 details on the simulation results. Section 6.1.1 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	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-

		manipulate the vehicle at the field.				scale launch vehicle. Section 6 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 3.4.1 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 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	The 15 psi is a standard for most ejection	Ejection charge calculations indicate a	Analysis	Recovery	Verified. A pressure of 15 psi was used to calculate the

	least a 15 psi pressure.	charges in hobby rocketry.	pressure of 15 psi is reached.			ejection charge sizes. Current values and the supporting calculations can be found in section 3.4.1.6.
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 incorporate U-Bolts. Section 3.1 details on bulkhead design.
TDR 4.1	The payload SHALL have a combined weight of no more than 9 lbf.	To maintain kinetic energy requirements in the associated NASA requirement the weight of the payload is limited.	The payload weighs less than 9 lbf.	Analysis	Aerodynamics; Payload	Verified. Launch vehicle systems were designed with a maximum payload weight of 9 lbf. Section 3.5.4 shows the launch vehicle stability analysis. Section 4 includes component weights for the payload.
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	Incomplete. Rover motor selection has been based on this requirement. Supporting analysis can be found in section 4.3. Section 6.1.2 details on the rover performance tests.
TDR 4.3	The payload vehicle SHALL cover a range of at least 2000 ft.	If the launch vehicle were to land at a maximum wind drift distance of 2500, the	The payload vehicle is capable of driving over 2000 ft at one time.	Test	Payload	Incomplete. The BURRITO Range Test explores the limits of the BURRITO rover.

		rover would have to travel at most 2000 ft.				This test is described in further detail in section 6.1.2.
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 4.3shows 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	Incomplete. The BURRITO performance testing is detailed in section 6.1.2.
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	Incomplete. The payload deployment demonstration is detailed in section 6.1.2.
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	Inspection	Payload	Verified. Two radial supports will be implemented in the final design. Section 4.6 shows CAD models

			cantilever upon deployment.			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	Incomplete. The SICCU Operational Test will determine the average amount of material collected by the system. Section 6.1.2 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.	Inspection	Payload	Verified. After sample collection, the SICCU is flush with the base of the BURRITO. Section 4.5 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 ft after sample collection.	Demonstration	Payload	Incomplete. The BURRITO performance testing is detailed in section 6.1.2.
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	Incomplete. Section 4.5 details on SICCU operation. Functionality will be demonstrated as a part of the SICCU Operational test, shown in section 6.1.2.
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	Incomplete. The retention system loading test will determine the point of failure of the retention system. Section 6.1.2 details on this procedure.
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 4.1.	The BURRITO is deployed from the launch vehicle.	Demonstration	Payload	Incomplete. The deployment demonstration will show the payload is capable of being deployed. The associated procedure is detailed in section 6.1.2.
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	Incomplete. The BURRITO orientation test will record the rover’s ability to adjust orientation. The test

						can be found in section 6.1.2.
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	A designated safety officer SHALL give a lecture on lab and launch safety for new members before launches and work days.	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 5.5	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. Procedure described in Appendix A show the instructions for motor assemble under mentor supervision.
TDR 5.6	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 5.7	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.

6.4 Financing

6.4.1 Budget

Table 6-31, below details the year-long budget for the 2019-2020 competition year.

Table 6-31 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)	3	$1,178.10	$3,534.30
	Van Rentals (# cars)	2	$198.00	$396.00
	Gas (Miles)	1144	$0.60	$686.40
	Subtotal:			**$7,783.50**
Promotion	T-Shirts	40	$14.00	$560.00
	Polos	30	$25.00	$750.00
	Stickers	500	$0.37	$185.00
	Banner	1	$250.00	$250.00
	Subtotal:			**$1,745.00**
	Total:			**$17,832.40**

6.4.2 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. 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 $5,500.

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 6-32, below, which compares the projected costs and incoming grants for the 2019-2020 school year.

Table 6-32 2019-2020 Funding Sources

Organization	Fall Semester Amount	Spring Semester Amount	School Year Total
Engineering Technology Fee	-	-	$1,500.00
SGA Appropriations	$900.00	$900.00	$1,800.00
Sponsorships	-	-	$3,600.00
NC Space Grant	-	-	$5,000.00
College of Engineering	-	-	$6,000.00
Total Funding:			**$17,900.00**
Total Expenses:			**$17,832.40**
Difference:			**$68.00**

6.5 Project Timelines

Table 6-33, below, shows the development schedule for this year's project. A Gantt chart depicting this information can be found in Appendix C.

Table 6-33 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

Table 6-34, below, shows the full-scale launch vehicle build schedule for this year's project. A Gantt chart depicting this information can be found in Appendix X.

Table 6-34 2019-2020 Full-Scale Build Schedule

Event/Task	Equipment/Facility	Required Personnel	Start Date	End Date/Submission
Order Parts	N/A	Treasurer	12/16/2019	1/10/2020
Laser cut Bulkheads and Fins	Laser cutter; CO2 Laser Glasses	Structures Lead	1/13/2020	1/14/2020
Cut Airframe Tubes	Drop Saw; Safety Glasses; Respirator	Structures Lead	1/13/2020	1/15/2020
Bulkhead Layups	Epoxy Resin; Nitrile Gloves; Safety Glasses	Structures Lead	1/14/2020	1/17/2020
Body Tube Layups	Epoxy Resin; Nitrile Gloves; Safety Glasses	Structures Lead	1/16/2020	1/16/2020
Bulkhead Assembly	Drill Press; Belt Sander; Safety Glasses	Structures Lead	1/17/2020	1/17/2020
Fin Can Assembly	Epoxy Resin; Nitrile Gloves; Safety Glasses	Structures Lead	1/20/2020	1/25/2020
Install Motor Tube	Epoxy Resin; Nitrile Gloves; Safety Glasses	Structures Lead	1/21/2020	1/21/2020
Laser cut AV Sled	Laser cutter; CO2 Laser Glasses	Recovery Lead	1/21/2020	1/21/2020
Install FWD Rail Button	Hand Drill; Safety Glasses	Structures Lead	1/22/2020	1/22/2020
AV Sled Fabrication	Wood Glue; Nitrile Gloves	Recovery Lead	1/22/2020	1/25/2020
Nosecone Bulkhead Installation	Hand Drill; Safety Glasses	Structures Lead	1/23/2020	1/24/2020
Install AFT Rail Button	Hand Drill; Safety Glasses	Structures Lead	1/24/2020	1/24/2020
Install Motor Retainer	Epoxy Resin; Nitrile Gloves; Safety Glasses	Structures Lead	1/24/2020	1/24/2020
Drill Pressure Ports	Hand Drill; Safety Glasses	Structures Lead	1/27/2020	1/27/2020
Drill Switch Holes	Hand Drill; Safety Glasses	Structures Lead	1/27/2020	1/27/2020
AV Bay Wiring	Soldering Iron; Safety Glasses	Recovery Lead	1/27/2020	1/31/2020
Payload Bay Assembly	Epoxy Resin; Nitrile Gloves; Safety Glasses	Payload Integration Lead	2/3/2020	2/7/2020
Payload Integration	N/A	Payload Integration Lead	2/10/2020	2/14/2020
Paint	Paint Booth; Respirator; Paint Suit; Safety Glasses	N/A	2/17/2020	2/21/2020

Table 6-35, below, shows the payload build schedule for this year's project. A Gantt chart depicting this information can be found in Appendix X.

Table 6-35 2019-2020 Payload Build Schedule

Event/Task	Equipment/Facility	Required Personnel	Start Date	End Date/Submission
Order Parts	N/A	Treasurer	12/16/2019	1/10/2020
Laser cut Chassis	Laser cutter; CO_2 Laser Glasses	Payload Vehicle Lead	1/13/2020	1/14/2020
Assemble Chassis	Wood Glue; Nitrile Gloves	Payload Vehicle Lead	1/15/2020	1/15/2020
Install Drive Motors	Soldering Iron; Safety Glasses	Payload Vehicle Lead	1/16/2020	1/20/2020
Install Battery	Soldering Iron; Safety Glasses	Payload Vehicle Lead	1/16/2020	1/20/2020
3D Print Electronics Bay	3D Printer	Payload Vehicle Lead	1/17/2020	1/20/2020
Assemble Electronic Components	Soldering Iron; Safety Glasses	Payload Vehicle Lead	1/20/2020	1/24/2020
Program Arduino	N/A	Payload Vehicle Lead; Sample Acquisition Lead	1/24/2020	1/27/2020
Configure Receiver	N/A	Payload Vehicle Lead	1/27/2020	1/29/2020
Install Electronics Bay	N/A	Payload Vehicle Lead	1/27/2020	1/29/2020
Install Caster Wheels	N/A	Payload Vehicle Lead	1/29/2020	1/30/2020
Install SICCU	N/A	Sample Acquisition Lead	1/29/2020	1/31/2020
Integrate with Retention System	N/A	Payload Integration Lead	2/3/2020	2/5/2020

A test execution schedule for both the payload and launch vehicle components can be found in Table 6-14 and Table 6-1.

Appendix A

Launch Checklist

PPE Required

Explosive – DANGER

Nitrile Gloves Required

Safety Goggles required

E-MATCH INSTALLATION:

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

Materials Required			
Item	**Number**	**Location**	**Confirmation**
Bulkhead #5	1	Bulkhead Box	
Bulkhead #4	1	Bulkhead Box	
Blue Tape	1	Launch Day Toolbox	

E-Match	4	Launch Day Toolbox	
Scissors	1	Launch Day Toolbox	
Wire Snips	1	Launch Day Toolbox	
Wire Strippers	1	Launch Day Toolbox	
TB Screwdriver	1	AV HDX Box	

EXCUTE THIS PROCEDURE ON 2 BULKEADS (#4 and #5) at the same time
PRIMARY:

- ❑ Unscrew all **UNOCCUPIED** terminal blocks on bulkheads #4 and #5
- ❑ Trim the e-match to approximately 7 in length using wire cutters
- ❑ Remove red plastic protective e-match cover from e-match
- ❑ Feed the e-match through the **P** wire hole
    - The e-match head should be on the side with blast caps
- ❑ 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 Confirmation: ______
- ❑ 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 Confirmation: ____________________
- ❑ Confirm all labels are still visible
- ❑ **SECONDARY:**
- ❑ Trim the e-match to approximately 7 in length using wire cutters
- ❑ Remove the red plastic protective e-match cover from e-match
- ❑ Feed the e-match through the **S** wire hole
- ❑ 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 Confirmation: ______________
- ❑ Place e-match head within the blast cap labeled **S**
- ❑ Bend the e-match wire such that it lies flat against the blast cap
- ❑ Secure the e-match wire to bulkhead with a small piece of blue tape, ensure that no holes are covered
- ❑ Confirm the e-match wire is curved over the outside edge of the blast cap
- ❑ Confirm the e-match head is flat on the cap bottom
- ❑ Using blue tape, tape the e-match wire to the outside of the of the blast cap

- ❑ Confirm the e-match in the **S** blast cap is connected to the terminal block labeled **S**
    - Safety Officer Confirmation: _________________
- ❑ Confirm all labels are still visible

AVIONICS BAY ASSEMBLY:

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

Materials Required			
Item	**Number**	**Location**	**Confirmation**
Bulkhead #4	1	AV Bay Box	
Bulkhead #5	1	AV Bay Box	
AV Sled (assembled)	1	Bulkhead #5	
Screw Switch	2	Bulkhead #5	
StratoLogger CF	2	Bulkhead #5	
AV Bay	1	Bulkhead Box	
9V Battery	2	AV HDX Box	
#4-40 screw	4	AV HDX Box	
#4-40 washer	4	AV HDX Box	
#4-40 nut	4	AV HDX Box	
1/4" Wrench	1	AV HDX Box	
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	
5/8" Wrench	1	Launch Day Toolbox	
Remove Before Flight Tag	2	Launch Day Toolbox	
#8 screw	4	Recovery Hardware	
Main Parachute bay	1	-	

- ❑ **Confirm the primary screw switch is turned to the off position**
  - **Primary Altimeter is NOT beeping**
- ❑ **Confirm the secondary screw switch is turned to the off position**
  - **Secondary Altimeter is NOT beeping**
- ❑ Use Multimeter to check primary battery voltages – 9V
  - Replace with fresh battery if less than 9V
  - Battery Voltage: _____
- ❑ Use Multimeter to check secondary battery voltage – 9V
  - Replace with fresh battery if less than 9V
  - Battery Voltage: _____
- ❑ Place batteries in the battery compartment
- ❑ Connect batteries to the battery clips
- ❑ Place battery compartment cover over batteries and secure with four (4) #4-40 machine screws, four (4) #4-40 hex nuts.
  - Recovery Lead Confirmation: ____________
- ❑ **Confirm the primary screw switch is turned to the off position**
  - **Primary Altimeter is NOT beeping**
- ❑ **Confirm the secondary screw switch is turned to the off position**
  - **Secondary Altimeter is NOT beeping**
- ❑ **DO NOT TURN ON ALTIMETERS PAST THIS POINT**
- ❑ Confirm wires between primary altimeter and **DP** terminal block are still connected
- ❑ Confirm wires between secondary altimeter and **DS** terminal block are still connected
- ❑ Confirm e-match wires are installed on **Bulkhead #5**
- ❑ Confirm the AV Sled is ready to be inserted into the AV Bay
  - Recovery Lead Confirmation: ______________
- ❑ 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
- ❑ Probe pressure ports with small screwdriver to confirm they are clear
  - Safety Officer Confirmation: ________________
- ❑ Confirm the **end of the AV bay labeled #5** is aligned with **bulkhead #5**
- ❑ 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 Confirmation: _______________
- ❑ Confirm wires leading to quick disconnects are installed on Bulkhead #4
- ❑ 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 Confirmation: _____________
- ❑ Lightly tug on the connected **MP** quick disconnects
- ❑ 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 Confirmation: _______________
- ❑ Lightly tug on the connected **MS** quick disconnects
- ❑ Confirm AV Sled alignment
  - Recovery Lead Confirmation: ___________________
- ❑ Slide bulkhead #4 onto the threaded rods until flush with body tube
- ❑ Slide (1) 5/16 inch washer onto each threaded rod
- ❑ Slide (1) 5/16 inch nut onto each threaded rod
- ❑ Slide (1) 5/16 inch cap nut onto each threaded rod
- ❑ Confirm the AV Bay alignment
  - Recovery Lead Confirmation: ____________
- ❑ Tighten until **SNUGG**
- ❑ Confirm ALL labels on AV Bay are still visible
- ❑ Recovery Lead Confirmation: ____________
- ❑ Confirm AV Bay assembly and bulkhead tightness
  - Recovery Lead Confirmation: ________________
  - Safety Officer Confirmation: _______________
- ❑ Slide the Main Parachute Bay onto the AV Bay coupler using the stars to align the holes
  - **Bulkhead #4** side
- ❑ Secure with four (4) #8 screws
- ❑ Use plumber's putty to seal any holes in the **#4 bulkhead**
  - **Seam between body tube and bulkhead**
- ❑ Use plumber's putty to seal any holes in the **#5 bulkhead**

DROGUE BLACK POWDER:

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

Materials Required			
Item	**Number**	**Location**	**Confirmation**
AV Bay (assembled)	1	-	
8.5x11, 20lb weight, 30% post-consumer recycled material copy paper	2	Recovery Tupperware	
Paper Towel Roll	1	Recovery Tupperware	
Blue Tape	1	Launch Day Toolbox	
Plumbers Putty	1	Launch Day Toolbox	
Scissors	1	Launch Day Toolbox	
Safety Glasses	4	PPE Toolbox	
Nitrile Gloves	4	PPE Toolbox	
Heavy Duty Gloves	1	PPE Toolbox	
Drogue Primary Charge (2.0 g)	2	AV HDX Box	
Drogue Secondary Charge (2.2 g)	2	AV HDX Box	

- ❑ Confirm that all members around the launch vehicle are wearing safety glasses
    - Safety Officer Confirmation: ___________________
- ❑ Confirm the members handling black powder are wearing nitrile gloves
    - Safety Officer Confirmation: ___________________
- ❑ Turn Midsection so that the blast caps on bulkhead #5 are facing up
- ❑ 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 towel
- ❑ The paper towel should fill the space, but not be packed in tightly!
- ❑ Place small (2-3 in.) strips of blue tape on top of the **DP** blast cap to cover the blast cap completely
    - Do NOT have any major overlaps but leave no gaps with the blue tape
- ❑ Confirm all edges are covered
    - Safety Officer Confirmation: _______________
- ❑ Wrap blue tape all the way around the outside of the blast cap to keep the top layers tight
- ❑ 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
- ❑ 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
    - Do NOT have any major overlaps but leave no gaps with the blue tape and
- ❑ Confirm all edges are covered
    - Safety Officer Confirmation: _____________
- ❑ 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 Confirmation: ______________
- ❑ Turn the AV Bay over onto a sheet of white copy paper
- ❑ Turn the AV Bay back over
- ❑ Confirm that no black powder has leaked onto the copy paper
    - If yes, Wipe copy paper clean and repeat the above steps
    - Safety Officer Confirmation: ________________

MAIN BLACK POWDER:

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

Materials Required			
Item	**Number**	**Location**	**Confirmation**
AV Bay (assembled)	1	-	

8.5x11, 20lb weight, 30% post-consumer recycled material copy paper	2	Recovery Tupperware	
Paper Towel Roll	1	Recovery Tupperware	
Blue Tape	1	Launch Day Toolbox	
Plumbers Putty	1	Launch Day Toolbox	
Scissors	1	Launch Day Toolbox	
Safety Glasses	4	PPE Toolbox	
Nitrile Gloves	4	PPE Toolbox	
Heavy Duty Gloves	1	PPE Toolbox	
Main Primary Charge (6.1 g)	2	AV HDX Box	
Main Secondary Charge (6.3 g)	2	AV HDX Box	

- ❑ Confirm that all members around the launch vehicle are wearing safety glasses
  - Safety Officer Confirmation: _________________
- ❑ Confirm the members handling black powder are wearing nitrile gloves
  - Safety Officer Confirmation: _________________
- ❑ Make a paper funnel by rolling a sheet of copy paper and securing with a piece of scotch tape
- ❑ Carefully pour the **Main Primary Charge** of black powder into the **MP** blast cap over the e-match head using the funnel for guidance
- ❑ Move the e-match so the black powder lies under the e-match head
- ❑ Fill the remaining space in the blast cap with fingertip size pieces of paper towel
  - The paper towel should fill the space, but not be packed in tightly!
- ❑ Place small (2-3 in.) strips of blue tape on top of the **MP** blast cap to cover the blast cap completely
  - Do NOT have any major overlaps but leave no gaps with the blue tape
- ❑ Confirm all edges are covered
  - Safety Officer Confirmation: ________________
- ❑ Wrap blue tape all the way around the outside of the blast cap to keep the top layers tight
- ❑ Fold down the excess blue tape on top of the blast cap

- ❑ Carefully pour the **Main Secondary Charge** of black powder into the **MS** blast cap over the e-match head using the paper funnel for guidance
- ❑ Move the e-match so the black powder lies under the e-match head
- ❑ Fill the remaining space in the blast cap with pieces of paper towel
- ❑ The paper towel should fill the space, but not be packed in tightly!
- ❑ Place small (2-3 in.) strips of blue tape on top of the **MS** blast cap to cover the blast cap completely
    - Do NOT have any major overlaps but leave no gaps with the blue tape
- ❑ Confirm all edges are covered
    - Safety Officer Confirmation: _______________
- ❑ 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 Confirmation: _______________
- ❑ Turn the AV Bay over onto a sheet of white copy paper
- ❑ Turn the AV Bay back over
- ❑ Confirm that no black powder has leaked onto the copy paper
    - If yes, wipe copy paper clean and repeat the above steps
    - Safety Officer Confirmation: _______________
- ❑ Clear the workspace of all black powder in preparation for launch vehicle assembly

MAIN PARACHUTE RECOVERY ASSEMBLY

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

Materials Required			
Item	**Number**	**Location**	**Confirmation**
Nosecone Assembly	1	-	
Fin Can Assembly	1	-	
Safety Glasses	5	PPE Toolbox	
Main Parachute (120 in)	1	Recovery Tupperware	

Deployment Bag (6 in)	1	Recovery Tupperware	
Nomex Sheet	1	Recovery Tupperware	
Main Parachute Shock Cord	1	Recovery Tupperware	
Quick link (#2-4)	4	Recovery Hardware Box	
Shear Pin	2	Recovery Hardware Box	
Electrical Tape	1	AV HDX Box	
Scissors	1	Launch Day Toolbox	
Plumbers Putty	1	Launch Day Toolbox	

- ❑ Confirm that all members handling the launch vehicle are wearing safety glasses
  - Safety Officer Confirmation: ___________
- ❑ Attach **quick link 3 to loop 3**
  - Do NOT tighten
- ❑ Seal Around Shock Cord hole with Plumbers Putty on bulkhead A (payload bay)
  - Recovery Lead Confirm: _________
- ❑ Attach **quick link 3** to **deployment bag loop 3**
  - Tighten by hand
- ❑ Fold length of shock cord **between loops 2 and 3** accordion-style
- ❑ Wrap with rubber band
- ❑ Confirm the rubber band is NOT too tight and NOT covering any part of parachute
  - Two fingers should fit snugly under the rubber band
- ❑ Confirm the shock cord is still folded accordion style within the rubber band
  - If not repeat the previous steps
- ❑ Fold length of shock cord **between loops 3 and 4** accordion-style
- ❑ Secure with a single rubber band
- ❑ Confirm the rubber band is NOT too tight and NOT covering any part of parachute
  - Two fingers should fit snugly under the rubber band
- ❑ Confirm the shock cord is still folded accordion style within the rubber band
  - If not repeat the previous steps
- ❑ Final check that all rubber bands are removed from main parachute and shroud lines
  - The rubber bands on the shock cord will remain
- ❑ Attach **quick link 2** to **loop 2**
  - Do NOT tighten
- ❑ Attach **Large Nomex Sheet 2** to **quick link 2**

- ❑ Attach **quick link 2** to **Main Parachute Loop 2**
  - Tighten by hand
- ❑ Route end of shock cord labeled 4 through the main parachute bay from the FWD end to AFT end
- ❑ Attach **quick link 4** to **loop 4**
  - 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 Confirmation: ____________
- ❑ Carefully insert the shock cord length **between loops 3 and 4** into main parachute bay from forward to AFT
- ❑ Wrap Main Parachute deployment bag in large nomex sheet
- ❑ Carefully insert the wrapped parachute into the space between stowed shock cords
- ❑ The deployment bag loop **labeled 2** should be pointed toward the nosecone
- ❑ The deployment bag should sit completely inside the main parachute bay
- ❑ Slide the Main parachute bay into the payload bay
- ❑ Cut (2) 4-40 nylon shear pins so they are ½ in in length
- ❑ Insert into shear pin holes until tight
  - If shear pins are loose, place small piece of electrical tape over shear pin heads
- ❑ Set plumbers putty on all screw heads
- ❑ Confirm the launch vehicle can hold its own weight from shear pins alone
- ❑ Hold at nosecone and let the launch vehicle hang
  - Structures Lead Confirmation: ____________

DROGUE PARACHUTE RECOVERY ASSEMBLY:

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

Materials Required			
Item	**Number**	**Location**	**Confirmation**
Fin Can	1	-	

AV bay Assembly	1	-	
Safety Glasses	5	PPE Toolbox	
Drogue Parachute (24 in)	1	Recovery Tupperware	
Nomex Sheet	1	Recovery Tupperware	
Drogue Parachute Shock Cord	1	Recovery Tupperware	
Quick link (#5-8)	4	Recovery Hardware Box	
Shear Pin	2	Recovery Hardware Box	
Electrical Tape	1	Launch Day Toolbox	
Scissors	1	Launch Day Toolbox	
Plumbers Putty	1	Launch Day Toolbox	

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

- ❑ Attach **quick link 8** to **loop 8**
- ❑ Do NOT tighten
- ❑ Attach **quick link 8** to fin can **bulkhead 8**
    - o tighten by hand
- ❑ Confirm the quick link is secured to the fin can bulkhead 8 U-bolt by visual inspection and pulling on shock cord
    - o Recovery Lead Confirmation: ___________
- ❑ Confirm the drogue parachute is properly folded
    - o Remove rubber band securing drogue parachute
    - o Firmly grasp it
- ❑ Confirm all rubber bands are removed from parachute and shroud lines
- ❑ Wrap nomex cloth around the drogue parachute
    - o Firmly grasp it
- ❑ Carefully insert the shock cord length **between loops 7 and 8** into fin can cavity
- ❑ Carefully insert the drogue parachute into the fin can cavity in the space between stowed shock cords
    - o The yellow Fruity Chutes logo should be facing the fin can
- ❑ Carefully insert the shock cord length **between loops 5 and 6** into the fin can cavity
- ❑ Slide AV Bay coupler into fin can cavity using the screw switch holes to align the shear pin holes
    - o Recovery Lead Confirmation: ____________
- ❑ Confirm the screw switches are visible through the holes
    - o Recovery lead Confirmation: _____________
- ❑ Cut (2) 4-40 nylon shear pins so they are ½ in length and insert into shear pin holes until tight
    - o If shear pins are loose, place small piece of electrical tape over shear pin heads
- ❑ Confirm the launch vehicle can hold its own weight from shear pins alone
- ❑ Hold AV Bay and let fin can hang
    - o Recovery Lead Confirmation: ______________

MOTOR ASSEMBLY:

Personnel Required		
Role	**Name**	**Initial**
Aerodynamics Lead	Ethan Johnson	
Safety Officer	Frances McBride	
Motor Personnel 1		

Materials Required			
Item	**Number**	**Location**	**Confirmation**
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 Toolbox	
Paper Towels	1	Recovery Tupperware	

- ❑ Follow the manufacturer's instructions for motor assembly with L3 mentor
    - A copy is listed below
- ❑ Open motor reload kit, ensure no plastic packages are open.
- ❑ Make sure you have all parts of the motor casing (casing, forward seal disk (if necessary), forward closure, aft closure)
- ❑ Use Vaseline/grease to lubricate threads of motor casing, forward closure, and aft closure
- ❑ Identify each type of O-ring, dimensions are listed on parts list in motor instruction booklet
    - If pictures of O-rings are included, size of O-rings and pictures will match
- ❑ Grease all O-rings (not delay spacers or insulators), make sure they do not blow away
- ❑ Assemble forward closure
    - Place smoke grain into smoke grain liner (white cardboard cylinder) until one face of smoke grain is flush with end of smoke grain liner
    - Grease that face of the smoke grain and liner
    - Insert assembled smoke grain into forward closure GREASED SIDE FIRST until seated against forward end of smoke grain cavity
- ❑ Use a knife or edge and run around the inside edge of both ends of the phenolic liner (DO NOT CUT THE LINER)
- ❑ Insert nozzle into one end of liner WIDER SIDE FIRST until liner flange is seated against end of liner
    - This end of the liner will be considered aft end
- ❑ HOLD LINER HORIZONTALLY FOR ALL REMAINING STEPS
- ❑ Open package of propellant grains
- ❑ Test fit first propellant grain into forward end of phenolic liner
    - If it fits, push into forward end of liner
    - If it doesn't fit, take a knife and scrape paper lining off of propellant grain and push into forward end of liner

- ❑ Test fit second propellant grain (scrape off paper lining if necessary)
  - o Push greased grain spacer O-ring into forward end of phenolic liner until seated against propellant grain before pushing second propellant grain until seated against O-ring
- ❑ Repeat steps 10 and 11 until there are no more propellant grains
- ❑ Lightly grease outside edge of assembled liner KEEP ASSEMBLY HELD HORIZONTAL
- ❑ Push assembled phenolic liner and propellant grains into motor casing until nozzle protrudes approximately 1 inch from end of casing
  - o This end of casing will now be the aft end
- ❑ Push forward insulator into forward end of casing until pressed against phenolic liner
- ❑ Push greased forward O-ring into forward end of casing until pressed against forward insulator
- ❑ Partially screw in assembled forward closure into forward end of motor casing
  - o Do not tighten completely, leave 2-3 threads exposed
- ❑ Place greased aft O-ring into the groove in the aft end of the nozzle until seated firmly in the groove
- ❑ Partially screw in aft closure into aft end of motor casing
- ❑ Tighten each closure
  - o If they do not tighten completely, make sure both sides are equally tightened
  - o Do not leave more than 2-3 threads exposed on each side
- ❑ Install nozzle cap
  - o Place nozzle cap over nozzle until snug
  - o Use knife to cut a triangle into nozzle cap
- ❑ Prep Ignitor
  - o Hold ignitor wire against the motor casing
  - o Designate appropriate length by marking wire with sharpie
  - o Separate ends of ignitor wire
  - o Strip ends of ignitor wire
  - o Recoil ignitor
  - o Store in field recovery toolbox
- ❑ Return to launch vehicle assembly location
- ❑ Prep Ignitor
  - o Hold ignitor wire against the motor casing
  - o Designate appropriate length by marking wire with sharpie
  - o Separate ends of ignitor wire
  - o Strip ends of ignitor wire
  - o Recoil ignitor
  - o Store in field recovery toolbox
- ❑ Return to launch vehicle assembly location

FINAL MEASUREMENTS:

Personnel Required		
Role	**Name**	**Initial**

Student Team Leader	Ashby Scruggs	
Aerodynamics Lead	Ethan Johnson	
Measurements Personnel 1		
Measurements Personnel 2		

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

- ❑ Unscrew motor retainer
- ❑ Slide motor casing into motor tube
- ❑ Secure motor casing using retainer screw
- ❑ Have a second team member confirm the motor retainer screw is tight
- ❑ Measure the center of pressure of the launch vehicle
    - Center of pressure is at ______ in from the nosecone
    - Team Lead Confirmation: ______________
- ❑ Use a green circular sticker to mark the center of pressure of the launch vehicle
- ❑ Using the rope and fish scale, locate the center of gravity of the launch vehicle
- ❑ Tie the rope around the middle of the launch vehicle
- ❑ Move the rope until the launch vehicle balances
- ❑ The balance point is the CG
    - Write the weight of the launch vehicle here: ________________
    - Should be approximately ___
- ❑ Use a pink circular sticker to mark the CG
- ❑ Measure the CG distance from the nosecone
    - Write the CG distance from the nosecone here: ________________
    - Should be approximately in
    - Team Lead Confirmation: _________________
- ❑ Confirm the CG and CP are AT LEAST 12.34 in apart (preferably more)
- ❑ Calculate the stability margin of the launch vehicle in calibers
    - (CP-CG)/D

  - Write stability margin here: ______
  - Team Lead Confirmation: _________________
- ☐ Fill the Field Recovery Toolbox with the necessary materials at this point

LAUNCH PAD PROCEDURE:

Personnel Required		
Role	**Name**	**Initial**
Student Team Leader	Ashby Scruggs	
Safety Officer	Frances McBride	
Recovery Lead	Gabe Buss	
Launch Pad Personnel 1		
Launch Pad Personnel 2		

Materials Required			
Item	**Number**	**Location**	**Confirmation**
Launch Vehicle (assembled)		-	
Motor ignitor		-	
Launch Rail Lubricant		-	
Nitrile Gloves	4	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 Bands	6	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	

- ❑ Confirm with RSO that field conditions are safe for launch
    - RSO Confirmation: ____________
- ❑ Confirm with RSO that launch rail is 1515
    - RSO Confirmation: ____________
- ❑ Submit launch vehicle and flight card to RSO for review
    - RSO Confirmation: ____________
- ❑ Record location of launch pad (GPS coordinates and compass bearings of prominent landmarks)
- ❑ Confirm the blast deflector is mounted on the launch rail
    - Safety Officer Confirmation: _____________
- ❑ Grease launch vehicle rail buttons and launch rail track
- ❑ Carefully slide launch vehicle onto launch rail
- ❑ Visually confirm that the launch vehicle slides smoothly
    - Team Lead Confirmation: _____________
    - Safety Officer Confirmation: ____________
- ❑ Rotate launch rail into upright position and lock into place
- ❑ Launch vehicle must be pointed downwind and 5° from vertical
- ❑ Confirm the launch rail is locked
    - Safety Officer Confirmation: ___________________
    - Alan Confirmation: _____________________
- ❑ Take team picture in front of launch vehicle
- ❑ Take Senior Design picture in front of launch vehicle
- ❑ All non-essential personnel must be directed to leave the launch pad
- ❑ Confirm all individuals remaining at launch pad wear safety glasses
    - Safety Officer Confirmation: ____________________
- ❑ Arm both altimeters:
- ❑ Turn Primary screw switch until tight.
- ❑ Confirm the PRIMARY altimeter (StratoLogger) is beeping correctly
- ❑ Refer to beep sheet
- ❑ Turn Secondary screw switch until tight.
- ❑ Confirm the SECONDARY altimeter (StratoLogger) is beeping correctly
- ❑ Refer to beep sheet
- ❑ **CONFIRM BOTH ALTIMETERS ARE ON BEFORE PROCEEDING**
    - Safety Officer Confirmation: ___________________
- ❑ Attach igniter to wooden dowel
- ❑ Insert igniter fully into motor tube
- ❑ Tape igniter into place at the bottom of launch vehicle
- ❑ Reinstall the red cap to the base of the motor
- ❑ Confirm that launch pad power is cut off
- ❑ Connect igniter to launch pad power
- ❑ Ensure pad continuity
- ❑ Readout should be between 1.5 and 3.5

- ❑ All personnel must navigate to safe locations behind launch table
- ❑ Pass the Primary Checklist and Field Recovery Toolbox to the Safety Officer
- ❑ LAUNCH!

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

Personnel Required		
Role	**Name**	**Initial**
Recovery Lead	Gabe Buss	
Safety Officer	Frances McBride	
Recovery Personnel 1		
Recovery Personnel 2		
Recovery Personnel 3		

Materials Required			
Item	**Number**	**Location**	**Confirmation**
Nitrile Gloves	4	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 Bands	6	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	

- [ ] Upon launch, watch the launch vehicle descend

- ❑ Observe where the launch vehicle lands
- ❑ Approach the launch vehicle on foot
- ❑ Once near the launch vehicle
    - ❑ 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
- ❑ All recovery team members put on safety glasses
    - ❑ Safety Officer Confirmation: _____________
- ❑ Team members manipulating the launch vehicle put on nitrile gloves
    - ❑ Perform this step even if you think all the black powder charges went off
    - ❑ Safety Officer Confirmation: ____________
- ❑ If the launch vehicle appears to be on fire or smoking, use the fire extinguisher to put out the flame
- ❑ If a parachute is open and pulling the launch vehicle
    - ❑ Do **NOT** grab hold of the shroud lines or shock cord
    - ❑ Approach the parachute from the billowed side
    - ❑ Use hands and body to pull down the parachute by the canopy
    - ❑ Repeat for second parachute if necessary
- ❑ Use a rubber band to secure the Main Parachute
- ❑ Use a rubber band to secure the Drogue Parachute
- ❑ Listen to the altimeters to determine flight data
    - ❑ Use the beep sheets below to record flight data
- ❑ If beeps are NOT heard from one of the altimeters for more than 10 seconds assume a black powder charge did NOT go off
- ❑ If the launch vehicle did NOT separate, assume a black powder charge did NOT go off
- ❑ Visually inspect the Bulkhead #4 for un-blown black powder charges
- ❑ If there is an un-blown black powder charge:
    - ❑ Equip heavy duty gloves before handling the body tube
        - ❑ Safety Officer Confirmation: ____________
- ❑ Visually inspect the bulkhead #5 for un-blown black powder charges
- ❑ If there is an un-blown black powder charge:
    - ❑ Equip heavy duty gloves before handling the body tube
        - ❑ Safety Officer Confirmation: ____________
- ❑ Record location of final resting position of launch vehicle
    - ❑ GPS coordinates
    - ❑ Relative locations of each section of the vehicle and any unconnected parts
    - ❑ Compass bearings of prominent landmarks
    - ❑ Compass bearing to launch pad
- ❑ Locate initial ground impact point
- ❑ Record location of initial ground impact point
    - ❑ GPS coordinates
    - ❑ Relative locations of each section of the vehicle and any unconnected parts
    - ❑ Compass bearings of prominent landmarks
    - ❑ Compass bearing to launch pad
- ❑ Inspect the landing site for non-biodegradable waste
    - ❑ Pick up any waste
- ❑ Pack up the launch vehicle and travel back to the launch site

Main Altimeter Beep Table – StratoLogger

Between each row there is a long beep

The Beeps: What do they mean	Write Beeps Here	Expected Output
An extra-long tone to indicate the start of the reporting sequence		Ignore, currently not important
A three to six-digit number representing the peak altitude in ft		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 mph		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 ft		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 mph		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

Appendix B

This appendix covers the out-of-process event procedures mentioned in section 5. They are as follows.

PREMATURE BLACK POWDER IGNITION

- ALL PERSONS CLEAR THE AREA
- CLEAR FLAMMABLE OBJECTS FROM THE AREA
- USE FIRE EXTINGUISHER TO EXTINGUISH FIRE

If Persons are Injured:
- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

LAUNCH RAIL TIPS DURING LAUNCH

- TAKE COVER IF NECESSARY
- CLEAR THE AREA IN THE DIRECTION OF THE TIP
- LISTEN TO RSO INSTRUCTIONS

If Persons are Injured:
- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

Once Hazard is Clear:
- FOLLOW FIELD RECOVERY CHECKLIST

CATO

- LISTEN TO RSO INSTRUCTIONS
- ALL PERSONS CLEAR THE AREA
- WAIT UNTIL CONDITIONS AT THE LAUNCH PAD ARE CLEAR OF HAZARDS

If Persons are Injured:
- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

BALLISTIC DESCENT

- LISTEN TO RSO INSTRUCTIONS
- DETERMINE LOCATION OF BALLISTIC DESCENT
- ALL PERSONS MOVE AWAY FROM DESCENT PATH
- MAINTAIN VISUAL CONTACT WITH LAUNCH VEHICLE

If Persons are Injured:
- APPLY EMERGENCY FIRST AID
- CALL 911 IF NECESSARY

Once Hazard is Clear:
- FOLLOW FIELD RECOVERY CHECKLIST
- INVESTIGATE CAUSE OF BALLISTIC DESCENT

BLACK POWDER SPILL

- ALL NON-DESIGNATED PERSONS CLEAR THE AREA
- EQUIP PPE FOR HANDLING BLACK POWDER
- CREATE A PAPER FUNNEL
- BRUSH THE SPILLED POWDER INTO THE FUNNEL USING GLOVED HANDS
- FUNNEL AS MUCH BLACK POWDER INTO ITS STORAGE CONTAINER AS POSSIBLE
- DISPOSE OF FUNNEL AND REMAINING BLACK POWDER
- USE WET WIPES TO CLEAN REMAINING BLACK POWDER

PARACHUTE UNFOLDS DURING PACKING

- DISCONNECT PARACHUTE FROM QUICK LINK
- RE-FOLD PARACHUTE ACCORDING TO LAUNCH DAY CHECKLIST
- RE-ATTACH PARACHUTE TO QUICK LINK
- HOLD PARACHUTE IN SHAPE DURING FURTHER ASSEMBLY

SHEAR PINS DO NOT FIT IN SHEAR PIN HOLES

- TRY OTHER BODY TUBE ORIENTATIONS

If Unable to Resolve:
- DRILL NEW SHEAR PIN HOLES

MISSING REQUIRED TOOL

- ASK TEAM MEMBERS FOR PERSONAL TOOLS
- ASK OTHER LAUNCH PATRONS
- ACQUIRE NEW TOOL FROM HARDWARE STORE

ALTIMETER INOPERATIVE DURING ASSEMBLY

- CHECK BATTERIES FOR PROPER POWER LEVEL (9 VOLTS) USING MULTIMETER
- CHECK FOR CONTINUITY BETWEEN ALTIMETER TERMINALS

If Altimeter Remains Inoperative:
- REPLACE ALTIMETER WITH BACKUP
- CONFIRM FUNCTIONALITY OF BOTH ALTIMETERS
- RESUME NORMAL CHECKLISTS

PARACHUTES RIPPED DURING FOLDING AND PACKING

- ATTEMPT TO PATCH THE TEAR

If Unable to Patch:
- CHECK FOR REPLACEMENT PARACHUTE
- ASK MENTORS FOR REPLACEMENT PARACHUTE
- ASK OTHER LAUNCH PATRONS FOR REPLACEMENT PARACHUTE

If Unable to Locate Replacement:
- VEHICLE UNSAFE TO LAUNCH

BODY TUBE DAMAGED

- DETERMINE NATURE OF DAMAGE
- CONSULT STRUCTURES LEAD

If Damage is Minor:
- ATTEMPT REPAIRS
- CONTINUE WITH APPROVAL OF STRUCTURES LEAD

If Damage is Major:
- VEHICLE UNSAFE FOR LAUNCH

EXCESS SCREW OR BOLT

- REPEAT CHECKLIST STEPS TO FIND CAUSE
- DISMANTLE AND REINSTALL HARDWARE

ALTIMETER INOPERATIVE ON LAUNCH PAD

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

If Altimeter Remains Inoperative:

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

RAPID WEATHER CHANGE IMMEDIATELY PRIOR TO LAUNCH

- LISTEN TO RSO INSTRUCTIONS
- REMOVE LAUNCH VEHICLE FROM LAUNCH RAIL
- FOLLOW FIELD RECOVERY CHECKLIST

PERMANENT HARDWARE DAMAGE AFTER LANDING

- REPLACE HARDWARE FOR FUTURE LAUNCHES
- RE-FLIGHT REQUIRED ON NEW HARDWARE
- RE-FLIGHT REQUIRED IF FLIGHT DATA LOST

FAILED MOTOR IGNITION

- LISTEN TO RSO INSTRUCTIONS
- WAIT UNTIL RSO APPROVES APPROACH
- EXPECT A POSSIBLE MOTOR IGNITION
- APPROACH LAUNCH PAD
- INSPECT LAUNCH PAD WIRING
- CONSULT RSO FOR FURTHER ACTION

NO IGNITOR CONTINUITY

- LISTEN TO RSO INSTRUCTIONS
- DESIGNATED PERSONNEL APPROACH THE LAUNCH PAD
- CHECK IF IGNITOR IS PROPERLY INSERTED IN THE MOTOR
- CHECK IF ALLIGATOR CLIPS ARE PROPERLY ATTACHED TO IGNITOR

If No Continuity Persists:

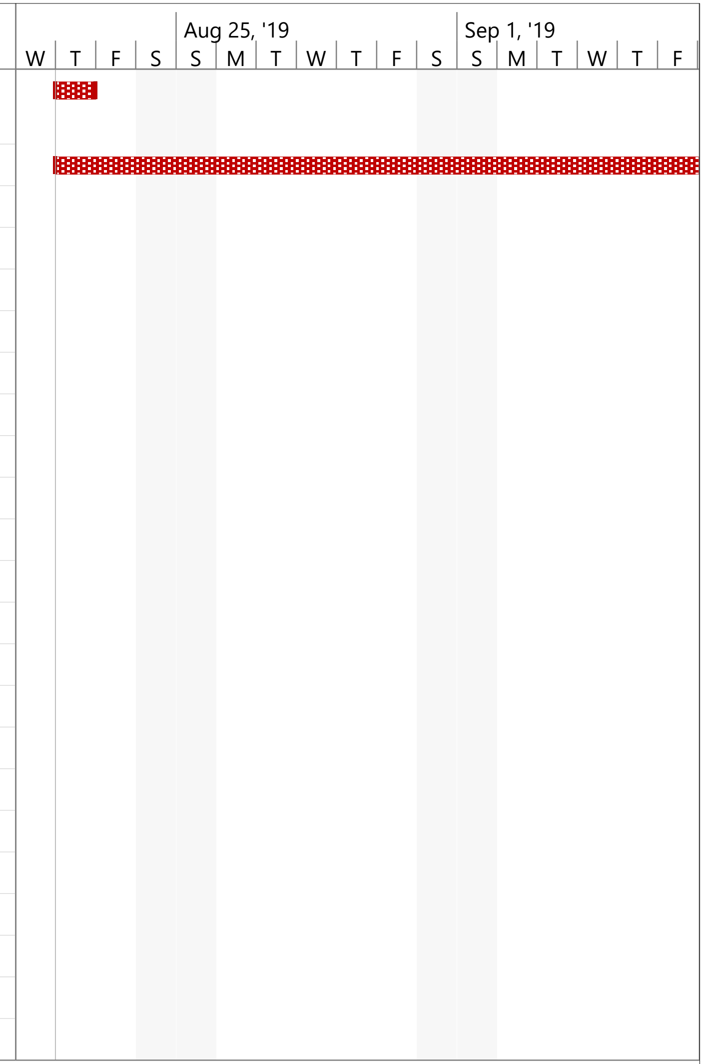
- SEEK RSO DIRECTION
- CHANGE LAUNCH PAD

SIMULTANEOUS DROGUE AND MAIN PARACHUTE DEPLOYMENT

- LISTEN TO RSO INSTRUCTIONS
- DETERMINE DESCENT PATH
- REMAIN CLEAR OF DESCENT PATH
- FOLLOW FIELD RECOVERY CHECKLIST

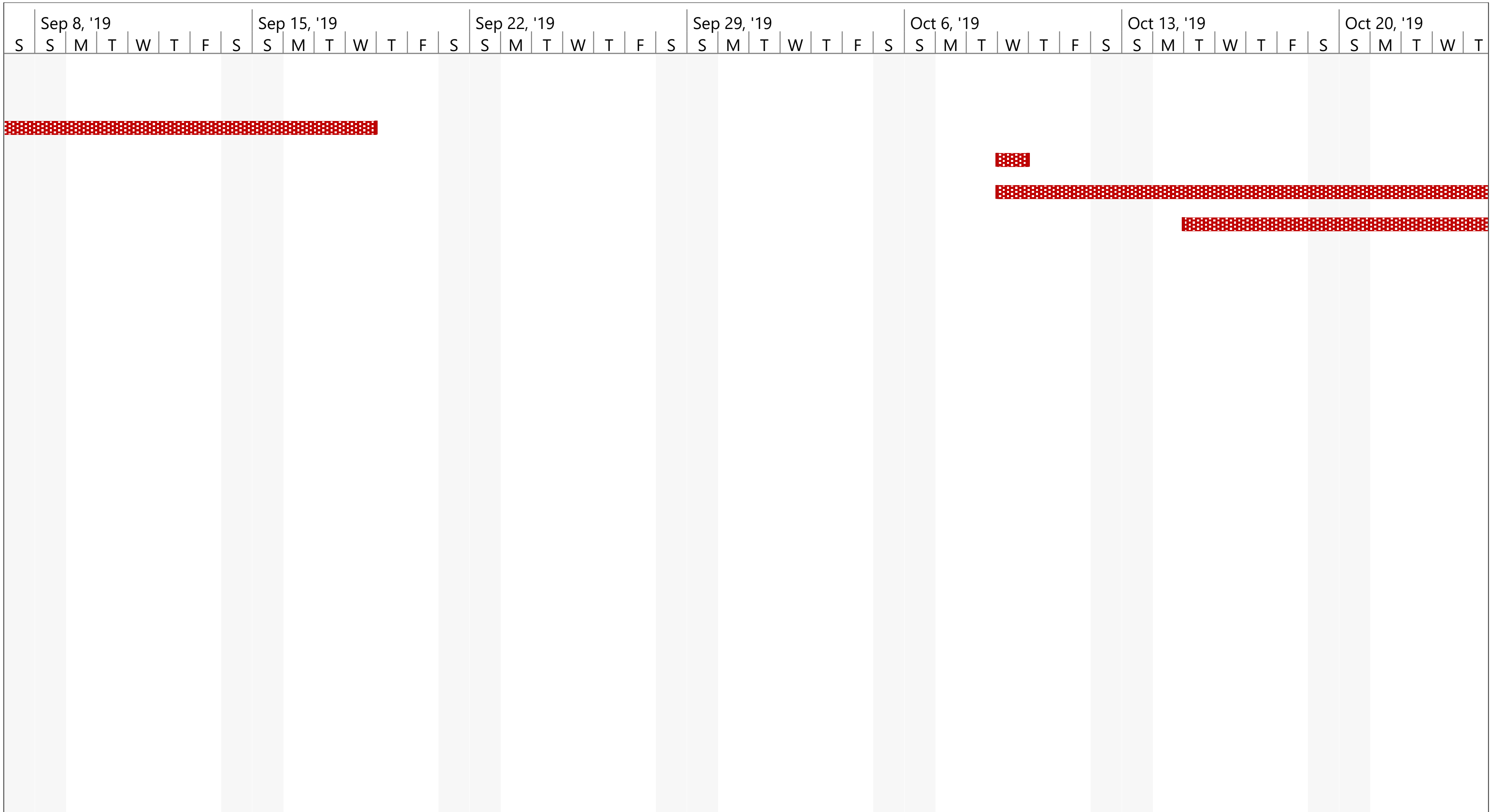
Appendix C

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 Constructio	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	



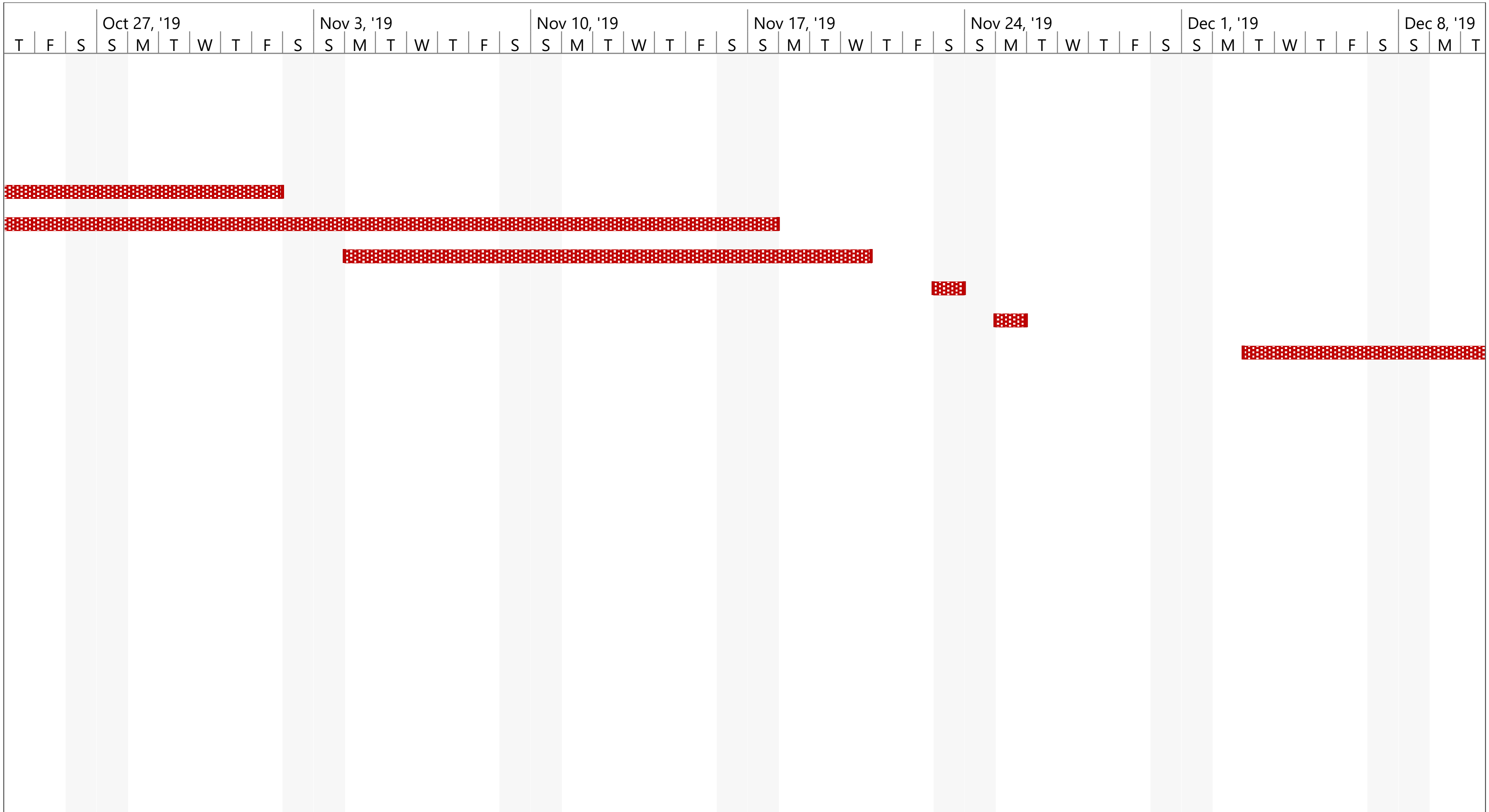
Project: Project Schedule
Date: Tue 1/7/20

Task		Inactive Task		Manual Summary Rollup	
Split		Inactive Milestone		Manual Summary	
Milestone		Inactive Summary		Start-only	
Summary		Manual Task		Finish-only	
Project Summary		Duration-only			



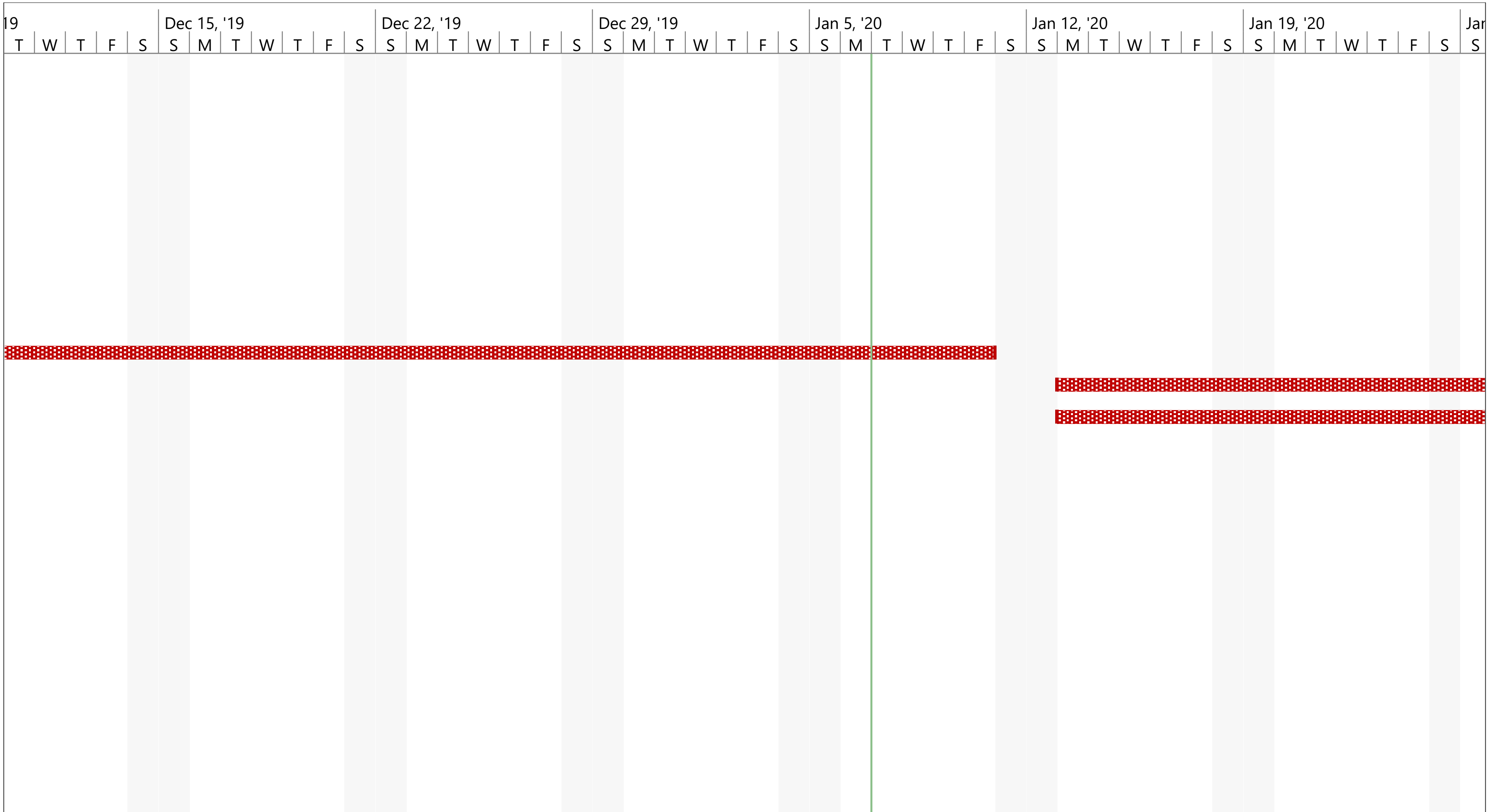
Project: Project Schedule
Date: Tue 1/7/20

Task		Inactive Task		Manual Summary Rollup	
Split		Inactive Milestone		Manual Summary	
Milestone		Inactive Summary		Start-only	
Summary		Manual Task		Finish-only	
Project Summary		Duration-only			



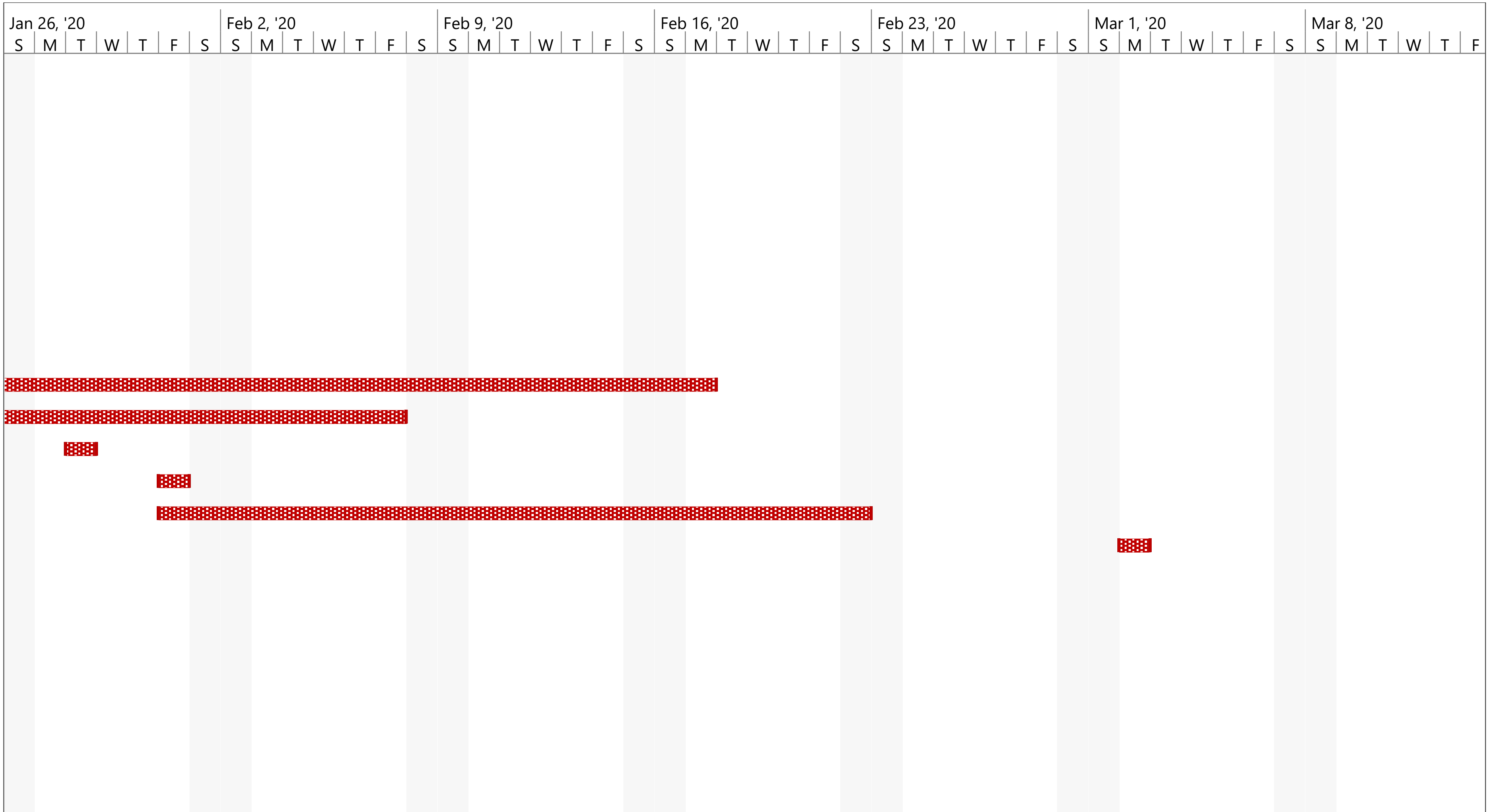
Project: Project Schedule
Date: Tue 1/7/20

Task		Inactive Task		Manual Summary Rollup	
Split		Inactive Milestone		Manual Summary	
Milestone		Inactive Summary		Start-only	
Summary		Manual Task		Finish-only	
Project Summary		Duration-only			



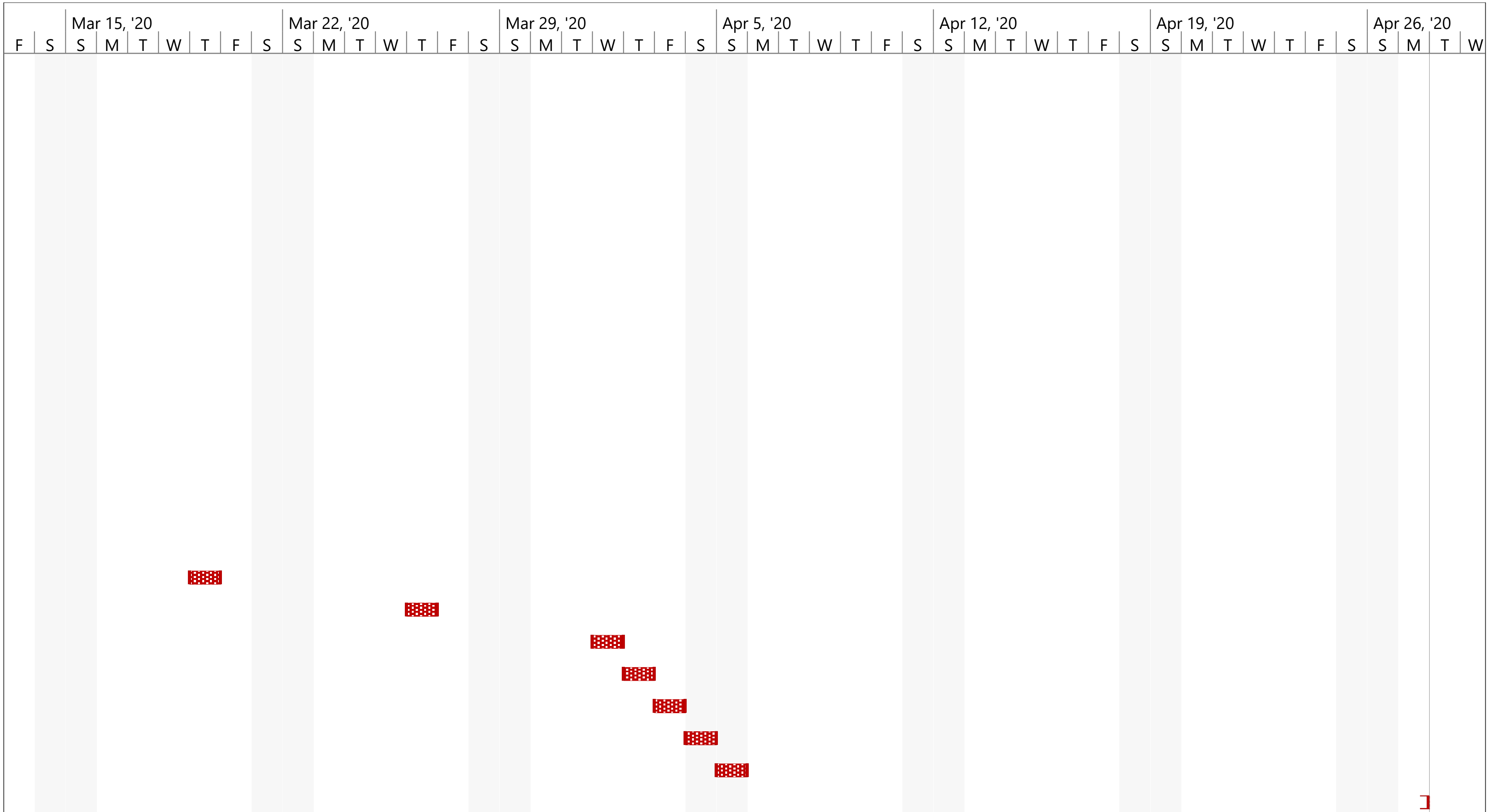
Project: Project Schedule
Date: Tue 1/7/20

Task		Inactive Task		Manual Summary Rollup	
Split		Inactive Milestone		Manual Summary	
Milestone		Inactive Summary		Start-only	
Summary		Manual Task		Finish-only	
Project Summary		Duration-only			



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

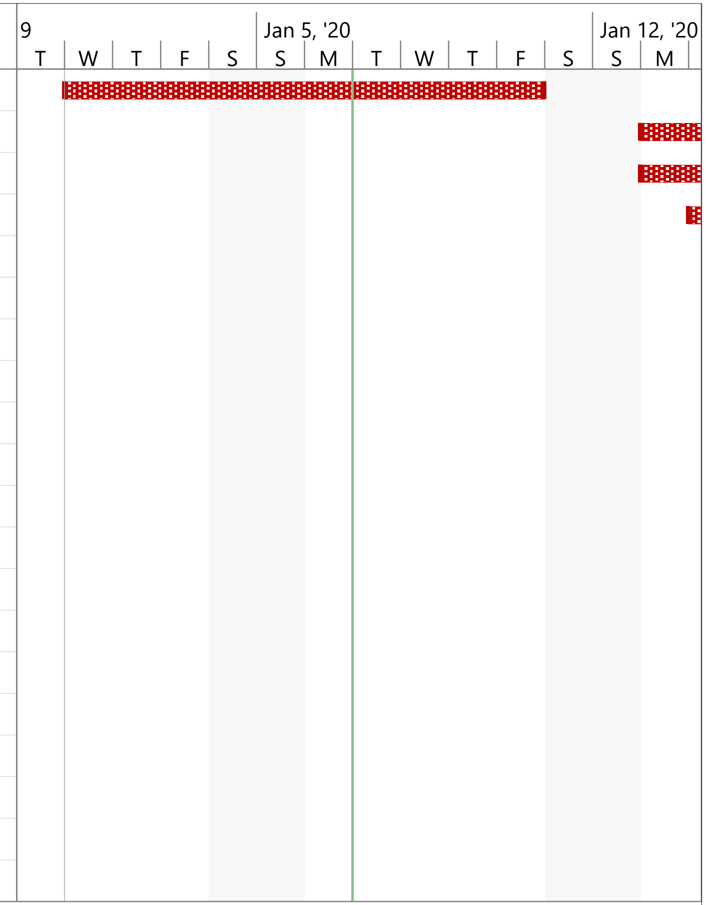
Task		Inactive Task		Manual Summary Rollup	
Split		Inactive Milestone		Manual Summary	
Milestone		Inactive Summary		Start-only	
Summary		Manual Task		Finish-only	
Project Summary		Duration-only			



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

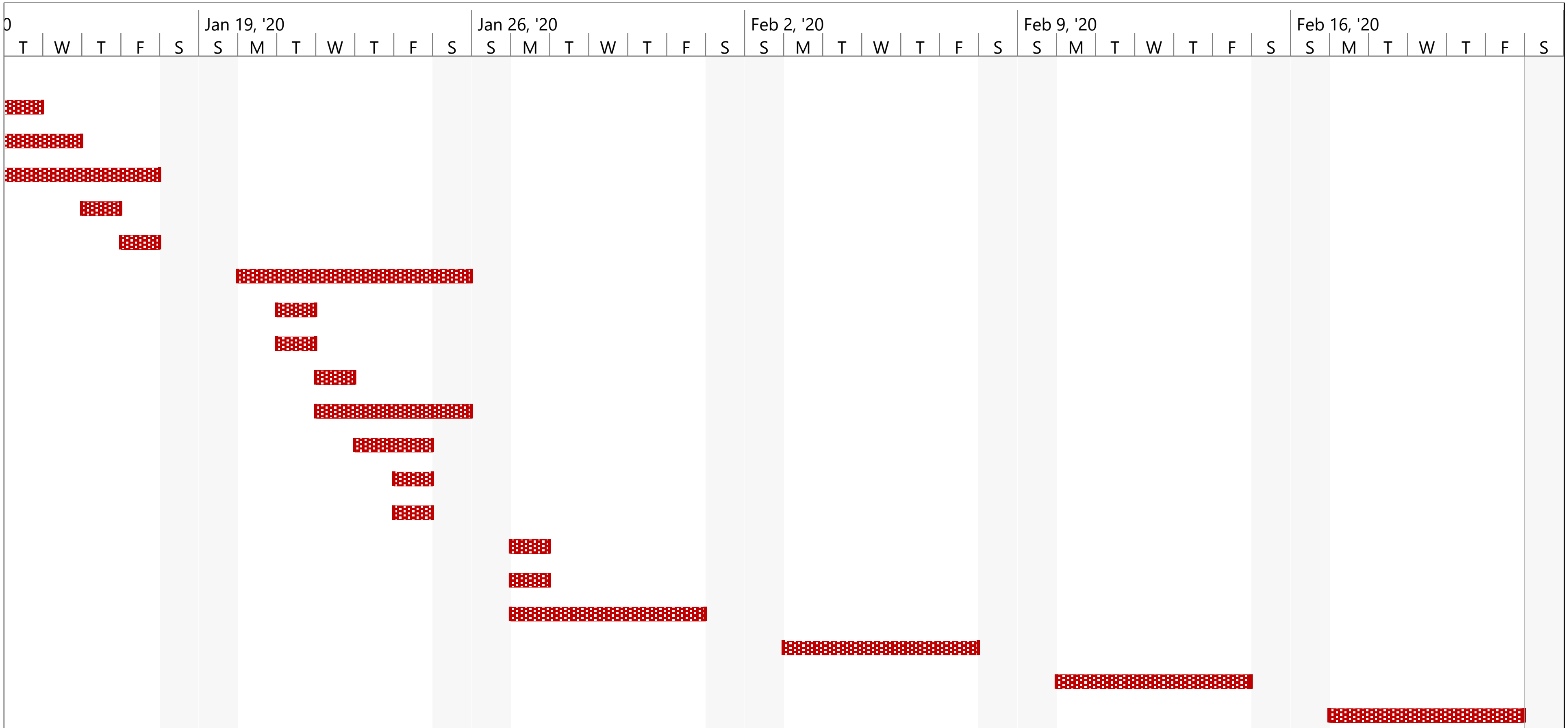
Task	Inactive Task	Manual Summary Rollup
Split	Inactive Milestone	Manual Summary
Milestone	Inactive Summary	Start-only
Summary	Manual Task	Finish-only
Project Summary	Duration-only	

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
1			Order Parts	8 days	Wed 1/1/20	Fri 1/10/20	
2			Lasercut Bulkheads a	2 days	Mon 1/13/20	Tue 1/14/20	
3			Cut Airframe Tubes	3 days	Mon 1/13/20	Wed 1/15/20	
4			Bulkhead Layups	4 days	Tue 1/14/20	Fri 1/17/20	
5			Body Tube Layups	1 day	Thu 1/16/20	Thu 1/16/20	
6			Bulkhead Assembly	1 day	Fri 1/17/20	Fri 1/17/20	
7			Fin Can Assembly	6 days	Mon 1/20/20	Sat 1/25/20	
8			Install Motor Tube	1 day	Tue 1/21/20	Tue 1/21/20	
9			Lasercut AV Sled	1 day	Tue 1/21/20	Tue 1/21/20	
10			Install FWD Rail Buttc	1 day	Wed 1/22/20	Wed 1/22/20	
11			AV Sled Fabrication	4 days	Wed 1/22/20	Sat 1/25/20	
12			Nosecone Bulkhead I	2 days	Thu 1/23/20	Fri 1/24/20	
13			Install AFT Rail Buttor	1 day	Fri 1/24/20	Fri 1/24/20	
14			Install Motor Retaine	1 day	Fri 1/24/20	Fri 1/24/20	
15			Drill Pressure Ports	1 day	Mon 1/27/20	Mon 1/27/20	
16			Drill Switch Holes	1 day	Mon 1/27/20	Mon 1/27/20	
17			AV Bay Wiring	5 days	Mon 1/27/20	Fri 1/31/20	
18			Payload Bay Assembl	5 days	Mon 2/3/20	Fri 2/7/20	
19			Payload Integration	5 days	Mon 2/10/20	Fri 2/14/20	
20			Paint	5 days	Mon 2/17/20	Fri 2/21/20	



Project: Launch Vehicle Build Sc
Date: Tue 1/7/20

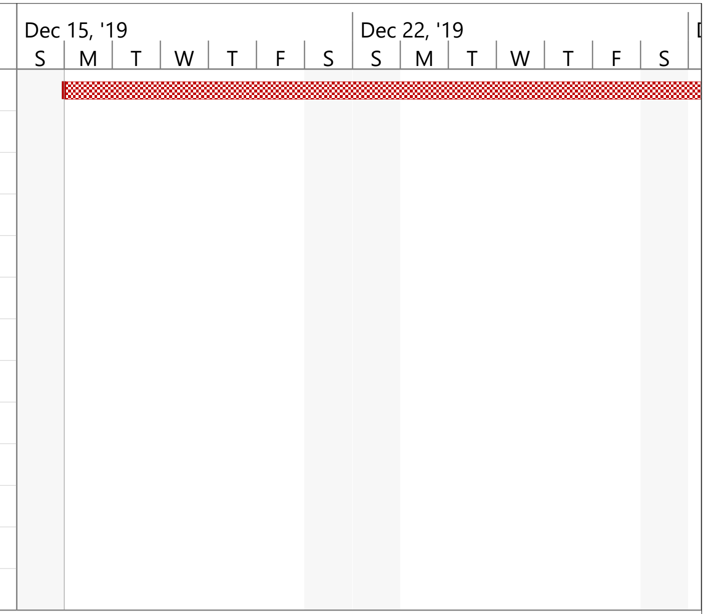
Task
Split
Milestone
Summary
Project Summary
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone



Project: Launch Vehicle Build Sc
Date: Tue 1/7/20

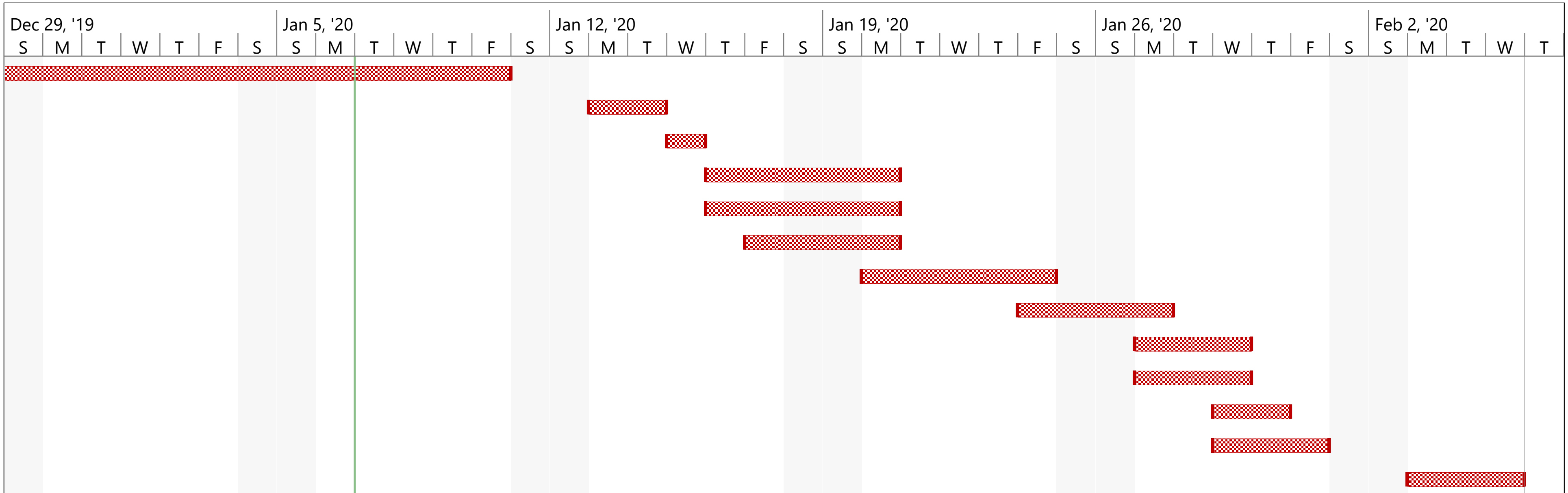
Task	Inactive Milestone	Start-only
Split	Inactive Summary	Finish-only
Milestone	Manual Task	External Tasks
Summary	Duration-only	External Milestone
Project Summary	Manual Summary Rollup	
Inactive Task	Manual Summary	

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
1			Order Parts	20 days	Mon 12/16/1	Fri 1/10/20	
2			Lasercut Chassis	2 days	Mon 1/13/20	Tue 1/14/20	
3			Assemble Chassis	1 day	Wed 1/15/20	Wed 1/15/20	
4			Install Drive Motors	3 days	Thu 1/16/20	Mon 1/20/20	
5			Install Battery	3 days	Thu 1/16/20	Mon 1/20/20	
6			3D Print Electronics B	2 days	Fri 1/17/20	Mon 1/20/20	
7			Assemble Electronic (	5 days	Mon 1/20/20	Fri 1/24/20	
8			Program Arduino	2 days	Fri 1/24/20	Mon 1/27/20	
9			Configure Receiver	3 days	Mon 1/27/20	Wed 1/29/20	
10			Install Electronics Bay	3 days	Mon 1/27/20	Wed 1/29/20	
11			Install Caster Wheels	2 days	Wed 1/29/20	Thu 1/30/20	
12			Install SICCU	3 days	Wed 1/29/20	Fri 1/31/20	
13			Integrate with Retent	3 days	Mon 2/3/20	Wed 2/5/20	



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

Task	Inactive Task	Manual Summary Rollup
Split	Inactive Milestone	Manual Summary
Milestone	Inactive Summary	Start-only
Summary	Manual Task	Finish-only
Project Summary	Duration-only	



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

Task	Inactive Task	Manual Summary Rollup
Split	Inactive Milestone	Manual Summary
Milestone	Inactive Summary	Start-only
Summary	Manual Task	Finish-only
Project Summary	Duration-only	