The Pennsylvania State University

LionTech Rocket Labs

2018 - 2019 Solium Project

Flight Readiness Review Report

046 Hammond Building, University Park, PA 16802
March 4th, 2019

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List of Acronyms

A&R	Avionics and Recovery
ABS	Acrylonitrile Butadiene Styrene
AV	Avionics
CDR	Critical Design Review
CFD	Computational Fluid Dynamics
EIT	Electronic and Information Technology
FAA	Federal Aviation Administration
FEA	Finite Element Analysis
EHS	Environmental Health and Safety
EUC	Engineering Undergraduate
GPS	Global Positioning System
HPCL	High Pressure Combustion Lab
LTRL	LionTech Rocket Labs
MDRA	Maryland Delaware Rocketry Association
MSDS	Material Safety Data Sheet
NAR	National Association of Rocketry
NASA	National Aeronautics and Space Administration
NFPA	National Fire Protection Association
PETG	Polyethylene Terephthalate Glycol
PLA	Polylactic Acid
PPE	Personal Protective Equipment
PSC	Pittsburgh Space Command
PSU	The Pennsylvania State University
PVA	Poly-Vinyl Alcohol
RSO	Range Safety Officer
SDS	Safety Datasheet
SLI	Student Launch Initiative
STEM	Science Technology Engineering and Mathematics
STTR	Small Business Technology Transfer
TRA	Tripoli Rocket Association
UPAC	University Park Allocation Committee
USD	United States Dollar
USLI	University Student Launch Initiative

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1. Summary of Preliminary Design Report

1.1 Team Summary

Team Name and Mailing Address

Lion Tech Rocket Labs: 236 S Barnard St, Unit 3, State College, PA 16801

Adult Educator/Club Advisor

Dr. David Spencer – dbs9@psu.edu (814) 865-4537

NAR Contact/Mentor

Justin Hess NAR L2 Certification - #102887 – jthess418@gmail.com

1.2 Launch Vehicle Summary

Size and Mass and Rail Size

The flight vehicle is designed to carry a rover payload along with the necessary flight systems for telemetry acquisition and a successful recovery. The flight vehicle's target apogee is 5,280 feet. A diameter of 6 inches was chosen to give adequate space for the rover, its retention system, and its deployment system. The length of the flight vehicle is 120 inches to provide enough space for the payload and the necessary avionics and flight systems. The flight vehicle's wet mass weight is 36.7 lbs, and will launch on a 10-foot tall, 15-15 rail. A model of the final flight vehicle with internal components visible can be seen below in Figure 1 and Figure 2 shows a picture of the fully assembled flight vehicle before the fullscale test flight.

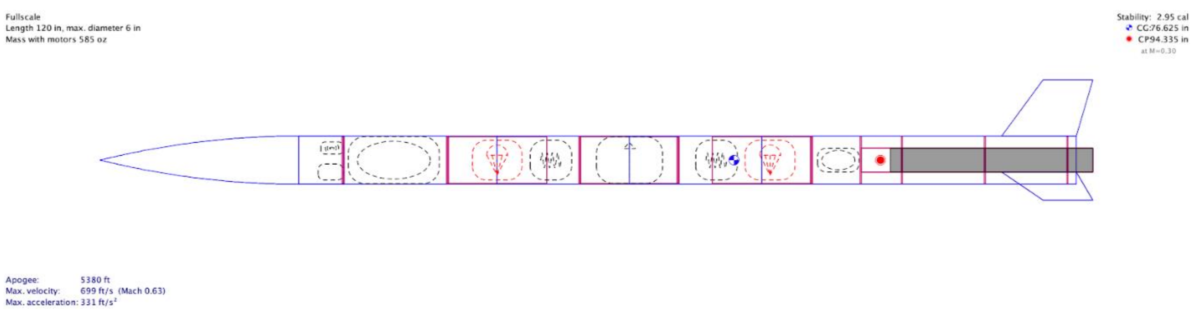


Figure 1. Side View of the Fullscale Flight Vehicle

Figure 2. Assembled Flight Vehicle before Fullscale Test Flight

Launch Day Motor and Target Altitude

The motor selection is based on the mission performance criteria outlined in the 2019 NASA Student Launch Handbook and utilizes OpenRocket to simulate flight characteristics. Through this motor selection process, the Cesaroni L1355 was selected as the vehicle's motor and will take the launch vehicle to the target apogee of 5,280 feet.

Recovery System

The rocket has a dual-deployment parachute recovery system where the primary altimeter deploys drogue parachute at apogee and the main parachute at 600 feet above ground level (AGL). The redundant altimeter has a two-second delay for drogue and deploys at 500 feet AGL for main. The drogue parachute is an 18" Fruity Chutes Classical Ultra and the main parachute is a 96" Fruity Chutes Iris Ultra. The avionics bay has a removable avionics board consisting of two independent Stratologger CF altimeters with corresponding independent power sources switches, initiators and black powder charges.

1.3 Payload Summary

Payload Title

Deployable Rover/Soil Sample Recovery System

Summary of Payload Experiment

The payload challenge chosen for this year's student launch competition is to build a rover that will be autonomously deployed from the launch vehicle to recover a 10 milliliter soil sample. The design features a rotating payload bay mechanism that will be used to align the rover to an upright position after the launch vehicle has landed and a 3D printed rover that has been optimized for spatial efficiency. The rover will be retained during flight with a solenoid locking mechanism that features a 3D printed lock. The rover will exit the rocket after a nose cone ejection using a black powder detonation to drive for 1 minute and recover the soil sample.

Milestone Review Flysheet

Milestone Review Flysheet 2018-2019

Institution	LionTech Rocket Labs	Milestone	CDR

Vehicle Properties	
Total Length (in)	120
Diameter (in)	6
Gross Lift Off Weigh (lb)	36.6
Airframe Material(s)	Carbon Fiber, Fiberglass, Blue Tube
Fin Material and Thickness (in)	Fiberglass, 3/16"
Coupler Length/Shoulder Length (in)	12 / 6

Motor Properties	
Motor Brand/Designation	Cesaroni L1355
Max/Average Thrust (lb)	393 / 306
Total Impulse (lbf-s)	905
Mass Before/After Burn (lb)	10.9 / 4.2
Liftoff Thrust (lb)	360
Motor Retention Method	Plywood centering rings, steel-infused epoxy

Stability Analysis	
Center of Pressure (in. from nose)	94.3
Center of Gravity (in. from nose)	76.4
Static Stability Margin (on pad)	2.96
Static Stability Margin (at rail exit)	2.05
Thrust-to-Weight Ratio	7.77
Rail Size/Type and Length (in)	15-15 / 120
Rail Exit Velocity (ft/s)	75.5

Ascent Analysis	
Maximum Velocity (ft/s)	698
Maximum Mach Number	0.62
Maximum Acceleration (ft/s^2)	331
Target Apogee (ft)	5280
Predicted Apogee (From Sim.) (ft)	5289

Recovery System Properties - Overall	
Total Descent Time (s)	83.6
Total Drift in 20 mph winds (ft)	2421.4

Recovery System Properties - Energetics		
Ejection System Energetics (ex. Black Powder)		4F Black Powder
Energetics Mass - Drogue Chute (grams)	Primary	1.5
	Backup	2
Energetics Mass - Main Chute (grams)	Primary	2
	Backup	3
Energetics Mass - Other (grams) - If Applicable	Primary	
	Backup	

Recovery System Properties - Recovery Electronics	
Primary Altimeter Make/Model	Perfect Flight StrologgerCF
Secondary Altimeter Make/Model	Perfect Flight StrologgerCF
Other Altimeters (if applicable)	NA
Rocket Locator (Make/Model)	Americaloc GL300W
Additional Locators (if applicable)	NA
Transmitting Frequencies (MHz) (all - vehicle and payload)	UMTS: 850/1900/2100 GSM/GPRS: 850/900/1800/1900
Describe Redundancy Plan (batteries, switches, etc.)	9V battery, toggle switch
Pad Stay Time (Launch Configuration)	2 hours

Recovery System Properties - Drogue Parachute				
Manufacturer/Model	Fruity Chutes, Classical Ultra			
Size or Diameter (in or ft)	18 in			
Main Altimeter Deployment Setting	Apogee			
Backup Altimeter Deployment Setting	Apogee + 2 seconds			
Velocity at Deployment (ft/s)	91			
Terminal Velocity (ft/s)	87.3			
Recovery Harness Material, Size, and Type (examples - 1/2 in. tubular Nylon or 1 in. flat Kevlar strap)	1/2 in kevlar flat strap			
Recovery Harness Length (ft)	24			
Harness/Airframe Interfaces	3/8 in steel U-Bolt			
Kinetic Energy of Each Section (ft lbs)	Section 1	Section 2	Section 3	Section 4
	1179.2	916.05	1362.68	NA

Recovery System Properties - Main Parachute				
Manufacturer/Model	Fruity Chutes, Iris Ultra			
Size or Diameter (in)	96			
Main Altimeter Deployment Setting (ft)	600			
Backup Altimeter Deployment Setting (ft)	500			
Velocity at Deployment (ft/s)	87.3			
Terminal Velocity (ft/s)	18.02			
Recovery Harness Material, Size, and Type (examples - 1/2 in. tubular Nylon or 1 in. flat Kevlar strap)	1/2 in kevlar flat strap			
Recovery Harness Length (ft)	27			
Harness/Airframe Interfaces	3/8 in steel U-Bolt			
Kinetic Energy of Each Section (ft lbs)	Section 1	Section 2	Section 3	Section 4
	50.59	38.86	58.06	NA

Milestone Review Flysheet 2018-2019

Institution	LionTech Rocket Labs	Milestone	CDR

Payload

	Overview
Payload 1 (official payload)	The payload is a rover that will be autonomously deployed from the launch vehicle after landing by a ground station control system. The rocket will be separated using an initiator and a black powder charge. The rover will be retained with a fail proof solenoid lock that has been verified to work during the vehicle demonstration flight. The rover will then travel at least 10 feet from the launch vehicle and recover a soil sample of 10 milliliters.
	Overview
Payload 2 (non-scored payload)	N/A

Test Plans, Status, and Results

Ejection Charge Tests	All ejection charges for main deployment, drogue deployment, and payload deployment will be tested on the ground prior to flight to ensure that systems are functioning properly. Extensive calculations have been performed that provide great confidence that all separations will occur as planned.
Sub-scale Test Flights	The subscale test flight was successful since the rocket was launched and recovered according to our expectations while not causing any significant safety concerns.The only anomaly observed during flight was the rocket "wobbling" as it left the launch rail. We believe this was due to sections of body tube that were not flush with each other while fully assembled. This left significant amounts of room for the rocket to "bend" and "flex" while it was not supported in flight. This anomaly did not compromise the safety of our flight or even the principles of our rocket design, but manufacuring processes will be adjusted in the future to avoid this problem.
Vehicle Demonstration Flights	The team successfully designed, constructed, launched, and recovered their 2018-2019 competition year rocket on February 9th. Launch day conditions were acceptable with little cloud cover, moderate winds of approximately 15 mph at the time of launch, and a temperature of 30 degrees°F. The rocket was launched from a launch rail at an angle of approximately 5 degrees and at 60 feet above sea level. The rocket had an apogee of 5,361 feet and took 84 seconds to land from apogee. All recovery systems perforemd exactly as expected, the launch vehicle experienced no structural damage, and the payload was successfully retained during flight.
Payload Demonstration Flights	N/A

Milestone Review Flysheet 2018-2019

Institution	LionTech Rocket Labs
Milestone	CDR

Transmitter #1			
Location of transmitter:	At the ground station with the team		
Purpose of transmitter:	To send signals to the rocket and the rover		
Brand	LoRa	RF Output Power (mW)	
Model	RFM95	Specific Frequency used by team (MHz)	915
Handshake or frequency hopping? (explain)	N/A		
Distance to closest e-match or altimeter (in)	At the ground station away from the ematches and altimeters		
Description of shielding plan:	Aluminum foil lining the inside of the rotating bay		

Transmitter #2			
Location of transmitter:	Nose Cone		
Purpose of transmitter:	GPS Locator		
Brand	Ameriloc	RF Output Power (mW)	GSM 850 and EGSM 900
Model	GL300W	Specific Frequency used by team (MHz)	850/1900/2100
Handshake or frequency hopping? (explain)	Hopping		
Distance to closest e-match or altimeter (in)	24 in to wired e-match and Arduino Mega		
Description of shielding plan:	Surrounded by Carbon- Fiber body tube		

Transmitter #3			
Location of transmitter:			
Purpose of transmitter:			
Brand		RF Output Power (mW)	
Model		Specific Frequency used by team (MHz)	
Handshake or frequency hopping? (explain)			
Distance to closest e-match or altimeter (in)			
Description of shielding plan:			

Transmitter #4			
Location of transmitter:			
Purpose of transmitter:			
Brand		RF Output Power (mW)	
Model		Specific Frequency used by team (MHz)	
Handshake or frequency hopping? (explain)			
Distance to closest e-match or altimeter (in)			
Description of shielding plan:			

Milestone Review Flysheet 2018-2019

Institution	LionTech Rocket Labs	Milestone	CDR

Transmitter #5			
Location of transmitter:			
Purpose of transmitter:			
Brand		RF Output Power (mW)	
Model		Specific Frequency used by team (MHz)	
Handshake or frequency hopping? (explain)			
Distance to closest e-match or altimeter (in)			
Description of shielding plan:			

Transmitter #6			
Location of transmitter:			
Purpose of transmitter:			
Brand		RF Output Power (mW)	
Model		Specific Frequency used by team (MHz)	
Handshake or frequency hopping? (explain)			
Distance to closest e-match or altimeter (in)			
Description of shielding plan:			

Additional Comments

2. Changes Made Since Proposal

2.1 Changes Made to Project Plan

Other than the revisions specified by the subsystems, no changes have been made to the project plan.

2.2 Changes Made to Vehicle Criteria

Launch Vehicle

Since CDR, there have been minimal changes to the launch vehicle. To better accommodate the four-grain casing of the rocket motor, the motor tube was constructed to be 2” longer towards the aft end. This design change does not drastically change the stability, center of mass or center of pressure characteristics of the launch vehicle. This change was motivated by the team switching the motor from a three-grain motor to a four-grain motor between PDR and CDR. The motor tube was extended two inches to accommodate the longer motor casing as a result. Instead of lengthening the booster body tube by two inches to match the motor casing, the motor tube simply extends two inches past the aft end of the booster body tube. This means that the motor tube now terminates even with the aft-most point of the fins instead of the aft end of the booster body tube. Additionally, the fin bracket design has been improved since CDR due to the results observed during the fullscale test flight. Small cracks were observed at a sharp edge so fillets have been added to the design to minimize this stress concentration. The material has also been changed to a more ductile thermoplastic to better withstand impact upon landing. Deeper analysis and further discussion of this change and the fullscale test flight are detailed later in the report.

Recovery System

The drogue parachute is now an 18” Fruity Chutes Classical Ultra which is larger than the 12” Fruity Chutes Classical Ultra detailed in CDR. This was an action item from CDR and the change was made to slow the rapid descent rate of the rocket down to a more controlled fall. The drift calculations show that the rocket will still land within the required landing zone.

The main parachute is now a 96” Fruity Chutes Iris Ultra which is larger than the 84” Fruity Chutes Iris Ultra detailed in CDR. This change was made to give the team a larger buffer on the kinetic energy requirements. The drift calculations show that the rocket will still land within the required landing zone.

The avionics board battery retainment mechanism is now a 3D printed plate that screws onto the avionics board. In CDR, the batteries were retained by a clip that was 3D printed onto the board. These clips were damaged or broken in a few of the test prints and were deemed not reliable enough. Additionally, this design resulted in batteries becoming stuck in the clip on occasions. The new panel still allows the same access to the batteries and their clips.

2.3 Changes Made to Payload Criteria

External Loading of Black Powder

Because of safety concerns during the assembly of the payload section on launch day, the deployment charge set up was modified so that black powder could be loaded through an external door. This change allows for the payload team to safely load the black powder and reduce the amount of time the payload section is armed during assembly.

Rover Motor Choice

After construction and testing of the rover, it was determined that the motors that were selected for CDR did not provide enough torque to allow the rover to climb over minor obstacles. New motors were selected that are similar in size and provide higher torque. Because the new motors are higher torque, the rover will operate using front wheel drive only and the back wheels will freely rotate.

Motor Mount

Because the motors had to be changed, the mounts that hold the motors had to be changed. The new mounts are 3D printed to hold two motors for front wheel drive. Additional wire clips were added to the motor mounts to hold the wires more securely.

Wheel and Axle Mount Connection

Because the rover now has two single shaft motors for the front 2 wheels, this increases the amount of horizontal space that the motors take up inside the payload bay. A small adjustment was made to the connection point between the wheel and the axle mount to increase spatial efficiency.

3. Vehicle Criteria

3.1 Design and Construction of Vehicle

Airframe

The airframe material for the flight vehicle is carbon fiber, constructed through the process of vacuum bagging. The material selection matrix for choosing this material is shown below in Table 1.

Table 1. Airframe Material Selection Matrix

		Carbon Fiber (Shrink Tape)		Carbon Fiber (Vacuum Bagging)		Glass Fiber		Blue Tube	
Attributes	**Weight**	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Strength	0.15	3	0.45	5	0.75	4	0.60	1	0.15
Cost	0.10	3	0.30	1	0.20	2	0.20	5	0.50
Workability	0.10	2	0.20	1	0.60	3	0.30	5	0.50
Material Weight	0.15	3	0.45	3	0.45	1	0.15	4	0.60
Educational Value	0.25	5	1.25	5	1.25	2	0.50	1	0.25
Safety	0.25	2	0.50	3	0.75	1	0.50	5	1.25
Total	1.00		**2.95**		**3.40**		**2.35**		**3.25**
Rank			**3**		**1**		**4**		**2**

The scores for categories in Table 1 are justified in Table 2, Table 3, and Table 4.

The tensile strength ratings given to the different materials can be found below in Table 2.

Table 2. Material Strength and Stiffness Comparison

Material	Tensile Strength [ksi]	Modulus [Msi]
Carbon Fiber	610-635	33-38
Glass Fiber	500-650	10.5-12.4
Blue Tube	15-25	0.58

The cost for the materials measured by cost per linear foot can be found below in Table 3.

Table 3. Material Cost Comparison

Material:	Cost/Foot [in $]:
Carbon Fiber (Shrink Tape)	52.36
Carbon Fiber Vacuum Bagging	61.56
Glass fiber	55
Blue Tube	18

When scoring weight for the potential materials, it was discovered that there are some discrepancies between the density given from the supplier's website and the OpenRocket database. Table 4 details the differences in densities between OpenRocket's database and the supplier's information.

Table 4. Density Discrepancy between OpenRocket and Supplier

	OpenRocket Density ($\frac{oz}{in^3}$)	Supplier Density ($\frac{oz}{in^3}$)
Glass Fiber	1.07	1.18
Blue Tube	0.75	0.54
Carbon Fiber	1.03	0.919

For carbon fiber the team believes that this discrepancy is caused by the specific fabric utilized. The process at which the tubes are cured will also have an effect on the density of carbon fiber. After the carbon fiber body tubes were completed, the density was measured to be 0.605 $\frac{oz}{in^3}$. This density is significantly smaller than expected but structural testing has not yet shown that the carbon fiber has a lower tensile strength than expected.

The team decided to include an educational value category this year. One of the project's objectives is to involve students in engineering projects and to bestow upon them knowledge that will be valuable in their future careers. Since the aerospace industry is placing a greater emphasis on composite materials, the team has decided it would be beneficial to research new ways to incorporate them in the project. Since carbon fiber is utilized heavily throughout the aerospace industry, it has the highest score in this category.

Final Selection

After all the scores were assigned and weighted, vacuum bagged carbon fiber had the highest score and was selected as the team's airframe material for the 2018-2019 competition year as a result. Calculations detailed in the testing plan section detail justification for either six or seven layers of carbon fiber that are necessary to withstand nominal flight forces. The fullscale launch vehicle utilized six layers of carbon fiber due to the reduced cost of using six layers compared to seven layers. The structural integrity of six layers of carbon fiber was verified during fullscale test flight where the carbon fiber airframe was not structurally compromised in any way.

Carbon Fiber Vacuum Bagging Process

Vacuum bagging was the chosen technique for making the carbon fiber airframe because it has many benefits that are not found in similar methods of carbon fiber tube fabrication. Vacuum bagged carbon fiber parts have a more uniform distribution of epoxy and resin during curing which yields a higher fiber content. This creates a part that is stronger and stiffer than a part the team can currently create with the shrink tape method.

In the process of vacuum bagging, plies of 3K-Plain Weave carbon fiber were cut to the dimensions of the needed airframe body tube as shown in Figure 3. Blue tube was wrapped in packing tape to help keep epoxy from sticking to the mandrel. Next, PVA (poly-vinyl alcohol) was applied on the packing tape to help detach the carbon fiber body tube from the mandrel. Three layers of PVA were applied to the mandrel to ensure a better release of the body tube, as shown in Figure ***4***. The plies of carbon fiber are then coated with System 2000 Epoxy Resin with 2060 Hardener and laid around a cylindrical mandrel to form carbon fiber tubes. Figure 5 shows the plies laid up on the mandrel. Afterwards, a layer of nylon release film and breather cloth are wrapped around the carbon fiber layers which are sealed with a final layer of nylon bagging film and sealant tape as shown in Figure 6. A pump with a nozzle is inserted through a cut hole in the nylon bagging film and sealed as seen in Figure 7. When the pump is turned on, the air inside the bag is sucked out by the pump which compresses the carbon fiber layers and removes excess epoxy from the carbon fiber. The vacuum is left on the carbon fiber for at least 24 hours at 12 psi to ensure a full cure while in the vacuum. After the tube has fully cured, the outer layers are removed and the carbon fiber tube is taken off of the mandrel.

Figure 3. Cutting Carbon Fiber Plies

Figure 4. Blue tube mandrel wrapped in packing tape prior to carbon fiber wrapping

Figure 5. Carbon fiber plies wrapped around mandrel

Figure 6. Wrapping the carbon fiber with nylon release and breather cloth layers and sealing the nylon bagging with sealant tape

Figure 7. Vacuum pump configuration while putting the vacuum on the tube

During the testing phase of vacuum bagging, one of the main problems faced by the team was the process of getting the cured carbon fiber tube off of the mandrel. Originally the plan was to use a blue tube mandrel wrapped in packing tape, coated in a polyvinyl alcohol (PVA) mold release film, and wrapped again in nylon release film. After the cure, the carbon fiber tube would then slide off the blue tube due to this combination of release film layers. After wrapping test pieces, it was found that it took an immense amount of force to be able to slide the cured carbon fiber off of the mandrels to the point where removing the carbon fiber from the mandrel was impossible. An aluminum mandrel was used instead with the same release films. The team predicted the PVA mold release film would coat better on this mandrel which would help with the smooth removal of the body tube from the mandrel. Unfortunately, these tests also resulted in the body tube being stuck to the mandrel. Body tubes needed to be cut in half in order to be removed from the mandrel. In the final airframe tube construction design, a blue tube mandrel was wrapped with packing tape and was immediately followed by the carbon fiber layer. After completely curing, the full body tube and mandrel would then soak in warm water for about 30 minutes. This resulted in the blue tube becoming weak enough that it could be stripped away, leaving only the carbon fiber body tube. The water would have no effect on cured carbon fiber material properties for the short soaking period.

While this process did eventually deliver acceptable results, it is far from an optimal solution. Mandrels of this size with the tolerances required are relatively expensive, so finding a solution which does not destroy the mandrel after each layup will be essential going forward. The team plans on doing research and testing after the competition launch for future projects using this layup process. Figure 8 depicts a fully constructed booster section body tube. Towards the aft end of the carbon fiber body tube, the motor casing can be seen.

Figure 8. Booster Section Body Tube

Figure 8 also shows two fins mounted in their respective fin brackets, along with a slot where the third fin bracket will be placed.

Bulkheads

Bulkheads are used on the ends of each coupler to help contain systems such as the avionics bay, and to act as attachment points for the parachutes. Each attachment point uses a coupler bulkhead and a body tube coupler attached together with an eye-bolt resulting in a combined thickness of ½”. This bulkhead design is shown below in Figure 9.

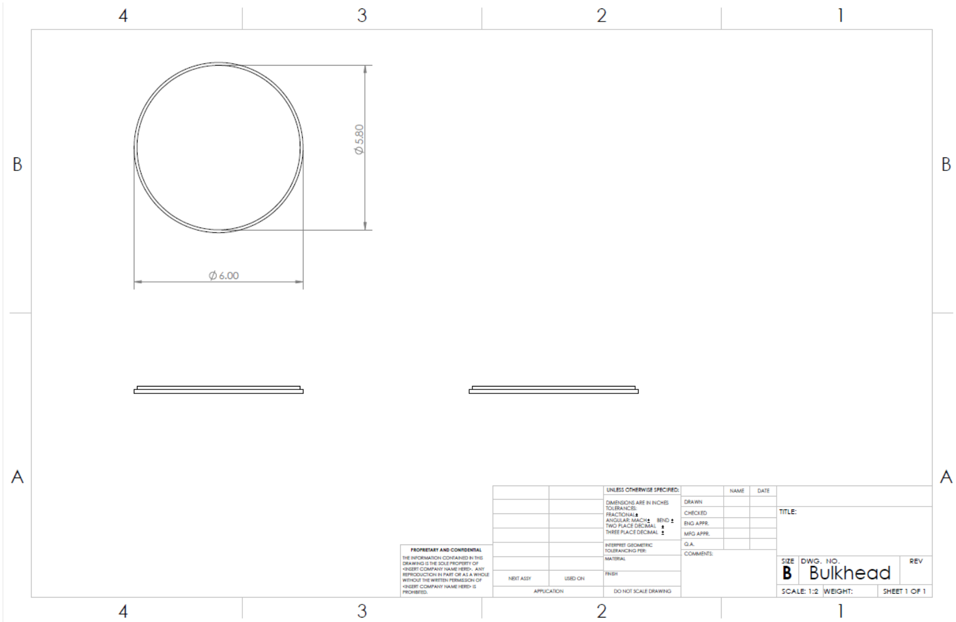


Figure 9. Bulkhead Assembly

The ¼ inch-thick plywood bulkheads were chosen based on the weighted design matrix shown in Table 5 and were purchased from Apogee Rockets. Attachment point bulkheads featured two bulkheads connected together. One of these bulkheads lay on the outer edge of the coupler and the other bulkhead was sanded down to fit tightly within the bulkhead itself. The bulkheads are then attached together by the U-bolt attachment point and epoxied into the coupler using steel-infused JB-Weld. The two bulkheads together help withstand parachute deployment forces, and allow for more epoxy to be used to join the bulkheads and coupler. All bulkheads performed as expected without failure during fullscale test flight.

Table 5. Bulkhead Material Selection Matrix

		Plywood		**G10 Glass Fiber**		**PLA**	
Attributes	**Weight**	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Strength	0.35	3	1.05	5	1.75	4	1.40
Cost	0.25	4	1.00	2	0.50	4	1.00
Mass	0.25	4	1.00	2	0.50	4	1.00
Workability	0.15	5	0.75	3	0.45	2	0.30
Total	1.00		**3.80**		**3.20**		**3.70**
Rank			**1**		**3**		**2**

Couplers

All couplers used in the launch vehicle were twice the diameter of the rocket in length as required by one of the team's derived requirements. Three couplers were used in total; two of the couplers are blue tube and the other coupler is fiberglass. The couplers connecting the payload to the drogue body tube and the coupler connecting the main to the drogue body tube are made out of blue tube because of its low cost and sufficient strength. The coupler connecting the main and booster section is made out of fiberglass to prevent potential zippering during main parachute deployment as observed on previous team projects. The actual diameters of the couplers were larger than the manufacturer's listed diameter and were sanded down to fit snugly in their respective body tubes. All couplers currently fit in their body tubes with the desired friction. Evenly spaced screw and shear pin holes were drilled to fasten body tubes to their respective couplers. These screw holes were drilled with sufficient arc-length between the screw holes and the end of body tube and coupler so stress concentrations would be minimized.

Motor Retention System

The motor retention system consists of a motor tube that is epoxied to three plywood centering rings with a plywood bulkhead motor block. The centering ring design is shown below in Figure 10.

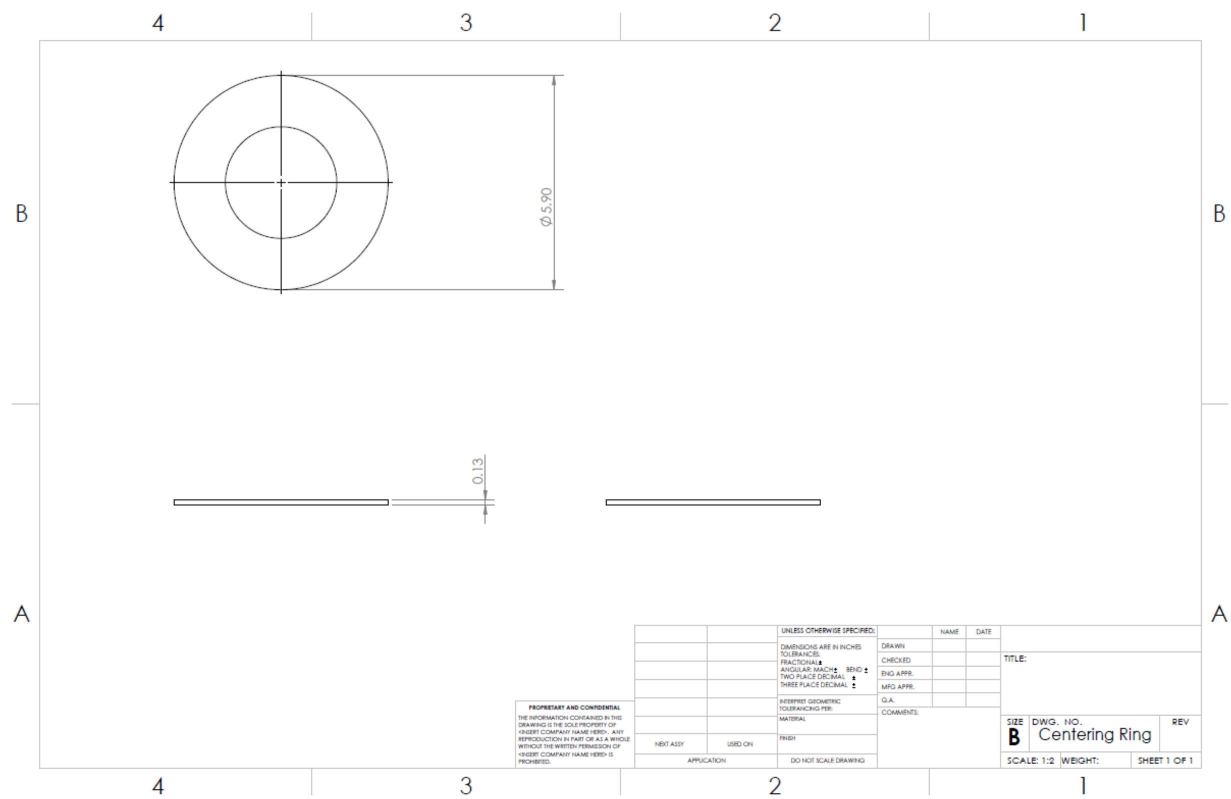


Figure 10. Centering Ring Design

The motor tube is fiberglass and is 26 inches long with an inner diameter of 3 inches to snugly fit the 75mm motor casing. The motor tube extends 2 inches past the aft end of the booster body tube and is even with the farthest-aft extent of the fins. Each centering ring is ⅛ inch-thick plywood and are placed at 3 inches, 13 inches, and 23 inches away from the aft end of the motor tube. The motor block is also ⅛ inch-thick plywood and is placed at the end of the motor tube, 24 inches from the aft end of the flight vehicle. The motor retention system is shown in Figure 11.

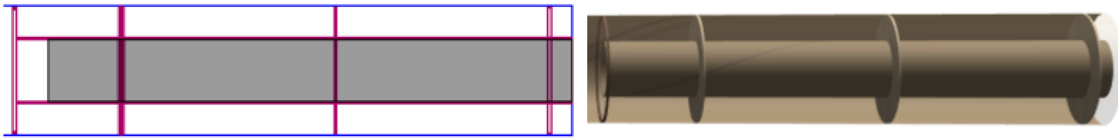


Figure 11. Side View and 3D Image of the Motor Retention System

Previous testing on the structural strength of the bulkheads, centering rings, and epoxy show a greater combined strength in the current system than the given maximum thrust of the motor on the system. The motor retention system was constructed by measuring out the placement of each of the centering rings on the motor tube. Centering rings were joined to the motor tube with generous amounts of steel-infused JB-Weld creating fillets at the joints. The centering rings were then joined to the carbon fiber body tube, also with generous amounts of steel-infused J-B Weld. The constructed motor retention system for this year’s competition launch vehicle was verified through a successful fullscale test flight.

Fins

The fins were designed to increase the stability of the launch vehicle by moving the center of pressure towards the aft end of the launch vehicle. The launch vehicle uses three fins constructed from G10 Fiberglass due to the material’s high tensile strength and high flexural modulus. A picture of a constructed fullscale fin is located in Figure 12. The chosen G10 Fiberglass thickness is $\frac{3}{16}$” to find a balance between the performance of the launch vehicle and the safety margins. Simulations conducted using AeroFinSim confirm that plywood does not have the necessary tensile strength, but that G10 Fiberglass can withstand the forces expected to be seen during flight and any potential fin flutter effects.

Figure 12. Constructed Fullscale Fin

The fins were cut with a Dremel tool from a $\frac{3}{16}$" sheet of G10 Fiberglass. After being cut, they were temporarily joined together with the outside edges lined up as accurately as possible. The fins were then all sanded down at the same time to exactly the same dimensions to ensure the stability of the rocket during flight. After construction the fins are placed into the 3D printed fin brackets, holes are screwed in the brackets and the fins simultaneously, and then the fins and brackets are bolted together.

The fins functioned exactly as intended during the fullscale test flight; they experienced no flutter and remained intact upon landing.

Fin Brackets

The material choice for the 3D printed fin brackets has changed since CDR. The proposed material chosen was Polycarbonate due to its superior strength and high glass transition temperature. However, during landing of the launch vehicle, the team noticed a slight crack in the fin bracket that absorbed most of the landing impact force. This was caused by a shear force exerted on the single fin during landing impact. After an in depth review of the material, the team discovered that Polycarbonate is more brittle than PLA. It will be able to absorb a larger tensile force, but will fail more abruptly without any signs of yielding. After researching various materials, the team decided to print the fin brackets out of PETG. It has a modulus of elasticity similar to PLA and a glass transition temperature similar to ABS. The team will reprint the fin brackets using this material. Fillets have also been added to stress concentration areas to reduce future fin bracket failure. The slit thickness of the fin brackets were increased slightly to remain flush with the booster section body tube.

Fin Retention

The team has decided to utilize 3D printed fin brackets to retain the fins during flight. This design feature was introduced two years ago and has been improved upon this year. The goal of the design is to easily remove and replace the fin brackets without replacing the fins. Because the fins are often the most common point of a structural failure on even nominal landings, this design specifically satisfies Requirement 2.10. No epoxy or permanent fastening methods are utilized with this fin retention system. The design flown on the fullscale test flight can be seen in Figure 13, Figure 14, and Figure 15.

Figure 13. Fullscale Test Flight Fin Bracket (1)

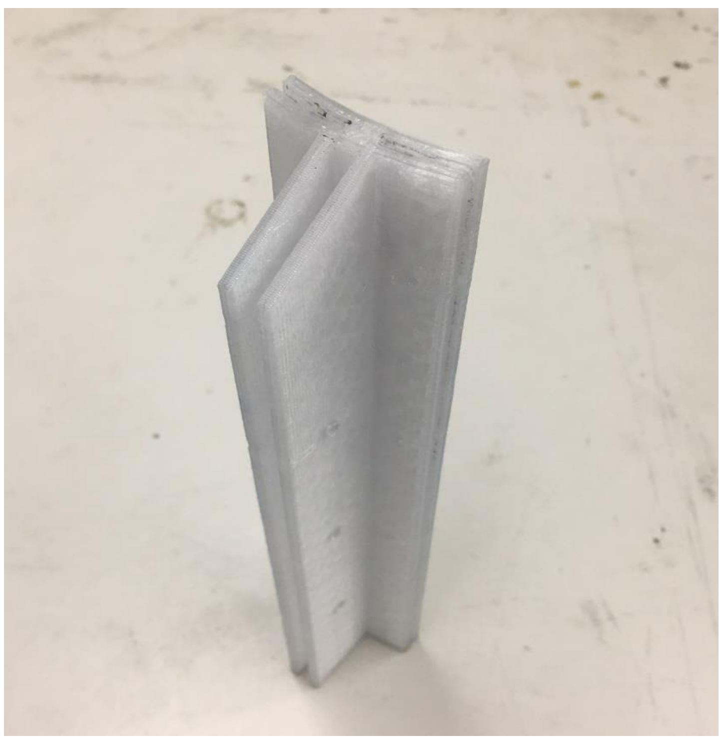


Figure 14. Fullscale Test Flight Fin Bracket (2)

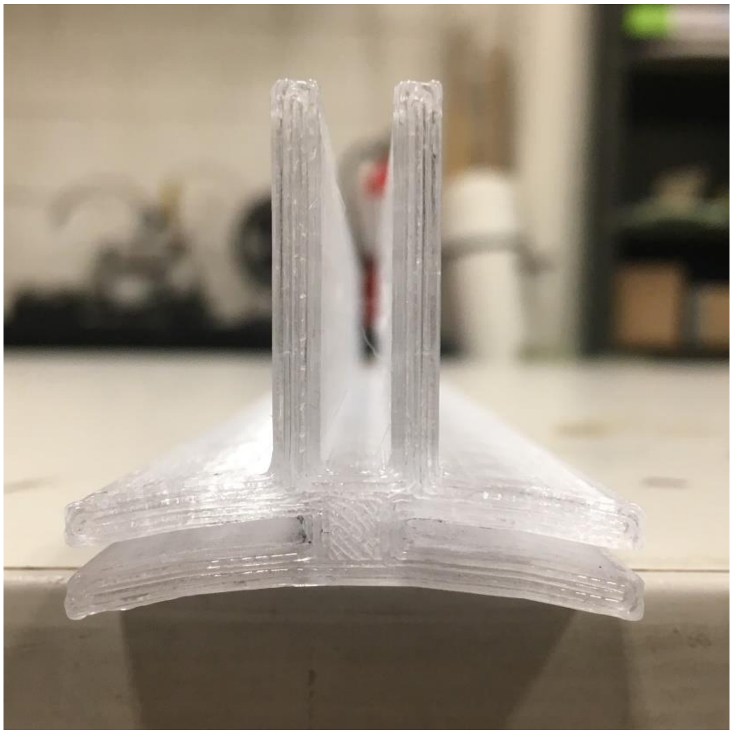


Figure 15. Fullscale Test Flight Fin Bracket (3)

There are holes to employ a screw and bolt retention system. This will allow team members to quickly replace a piece if it were to fail before or after launch. The fin brackets will lay on both the interior and the exterior of the body tube to provide extra structural support. The body tube will be cut from the aft edge to allow for the fin brackets to be inserted and laid flush with the aft end of the body tube. Eight screws will be placed in each fin bracket to keep them attached to the airframe during the entire flight. The fins will also be fastened with nuts and bolts through the top section of the brackets.

As detailed earlier in this section, the fin brackets have been redesigned to include a fillet and a different construction material after observing the results of the fullscale test flight. This new design is not different in any dimension from the brackets flown on the fullscale test flight except for the inclusion of the stress-reducing fillet.

Camera System

As part of the Team Derived Requirements, a down body camera has been included to supply visual data of flight performance and monitor fin flutter. The exterior portion of the camera is a Raspberry Pi Camera Module v2 with a width of 1 in and length of 1 in. The design has again been improved from last year’s much bulkier design due to using a different camera system. Figure 16 shows the more spatially efficient design for this year’s competition.

Figure 16. Assembled camera system on launch vehicle before fullscale test flight

To securely seat the camera on the exterior of the rocket, a 3D printed cover was designed to tightly hold the camera to the body while also providing aerodynamic efficiency. This cover is printed in PLA material due to its lightweight characteristics and non-structural role.

The Raspberry Pi running the down body camera is located at the forward end of the booster body tube. The Raspberry Pi is mounted to a 3D printed plate via screws and powered by a 4400 mAh lithium-ion-polymer battery. The battery is securely contained on the other side of the 3D printer plate and visually marked to identify it as a chemical battery. This 3D printed assembly, shown in Figure 17, is screwed into a centering ring which is epoxied into the forward end of the booster body tube. The system is powered on by a toggle switch that can accessed while the rocket is vertical and undergoing preflight activation on the launch pad. This system performed exactly as intended during the fullscale test flight and provided the team with valuable data on separation events, descent, and how landing affected the fins.

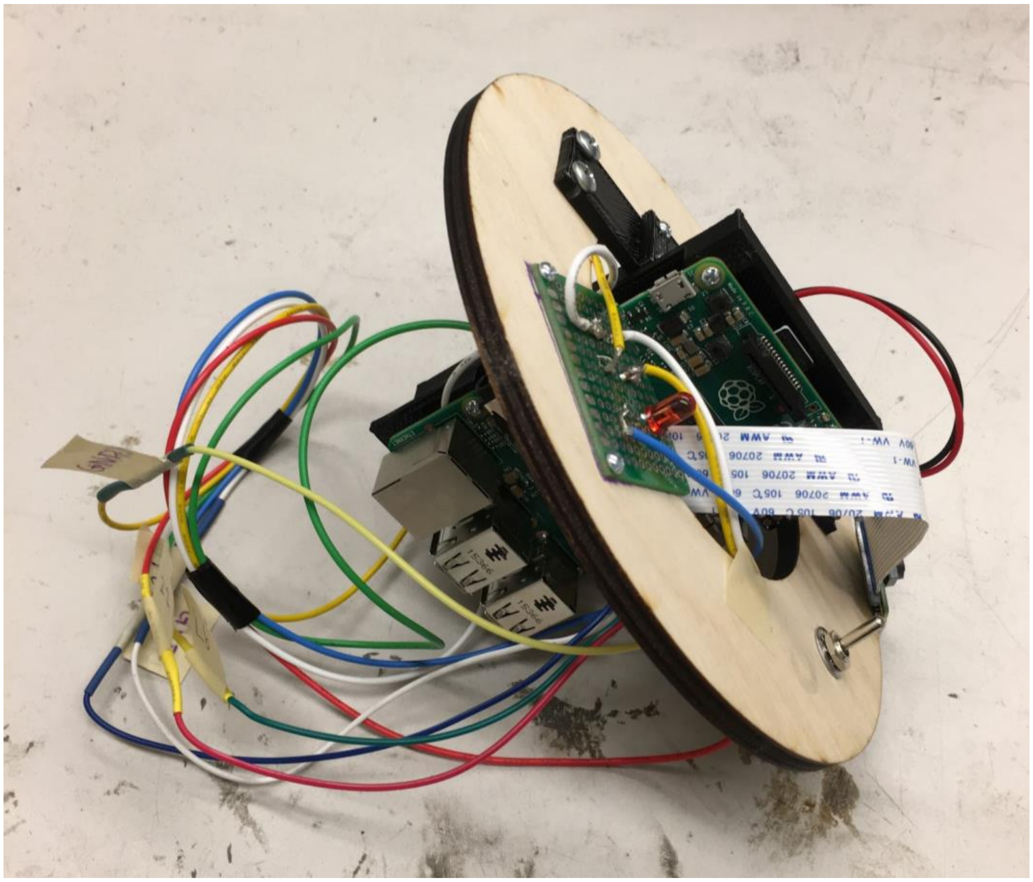


Figure 17. Raspberry Pi and Battery for the Camera System

Separation Points

The current sectioning of the launch vehicle has been chosen so that each subsystem has their own section to work on during launch day. This allows the subsystems to operate independently of one another which reduces the amount of time needed to assemble the launch vehicle.

The launch vehicle will use three separation points: two for parachute deployment and one for rover deployment. The separation point for the drogue parachute is located between the drogue body tube and the payload body tube. The separation point for the main parachute will be placed between the main parachute body tube and the booster body tube. The location of the two separations points for parachute deployment were chosen so that only one avionics bay will be needed for the launch vehicle. Additionally, in this configuration, the parachutes will be ejected out of their respective body tubes rather than ejected into the body tubes. Ejecting the parachutes into the body tube was avoided because it could cause the parachute to potentially become stuck in the body tube and not properly deploy.

The separation point for rover deployment is located between the nose cone and the payload body tube. This separation point was chosen to ensure that the rover would not get caught in the parachute or part of the shock cord. The rover deployment will separate the entire nose cone from the body tube, so the team has decided upon doing a ground-separation to minimize its flight risk.

All flight-critical separation points functioned exactly as intended during the fullscale test flight and the ground test prior to that launch. Only the payload to nose cone separation point was not tested during the fullscale test flight. This was due to an operational issue with payload hardware and not a failure of the separation mechanism.

Nose Cone

The nose cone of the flight vehicle is designed to minimize aerodynamic drag on the flight vehicle while being structurally stable and as light as possible. When choosing materials for the nose cone, choices were limited to already manufactured nose cones that fit the current dimensions of the flight vehicle. After researching many nose cone manufacturers such as Apogee Components and Madcow Rocketry, glass fiber nose cones were the only option that fit the diameter specifications for the launch vehicle.

The selection matrix table, Table 6, is shown below.

Table 6. Nose Cone Selection Matrix

		Ogive 4:1		**Von Karman 5.5:1**		**Conical 5:1**	
Attributes	**Weight**	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Availability	0.15	5	0.75	5	0.75	5	0.75
Cost	0.25	3	0.75	3	0.75	3	0.75
Drag	0.25	3	0.75	5	1.25	2	0.5
Mass	0.35	4	1.4	2	0.7	4	1.4
Total	1.00		**3.65**		**3.45**		**3.4**
Rank			**1**		**2**		**3**

Based on the selection matrix presented above, an Ogive 4:1 nose cone was chosen for the launch vehicle. This nose cone was purchased from Madcow Rocketry and has a weight of 55 oz. Figure 18 pictures the nose cone purchased from Madcow Rocketry.

Figure 18. Picture of Nose Cone

The nose cone withstood all aerodynamic stresses and impact forces during fullscale flight.

Ballast Container

The team 3D printed a ballast box to contain the ballast necessary to get the launch vehicle to the target apogee of 5,280 feet. This container will be screwed into the nose cone shoulder bulkhead with four corner screws to keep it structurally retained during flight. This design is very similar to the contained retaining the GPS in the flight vehicle. Figure 19 pictures the SolidWorks model of the ballast container on the left and its cap on the right. Figure 20 pictures the final 3D printed ballast container in the nose cone shoulder that was used for the vehicle demonstration flight and that will be used on competition flight.

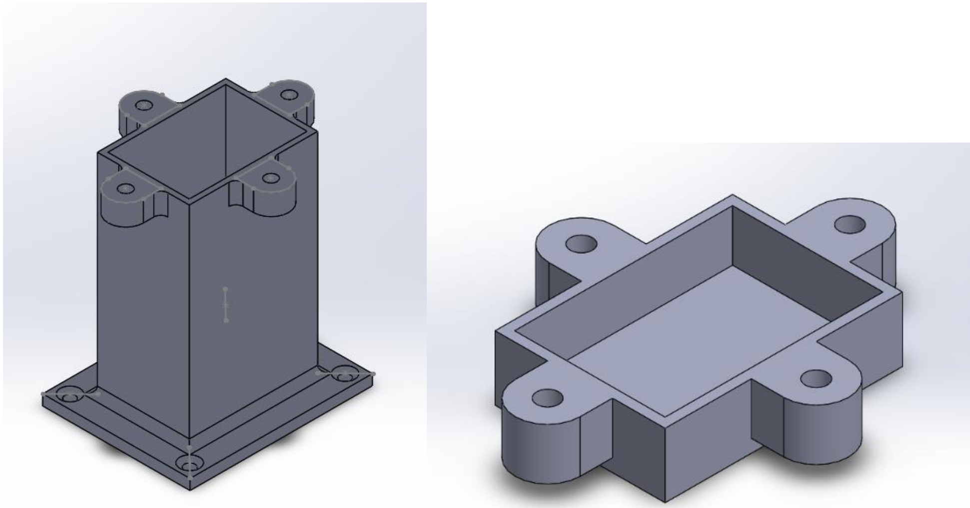


Figure 19. SolidWorks Model of the Ballast Box (left) and Its Cap (right)

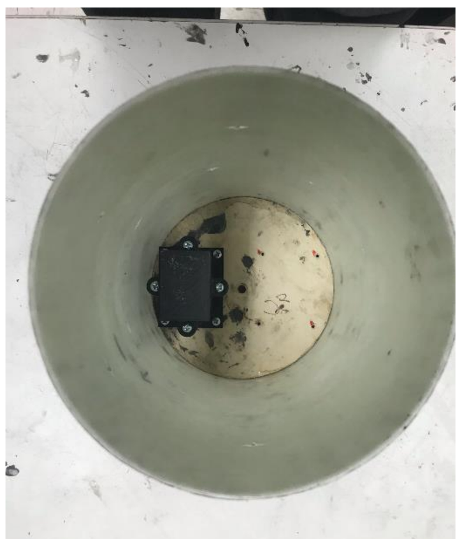


Figure 20. Constructed ballast box screwed into the nose cone bulkhead

Figure 21 shows a SolidWorks CAD model of the flight vehicle in its fully-assembled, launch day configuration. The body tubes are wireframe to show internal components such as couplers and electronics. The parachutes and shock cord have been omitted from this model due to their difficulty to model. The fully constructed launch vehicle can be seen on the launch pad before its vehicle demonstration flight in Figure 22.

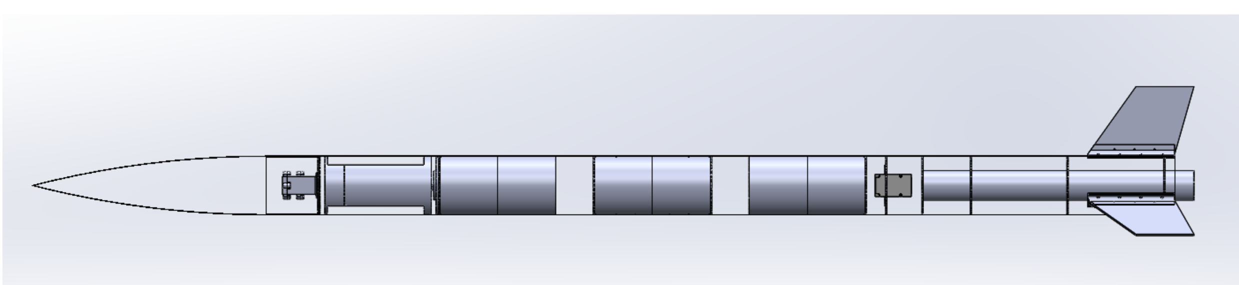


Figure 21. SolidWorks Model of the Flight Vehicle

Figure 22. Fully constructed launch vehicle on the launch pad before vehicle demonstration flight

3.2 Recovery Subsystem

The recovery system components include the avionics board, avionics bay structure, all-threads, parachutes and harnesses, GPS, charge wells, ejection charges, electromagnetic shielding, and the shear pins at the separation points of the rocket. The avionics board contains two independent sets of altimeters, charges, mechanical switches, initiators, and 9V batteries for power sources. By designing an avionics bay that contains a secondary recovery system, the team has ensured redundancy in the systems that guarantee parachute deployment at the selected altitudes even with a failure of one system.

Shown below in Figure 23 on the left is the model of the avionics bay and attached bulkheads that will be contained inside the avionics coupler. The finished avionics bay after it was constructed is shown below in Figure 23 on the right hand side**.** The recovery harness will attach on to the U-Bolt and is packed into the flight vehicle outside of the avionics coupler bulkheads.

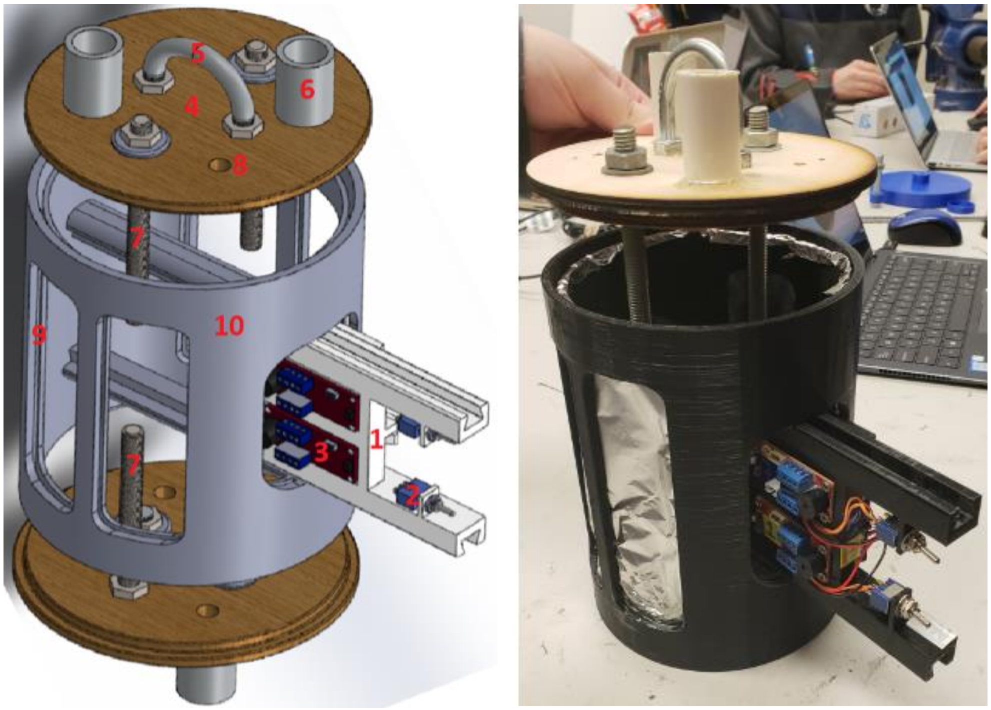


Figure 23. Colonnaded avionics bay SolidWorks model (left) and constructed assembly (right)

The following list refers to the numbering schema in Figure 23.

1. Avionics Board
2. Mechanical Switch
3. StratologgerCF Altimeter
4. Avionics Bulkhead
5. U-Bolt
6. Charger Well
7. All-Thread Rod
8. Initiator Wire Pass-Through Hole
9. Faraday Cage Channel
10. Avionics Bay

Avionics Bay

The avionics bay is 3D printed using PLA and epoxied to the inside of the avionics coupler. The bulkheads on either side of the bay channel the stresses during flight between them, and allow the avionics boards on the sliders inside to remain unstressed during flight. The avionics bay has a slot in the top that allows the bulkhead's inner panel to sit inside of outer wall. The avionics bay contains a channel that runs throughout the structure that allows the faraday cage to be one seamless piece.

Figure 24. Faraday cage slots in SolidWorks model (left) and constructed avionics bay (right)

In Figure 24, the SolidWorks model for the slots is shown on the left and the faraday cage installed inside the slots in the avionics bay is shown on the right. The faraday cage is used to shield the electronic components of the avionics board from any potential electromagnetic interference. Aluminum foil was chosen to create the faraday cage due to its electrical conductivity and capability of absorbing and reflecting electromagnetic signals. The faraday cage was created by inserting three layers of the foil into a slit between the inner and outer walls of the avionics bay. The aluminum foil was also epoxied to the interiors of the bulkheads using J-B Weld to ensure the avionics board is completely surrounded by the faraday cage.

Avionics Bay Door

The avionics bay door and the avionics coupler are shown below in Figure 25. The avionics bay door is designed to allow the avionics board to be easily accessed at any time once the rocket has already been assembled. The door is secured to the rocket with four screws in its corners. These four screws penetrate through the avionics bay coupler and thread into the avionics bay, securing all three components together. There is a hole located in the center of the door that allows the pressure of the avionics bay to equalize with the atmospheric pressure. The avionics door has been designed to satisfy several team requirements relating to quick assembly and safe avionics arming.

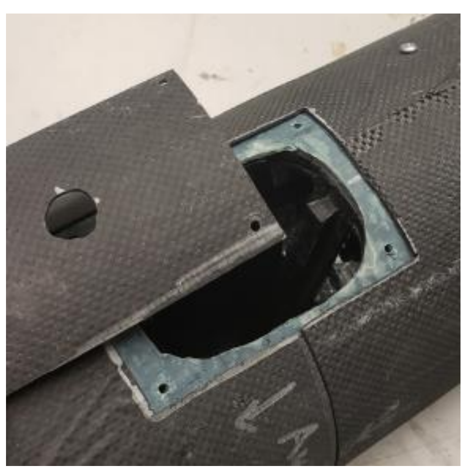


Figure 25. Avionics Bay Door

Bulkheads

In Figure 26, the SolidWorks and constructed bulkhead are pictured. The drogue and main bulkheads are identical in their design and construction.

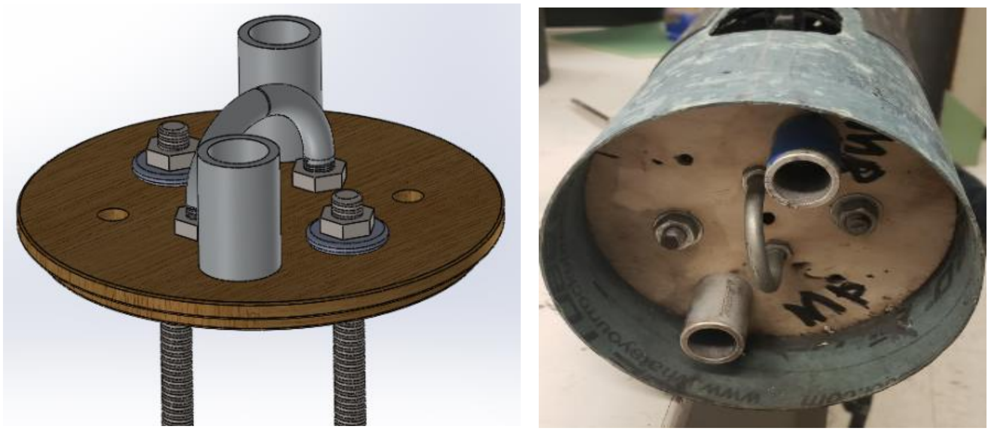


Figure 26. Avionics bulkhead in SolidWorks model (left) and constructed avionics bay (right)

The wooden bulkheads for the avionics bay were constructed by using steel-infused JB-Weld to epoxy together a coupler bulkhead and a coupler bulkhead that was sanded down to fit inside the 3D printed avionics bay. Two holes were drilled for the placement of the two all-thread rods which are secured in place using a washer and nut on both the inside and outside of the bulkheads. The U-bolts are also attached to the bulkheads using washers and nuts on the inside and just two nuts on the outside of the bulkhead. To complete the faraday cage, three layers of thin foil where epoxied to the inner surface of both bulkheads so that they contact the foil in the slots when they are placed on the avionics bay. This setup ensures that no signals can interfere with the altimeters, and that neither bulkhead has any freedom to move relative to the other.

Avionics Board

The avionics board contains two completely independent altimeter systems. The finished flight tested design is shown in Figure 27. The SolidWorks model of the avionics board and attached components is pictured in Figure 28.

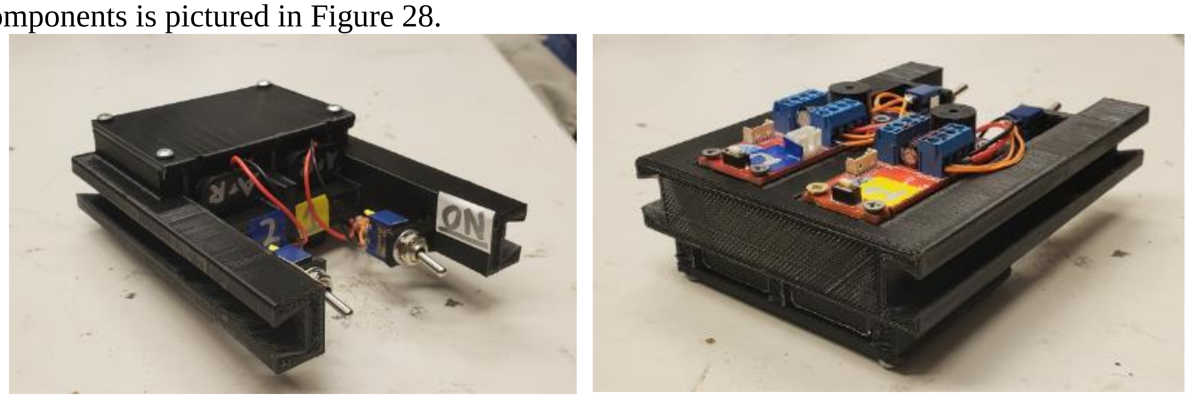


Figure 27. Avionics board face down (left) and face up (right)

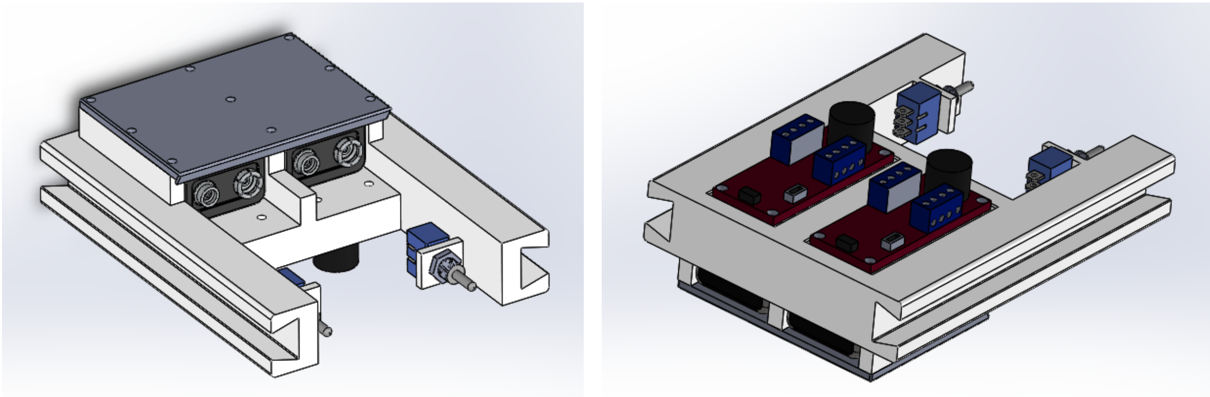


Figure 28. SolidWorks model of avionics board face down (left) and face up (right)

The wiring schematic for the avionics board is shown below in Figure 29, this wiring layout is entirely contained on the avionics board. All of the electrical components of the avionics board are wired together using standard 16 gauge electrical wire.

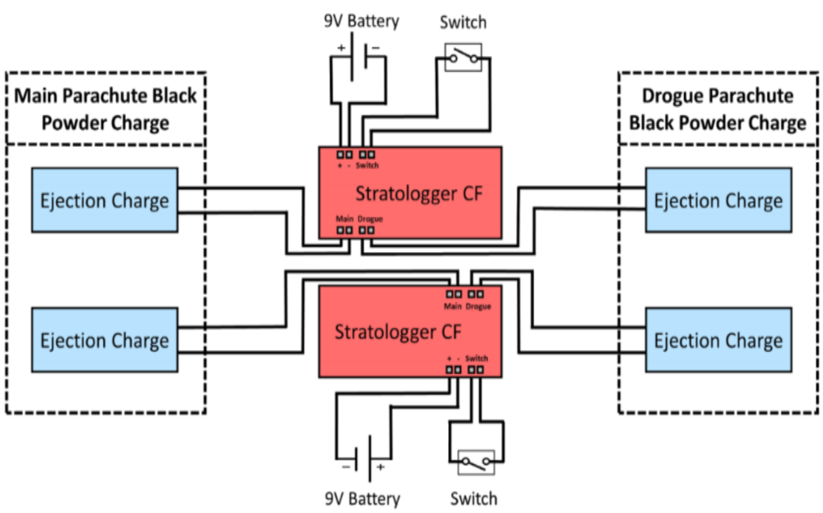


Figure 29. Wiring Schematic of Altimeters

Batteries

On the left side of Figure 28**,** the battery clip holder and the batteries inside of their slots can be seen. The two Duracell 9 volt batteries each slide into battery slots on the avionics board and a battery holder panel is screwed onto the back using four corner screws to secure them in place. To prevent the batteries from falling out there is a clip on the panel that hangs down holding the batteries in their slots.

Switches

The toggle switches are each placed into two tabs with holes in them on the avionics board. The switches are then screwed on with nuts and labels are placed on the avionics board to indicate the on position. The attached wires that connect to the altimeters are soldered on to the two leads.

Altimeter

The altimeters can be seen on the right hand side of Figure 27 and Figure 28. The altimeters are located on the opposite side of the avionics board as the batteries are, and each altimeter is secured to the avionics board with four corner screws. Each Stratologger CF altimeter located on the avionics board is wired to a 9 volt battery and a toggle switch through the ports labeled power, switch, main and drogue. The altimeters are also each separately connected to two initiators which will ignite the ejection charges for both the main and drogue parachutes. The redundant altimeter will be on a delay to ensure that both ejection charges do not detonate at the same time to avoid overpressurization of the body tubes. The redundant altimeter has a two-second delay for drogue and deploys at 500 feet above ground level for main.

Initiators

In Figure 29, the initiators are the lines running from the Stratologgers to the ejection charges. The primary altimeter has the primary main and primary drogue initiator wired to it, and the redundant altimeter has the main redundant and drogue redundant initiator wired to it. All four wires are identical and are thus labeled following the launch procedures to avoid confusion on launch day. The initiators are threaded through small holes drilled in the bulkheads to allow them to reach from the avionics board to the charge wells outside the avionics bay. Once the initiators are threaded through the holes in the bulkheads, the holes are covered on the outside of the bulkheads with putty and further sealed with tape to mitigate blowback. This prevents any hot gases from the ejection charges to enter the avionics bay, and prevents the ejection charge explosion from pressurizing the avionics bay as well.

Blast Caps

There are two blast caps located on the exterior side of each avionics bay bulkhead that are used to contain the black powder that is used for main and drogue parachute deployment. The blast caps are loaded on launch day following the launch procedures. They are made out of PVC pipes with an approximate length of 1” and a diameter of 1”. Each blast cap was epoxied to the bulkheads using a generous amount of J-B Weld to ensure structural integrity. Both materials have been shown to work effectively on previous rockets and in the team’s vehicle demonstration flight.

Recovery Harness

The recovery harness used for both main and drogue is shown in Figure 30. The quicklink labeled 1 attaches to the payload bulkhead in the drogue section, and attaches to the booster section bulkhead in the main section. The quicklink labeled 2 attaches the parachute to the fire blanket and the shock cord. The quicklink labeled 3 is attached to the bulkhead in the avionics section.

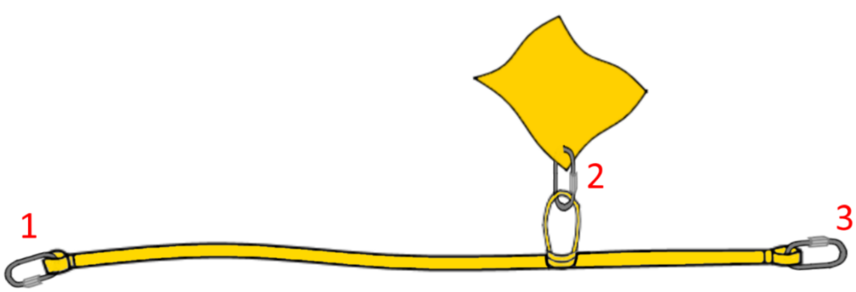


Figure 30. Recovery Harness

Fire Blanket

The Nomex fire blanket on each shock cord is of sufficient size to completely cover the parachute. This completes the team requirements of preventing the parachute from snagging inside the body tube and from being burned or torn during separation events.

Shock Cords

The shock cords used are made out of a ½" width flat strap Kevlar cord that was chosen because of its strength and durability. For the main parachute, the shock cord has a length of 27 feet and has the main parachute connected to it ⅔ of the way towards the avionics coupler. The drogue parachute shock cord has a length of 24 feet, and will also have the parachute connected to it ⅔ of the way towards the avionics coupler. The shock cords will be attached to the U-bolt attachments at the end of each body tube section with $\frac{3}{8}$" steel quick links. These lengths for the shock cords were chosen to ensure the body tubes will not collide with each other once both the main and drogue parachutes have deployed.

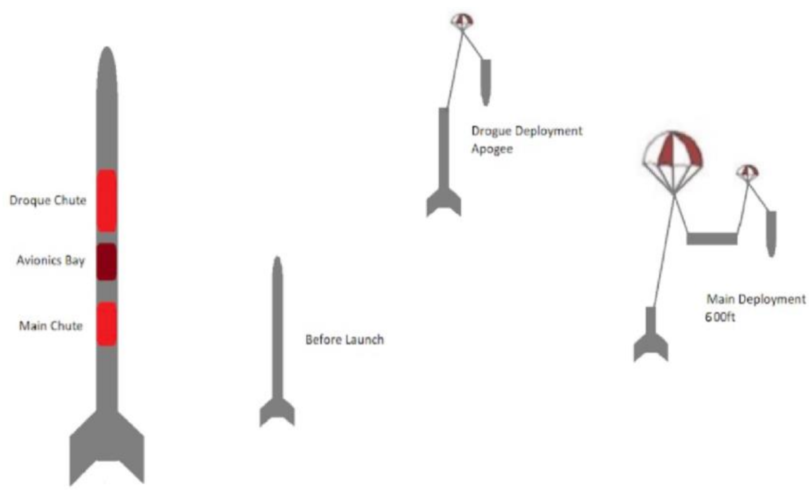


Figure 31. Deployment Events

Parachutes

The parachutes were chosen for their coefficient of drag, and size. Drogue parachute is approximately 18 inches in diameter and main is approximately 96 inches in diameter. The parachutes are folded and wrapped within the fire blanket so they can exit the rocket while mitigating the chances of ripping, getting caught on screws, or potentially igniting. The parachutes are packed following the launch procedures. A depiction of the separation events is shown above in Figure 31.

GPS System

The GPS the team is using is the Americaloc GW300 which is pictured in Figure 32 within its mount on the right hand side. This transmitter uses an AT&T brand cell phone SIM card to relay its position and it operates at 850 MHz. Since this GPS unit actively sends out its position, all the electronics in the rocket will have shielding to prevent interference. The GPS will be contained within a 3D-printed bracket and screwed into the nose cone bulkhead using four corned screws. This setup inside of the nose cone shoulder is pictured in Figure 32. The 3D-printed bracket with the GPS in it is shown in Figure 33. A fully charged GPS will last two weeks before running out of battery which allows the team to turn on the GPS and then seal it inside the nose cone hours before launch. The GPS has a remote connection such that the team is continuously receiving data from the GPS.

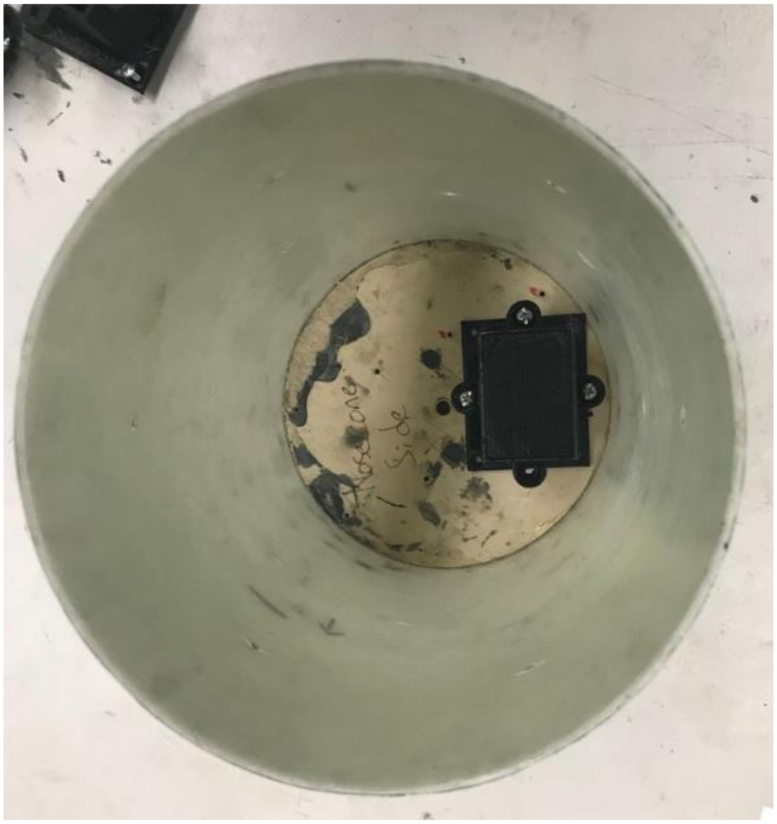


Figure 32. GPS Mount in Nose Cone Shoulder

Figure 33. GPS in 3D Printed Bracket

Separation Charges

After selecting an ejection charge and a containment method for the ejection charge, the team was able to calculate the required black powder charge. Table 7 lists the masses of black powder the team will use for drogue and main parachute ejections. These amounts were chosen based on previous year's knowledge of what amount of black powder is able to reliably and safely separate the rocket.

Table 7. Black Powder Calculation

	Full scale Drogue	Full scale Main	Full scale Drogue Redundant	Fullscale Main Redundant
4F Black Powder (grams)	1.5	2	2	3
Body tube diameter	6"	6"	6"	6"
Body tube length	16"	16"	16"	16"

Using the dimensions of the drogue parachute bay and main parachute bay the team is able to calculate the number of shear pins that a given mass of black powder will break. The calculation for the volume of the chamber that is pressurized by the explosion is shown in the Equation 1.

$$V = \frac{\pi D^2 L}{4} \quad (1)$$

The volume is then substituted into Equation 1 for V where N is the mass of black powder in grams from Table 7. D is the body tube diameter from Table 7 and L is the body tube length from Table 7. P is the pressure in psi that will result from the black powder detonation in the chamber. Equation 2 assumes that the pressure inside will have equalized with the atmosphere prior to detonation and also contains the conversions from pounds to grams and the gas constant.

$$P = \frac{\left(N * \left(\frac{1lbf}{454grams}\right) * 266\ ^{in\ lbf}/_{lbm} * 3370^0 R\right)}{V} \quad (2)$$

Equation 3 solves for the force required to break the shear pins in lbs. P is the chamber pressure calculated from Equation 2 and D is the chamber diameter.

$$F = \frac{\pi}{4} P D^2 \quad (3)$$

The team is using brand 2-56 shear pins for all separation points on the flight vehicle. These shear pins fail at an average shear force of 25 lbs which has been confirmed in past flights, ground tests, and is listed on the shear pins manufacturer's site. Once the total force is known, it is divided by 25 and then rounded down for the maximum number of shear pins that amount of black powder will break. The number of 2-56 shear pins the team calculated is listed in the second row of Table 8. A factor of safety listed in row two of Table 8 was then applied to each of the results to account for any unknown factors. The last row in Table 8 has listed the number of shear pins the team plans on using on the flight vehicle for drogue and main separation points. The redundant charges fire into the same chamber as the main charges so they must have the same number of shear pins. These shear pin calculations were verified through successful separation events in the vehicle demonstration flight.

Table 8. Shear Pin Calculation

	Drogue Primary	Main Primary	Drogue Redundant	Main Redundant
Calculated number of 2-56 shear pins	5	6	6	10
Factor of Safety	1.5	1.25	2	2
Actual number of 2-56 shear pins used	3	5	3	5

3.3 Mission Performance Predictions

Final Flight Vehicle

An OpenRocket model has been created to model the as-built flight vehicle. The model's center of pressure (CP) is located 94.34 inches aft of the tip of the nose cone, and the measured center of gravity (CG) is located 76.625 inches aft of the tip of the nose cone. The final flight vehicle has a diameter of 6 inches, with a static stability margin of 2.96 calibers. The OpenRocket model is shown in Figure 34, with breakdown of the component weights, sans motor, used within the model shown in Table 9. The target apogee of exactly 5,280 feet will be achieved through altering the rocket's mass very slightly via incorporated ballast, along with minor adjustments to the angle of the launch rail.

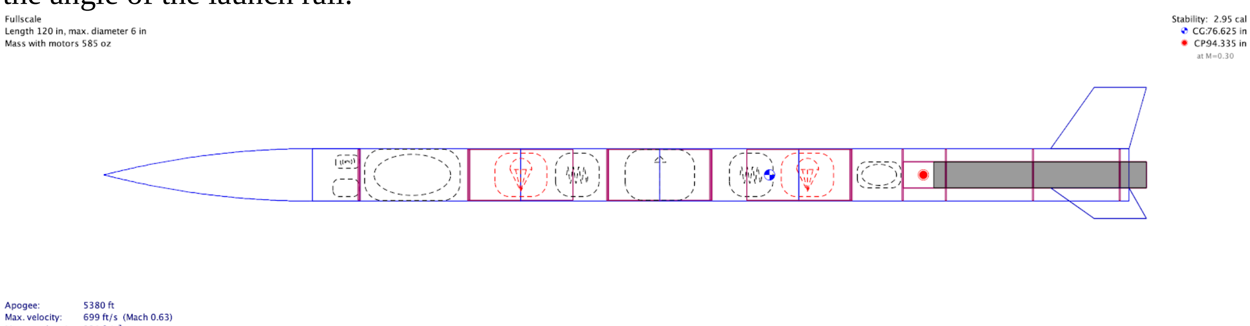


Figure 34. Fullscale OpenRocket Model

Table 9. Component Weights

Component	Weight (oz)
Nose Cone	65.0
Payload Section	72.1
Payload-Main Coupler	9.5
Drogue Section	29.9
Drogue-Main Coupler	55.7
Main Section	43.2
Main-Booster Coupler	13.0
Booster Section (No Motor)	124.0

To characterize the flight of the launch vehicle during the competition launch, simulations have been conducted via both methods with expected launch day conditions as parameters. The OpenRocket simulation was run with wind speeds averaging at 5 mph, turbulence intensity at 10%, ambient temperature at 65 degrees Fahrenheit, pressure at 1 atmosphere, and the launch site located at Bragg Farm north of Huntsville. The competition launch simulation flight profile and stability profile are shown below in Figure 35 and Figure 36, respectively.

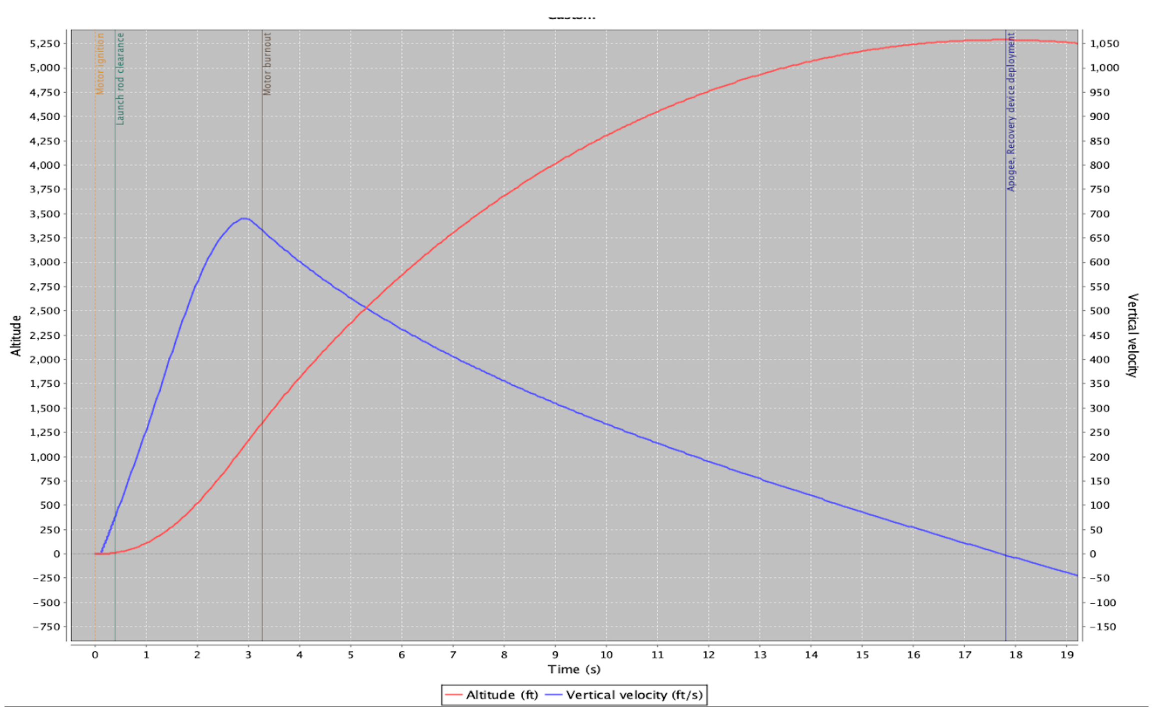


Figure 35. Competition Launch Simulation: Flight Profile

It is shown in Figure 35 that a maximum velocity of 698 ft/s is reached just before motor burnout at 2.9 seconds and an altitude of approximately 3,400 ft. This maximum velocity is well within the imposed limit of Mach 1 and occurs a safe distance from the launch pad. The rocket's velocity off a 10 ft rail is 75.5 ft/s, which is well above the imposed minimum of 55 ft/s and above the team's mission success criteria of 65 ft/s. The flight profile also indicates an apogee of exactly 5,289 feet, well within the margin of variance in the impulse of the motor and deviation in winds at altitude.

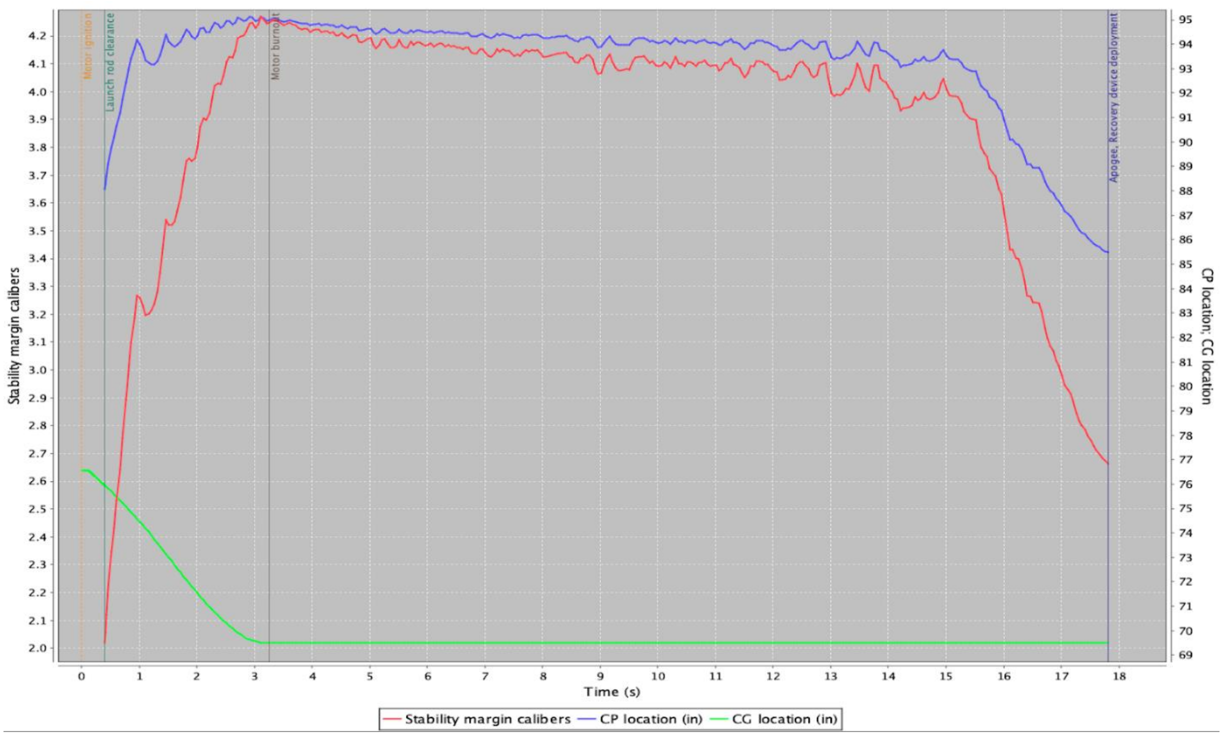


Figure 36. Competition Launch Simulation: Stability Profile

As in indicated in Figure 36, the stability off the launch rail is 2.05 calibers. This is above the team's mission success criteria and is indicative of a very stable flight, even in the low-velocity / low-altitude regime. After clearing the rail, the stability quickly climbs to about 3.3 calibers before slowly increasing to 4.2 calibers at burnout.

The thrust curve and the mass have both been plotted in Figure 37. This figure shows that the Cesaroni L1355 motor has the necessary characteristics to achieve a safe thrust-to-weight ratio and the minimum rail velocity for stable flight as the rocket leaves the pad.

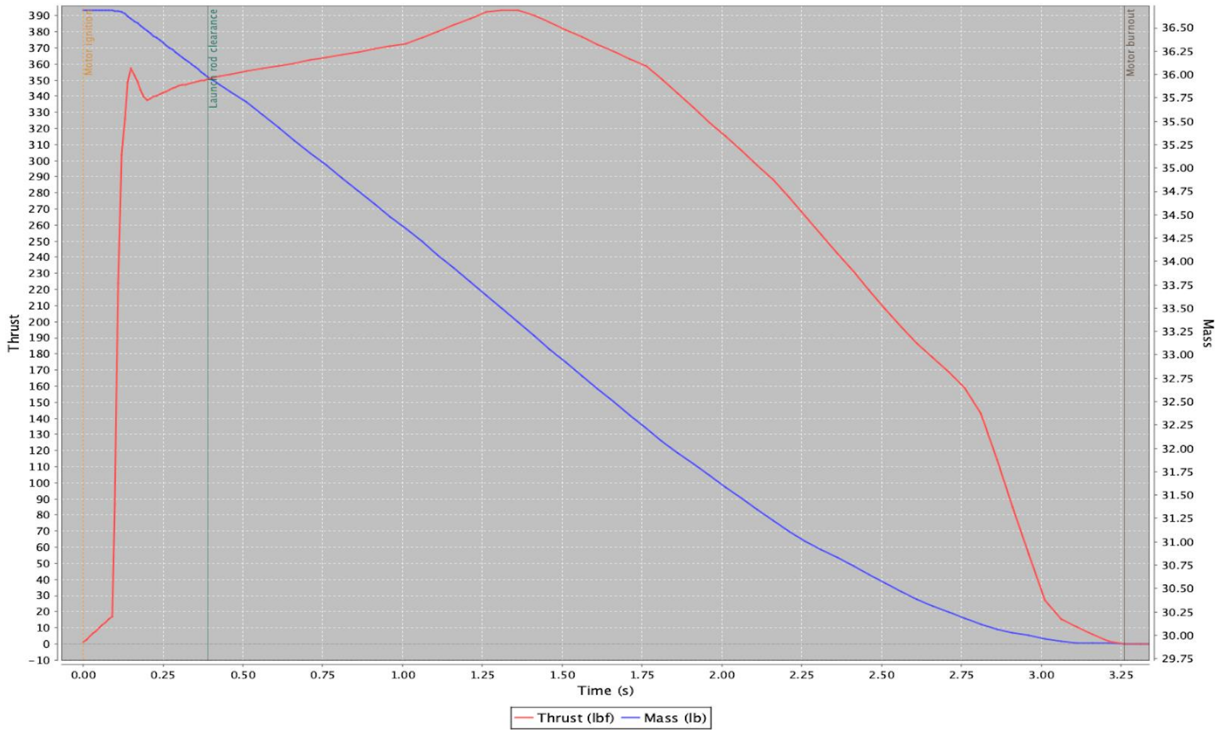


Figure 37. Competition Launch Simulation: Thrust and Mass versus Time

This flight vehicle's ability to withstand these profiles was verified during the fullscale test flight. The structural integrity of the vehicle was verified via post-flight inspection of every component. The only signs of fatigue or fracture were the small cracks that developed on the impacted fin bracket upon landing. These cracks did not cause a total failure of the fin bracket and the flight vehicle could have been prepared to relaunch that same day. The flight characteristics of the vehicle were proven through observational evidence and flight telemetry analysis indicating that our minimum off-the-rail velocity was achieved.

Verification of OpenRocket

To verify the OpenRocket simulation results, the center of pressure, center of gravity, and flight apogee were calculated using LTRL's own MATLAB script.

To calculate the center of pressure, the following calculations were conducted. First, the center of pressure of the nosecone, X_n, was calculated using Equation 4.

$$X_n = 0.466 * L_n \tag{4}$$

X_n is the location of the center of pressure for the fins as measured from the tip, L_n is the length of the nose cone which is multiplied by a constant given for Ogive nose cones. The center of pressure of the fins was then calculated using Equation 5.

$$X_f = X_b + \frac{X_r * (C_r + 2 * C_t)}{3 * (C_r + C_t)} + \frac{1}{6} * \left(C_r + C_t - \frac{C_r * C_t}{C_r + C_t}\right) \tag{5}$$

X_f is the location of the center of pressure of the fins as measured from the tip, X_b is the length from the tip to the fin root chord, X_r is the length from the fin root leading edge to the fin tip leading edge, C_r is the fin root chord length, and C_t is the fin tip chord length. The coefficient for the center of pressure of the fins, C_{nf}, was calculated using Equation 6.

$$C_{nf} = 1 + \frac{R}{S+R} * \frac{4N\left(\frac{S}{D}\right)^2}{1 + \sqrt{1 + \left(\frac{2 * Lf}{C_r + C_t}\right)^2}} \tag{6}$$

Where R is the radius of the rocket body, S is the semi span of the fins, N is the number of fins, and L_f is the length of fin mid-chord line. The center of pressure as measured from the tip, X, was calculated using Equation 7.

$$X = \frac{C_{nn} * X_n + C_{nf} * X_f}{C_{nn} + C_{nf}} \tag{7}$$

Where C_{nn} is the coefficient for the center of pressure for the nose cone. The center of pressure was calculated to be 94.46 inches aft of the tip.

To calculate the center of gravity, cg, Equation 8 was used.

$$cg = \frac{d_n * m_n + d_p * m_{payload} + d_m * m_m + d_d * m_d + d_b * m_b}{M} \tag{8}$$

Where d_n is the distance from the center of mass of the nose cone to the tip, m_n is the mass of the nose cone, d_p is the distance of the center of mass of the payload section to the tip, $m_{payload}$ is the mass of the payload section, d_m is the distance of the center of mass of the main parachute section to the tip, m_m is the mass of the main parachute section, d_d is the distance of the center of mass of the drogue section to the tip, m_d is the mass of the drogue section, d_b is the distance of the center of mass of the booster section to the tip, m_b is the mass of the booster section, and M is the total mass of the rocket.

The center of gravity was calculated to be 76.40 in. aft of the tip.

To calculate the flight apogee, the altitude at which the motor burnout occurs must first be calculated. To calculate the burnout altitude, first the average mass, m_a, must be calculated. The average mass was calculated using Equation 9.

$$m_a = m_r + m_e - \frac{m_{prop}}{2} \tag{9}$$

Where m_r is the mass of the rocket without a motor, m_e is the mass of the motor, m_{prop} is the mass of the propellant. The aerodynamic drag coefficient, k, was calculated using Equation 10.

$$k \quad = \frac{1}{2} * \rho * C_d * A \tag{10}$$

Where ρ is the density of air, C_d is the drag coefficient, and A is the cross-sectional area of the rocket. The burnout velocity, q_1, was calculated using Equation 11.

$$q_1 \quad = \sqrt{\frac{T \; - \; (m_a * g)}{k}} \tag{11}$$

Where T is the average thrust of the motor, ma is the average mass of the rocket, and g is the gravitational constant. The burnout velocity decay coefficient, x_1, was calculated using Equation 12.

$$x_1 \quad = \frac{2 * k * q_1}{m_a} \tag{12}$$

The burnout velocity, v_1, was calculated with Equation 13.

$$v_1 \quad = \; q0_1 * \frac{1 - \mathrm{e}^{-x_1 * t}}{1 + \mathrm{e}^{-x_1 * t}} \tag{13}$$

Where t is time at motor burnout. Finally, the altitude at which the motor burnout occurs, y_1 was calculated using Equation 14.

$$y_1 \quad = \; -\frac{m_a}{2 * k} * \ln\left(\frac{T \; - \; (m_a * g) - \; (k * {v_1}^2)}{T - m_a * g}\right) \tag{14}$$

With the burnout altitude known the total altitude coasted can be calculated. To calculate the cost distance, the coast mass, m_c, must first be calculated. The coast mass was calculated using Equation 15.

$$m_c \quad = \; m_r \; + \; m_e \; - \; m_{prop} \tag{15}$$

Where m_r is the mass of the rocket, m_e is the mass of the motor, and m_{prop} is the mass of the propellant. Next, the coast velocity coefficient, q_c, was calculated using Equation 16.

$$q_c \quad = \sqrt{\frac{T - m_c * g}{k}} \tag{16}$$

Where T is the average thrust of the motor, g is the gravitational constant, and k is the aerodynamic drag coefficient. The coast velocity decay coefficient, x_c, was calculated using Equation 17.

$$x_c = \left(\frac{2 * k * q_c}{m_c}\right) \tag{17}$$

The coast velocity, v_c, was calculated using Equation 18.

$$v_c = q_c * \frac{1 - \mathrm{e}^{-x_c * t}}{1 + e^{-x_c * t}} \tag{18}$$

The coast distance, y_c, was calculated using Equation 19.

$$y_c = \frac{m_c}{2 * k} * \ln\left(\frac{m_c * g + k * v_c^2}{T - m_c * g}\right) \tag{19}$$

Lastly, the flight apogee altitude, PA, was calculated using Equation 20.

$$PA = y_1 + y_c \tag{20}$$

Running a simulation with expected competition, the flight apogee altitude was calculated to be 5,412 ft. The code used to calculate these values can be seen in Appendix C: Verification of OpenRocket Flight Calculations.

With the results of both simulation techniques, the team compared the two sets of results. A comparison of the OpenRocket results and the MATLAB results is in Table 10. All margins of error were below 6%.

Table 10. OpenRocket and MATLAB Stability, Characteristics, and Apogee

	OpenRocket	MATLAB	Margin of Error
Center of Pressure (inches from tip)	94.34	94.46	0.13%
Center of Gravity (inches from tip)	76.57	76.40	0.22%
Static Stability (Calibers)	2.96	3.01	1.61%
Altitude at Apogee (feet)	5289	5621	5.91%

The larger discrepancy in the predicted apogee altitudes is likely due to our MATLAB simulations simplistic calculation of altitude. The simulation does not account for any angle in the launch rail, winds horizontal to the flight path, turbulence in the air, or a changing coefficient of drag due to airspeed. However, OpenRocket has proven to be very accurate in predicting apogee in past competition years and is weighted more heavily for apogee predictions as a result. The apogee reached in the fullscale test flight also supports the accuracy of the OpenRocket projected apogee. Regardless, the team will continue to improve the MATLAB simulation to account for the various factors listed previously.

Avionics and Recovery Modeling

The team used a MATLAB script to fully model the launch vehicle's parachute deployment events, descent, and landing. The team used OpenRocket's flight predictions as a second mode of verification to verify MATLAB's result. LTRL's MATLAB rocket descent simulation program runs a recovery model in which the force balance between gravity and drag is integrated over time with separate phases for drogue and main. The model assumes that the parachutes do not deploy and expand instantaneously, but rather assumes the parachutes expand in a linear fashion. In this MATLAB model, the parachute area increases linearly with respect to time until the deployment time is complete.

Changes to Model

The C_D of the rocket body will be increased by 5%, and the C_D of the main parachute decreased by 5%. This results in the rocket to have a max drift distance of greater than 2,500 ft in 20 mph winds. To solve this problem, the team will look into using a different 18 in parachute that has a lower C_D to keep the maximum drift distance within 2500 ft. The C_D of this parachute will be tested by the team to better make this decision before competition launch. The new values for descent velocity were simulated and the descent velocity graph in Figure 38 is shown below. The adjusted drift distance is shown below in Figure 39. This causes the drift distance to be even shorter than was actually observed. This is most likely caused by higher wind speeds when the rocket is higher in altitude. The team will look into adding a function in the script to add faster wind speeds at higher elevations.

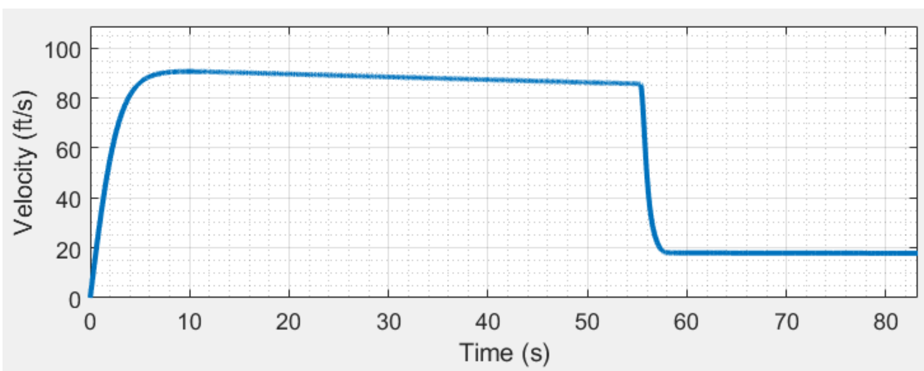


Figure 38. Adjusting MATLAB Descent Velocity

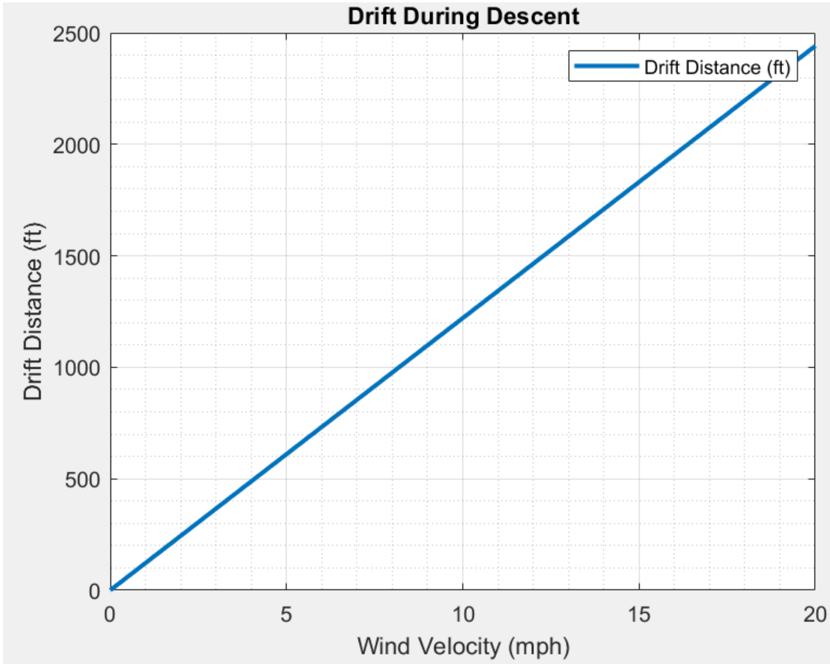


Figure 39. Adjusted MATLAB Drift during Descent

Parachute Selection

The parameters of the parachute's coefficients of drag are based on experimentally derived values from previous launches. The 18" Fruity Chutes Classical Ultra drogue parachute is estimated to have a coefficient of drag of 1.6, and the 96" Fruity Chutes Iris Ultra main parachute is estimated to have a coefficient of drag of 1.8. These numbers are slightly lower than the manufacturer's estimate, this is due to wear and tear on the parachutes and the manufacturer's own overestimation. Using OpenRocket and MATLAB, the team is able to confirm that these parachutes will land the rocket within the landing zone and with a safe amount of kinetic energy.

Descent Time

The team's MATLAB model calculated that the rocket will take 83.6 seconds to descend from apogee to landing. The predicted descent altitude and velocity by time from the MATLAB model can be seen in Figure 40. OpenRocket predicts the launch vehicle's descent time from apogee to be 88.2 seconds. The predicted descent velocities from Open Rocket can be seen in Figure 41. This verifies the team's MATLAB model prediction that the launch vehicle will fulfill requirement 3.10.

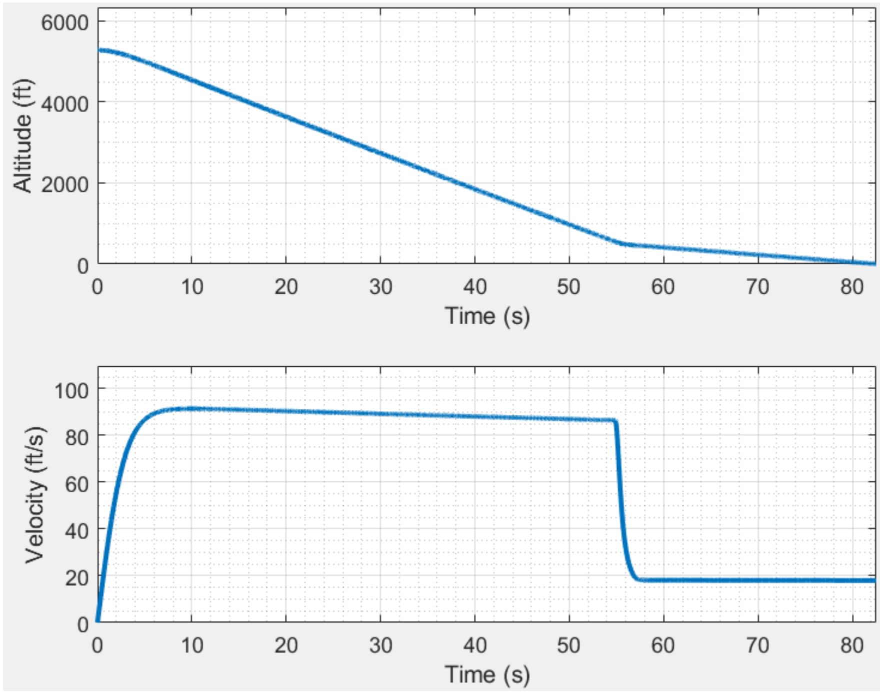


Figure 40. MATLAB Altitude and Velocity vs Time

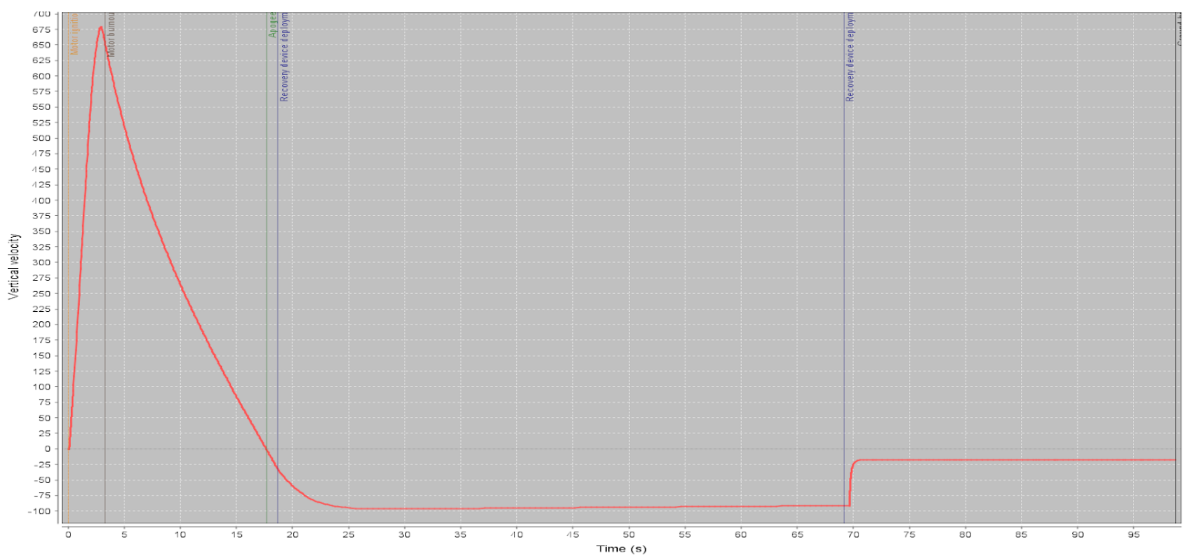


Figure 41. OpenRocket Velocity versus Time

Kinetic Energy

The MATLAB simulations predicted that the landing velocity of the rocket is 18.02 ft/s. OpenRocket's predicted landing velocity of the rocket is 17.8 ft/s. Kinetic energy of each body tube section was calculated using Equation 21. The kinetic energy of each section of the rocket at landing is given in Table 11. This confirms the requirement that the flight vehicle will land under 75 ft*lbs.

$$KE = \frac{1}{2}mv^2 \tag{21}$$

Table 11. Kinetic Energy by Section

Section	Mass (oz.)	Kinetic Energy at landing (MATLAB)	Kinetic Energy at landing (OpenRocket)
Nose cone	160.5	50.59 ft*lbs	49.42 ft*lbs
Avionics	123.3	38.86 ft*lbs	37.95 ft*lbs
Booster	184.2	58.06 ft*lbs	56.71 ft*lbs

The booster section is the heaviest section of the rocket and is most likely to impact the ground with an unsafe force. The kinetic energy of the booster section form after apogee to landing is shown in Figure 42. Mitigations for the failures of the main parachute deploying and slowing the rocket down are given in the team's FMEA tables.

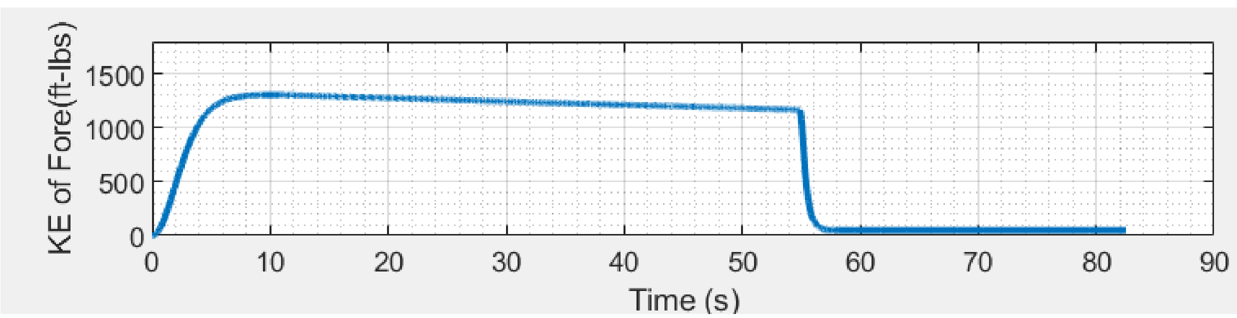


Figure 42. Kinetic Energy of Booster Section

Drift Distance

To ensure safe descent of the rocket within the landing zone, the team calculated drift distances for 5 mph, 10 mph, 15 mph, and 20 mph wind speeds. These calculations assumed there would be no launch angle and that the drogue parachute would deploy directly over the launch site. In Figure 43, the distance the rocket drifts from apogee is shown using MATLAB. OpenRocket drift distance from apogee that the launch vehicle with experience is 2235ft in 20 mph winds. This means OpenRocket predicts a drift distance that is approximately 200 feet shorter than the MATLAB model in 20 mph wind. This is due to OpenRocket not accounting for body tube drag once the drogue parachute has deployed. If OpenRocket accounted for this extra body tube drag, the launch vehicle would drift further.

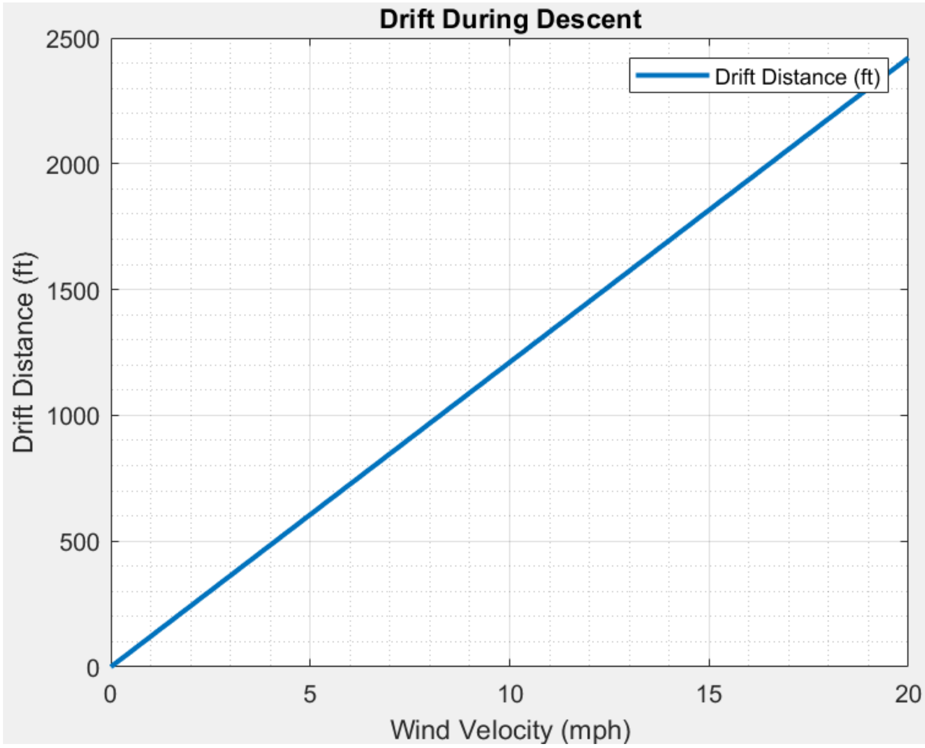


Figure 43. MATLAB Calculated Drift during Descent

Exact drift distances by MATLAB from apogee to landing for wind velocity are given in Table 12.

Table 12. MATLAB Drift Distance Calculations

Wind velocity	5 mph	10 mph	15 mph	20 mph
Drift distance	605.35 ft	1210.7 ft	1816.05 ft	2421.4 ft

3.4 Vehicle Demonstration Flight Results

Launch Day Conditions

The team successfully designed, constructed, launched, and recovered their 2018-2019 competition year rocket on February 9th. Launch day conditions were acceptable with little cloud cover, moderate winds of approximately 15 mph at the time of launch, and a temperature of 30 degrees°F. The rocket was launched from a launch rail at an angle of approximately 5 degrees and at 60 feet above sea level. The rocket had an apogee of 5,361 feet and took 84 seconds to land from apogee. The launch vehicle can be seen during its ascent in Figure 44.

Figure 44. Fully constructed launch vehicle in ascent during vehicle demonstration flight

Predicted and Actual Ascent Results

The simulated flight profile with the launch day atmospheric conditions, detailing altitude and vertical velocity versus time, are shown in Figure 45.

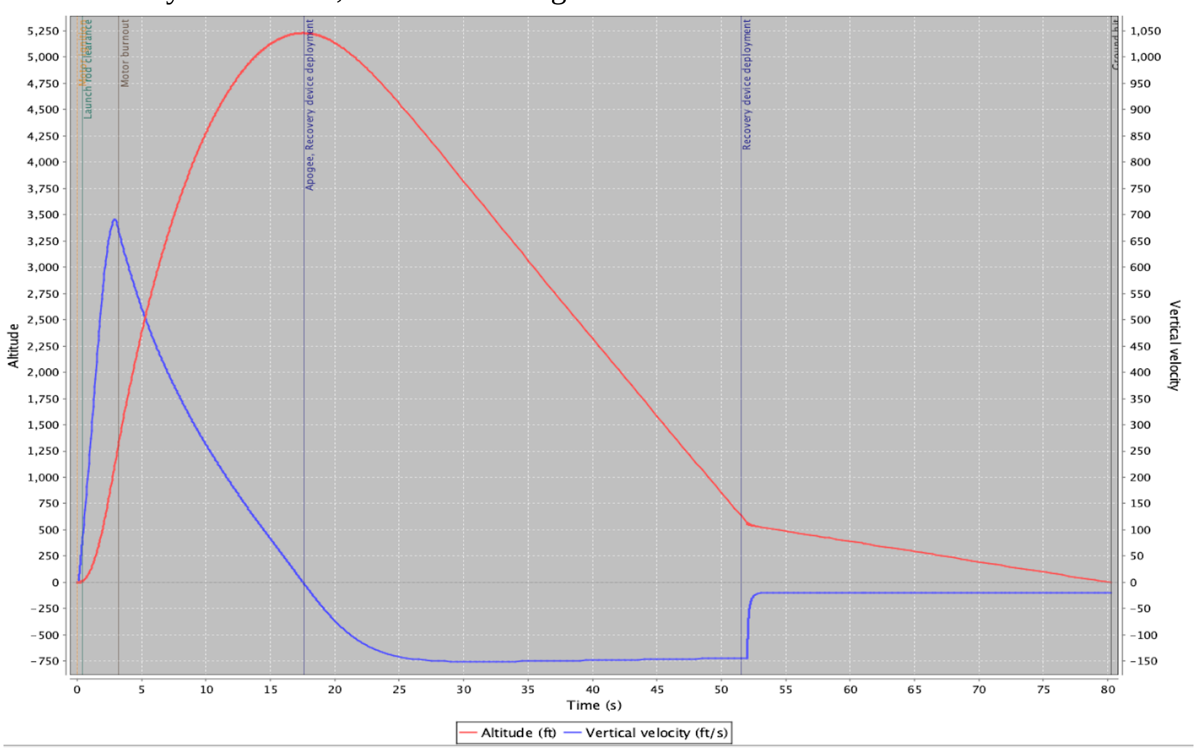


Figure 45. Vehicle Demonstration Flight Simulation: Flight Profile

This simulation shows that an apogee of 5,231 feet is reached at 17.5 seconds after ignition. This differs from the actual apogee of 5,361 feet by 2.4%. This difference can be sufficiently accounted for by turbulence at altitude and variance in the motor's total impulse. The launch vehicle contained two ounces of ballast during the vehicle demonstration flight.

This simulation shows that a maximum velocity of 691 ft/s is reached just before motor burnout at approximately 2.9 seconds at an altitude of approximately 1,100 feet. This maximum velocity is well within the imposed limit of Mach 1 and occurs a safe distance from the launch pad. The rocket's velocity off a 10 feet rail is 75.5 ft/s which is well above the imposed minimum of 55 ft/s. To ensure the stability of the flight vehicle off of the rail and throughout flight, a simulated stability profile was created from the OpenRocket model below in Figure 46.

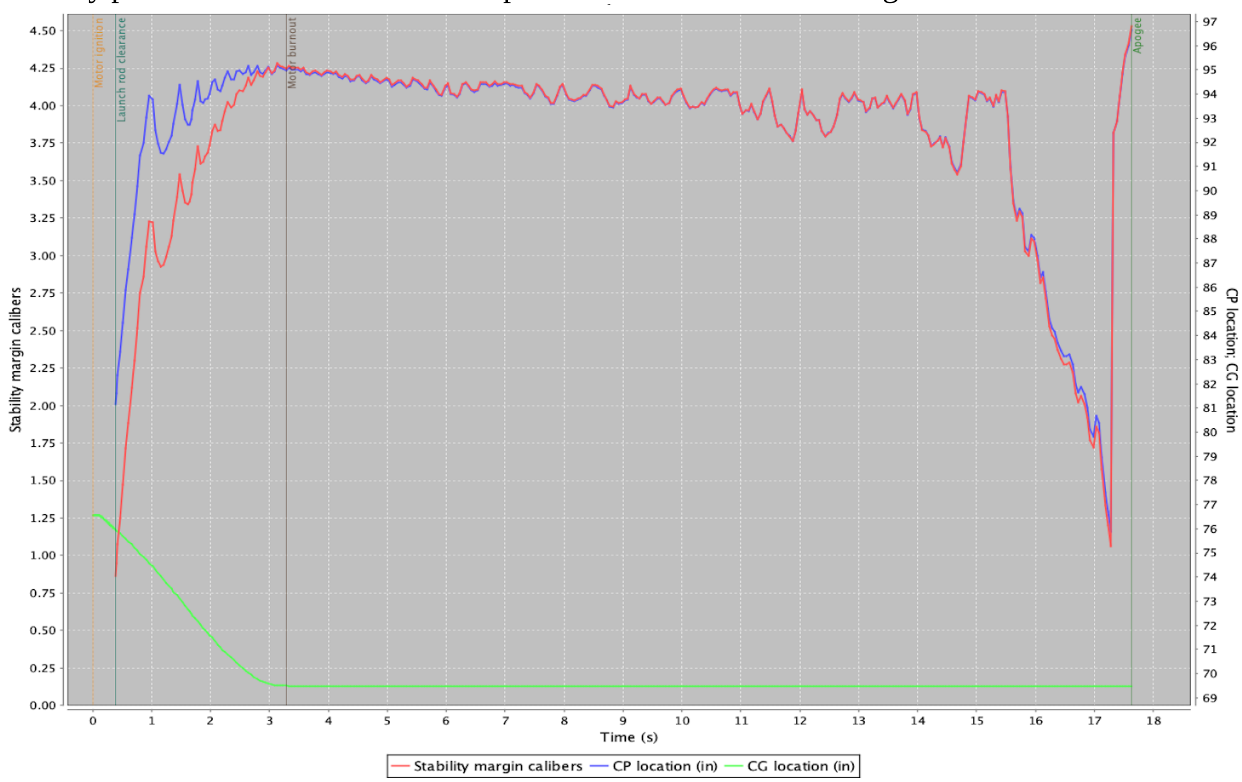


Figure 46. Vehicle Demonstration Flight OpenRocket: Stability Profile

The stability off the launch rail is 1.0 calibers. This relatively low stability is due to the high winds on launch day. Even with the high winds, the rocket still maintained the accepted stability of 1.0 calibers off the rail. After leaving the rail, the stability rapidly increases to approximately 3.2 calibers before slowly climbing to 4.2 calibers at motor burnout. It is apparent that the thrust curve for the Cesaroni L1355 motor has the necessary characteristics to achieve the minimum rail velocity for stable flight as the rocket leaves the pad.

Predicted Descent

The team primarily relies on MATLAB to predict the vehicle's descent. The model is updated with all the vehicle dimensions and masses prior to calculating trajectories. The following calculations are assuming drogue deploys directly above the launch rail. The drift distance in

Figure 47 predicted a drift distance of 1873 ft. This calculation was verified through OpenRocket which yielded a drift distance of 1850 ft.

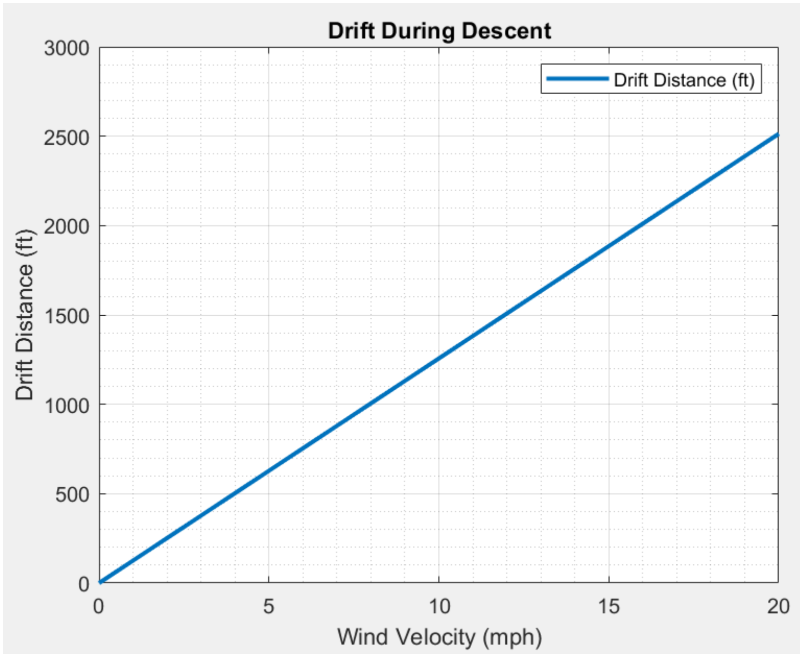


Figure 47. MATLAB Drift during Descent

The graph of predicted descent time and velocity for the rocket on launch day is shown below in Figure 48.The predicted descent time was 87.3 s from apogee. The average descent velocity under drogue was predicted to be 85.9 ft/s and 18.7 ft/s under main.

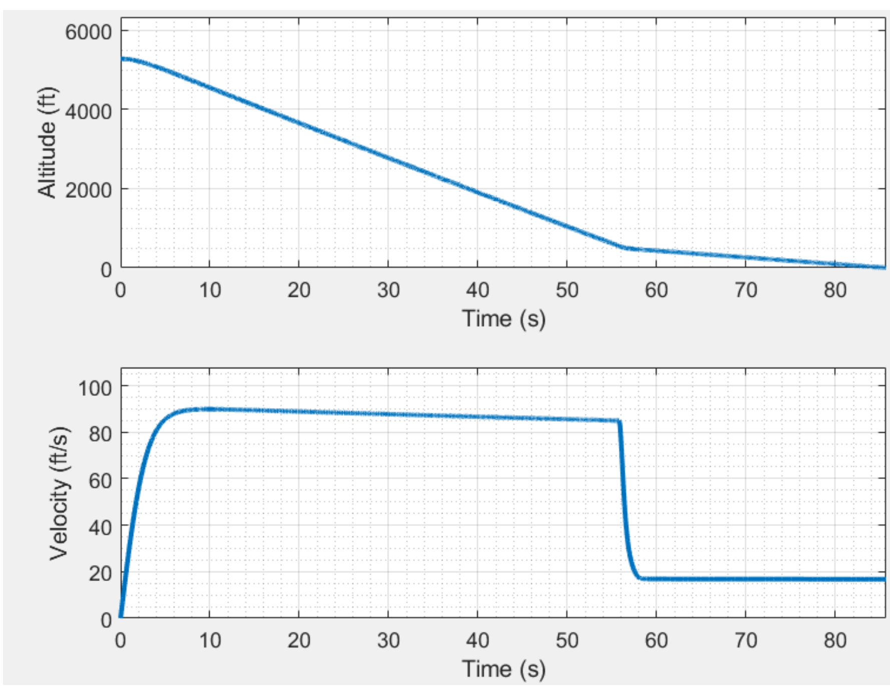


Figure 48. MATLAB Predicted Descent Velocity

Actual Descent

Figure 49 is the data gathered from the primary altimeter during flight. The descent speed under drogue was approximately 90 ft/s which was 4.77% faster than predicted. The descent speed under main was 19.5 ft/s which was 4.27% faster than what was predicted. The descent time after apogee was approximately 84.0 s until landing which was 3.78% faster than predicted.

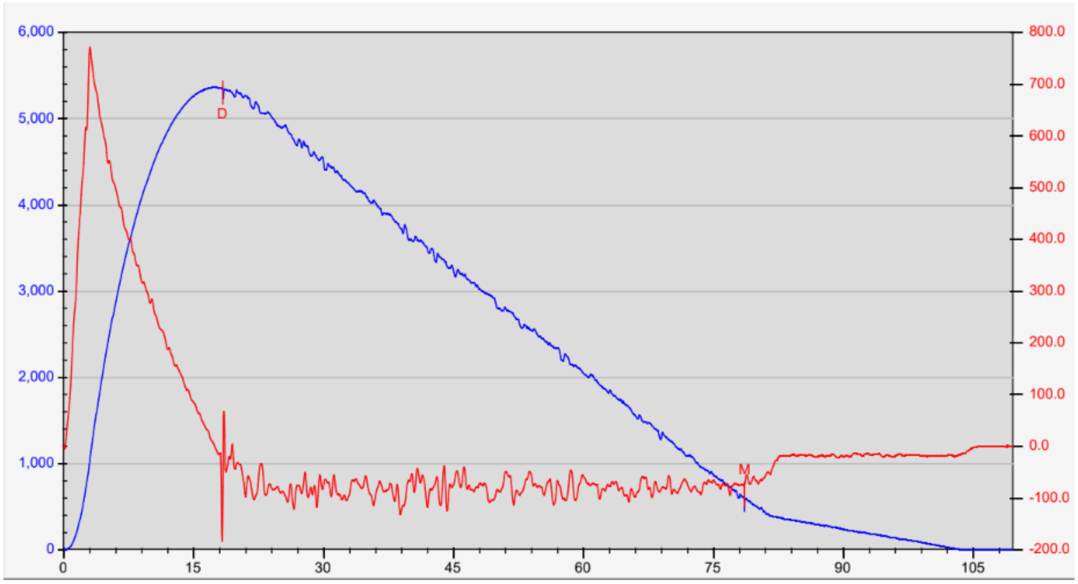


Figure 49. Vehicle Demonstration Flight Altimeter Data

The drift distance from launch to landing is shown below in Figure 50. At 2,195 ft, this drift distance was 18.65% further than expected with the 15 mph winds.

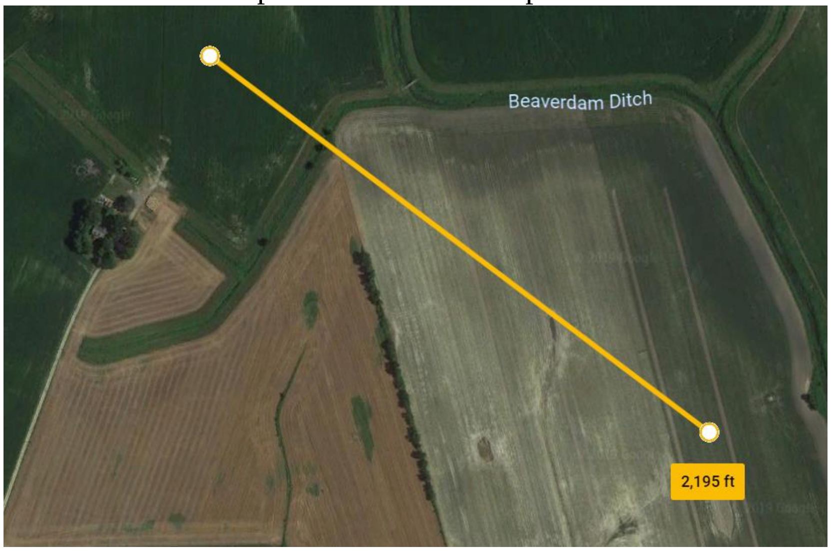


Figure 50. Drift Distance for Vehicle Demonstration Flight

Deployment

Marked in Figure 49 are two red lines labeled D and M for drogue and main deployment. The location of these two show that the altimeters reported firing the separation charges at the expected time. This confirmed that both parachutes deployed and unfolded successfully. Descent under drogue parachute is shown below in Figure 51 on the left, and descent after main has deployed is shown in Figure 51 on the right. The sections did not collide with each other during descent confirming the team's requirement.

Figure 51. Parachute descent under drogue (left) and main (main) during vehicle demonstration flight

Comparison between Predicted and Actual Flight for Descent

The descent speed under drogue and main were off by less than 5%. The inaccuracy in drogue descent is expected since the team has no way to model the tumbling of the rocket body prior to being flown. This slight over estimation on descent speed caused the descent time to be estimated at only 2 seconds faster than actual descent time.

Subscale fell significantly faster than predicted and after adjusting the drag coefficients, 75% of the error was corrected. Subscale descended significantly faster than the model predicted even when comparing the results with fullscale data prior to it being updated from subscale testing. At lower Reynolds numbers on the subscale components, the drag on the parts is much less. To compensate for this, next year the team will use a different MATLAB script for subscale than fullscale to account for this effect.

The rocket did drift 250 ft further than expected. 50 ft of this 250 ft overestimation can be accounted for by the rocket going 80 ft higher than modeled. The other 200 ft can be accounted for by noticing the higher variance in tumbling, and inferring that the wind speed was 3 mph to 5 mph faster at altitude. Where the rocket would have landed in higher winds matches with where the rocket actually landed.

The rocket landed within the required distance from the launch pad and at a speed that did not produce an impact energy on any individual section greater than 75 ft lbs. This satisfies the NASA requirements for the recovery system.

Subscale and Fullscale Test Flight Similarities

Both subscale and fullscale flights were successful in their aims to inform the team on the design choices made and validate those choices. Both flights were also accurately simulated before launch with OpenRocket and MATLAB.

There were two major differences between the flights: the launch operations procedures and the wobble seen during subscale. During the subscale flight, assembly procedures were simplified drastically due to the lack of payload hardware present. But for fullscale, the structures team had to work closely with the payload team to ensure that all assembly procedures were carried out in the correct order. The other difference between the flights was the noticeable oscillations seen during the subscale launch. This was due to body tubes that did not sit flush against one another, this failure was specifically mitigated during fullscale construction. The fullscale test flight did not see any oscillations during ascent such as seen during subscale.

During both subscale and fullscale flight the altimeters and ejection system performed exactly as intended an expected. The descent rate during both flights was faster than predicted for drogue and main. The model was significantly more accurate when modelling fullscale descent speed due to the modifications made to the model after subscale flight which increased the accuracy 10%. The drift calculations in both tests were accurate to within 10% and did not change much between flights. One of the reasons for this was due to the wind speeds being almost 15 mph faster during the fullscale launch which increases the drift distance and makes it more likely to be inaccurate.

Drag Coefficient

To estimate the drag coefficient of our rocket, a MATLAB simulation was conducted. Using the component masses and apogee measured on the day of launch, the drag coefficient was adjusted until the simulated apogee matched the actual apogee to an accuracy of $3.4*10^{-4}$%. The drag coefficient that produced this result was 0.60. This drag coefficient very closely matches the drag coefficient of 0.58 that the OpenRocket program predicted.

Payload Vehicle Demonstration Flight Results

Successful flight criteria are determined by the NASA and some of the team derived requirements. Meeting all of these requirements would demonstrate a successful flight. Flight criteria include retaining the rover during flight, deploying the autonomous rover from the launch vehicle, the autonomous rover driving 10 feet, and collecting a 10 mL soil sample. Other qualifications for a successful flight include the successful operation of the communications system and the rover having the correct orientation upon landing.

The rover was successfully retained during flight by the solenoid locking mechanism because it was not displaced during the post flight analysis. However, because the ground station software failed on launch day, there was no way to verify that the solenoid would have unlocked the rover until it was returned to Penn State for further testing. The solenoid locking mechanism did successfully operate post flight when this additional test was conducted.

The ground station failed on launch day because the ground station was not operating on the correct computer. Due to a long wait time between arrival at the launch site and recovery of the rocket, the normal ground station computer’s battery died and a different computer was used. The ground station was unable to connect with the rocket and the nose cone was not deployed.

The rotating payload bay was successful because the rover had the correct orientation after landing. All of the electronics on board the rocket were unharmed post flight.

4. Safety

LTRL understands that there are many inherent dangers when building, testing, and launching high powered model rockets. In the safety plan below, LTRL outlines the risks and hazards identified throughout the process of constructing, testing, and launching of the rocket, along with the preliminary steps to mitigate them.

4.1 Safety Officer Responsibilities

Ben Akhtar is the Safety Officer for LionTech Rocket Labs during the 2018-2019 season. As Safety Officer, he is responsible for the overall safety for the team, students, the public, and any other persons involved or at any LionTech Rocket Lab events. In the 2019 spring semester, Ben Akhtar is studying abroad and will not be able to oversee construction, testing, nor launch day assembly of the rocket and cannot enforce safety procedures as a result. Because of this, Matt Easler, the team's Flight Systems Lead, will act as the interim safety officer during construction, testing, and launch day procedures for duration of the 2019 spring semester.

Statement of Work Requirements

The statement of work requirements for Safety provided by NASA are shown in Team Derived Requirements.

Safety Requirements Verification

LTRL has created a set of team derived responsibilities that will increase and ensure further safety throughout the 2018-2019 season. These responsibilities can be found in Requirements Verification.

4.2 Safety Statement

LTRL will comply with all National Association of Rocketry (NAR), Federal Aviation Authority (FAA) and National Fire Protection Association (NFPA) regulations pertaining to high powered model rocketry. For convenience, and to help ensure the safety of LTRL members and the general public, LTRL will only launch at NAR or Tripoli Rocket Association certified club launches. LTRL and its members will comply with all instructions and guidance issued by the Range Safety Officer (RSO) of these launches. LTRL and its members will also comply with all instructions and guidance issued by the RSOs at the USLI launch in Huntsville.

4.3 NAR and TRA Regulations

NAR Safety Code

Table 13 describes every component of the NAR High Power Rocket Safety Code and how LTRL plans on following with each and every rule or regulation.

Table 13. NAR Safety Code

NAR High Power Rocket Safety Code	LTRL Policy to Follow the Code
1. **Certification.** I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.	Only NAR motor certified team members or Justin, the team's NAR mentor will be allowed to purchase, handle, pack, or deal with the appropriate rocket motors.
2. **Materials.** I will use only lightweight	Payload and the Structures subsystems will

materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.	consider and select materials that follow this guideline while factoring in the weight, strength, durability, and other factors in their selection.
3. **Motors.** I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.	All motors will be purchased from professional, certified sellers such as AMW Pro-X. All motors and black powder are stored in the High Pressure Combustion Laboratory (HPCL), which is equipped with a type 4, indoor, portable BTFE explosives magazine. The lab that holds the motors is locked, and the area where the magazine is located in is only accessible to members with the proper NAR certification. Only appropriate motor certified NAR members shall be allowed to handle the rocket motors.
4. **Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.	To ensure proper safety protocol, the Range Safety Officer will have final say over any possible issues with the ignition system on launch day. Additionally, to ensure that charges do not go off prematurely, the altimeters will not be armed until on the launch pad. Finally, the onboard energetics will not be installed until on the launch site and given the go ahead that our rocket may fly.
5. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	Only the Range Safety Officer or Safety Officer of LTRL may disconnect the battery or remove the launcher's safety interlock. The Safety Officer will remind all members of LTRL of this on the launch site and ensure all members stand a safe distance away until the rocket has either fired or been completely disconnected for at least 2 minutes.
6. **Launch Safety.** I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch	The Safety Officer will alert the team and the public before countdown begins to ensure proper awareness of the launch and safety risks. LTRL will make sure to follow the Minimum Distance Table at the very least and

pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.	follow any other rules given by the Range Safety Officer on the day of the launch. Additionally, the team will be in compliance with all the other stated rules and ensure proper stability of the rocket for safety and proper flight.
7. **Launcher.** I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.	LTRL and the Safety Officer will ensure to use the rails provided by the NAR at any launches and the competition. Furthermore, LTRL and the Safety Officer will ensure a proper launch angle and that there are no fire hazards below or near the exhaust of the rocket motor.
8. **Size.** My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.	LTRL will not exceed the total impulse when using a rocket motor or motors in their rockets.

9. **Flight Safety.** I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.	Weather conditions and wind conditions will be checked before each launch to ensure that LTRL follows these guidelines and if there is a possible safety risk, does not launch their rocket at that time. Additionally, the Safety Officer will ensure throughout the construction of the rover that no flammable objects could exist to create a flight hazard. The team will ensure that all launches have adequate FAA waivers in place for the rocket launch.
10. **Launch Site.** I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).	All launches will be at NAR/TRA events. All launches will be at either Maryland Delaware Rocketry Association (MDRA) or Pittsburgh Space Command (PSC). If any issues arise, the Range Safety Officer will have the final say over any decisions to launch at that site.
11. **Launcher Location.** My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.	The team will ensure that the NAR sites they launch at comply with this rule and that if there is an issue that the Range Safety Officer alert the team immediately. The Range Safety Officer will have the final say over any decisions to launch at this site.

12. **Recovery System.** I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.	The Avionics and Recovery subsystem will design, construct, and test to ensure that all avionics bays are safe for flight use. All rockets will use a dual deployment system with a drogue and main parachute. Additionally, only Kevlar recovery system wadding shall be added to the rocket. The Avionics and Recovery subsystem will also follow the launch day checklist to prevent any issues that may arise before launch. If any issues arise that cannot be fixed properly, the team shall not launch.
13. **Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.	LTRL will make sure that if necessary, proper professionals are contacted to retrieve the rocket.

4.4 Lab Safety

Design and construction of both the Subscale and fullscale requires the use of power tools, such as a Dremel, a drill, and a finishing sander. Additionally, it requires the use of potentially harmful chemicals, typically epoxies. These create hazards, which can be mitigated by following proper protocols and rules and wearing proper personal protective equipment (PPE) and exercising extra caution when necessary to ensure the safety of all team members. To create a proper atmosphere, where safety is of the utmost importance, and to educate members about proper chemical safety and disposal, basic laboratory safety, and the proper use of PPE, all team members are required to take safety training that is offered through Penn State's Environmental Health and Safety (EHS). In addition, safety and emergency equipment is available to LTRL members in the lab and at launches.

Safety Training

All LTRL team members are required to take a four-part Initial Lab Safety and Hazards Awareness training course offered online by Penn State's EHS. The course consists of four training videos: Introduction to Safety, Chemical Safety, Hazardous Waste Management and Disposal, and Emergency Preparedness. Each training video concludes with a quiz. Members must score at least an 80% to pass that portion of the training. LTRL Members who have already completed the initial course in a previous year can take a refresher course instead. The refresher course is also offered online, in a similar training video format. Members must score an 80% to pass the quiz at the end of the video. If they do not score 80% or higher, they must retake the quiz. If they do not pass after two times, they are required to set up an appointment with the Safety Officer and review all the topics covered in the videos and ask any questions they may have. In either case, participating in the four-part training course or the refresher, after passing the quiz, a certificate is generated, which is then submitted and verified by the Safety Officer, allowing that team member to work in the laboratory. The Safety Officer keeps both a physical and electronic database recording all members who have completed their safety training and are allowed to work in the laboratory. The physical storage of the safety certificates is in a binder, located within the laboratory. If a member has yet to complete their training once work beings in the laboratory, the appropriate subsystem lead is notified about which members are not compliant with the Safety Training requirement. Members who have not completed safety training are not allowed to work in the lab.

Safety and Emergency Equipment

Safety glasses, dust masks, and gloves are available in the LTRL lab. They are also brought to launches and used as necessary. In case of an emergency, a first aid kit is available in the lab and brought to launches. Fire extinguishers, both dry chemical and CO_2 types, are available in the hallway directly outside of the lab. Additionally, there is a bathroom directly down the hallway from the lab in the case a team member needs to wash a chemical off.

4.5 Local/State/Federal Law Compliances

The team has closely examined, reviewed, and acknowledged all regulations regarding unmanned rocket launches and motor handling. The following regulations are included in the team's safety manual and available to all members: Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C, Code of Federal Regulation 27 Part 55: Commerce in Explosives; and fire prevention, and NFPA 1127 "Code for High Power Rocket Motors"

The team's preferred launch sites are listed below in Table 14.

Table 14. Preferred launch sites for the 2018-2019 competition

Field Location (Group Name)	Status	Team Use
Grove City, Pittsburgh (Pittsburgh Space Command)	1) Waiver up to 8,700 ft 2) Only two hours travel 3) Moderate size 4) Friendly and helpful 5) Available once a month	1) Ideal site for test launches 2) Best location for travel 3) Ideal for low to moderate wind speeds
Higgs Farm and Central Sod Farm in Maryland (Maryland Delaware Rocketry Association)	1) Waiver up to 16,900 ft 2) 4 ½ hours travel 3) Large size 4) Typically available more than once per month	1) Ideal site for test launches 2) Inconvenient due to travel 3) Ideal for higher wind speeds

All of these launch sites are in compliance with all federal, state, and local regulations as well as any rules and regulations put forth by the NRA. Additionally, both sites are have a high standard of safety. LTRL's main launch site for the 2018-2019 season will be in Grove City, Pennsylvania through Pittsburgh Space Command, which is an NRA affiliated launch site.

4.6 Motor Safety

LTRL plans to use an I-class motor for the subscale rocket. Last year a J-class motor was used. Additionally, LTRL used an L-class motor for the fullscale last year and LTRL tentatively plans that a similar class motor will be used for fullscale this year. The rocket motors are purchased, handled, and transported by Justin Hess. Justin Hess holds a NAR Level 2 certification. Any team member who has obtained at minimum a Level 2 certification will also be allowed to assist in this process. Additionally, Matt Easler, the team's Flight Systems lead and Gregory Schweiker, the team's President, currently hold NAR Level 1 certifications and are attempting their Level 2 certification launches during the season. An individual who has obtained at least a Level 2 certification has demonstrated that they understand the safety guidelines regarding motors and the proper procedures for purchasing, handling, and transporting them. Any certified team member that partakes in any of these activities is responsible for the appropriate safety measures. All motors are stored in the High Pressure Combustion Lab (HPCL) when not in use. The HPCL has storage magazines for H/D 1.1 and H/D 1.3 energetic materials and propellants. These magazines are sited, licensed, and operated in compliance with all local, state, and federal regulations. The motors for all launches will be transported by car to the launch site.

Motor CATO Awareness and Prevention

In order to ensure the team's utmost safety, the team will monitor and reference the Manufacture Notifications and Modification Announcements at http://www.motorcato.org/ to ensure that scheduled motors for subscale and fullscale have no warnings issued or a higher risk for a hazard. Additionally, if a catastrophic event at take-off (CATO) occurs during any launch this season, the team will report through the malfunctioning engine statistical survey (MESS) to assist other teams and peoples in tracking the reliability of rocket motors.

4.7 Hazard Analysis

Risk Assessment Matrix

By thoroughly examining every human interaction, environment, rocket system and components, and previous year's hazards, hazards for this season have been identified. These hazards are not the only hazards that may occur during the construction, testing, or launching of the rocket and as new hazards and risks are identified with new rocket components. These hazards will be added to the list of hazards and thoroughly analyzed to properly mitigate their risk. Hazard identification and risk assessment are vital to the safety and success of the team and the safety of the public.

Each currently identified hazard has been thoroughly evaluated through a risk assessment matrix that first identifies the hazard, then lays out the possible causes of the hazard, and the effects of the hazard occurring. Additionally, the risk assessment matrix identifies the likelihood and severity of the said hazard and mitigations of those hazards to demonstrate the pre-mitigation risk and the post-mitigation risk.

To determine the likelihood of every hazard, a score from one to five, with a score one being the highest, was given. To accurately give a likelihood score, the following conditions were considered:

- All team members have undergone proper lab safety training and understand how to properly use the equipment
- All team members understand when they are required to wear PPE and how to properly use the PPE to prevent harm
- All team members understand all rules set forth in the safety manual and any laws and regulations that may be in place relating to the project at hand
- All procedures were correctly followed during testing, launching, and construction of the rocket
- Any equipment was properly inspected before use and if determined inadequate, was properly disposed
- Any component used during testing, launching, or construction of the rocket was properly inspected before and if determined inadequate was either properly disposed of or replaced to ensure a safe build of the rocket for any tests or launches

The criteria for the selection of the likelihood value is outlined below in Table 15.

Table 15. Likelihood Value Criteria

Likelihood		
Description	**Corresponding Value**	**Criteria**
Almost Certain	1	Greater than a 90% chance the hazard will occur
Likely	2	Between a 90% and 50% chance the hazard will occur
Moderate	3	Between a 50% and 25% chance the hazard will occur
Unlikely	4	Between a 25% and 5% chance the hazard will occur
Improbable	5	Less than a 5% chance the hazard will occur

A severity value has been assigned from 1 to 4 for all hazards, with a value of 1 being the most severe. To determine the severity value for each hazard, a set of criteria has been established based on injuries, damage to any equipment and/or the rocket, and any possible environmental damage, which will be compared to the possible outcome of the hazard or issue. This criteria can be found below in Table 16.

Table 16. Severity Value Criteria

Severity		
Description	**Corresponding Value**	**Criteria**
Catastrophic	1	Could result in any number of deaths, irreversible damage to the environment, mission failure, or monetary loss upwards of $5k.
Critical	2	Could result in severe injuries, many moderate environmental impacts or a severe but reversible environmental impact, partial mission failure, or monetary loss between $500 and $5k.
Marginal	3	Could result in minor injuries, a number of minor environmental effects or one moderate one, a complete failure of non-mission essential system, or a monetary loss between $100 and $500.
Negligible	4	Could result in insignificant injuries, a minor environmental impact, a partial failure of a non-mission essential system, or monetary loss of less than $100.

By using the likelihood value and the severity value, an appropriate risk level has been determined and assigned using the risk assessment matrix found in Table 17. The matrix identifies all combinations of severity and likelihood as either, low, moderate, or high risk. An ideal outcome for the team is to have all hazards to be at a low risk by the time the competition launch occurs to ensure the safest environment. Hazards that are above a low risk level and are not an environmental risk that the team has no control over will be readdressed through a number of different options including redesign, additional safety regulations, analysis and tests, or other measures that may be required. Additionally, through verification systems, the risk may be further mitigated.

Table 17. Risk Assessment Matrix

Risk Assessment Matrix				
Likelihood Value	**Severity Value**			
	1-Catastrophic	2-Critical	3-Marginal	4-Negligible
1-Almost Certain	2-High	3-High	4-Moderate	5-Moderate
2-Likely	3-High	4-Moderate	5-Moderate	6-Low
3-Moderate	4-Moderate	5-Moderate	6-Low	7-Low
4-Unlikely	5-Moderate	6-L ow	7-Low	8-Low
5-Improbable	6-Low	7-Low	8-Low	9-Low

Preliminary risk assessments have been evaluated for possible hazards that have been identified so far in the design process for the 2018-2019 season. Identifying the hazards this early in the design process allows the team to pay special attention to possible failure mechanisms within at risk components. By redesigning, analyzing and testing, or creating safety procedures, the mechanisms can be reduced or further understood while creating a safer environment for the team at this design stage. The team will work through the design stage and throughout the year to mitigate current hazards and any other hazards that are identified throughout the year.

At this time, some identified risks are unacceptably high. This is because all risks have been identified and addressed through some early concept design work, recommended processes, and hand calculations as testing has not been able to occur yet for the specified risks. As these risks are analyzed and tested, designs will be mitigated and verified as safe or redesigned. Risk levels will only be lowered once physical testing or evidence has proven the safety of the mechanism and the design are verified.

Overall Team Risk Assessment

During the project there are many possible hazards that could hinder the team as a whole, not just for specific subsystems. These all do not relate to the environment.

Lab and Learning Factory Risk Assessment

During the construction and manufacturing of components for the rocket, there will be many risks associated. All of this construction and manufacturing will be conducted either at the Learning Factory or the LTRL Lab. The hazards assessed from working with machines, tools, or chemicals can be found in Table ***18***.

Structures Risk Assessment

The hazards found in Table 22**Error! Reference source not found.** are hazards that could be encountered during the launch of the vehicle or the assembly of the vehicle.

Propulsion Risk Assessment

Because the team is buying commercially produced motors, this area is of lower risk than if team produced its own motors. There are still risks associated, however. The team plans on allowing only members who have proper motor level certifications to use, handle, purchase, and work with the rocket motors. The team plans on accurately producing a stable rocket that can handle the rocket motor the team chooses. All hazards associated with propulsion are found in

Table 23.

Avionics and Recovery Risk Assessment

Because LTRL is required by NASA to use dual deployment, many of the hazards stated would be possible for all of the systems. To be concise, all the stated hazards will only be stated once. The hazards that are associated with avionics and recovery can be found in Table ***24***.

Payload Risk Assessment

Because the team is planning on building a rover this year, there are many associated hazards or possible outcomes that could cause a failure or pose a safety concern. The team plans to ensure that the payload is properly secured, which will require many different components to ensure safe deployment, testing, assembly, and other flight hazards. The hazards that are associated with the payload can be found in

Table 25.

Hazards to the Environment Risk Assessment

During construction, testing, or launching of the rocket there may be hazardous to the environment. The associated hazards can be found in Table ***19***.

Environmental Hazards to Rocket Risk Assessment

The hazards found in

Table 20 are risks that the environment could impact the rocket or a component of the rocket. Unfortunately, the team has no control over environmental hazards and cannot reduce the risk of the hazard. Because of this, these hazards can be considered outside of the team's ideal scenario of having all hazards be at a low risk level. To ensure proper safety, if the environment poses a moderate risk to the rocket or a component of the rocket, the launch will be delayed until the Safety Officer lowers the risk level to low and approves the team to consult the Range Safety Officer to see if it is safe to launch.

Launch Procedures

Throughout the season, the Safety Officer is responsible for writing, maintaining, and ensuring that up to date and proper launch procedures are available at any time. These are critical to team members, the public, the range's personnel, the equipment, and the environment. Checklists will be required for all launches. These checklists can be seen under Launch Day Procedures.

These checklists are divided into checklists for each subsystem for pre-launch preparations, necessary launch day equipment, and launch day. By creating these checklists, each subsystem remains more organized and can quickly and effectively prepare for launch day. For a checklist to be considered complete, the head of the appropriate subsystem must sign off on that checklist after verifying every single item on the checklist has been completed. The Safety Officer will collect and verify the completion of all subsystem checklists. Once all subsystems have completed their appropriate tasks, the final assembly of the launch vehicle may be occur. Once the final assembly is complete, all subsystem leads and executive members, including the Safety Officer, must approve the rocket for launch. Once the rocket is a go for launch, the launch pad checklist can be started. Subsystem leads or executive members will be assigned a specific component of the rocket to track during the flight and recovery of the rocket. If the Safety Officer or Range Safety Officer determine something may be unsafe at any time, then they may call off the launch at any time if they believe the risk level is too high.

Safety Data Sheets (SDS)

All potentially hazardous materials that the team has stored in the lab or will be used throughout the competition have been identified and appropriate SDS have been found. These SDS can be found in Appendix A: MSDS Sheets. This appendix will include the name and the first page for each SDS along with the corresponding link to that SDS to view the full SDS.

4.8 Safety Risk Assessment

Table 18. Lab and Learning Factory Risk Assessment

Lab and Learning Factory Risk Assessment										
Hazard	**Cause**	**Effect**	**Pre-Mitigation Likelihood**	**Pre-Mitigation Severity**	**Pre-Mitigation Risk**	**Mitigation**	**Post-Mitigation Likelihood**	**Post-Mitigation Severity**	**Post-Mitigation Risk**	**Verification**
The use of chemical components.	Chemical fumes being inhaled or splashed onto a person.	Possible mild to severe burns or asthma aggravation due to inhalation of fumes.	2	2	4-Moderate	MSDS data sheets will be available to all members in the lab. Additionally, all team members must understand the risks that the chemical poses. All members will also wear nitrile gloves and have their body covered in clothing.	4	2	6-Low	All members must agree to wear appropriate clothing in the lab and take proper training before working with any chemical to ensure they understand the risks.
The use of power tools such as saws, sanders, drills, or blades or other machines.	Not wearing the proper personal protection equipment.	The team member may have particulates enter their throat or lodge in their skin.	2	2	4-Moderate	All team members will be taught which personal protection to use with each tool. Each team member will be tested of their knowledge before being allowed to enter the lab.	4	2	6-Low	All team members will only operate power tools in the presence of a lead or executive member to ensure proper

										protocols are followed.
A high voltage shock.	Improper use of welding leads to a team member being shocked.	A team member could suffer a severe injury or death.	3	1	4-Moderate	All members must have certified training prior to welding. Two certified team members will be present when welding. One to watch for possible mistakes and one to weld.	5	1	6-Low	All members with welding training shall present them to the Safety Officer before they are allowed to weld. If they do not, they shall not be permitted to use the welding equipment during the season.
The use of chemical components.	Improper use of the chemical components or improper mixing.	The rocket may be damaged or the team member could start a fire harming team members.	3	2	5-Moderate	There will be a fire extinguisher kept in the lab at all times. Additionally, all team members will be instructed to carefully read all instructions before using any chemicals and working with a lead when mixing potentially dangerous chemicals.	4	2	6-Low	All team members will only be allowed to enter the lab with a lead or executive member. All chemicals will be stored in the lab.
The use of power tools such as saws, sanders, drills, or blades or	Improper use of the tool or lab equipment from poor training.	Possible burns or cuts to team members. The rocket or tool may also be damaged.	3	2	5-Moderate	All members using the tool must have knowledge and training with using that tool. If they are using the tool for the first time,	4	2	6-Low	All members with proper training for specific tools shall be kept in a

other machines.						they shall be taught properly by a lead or executive member and then watched to make sure they properly follow procedure. Additionally, all members are required to wear safety glasses in the lab. Finally, if applicable, a vacuum will be placed near the point of cutting or drilling to ensure particulates or shards are properly disposed of.				log within the lab. When a member wishes to use a tool, a lead or executive member may check to see if they have the proper training. If they do not, the proper steps will be taken.
During sanding a team member may have particulates enter their throat.	The team member did not properly use their PPE.	This could cash a rash, a sore throat, nose, eyes, and possible asthma.	2	3	5-Moderate	All individuals will be required and taught how to use proper PPE during sanding and using other tools. Additionally, team members will have to wear long sleeves and long pants.	3	3	6-Low	All members will be made aware of the risks of sanding and all team members will have specific PPE just for them labeled in the lab.
Metal shards entering piercing the skin.	The use of a drill or other cutting equipment to machine metal parts.	Metal splinters lodged in the skin or in the eyes.	2	2	4-Moderate	When entering the lab, all team members must have closed toe shoes, long pants, long sleeves, wear gloves when machining, and wear safety glasses. If applicable, a vacuum will be placed near the place of cutting or drilling	2	5	7-Low	When metal is being cut, it will be required that at least two members are there to work together, one to use the vacuum and one to cut the metal.

										Additionally, the one cutting must have approval and proper training to use the tool to cut the metal.
The use of white lithium grease.	The grease contacts the skin while putting the motor inside the rocket.	The member may have skin irritation.	2	3	5-Moderate	All members will be required to wear gloves and safety glasses when working with hazardous substances.	4	3	7-Low	All team members will be made aware of the risks and have proper training to work with hazardous substances.
A team member may get burns while soldering.	Improper use of the soldering iron.	The team member may suffer minor to severe burns.	3	3	6-Low	All team members will be taught how to properly solder and their first few times will be supervised by an experienced member.	4	3	7-Low	All members with proper training for specific tools shall be kept in a log within the lab. When a member wishes to use a tool, a lead or executive member may check to see if they have the proper training. If they do not, the proper steps will be taken.

Table 19. Rocket Hazards to Environment Risk Assessment

Rocket Hazards to Environment Risk Assessment										
Hazard	**Cause**	**Effect**	**Pre-Mitigation**	**Pre-Mitigation Severity**	**Pre-Mitigation Risk**	**Mitigation**	**Post-Mitigation**	**Post-Mitigation**	**Post-Mitigation Risk**	**Verification**
There is unsuccessful deployment of recovery systems.	The deployment charges fail to ignite, or insufficient deployment charges or improper pressure readings.	The launch vehicle plummets to Earth at a higher than expected speed resulting in a damaged launch vehicle and debris around the launch area.	3	1	4-Moderate	Both separation charge calculations and separation tests will be done separately to ensure all sections separate properly.	5	1	6-Low	At least 3 ground tests will take place before the launch to ensure that the coupler can separate properly. Additionally, black power charges will be calculated by using precisely 4.5 grams of black powder into each canister.
There is a fire on the launch pad.	After motor ignition, dry grass and brush may catch fire	A wild fire occurs in the local area if not properly contained,	3	2	5-Moderate	All launches shall be properly equipped with a fire extinguisher and the Safety Officer and others	4	2	6-Low	In compliance with the NAR, we will not launch within

	around the launch pad.	destroying wildlife.				will ensure that there is no dry grass or brush under the rocket or around the launch pad.				100ft of brush or dry grass according to launch procedures. And a fire extinguisher shall be present at each launch.
Rocket debris is scattered around the launch site.	Rocket parts are not properly secured or come apart during the flight.	The rocket could possibly start a fire if extremely hot or become a hazard to local wildlife.	2	2	5-Moderate	All rocket parts must be checked before launch during launch procedures to ensure proper securement. Additionally, all parts will be tested to ensure they can withstand wind forces during flight.	4	2	6-Low	The President and Safety Officer will inspect the rocket before it is launched and check off that all parts are securely fastened and ready for a launch.
The motor CATOs.	There is a motor defect.	The launch vehicle is destroyed and debris is launched everywhere.	5	1	6-Low	The motor shall be purchased from a reputable, commercial source before the launch.	5	1	6-Low	Use motorcato.org and any information from the appropriate manufacturer to verify no problems with the type of motor the team is using

										before purchasing the motor and before launch. Additionally, follow steps 1-4 of Case Assembly in Launch Day Procedures to ensure that the motor has no visible issues before launch.
There is chemical contamination to local water sources.	Batteries or other hazardous materials leaking out into water systems.	The leaking materials contaminate the local water system, making it undrinkable to local wildlife.	4	2	6-Low	All batteries will be new and inspected prior to launch.	5	2	7-Low	Launch procedures require visual inspection of all batteries and the Safety Officer will verify that the batteries are new and undamaged before allowing them into the rocket.

Table 20. Environmental Hazards to the Rocket Risk Assessment

Environmental Hazards to the Rocket Risk Assessment										
Hazard	**Cause**	**Effect**	**Pre-Mitigation Likelihood**	**Pre-Mitigation Severity**	**Pre-Mitigation Risk**	**Mitigation**	**Post-Mitigation Likelihood**	**Post-Mitigation Severity**	**Post-Mitigation Risk**	**Verification**
The rover becomes stuck because of mud or dirt.	Tilling of the fields or recent rain causes the fields to be hard to traverse for the rover.	The wheels will be unable to gain proper traction resulting in the mission failure for the payload.	2	2	4-Moderate	Ensure that the wheels will be able to handle difficult terrains and travel the necessary distance.	4	2	6-Low	Test drive the rover at least 5 times throughout the design process to ensure the rover can adequately drive over the soil in any condition.
The recovery system or payload electronics are damaged by environmental conditions.	Extreme cold, extreme heat, or rain could damage the electronics.	The electronics fail to properly work, resulting in a total mission failure.	3	1	4-Moderate	All electronics will be shielded properly from rain and light and verified to work under the anticipated operating temperature. If there are heavy rains, it will ensure the rocket and payload do not launch or operate.	5	1	6-Low	All electronics will be encased in 3D printed parts that protect them from the anticipated light and precipitation. All flight conditions will be verified

										before launch to ensure the electronics can properly operate.
Poor weather conditions including snow, rain, sleet, ice, clouds, high winds, extreme heat or cold.	N/A	The rocket may be unable to launch or the rocket may be damaged when launched or necessary components fail.	3	1	4-Moderate	The team will not launch the rocket in any poor weather and will require the sign off by both the Safety Officer and President to launch the rocket.	5	1	6-Low	Checking for proper weather conditions before the launch will be required. On launch day, the launch checklist will include checking the weather conditions. It will require the Safety Officer and President to sign off.
There is damage to the structure of the rocket or a launch pad fire occurs.	Hot temperatures combined with direct sunlight cause the inside of the rocket to get extremely hot.	High temperatures and extended exposure to sunlight causes overheating in the batteries, leading to a fire.	3	1	4-Moderate	Ensure that batteries are stored in insulated bags until needed and the rocket is kept under a tent when possible.	5	1	6-Low	The team shall try to bring a tent if at possible. All batteries will remain in their insulated bags until approval by the President or Safety Officer is given

										to remove them.
The rover mission is halted because of large debris.	There is large debris in the rover's path.	The mission will be halted and payload would experience a mission failure	3	2	5-Moderate	The rover will have the necessary sensors and wheels to either avoid or go over any debris.	4	2	6-Low	The rover was tested to effectively be able to maneuver throughout the testing process.
The launch is pad is not level.	The launch pad sinks due to soft ground or is improperly leveled.	The launch vehicle is launched at an unanticipated launch trajectory.	4	2	6-Low	The launch pad will be leveled prior to the launch vehicle being installed on it.	5	2	7-Low	The President and Safety Officer will sign off on the leveling of the launch pad to ensure it is properly handled.
The parachute or rocket body are damaged.	High winds or trees cause damage.	The recovery equipment being damaged causes the rocket to not properly land and the rover to not deploy.	4	2	6-Low	To mitigate this issue the team will not launch when winds exceed 15 mph and ensure that he launch field adheres to the launching distances in the NAR handbook.	5	2	7-Low	The weather will be checked throughout the day leading up to and including the day of the launch to check the wind speed. Before launching, a discussion with the Safety Officer may occur to ensure

										that it is safe to launch the rocket.
The vehicle assemble is difficult in the field.	Many or excessive changes in temperature or humidity cause swelling and/or shrinking of components.	New stresses are induced and increased separation between components may be introduced, causing the possibility of failed separations.	2	4	6-Low	All fits will be verified before leaving to the launch site. Sand paper will be brought in case minute adjustments are required.	4	4	8-Low	These steps will require the approval of both the President and Safety Officer during the launch procedures.

Table 21. Rocket Hazards to Environment Risk Assessment

Rocket Hazards to Environment Risk Assessment										
Hazard	**Cause**	**Effect**	**Pre-Mitigation Likelihood**	**Pre-Mitigation Severity**	**Pre-Mitigation Risk**	**Mitigation**	**Post-Mitigation Likelihood**	**Post-Mitigation Severity**	**Post-Mitigation Risk**	**Verification**
There is unsuccessful deployment of recovery systems.	The deployment charges fail to ignite, or insufficient deployment charges or improper pressure readings.	The launch vehicle plummets to Earth at a higher than expected speed resulting in a damaged launch vehicle and debris around the launch area.	3	1	4-Moderate	Both separation charge calculations and separation tests will be done separately to ensure all sections separate properly.	5	1	6-Low	At least 3 ground tests will take place before the launch to ensure that the coupler can separate properly. Additionally, black power charges will be calculated by using precisely 4.5 grams of black powder into each canister.
There is a fire on the launch pad.	After motor ignition, dry grass and brush may catch fire around the launch pad.	A wild fire occurs in the local area if not properly contained,	3	2	5-Moderate	All launches shall be properly equipped with a fire extinguisher and the Safety Officer and others will ensure that	4	2	6-Low	In compliance with the NAR, we will not launch within 100ft of brush

		destroying wildlife.				there is no dry grass or brush under the rocket or around the launch pad.				or dry grass according to launch procedures. And a fire extinguisher shall be present at each launch.
Rocket debris is scattered around the launch site.	Rocket parts are not properly secured or come apart during the flight.	The rocket could possibly start a fire if extremely hot or become a hazard to local wildlife.	2	2	5-Moderate	All rocket parts must be checked before launch during launch procedures to ensure proper securement. Additionally, all parts will be tested to ensure they can withstand wind forces during flight.	4	2	6-Low	The President and Safety Officer will inspect the rocket before it is launched and check off that all parts are securely fastened and ready for a launch.
The motor CATOs.	There is a motor defect.	The launch vehicle is destroyed and debris is launched everywhere.	5	1	6-Low	The motor shall be purchased from a reputable, commercial source before the launch.	5	1	6-Low	Use motorcato.org and any information from the appropriate manufacturer to verify no problems with the type of motor the team is using before

										purchasing the motor and before launch. Additionally, follow steps 1-4 of Case Assembly in Launch Day Procedures to ensure that the motor has no visible issues before launch.
There is chemical contamination to local water sources.	Batteries or other hazardous materials leaking out into water systems.	The leaking materials contaminate the local water system, making it undrinkable to local wildlife.	4	2	6-Low	All batteries will be new and inspected prior to launch.	5	2	7-Low	Launch procedures require visual inspection of all batteries and the Safety Officer will verify that the batteries are new and undamaged before allowing them into the rocket.

4.9 Failure Modes and Analysis (FMEA)

Table 22. Structures Risk Assessment

Structures Risk Assessment										
Hazard	**Cause**	**Effect**	**Pre-Mitigation Likelihood**	**Pre-Mitigation Severity**	**Pre-Mitigation Risk**	**Mitigation**	**Post-Mitigation Likelihood**	**Post-Mitigation Severity**	**Post-Mitigation Risk**	**Verification**
A premature ejection of the nosecone.	Early ejection of the nose cone deployment charge due to faulty wiring or shear pin failure.	The nose cone goes into free fall, possibly causing damage to anything in the surrounding area.	2	2	4-Moderate	Test for continuity and wiring for charges before launch. Optimize shear pin locations and use stress analysis to ensure the nose cone will eject only when needed.	3	3	6-Low	The nose cone was successfully retained during fullscale test flight. Stress analysis also shows that the design currently ensures that the shear pins will keep the nose cone attached until the charge.
There is a failure in the	If the motor force is stronger	The flight vehicle would	4	1	5-Moderate	Use load testing on the motor block and	5	1	6-Low	The max thrust from

motor retention system.	than expected, the motor could break free of the motor retention system.	become unstable and be hazardous to anything in the immediate area.				centering rings to ensure that the forces from the motor do not exceed the failure limit of the motor retention system.				the motor (892 N) does not exceed the failure limits of the motor retention system. This was verified through successful motor retention during fullscale test flight.
The airframe or coupler experiences zippering.	Zippering occurs due to the force of the shock cord on parachute deployment.	The airframe/coupler becomes unusable for future launch, and may cause pieces to freefall.	2	3	5-Moderate	Use shock-absorbers on the shock cord where it contacts the coupler.	3	4	7-Low	The use of shock-absorbers during fullscale test flight mitigated and stopped any possible zippering to the coupler.
The airframe experiences buckling.	Intense G-forces cause the airframe to buckle.	This weakens the structural integrity of the airframe, and makes it unable	4	2	6-Low	Load test the materials used for the airframe and couplers to ensure the airframe is strong enough to	5	2	7-Low	After a thorough analysis of the airframe after fullscale test

		to safely launch in the future.				resist buckling.				flight, it was determined that the airframe experienced no buckling during any phase of the launch.
The airframe separates prematurely.	Airframe could separate prematurely due to stronger than expected Drag or internal pressure.	Premature separation would cause Parachutes deploy early and lead to a failure to reach altitude.	2	4	6-Low	Use analysis models such as OpenRocket and formulaic analysis to ensure drag and internal pressure will not cause separation. The team will purchase couplers with a length that is at least 1.5 times the diameter as stated in team requirements to ensure proper connection between sections.	3	4	7-Low	Fullscale test flight displayed that the drag and internal pressure will not exceed the maximum amounts and the airframe will remain together throughout the flight. Couplers were constructed to be a length that is twice the diameter.
The shock cord attachment points fail.	Higher than expected forces on the shock	Attachment point failure would result in	4	2	6-Low	Load test shock cords and the epoxy bulkhead connections	5	2	7-Low	The shock cord used during

	cord during parachute deployment could cause the shock cord to rip or the bulkhead attachments to be ripped out of the body tube.	either a shock cord replacement or a bulkhead replacement. In either case, the launch vehicle would not be able to launch in the foreseeable future. Failure would also result in free falling debris.				to ensure that the failure limit of both are far greater than the forces expected during parachute deployment.				fullscale test flight will be used for launch day as well. The shock cord did not fail during test flight, nor did the bulkheads.
The fin bracket fails on launch.	There is a possibility for the fin brackets to fracture on launch if the forces on it exceed the expected forces at takeoff and parachute deployment.	Fin bracket failure would possibly cause free-falling debris during flight and would make the fractured fin bracket unusable for future flights.	4	2	6-Low	Use load testing on a fin bracket to ensure the failure limit is much greater than expected forces throughout the flight.	5	2	7-Low	The forces during fullscale launch did not break any fin brackets.
The body tube fractures on launch.	There is a possibility for the body tube to fracture on launch if the forces on it	The fractured body tube would be unstable during flight and would be unable to be	4	2	6-Low	Use load testing on a test piece of body tube to ensure that the failure limit of the body tube is much greater than any force	5	3	8-Low	The forces on the body tube during launch and parachute deployment do not exceed

	exceed the expected forces at takeoff and parachute deployment.	used for future flights.				expected throughout the launch.				the failure limits of the body tube as fullscale launch displayed.
The body tube fractures on landing.	If a body tube part lands too hard or lands awkwardly there is a possibility for the body tube to fracture.	The fractured body tube part would be unable to use for a future flight.	4	3	7-Low	Use load testing on a test piece of body tube to ensure that the failure limit of the body tube is much greater than the force of landing.	5	3	8-Low	The body tube withstood landing during fullscale test flight displaying that the body tube will not fracture upon landing in a nominal flight.
The fin separates from the bracket.	The fins separate from the fin brackets during flight due to vibrations loosening of bolts due to vibrations throughout the flight.	Separation would cause potential free-falling debris during flight.	4	3	7-Low	Use vibration simulations to ensure that bolts will not loosen enough to allow for separation. Also, inspect bolts before flight to ensure that they are tight.	5	3	8-Low	As stated in step 8 of Booster Section in Launch Day Procedures, all screws will be ensured to be tightly fitted so that fins do not separate from the fin

										brackets during flight. Fullscale flight demonstrated that the fins will not separate if properly secured.
The camera fails.	The camera on the flight vehicle fails to record the flight.	If the camera does not work correctly the flight recording will be lost.	3	4	7-Low	Check the camera before flight.	4	4	8-Low	As stated in step 20 of Setup on the Pad in Launch Day Procedures, the camera will be ensured to be working properly and turned on before launch.
The fins fail during flight.	Failure is caused by fin flutter due to stronger than expected forces on the wings.	The fins may break off of the vehicle and go into freefall and would cause the flight to become unstable.	4	4	8-Low	Use analysis models such as OpenRocket and AeroFinSim to ensure that fin flutter will not cause failure.	5	4	9-Low	Analytic models were verified by fins undergoing no fin flutter on fullscale test flight as

										shown by the downbody camera.
Fin bracket fracture on landing	If the flight vehicle lands directly on a fin bracket or fin, there is a possibility for the fin bracket to fracture.	The fin bracket would be unable to be used for future flights.	4	4	8-Low	Use load testing on a fin bracket to ensure that the fin bracket failure limit is much greater than the forces of impact on landing. Also, make fin brackets easily replaceable.	5	4	9-Low	The fin brackets slightly cracked on fullscale launch and a new 3D printed material is no being used. Additionally, fin brackets are easily replaceable so that, if needed, the launch vehicle can relaunch within 10 minutes as the team brings extra fin brackets.
The camera cover fails.	The camera cover has the possibility to detach from the flight vehicle if	If the camera cover detaches, the camera will not be protected and could result	4	4	8-Low	Use load testing on the camera cover to ensure its failure limit is much greater than any forces expected	5	4	9-Low	The camera cover remained on the rocket throughout the

	forces on it exceed what is expected, especially at launch and at parachute deployment.	in a loss of footage. The cover would also be free-falling debris.				throughout the flight.				entire fullscale launch, ensuring it will remain during flight unless extreme circumstances occur. Additionally, the camera cover will be properly fastened and checked before launch as stated in step 4 of Booster Section in Launch Day Procedures.

Table 23. Propulsion Risk Assessment

Propulsion Risk Assessment										
Hazard	**Cause**	**Effect**	**Pre-Mitigation Likelihood**	**Pre-Mitigation Severity**	**Pre-Mitigation Risk**	**Mitigation**	**Post-Mitigation Likelihood**	**Post-Mitigation Severity**	**Post-Mitigation Risk**	**Verification**
The Motor CATOs.	The motor components fracture.	There is destructive damage to rocket that results in a critical failure.	5	1	6-Low	Inspect motor grains and components prior to installation. Assemble the motor according to the assembly instructions with another observing. Check for fracture on any motor components after the launch. Research selected motor for any known problems or defects.	5	1	6-Low	Use motorcato.org and any information from the appropriate manufacturer to verify no problems with the type of motor the team is using before purchasing the motor and before launch. Additionally, follow steps 1-4 of Case Assembly in Launch Day Procedures to ensure that the motor has no visible issues before launch.

The motor does not stay retained.	The motor thrust pushes the motor through the motor block.	There is destructive damage to rocket.	5	2	7-Low	Verify that the motor retention system can handle the motor impulse by doing either static motor testing, load tests on the motor tube, or flight tests	5	2	7-Low	The max thrust from the motor (892 N) does not exceed the failure limits of the motor retention system. This was verified through successful motor retention during vehicle demonstration flight,
The motor does not stay retained.	The ejection charges push motor out of the rocket.	The motor does not retain in rocket, causing a ballistic motor.	5	2	7-Low	Explicitly follow launch day procedures to ensure that the motor is correctly assembled.	5	2	7-Low	Explicitly follow steps 1-7 of Case Assembly in Launch Day Procedures to ensure that the motor has no visible issues before launch.
The motor does not ignite.	The initiators fail to properly ignite the motor.	The rocket remains static.	3	4	7-Low	Use recommended igniters. Properly store the motors to prevent oxidation. Verify the initiator is inserted fully to the top of the motor grains on the launch pad.	4	4	8-Low	Follow steps 5-7 on Initiator Installation in Launch Day Procedures to ensure the initiator is in contact with the propellant.

Table 24. Avionics and Recovery

Avionics and Recovery Risk Assessment										
Hazard	**Cause**	**Effect**	**Pre-Mitigation Likelihood**	**Pre-Mitigation Severity**	**Pre-Mitigation Risk**	**Mitigation**	**Post-Mitigation Likelihood**	**Post-Mitigation Severity**	**Post-Mitigation Risk**	**Verification**
The drogue section shear pins do not break during separation.	The separation charge was insufficient to break the shear pins.	The drogue parachute does not deploy and the rocket continues on ballistic a trajectory. This will result in structural failure in the launch vehicle upon main deployment and will be a critical safety concern.	3	1	4-Moderate	The team will use a factor of safety to ensure that the charge required to break the shear pins is greater than calculated. The redundant system will have 50% more than the primary separation charge.	5	1	6-Low	Successful ground tests of the main separation event were performed to ensure proper deployment prior to fullscale test launch. Separation charge calculations were verified through successful separation during full scale flight.
The mechanical switch	The switch is mechanically agitated to the	The altimeter circuit is closed and turns the	4	1	5-Moderate	The team will use a sturdy switch and properly fasten it in	5	2	7-Low	Ensure the switch is properly and

disconnects during flight.	off position during flight.	altimeter off. The altimeter is not able to record altitude or deploy the parachutes.				place.				securely set into the on position and will not disconnect during flight as according to step 7 of Avionics Board Assembly in Launch Day Procedures.
An electromagnetic interference triggers an altimeter at an undesired time.	Altimeter is exposed to sufficient amounts of electromagnetic radiation to complete the altimeter's circuit. A potential failure of the Faraday cage will increase the likelihood of this occurring.	The altimeter prematurely activates an initiator. As a result, the rocket will separate and deploy one of its parachutes during ascent, or descent at incorrect altitudes. Premature deployment during ascent would cause instability and structural damage from shock cord zippering. Premature	3	2	5-Moderate	The avionics bay will be fully enclosed in a tin foil Faraday cage.	5	2	7-Low	The Faraday cage has been tested in the lab to ensure complete signal blackout inside. All altimeters performed nominally during fullscale test flight.

		deployment during descent will result in drift distances over 2500 ft. and disqualification.								
The altimeter is damaged during launch.	The flight forces cause the altimeter to become unsecured and damaged from ricochet.	If damage is critical, the altimeter will not be able to ignite its initiators at the correct altitudes. This will result in ejection charges not igniting and failure of separation and parachute deployment as a result. The rocket will fall ballistically as a result. This will result in structural failure in the launch vehicle upon impact and will be a critical safety concern. If damage is non-critical, the altimeter will not be able to retrieve	4	2	6-Low	The altimeter will be screwed to the avionics board, which will be friction fit on rails to the avionics bay. The team will use a fully redundant system.	5	2	7-Low	Ensure the altimeters are properly screwed into the avionics board following step 4 of Avionics Board Assembly in Launch Day Procedures.

		mission critical flight data.								
The drogue parachute remains inside the body tube during separation.	Screws connecting couplers to body tubes may catch the drogue parachute during deployment and prevent its ejection from the body tube. The drogue parachute may also become stuck due to the friction between the parachute and the inside of the body which would prevent full ejection.	The rocket will fall ballistically until main parachute deployment. If the rocket is falling at ballistic speeds at main deployment, then the main parachute may not fully deploy before landing and will cause significant airframe zippering.	4	2	6-Low	Screws inside of the body tubes will be filed down. Baby powder will be spread lightly over the parachute fire blanket to decrease its coefficient of friction.	5	2	7-Low	According to A&R Launch Day Procedures, Main Section, step 9, talcum powder will be added to the outside of the parachute to ensure it does not stick during deployment. Successful drogue parachute deployment was verified through nominal deployment in during full scale flight.
The recovery harness breaks during separation or descent.	Flight forces exceed the maximum load that either the shock cord, quick link, or	Individual sections of the rocket will impact the ground at terminal velocity	4	2	6-Low	The recovery harnesses being used will be rated to withstand forces and order of magnitude greater than	5	2	7-Low	Following launch day procedures for drogue section, points 1-7 specify how drogue

	U-bolt can handle.					expected in flight forces.				parachute will be inserted and kept in the rocket using the proper shock cord and U-bolts tested to properly handle the load. Points 1-8 in main section procedures specify how main parachute will be inserted into the rocket using the proper shock cord and U-bolts tested to properly handle the load. The recovery harness performed nominally during fullscale test flight.

The flight vehicle lands outside of maximum drift distance.	Simulations inaccurately predicted launch day conditions and the rocket drifts further than the allowable safe distance during descent.	The rocket could land outside of the property designated for launches and other rocket activity. This could lead to loss of the rocket, damage or destruction of property, or even injury to bystanders.	5	2	7-Low	Simulations will be conducted to verify that the design meets the requirements. The simulations will be improved by comparing previous flight data to previous simulations.	5	2	7-Low	Simulations and the team's MATLAB model was verified through fullscale test flight drift results.
The altimeter loses connection with initiators.	The initiator's wire connection with altimeter is not adequately secured, and this connection becomes separated during flight due to forces experienced.	The initiators will not receive the required voltage from the altimeter and will not ignite at the correct altitudes. This will result in ejection charges not igniting and failure of separation and parachute deployment as a result. The rocket will fall ballistically as a result. This will result in structural	3	3	6-Low	All connections will be securely fastened with screws on both ends. The team will have a fully redundant deployment system.	5	3	8-Low	All connections will be tug tested according to A&R Launch Procedures, Avionics Board Assembly Step 5 to ensure they are secured.

		failure in the launch vehicle upon impact and will be a critical safety concern.								
The altimeter does not properly register altitude.	The pressure port required for the altimeter to register altitude is not large enough for the altimeter to accurately read the atmospheric pressure.	An accurate altitude is not properly read, and the team is disqualified from the altitude competition. If the registered altitude is greatly inaccurate, then the drogue parachute may not occur at exact apogee and cause zippering of the airframe as a result. Additionally, the main parachute deployment will not occur at the designated altitude which may result in drift distances over 2500 ft., or incomplete full deployment of	3	3	6-Low	The team will ensure the port hole for pressure equalization is an adequate size to maintain atmospheric pressure inside the avionics chamber. The altimeters will be tested on multiple prior launches to confirm their reliability. There will be a fully redundant altimeter onboard the flight vehicle.	5	3	8-Low	Both altimeters will be properly setup and ready to launch according to Launch Day Procedures, Setup on Pad, steps 9-14.

		main parachute which would result in structural damage of the launch vehicle.								
The main section shear pins do not break during separation.	The separation charge was insufficient to break the shear pins.	Main parachute does not deploy and the rocket impact the ground with an unsafe velocity. This will result in structural failure in the launch vehicle upon impact and will be a critical safety concern.	3	3	6-Low	The team will use a factor of safety to ensure that the charge required to break the shear pins is greater than calculated. The redundant system will have 50% more than the primary separation charge.	5	3	8-Low	Successful ground tests of the drogue separation event were performed to ensure proper deployment prior to fullscale test launch. Separation charge calculations were verified through successful separation during full scale flight.
The main parachute remains inside the body tube during separation.	Screws connecting couplers to body tubes may catch the main parachute during deployment and	The rocket will fall at a high descent rate until impact. This would result in body tube sections not meeting the 75 ft-	4	3	6-Low	Screws inside of the body tubes will be filled down. Baby powder will be spread lightly over the parachute fire blanket to decrease	5	3	8-Low	According to A&R Launch Day Procedures, Main Section, step 9, talcum powder will be added to

	prevent its ejection from the body tube. The main parachute may also become stuck due to the friction between the parachute and the inside of the body which would prevent full ejection.	lbs. kinetic energy requirement and the team will be disqualified. Additionally, the rocket will experience non-nominal impact forces and will have structural damage.				its coefficient of friction.				the outside of the parachute to ensure it does not stick during deployment. Successful main parachute deployment was verified through nominal deployment in during full scale flight.
The drogue parachute is damaged during separation.	Screws connecting couplers to body tubes may catch the drogue parachute during deployment and cause partial tearing. Explosive forces and potential fire from ejection charges may also cause	The rocket will fall at a descent velocity faster than expected. If the rocket is falling too fast during main deployment, then the main parachute may not fully deploy before landing and will cause significant airframe zippering.	4	3	7-Low	Proper packing methods of the parachute will be followed. Protrusions inside the drogue parachute chamber and around the exit will be smoothed down. A Nomex blanket will completely cover the parachute preventing potential ignition of the parachute from ejection charge.	5	3	8-Low	According to A&R Launch Day Procedures, Drogue Section, step 6, A Nomex blanket will cover the parachute. Screws in the drogue section were shaved down. Drogue parachute was not damaged

	damage to the drogue parachute.									during fullscale test flight.
The main parachute is damaged during separation.	Screws connecting couplers to body tubes may catch the main parachute during deployment and cause partial tearing. Explosive forces and potential fire from ejection charges may also cause damage to the main parachute.	The rocket will fall at a higher descent rate until impact. This would result in body tube sections not meeting the 75 ft-lbs. kinetic energy requirement and the team will be disqualified. Additionally, the rocket will experience non-nominal impact forces and will have structural damage.	4	3	7-Low	Proper packing methods of the parachute will be followed. Protrusions inside the main parachute chamber and around the exit will be smoothed down.	5	3	8-Low	According to A&R Launch Day Procedures, Main Section, step 6, A Nomex blanket will cover the parachute. Screws in the main section were shaved down. Main parachute was not damaged during fullscale test flight.
The main parachute does not unfold after exiting the body.	Tangling of the main parachute strings due to improper packing cause the parachute to not full deploy after ejection.	The rocket will fall at a higher descent rate until impact. This would result in body tube sections not meeting the 75 ft-lbs kinetic energy requirement and	4	3	7-Low	Proper packing methods of the parachute will be followed.	5	3	8-Low	Parachute packing methods detailed in A&R Launch Procedures Main Section, steps 1-6 will be followed and used to

		the team will be disqualified. Additionally, the rocket will experience non-nominal impact forces and will have structural damage.								ensure proper deployment.
The kinetic energy is over maximum landing threshold.	Simulations inaccurately predicted the descent rate of the rocket leading to a higher kinetic energy upon landing than the allowable limits.	If sections of the rocket land with kinetic energy greater than the maximum allowable, excessive harm could come to property and people within the designated landing areas.	4	3	7-Low	Simulations will be conducted to verify that the design meets the requirements. The simulations will be improved by comparing previous flight data to previous simulations.	5	3	8-Low	The team's kinetic energy calculations were verified through fullscale flight which did not have sections of the rocket exceed the allotted kinetic energy threshold.
The onboard 9V battery supplying voltage for the altimeter does not have the required voltage to fully power the altimeter.	This hazard would only potentially occur if the launch vehicle needs to be left on the launch pad while the team is waiting for their launch volley.	The altimeter is not powered and is not able to ignite its initiators at the correct altitudes. This will result in ejection charges not igniting and failure of separation and	3	4	7-Low	The team will use only newly purchased standard commercially issued 9V batteries. The team will have a fully redundant deployment system.	5	4	9-Low	Per A&R Launch Procedures, Avionics Board Assembly Step 1, the new batteries will be checked right before

		parachute deployment as a result. The rocket will fall ballistically as a result. This will result in structural failure in the launch vehicle upon impact and will be a critical safety concern.								launch to ensure they are fully charged using a Voltmeter.
The 9V battery clip connecting the altimeter to the battery disconnects during the flight.	The flight forces cause the battery clip to disconnect from the battery.	The altimeter is no longer powered and is not able to ignite its initiators at the correct altitudes. This will result in ejection charges not igniting and failure of separation and parachute deployment as a result. The rocket will fall ballistically as a result. This will result in structural failure in the launch vehicle upon impact and	3	4	7-Low	All connections will be securely fastened with screws on both ends. The team will have a fully redundant deployment system.	5	4	9-Low	All connections will be tug tested according to A&R Launch Procedures, Avionics Board Assembly Step 5 to ensure they are secured.

		will be a critical safety concern.								
The body sections collide during descent under parachute.	Body sections descend at a similar altitude to each other.	Collisions between sections damages them and internal components.	3	4	7-Low	Shock cord lengths will be different between main and drogue. The parachutes will be attached at the 1/3rd point so that attached sections are different distances to prevent collisions.	5	4	9-Low	Downbody camera footage and camera footage from team members on the ground verify that the body sections did not collide during parachute descent during fullscale test flight.
The drogue parachute does not unfold after exiting the body.	Tangling of the drogue parachute strings due to improper packing cause the parachute to not full deploy after ejection.	The rocket will fall at a descent velocity faster than expected. If the rocket is falling too fast during main deployment, then the main parachute may not fully deploy before landing and will cause significant	4	4	8-Low	Proper packing methods of the parachute will be followed.	5	4	9-Low	Parachute packing methods detailed in A&R Launch Procedures Drogue Section, steps 1-6 will be followed and used to ensure proper deployment.

		airframe zippering.								
The main parachute deploys at apogee.	Incorrect packing of parachutes during launch preparation causes the main deployment to be packed where the drogue parachute is supposed to be packed. Another potential cause of this hazard is the incorrect wiring of the altimeter so that the main parachute initiators are wired into the drogue deployment port of the altimeter.	Main parachute deployment at apogee would result in extreme drift distances that would disqualify the team and increase the difficulty of the recovery of the launch vehicle.	4	4	8-Low	Wires will be colored according to a schema and labeled. Connected wires will be double checked before launch. Parachutes will clearly be marked down on which section they are packed into.	5	4	9-Low	According to Launch Day Procedures, Main Section, step 9 specifically states where the parachute is to be packed and needs to be signed off on. Additionally, according to Launch Day Procedures, Initiator Installation, the correct initiator will be hooked up the correct altimeter section and later verified.
The main parachute recovery harness becomes	The rocket is tumbling violently when main deploys ejecting it into	One or both of the parachutes does not fully open resulting in a lower surface area	4	4	8-Low	The rocket will not be launched in high winds. The parachutes are packed in opposite	5	4	9-Low	Downbody camera footage and camera footage from

tangled in drogue recovery harness.	the drogue recovery harness, or in such a manner that the subsequent tumbles tangle them before main can unfold.	and the rocket descending quickly. This can result in damage to the rocket or what it lands on.				ends of the avionics bay so they deploy away from each other.				team members on the ground verify that parachutes harnesses did not tangle during parachute descent during fullscale test flight.

Table 25. Payload Risk Assessment

Payload Risk Assessment										
Hazard	**Cause**	**Effect**	**Pre-Mitigation Likelihood**	**Pre-Mitigation Severity**	**Pre-Mitigation Risk**	**Mitigation**	**Post-Mitigation Likelihood**	**Post-Mitigation Severity**	**Post-Mitigation Risk**	**Verification**
Rover containment fails during launch.	The retainment electronics fail and eject the nose cone prematurely.	Can cause large instability during launch, and free-falling body sections pose a serious danger to bystanders on the ground.	3	1	4-Moderate	Operate the communications system on a 915 MHz frequency to ensure that the signal cannot activate due to interference.	5	1	6-Low	Multiple ground tests and the fullscale test flight have verified that the communications system will operate as expected.
Soil sample recovery failure.	Damage to electronics during flight.	This would not allow the rover to complete its mission.	3	3	6-Low	Verify strong soldering connections in the electronics.	4	3	7-Low	Perform post separation ground testing of the soil recovery. This test will verify that everything post landing will work as expected.
Physical	Black powder	Electronics	4	3	7-Low	Align the black	5	2	7-Low	Multiple ground

damage to rover.	covering the electronics.	become not operational				powder charge to be on top of the shelf so that debris does not go towards the rover.				tests have verified that the rover will not be damaged due to pressurization or black powder residue.
Deployment mechanism fails to activate.	Communications system cannot communicate with the launch vehicle.	The rover would not be able to exit the vehicle and recover the soil sample.	2	3	5-Moderate	Ensure all wiring can withstand flight conditions	5	3	8-Low	Multiple ground tests and fullscale launch have confirmed that the communications system can withstand forces during deployment.
Deployment mechanism fails to activate	Faulty initiator.	The rover would not be able to exit the vehicle and recover the soil sample.	3	3	6-Low	Test the continuity of the initiator before launch.	5	3	8-Low	Multiple lab experiments and ground tests have been performed to confirm the behavior of initiators. All initiators will continue to be checked for continuity before use.

Rover containment fails during launch.	Ascent and descent forces experienced during flight.	The rover becomes unsecured during flight. This can cause damage to the rover and instabilities during flight.	3	3	6-Low	Test the solenoid locking mechanism on the fullscale launch vehicle.	5	3	8-Low	Fullscale test flight verified that the containment mechanism can hold the rover in place during flight.
Physical damage to rover electronics	Forces experienced during flight or during nose cone separation.	Could cause the rover to not be operational	4	3	7-Low	Trim all soldered wire connections to ensure that nothing can short due to an acceleration. Verify all soldering connections are strong and will not break.	5	3	8-Low	Fullscale test flight has verified that no electronics in the payload section will be damaged due to flight conditions..
Structural damage to payload bay.	Impact forces from the rocket hitting the ground during landing.	The black powder would not be able to pressurize the payload bay to deploy the nose cone.	4	3	7-Low	The payload bay will be made of carbon fiber which will be checked for voids.	5	3	8-Low	Fullscale launch has verified that deployment will not cause any structural damage to the launch vehicle or payload bay.

4.10 Launch Day Procedures

Motor Preparation

Hardware List

Quantity is one of each item unless otherwise specified ([N] Item)

- 75mm Cesaroni 4-Grain Motor Case
- 75mm Aft Closure
- 75mm Forward Seal Disk (FSD)
- 75mm Smoke Charge Enclosure
- 75mm Cesaroni Spacer Ring
- 75mm Forward Closure
- Liner
- Nozzle
- Nozzle Cap
- [3] Propellant Grains
- Smoke Charge
- [2] Forward and Aft O-rings (1⁄8” thick x 2 3⁄4” O.D.)
- FSD O-ring (3/32” thick x 2 9/16” O.D.)
- [2] Grain Spacer O-rings (1/16” thick x 2 1⁄2” O.D.)
- Lubricating grease and popsicle stick
- Sharp blade (exacto knife or multitool blade)

Pre-Assembly

1. **Required PPE: Latex gloves.** Apply a light coat of grease to all threads and O-rings (except the grain spacer O-rings). Caution: When working with the grease, the team member applying it needs to be wearing latex gloves. The grease can be an irritant if it comes into contact with skin. This caution applies to any and all later steps that involve working with grease.

Propulsion Lead Sign-off: ____

Case Assembly

1. Use a sharp blade to deburr the forward and aft inside edges of the liner tube to provide more friction for the fit of the nozzle and forward closure assembly. Warning! Using a sharp blade carelessly can result in serious injury. When using the blade, always concentrate completely on the task at hand.
2. Insert the larger diameter portion of the nozzle into the aft end of the liner and slide the nozzle all the way in to the point that the flange is in contact with the aft edge of the liner.
3. Ensure that all following procedures are carried out with the assembly in the horizontal position.
4. **Required PPE: Latex gloves.** Install the propellant grains into the liner, sliding them in from the forward end. Place a Grain Spacer O-ring between each propellant grain, and again ensure that they are not lubricated with grease. Warning! Before handling the propellant grains, the handler needs to put on well- fitting latex gloves. The propellant

grains are classified as a dangerous explosive and can result in serious harm if not handled properly.

5. Once the propellant grains are installed in the liner, avoid letting any personnel stand directly in line with either end of the case assembly.
6. Place the lubricated FSD O-ring into the groove in the FSD.
7. Insert the end of the disk with a smaller cross-sectional area into the forward end of the liner so that the FSD O-ring is no longer visible and the flange on the FSD is in contact with the forward edge of the liner.
8. Apply a light coat of lubricating grease to the outside of the liner to facilitate liner assembly removal from the case after launch.
9. Insert the liner assembly into the aft end of the motor case until the nozzle protrudes from the aft end of the case by 1 3⁄4”.
10. Place the lubricated Forward O-ring into the groove in the Smoke Charge Enclosure.
11. Insert the Smoke Charge into the aft end of the Smoke Charge Enclosure.
12. Insert the fully assembled Smoke Charge Enclosure into the forward end of the motor case until it is firmly in contact with the forward most propellant grain.
13. Insert the 75mm Cesaroni Spacer Ring into the forward end of the motor casing until it touches the forward end of the Smoke Charge Enclosure.
14. Thread the Forward Closure into the forward end of the motor casing until it is firmly in contact with the forward end of the Spacer Ring, completing the Forward Closure Assembly.
15. Place the lubricated Aft O-ring into the groove on the aft end of the nozzle.
16. Thread the Aft Closure into the aft end of the motor case until the flange is firmly in contact with the aft face of nozzle flange.

Propulsion Lead Sign-off: ____

Flight Systems Lead Sign-off: ____

Safety Officer Sign-off: ____

Vehicle Assembly

Hardware List

Quantity is one of each item unless otherwise specified ([N] Item)

- 4:1 Ogive Fiberglass 6" Filament Wound Nose Cone with Metal Tip
- 24” Payload Carbon Fiber Body Tube
- 16” Drogue Carbon Fiber Body Tube
- 16” Main Carbon Fiber Body Tube
- 38” Booster Carbon Fiber Body Tube
- 12” Payload-Drogue Blue Tube Coupler
- 12” Avionics Bay Blue Tube Coupler
- 12” Main-Booster Blue Tube Coupler
- Avionics Bay Door

- Payload Bay Door
- Phillips Screwdriver
- [Sixteen (16)] 2-56 Shear Pins
- [Thirty-Four (34)] 1⁄2” #6 Screws
- GPS System
- Down Body Camera System

Warning! Safety glasses must be worn by every team member in the vicinity when a power drill is in operation.

Nose cone

1. Slide the GPS Case down the all-thread rod on the nose cone shoulder bulkhead.
2. Fasten the case to the nose cone shoulder bulkhead with a washer and a nut.
3. Turn the GPS on, and verify the GPS is on by checking the activity lights.
4. Insert the GPS into the GPS case.
5. Close the GPS Case, and verify the case is closed with a manual tug test.
6. Insert the shoulder coupler into the open end of the nose cone.
7. Align the depth markings and the registration marks on the shoulder with the matching markings on the nose cone.
8. Screw in a half-inch #6 screw into each of the six (6) holes near the aft edge of the nose cone.

Structures Lead Sign-off: ____

Payload Section

1. Once the GPS is installed in the nose cone and the payload is installed in the payload body tube, insert the payload body tube over the aft end of the nose cone shoulder so that the eight (8) shear pin hole side of the payload body tube is over the nose cone shoulder.
2. Align the depth markings and the registration marks on the nose cone with the matching markings on the payload body tube.
3. Insert eight (8) 2-56 shear pins into the shear pin holes to connect the nose cone shoulder and payload separation point.
4. After the rover and nose cone deployment are ready for launch, insert the payload-drogue coupler into the payload section.
5. Align the depth markings and the registration marks on the payload body tube with the matching markings on the payload-drogue coupler.
6. Screw in six (6) half-inch #6 screws into the six (6) holes near the forward edge of the payload-drogue coupler to attach the payload body tube and the payload-drogue coupler

Structures Lead Sign-off: ____

Drogue Section

This section has a 12” Fruity Chutes Classic Elliptical drogue parachute.

1. Connect one quicklink to each the end of the 24 ft shock cord labeled “drogue to av-bay.”
2. Lay the folded parachute out next to the shock cord 2/3rd of the way up the shock cord from the AV Bay.
3. Run the parachute shroud lines under the shock cord and then loop them over the parachute.
4. Pull the shroud lines tight, this will tie the parachute to the shock cord.
5. Connect the third quicklink to the fire blanket and the other end to the knot where the parachute connects to the shock cord.
6. Cover the parachute and shroud lines with the fire blanket. Warning! The Nomex blanket must completely cover the side of the parachute facing the charges, or the parachute could be burned and damaged.
7. Making sure the shock cord runs through the drogue body tube, attach the quicklink on the end closest to the parachute the the U-bolt in the payload-drogue coupler.
8. Attach the quicklink on the end furthest from the parachute the the U-bolt in the AV Bay.
9. Insert the shock cord into the drogue body tube, followed by the drogue parachute. Note: If the parachute sticks, talcum powder will help it to slide in easily. Caution: A sticky parachute will not deploy easily and might cause a recovery failure.
10. Insert the aft end of the drogue body tube over the avionics bay coupler.
11. Align the depth markings and the registration marks on the forward end of the main body tube with the matching markings on the aft end of the drogue body tube.
12. Screw in six (6) half inch #6 screws into the six (6) screw holes to attach the avionics bay to the drogue body tube.
13. Insert the drogue-booster coupler into the forward end of the drogue body tube. Caution: Verify that the shock cord is entirely enclosed within the airframe, if the shock cord catches or snags on any hardware, it could result in a recovery failure.
14. Align the depth markings and the registration marks on the drogue body tube with the matching markings on the payload section.
15. Insert three (3) 2-56 shear pins into the shear pin holes to connect the payload-drogue coupler and the drogue body tube attachment point.

Structures Lead Sign-off: ____

A&R Lead Sign-off: ____

Avionics Bay

1. Place one bulkhead against the avionics bay inner coupler so that the holes for the all-thread rods are on either side of where the avionics board resides.
2. Insert the insulated all-thread rods through the all-thread rods hole in the bulkhead.
3. Place the second bulkhead on the opposite side of the avionics bay such that the all-thread rod going through the orange hole in the first bulkhead, goes through the orange hole in the second bulkhead. Make sure the blue hole all-thread rod in the first bulkhead goes through the blue hole in the second bulkhead.
4. Screw in the all-threads and the nuts on either end and ensure that they are secure.

5. Insert the avionics board along the avionics board runners in the avionics bay and slide it back in until it contacts the back of the avionics board runners.

A&R Lead Sign-off: ____

Payload Assembly

Warning! Only leads should handle the black powder and the initiators.

1. Ensure that the correct code is loaded onto the communications system.
2. Mount communications system on removable shelf one.
3. Secure shelf one to the containment mechanism.
4. Secure counterweight to removable shelf two.
5. Secure shelf two to the containment mechanism.
6. Mount solenoid on the inside of the containment mechanism.
7. Secure solenoid wires to the containment mechanism with electrical tape.
8. Verify that the mechanical switch is in the off position.
9. **Required PPE: Latex gloves and safety glasses.** Have a lead put on gloves and safety goggles. Caution: Handle black powder with caution. Black powder is explosive and harmful if ingested.
10. The team member with the appropriate PPE will measure 2 grams of black powder into a plastic vial.
11. The same team member will pour the black powder into the blast cap located on the inside of the containment mechanism. Caution: Ensure that none of the electronics are turned on in the communications system and batteries are not plugged in.
12. **Required PPE: Latex gloves and safety glasses.** Another team member wearing gloves and safety goggles will place the initiator into the blast cap, followed by shredded packing material and electrical tape.
13. Plug batteries into the communications system.
14. Slide the containment mechanism into the inside of the rocket.
15. Grease the bolt that secures the containment mechanism.
16. Slide the bolt into the bulkhead on the opposite side of the containment mechanism.
17. Secure the bolt using a nut on the inside of the containment mechanism on the axis of rotation.
18. Slide the rover into the containment mechanism ensuring that the metal rod on the rover slides into the solenoid lock.
19. Use the ground station communications GUI to send a message to the rocket to secure the rover inside the containment mechanism.
20. Lightly pull on the rover to ensure the rover is secured and the solenoid is working properly.

Warning! Handle the body tube carefully so as to not displace any of the tape of black powder.

DANGER! THE BODY TUBE NOW CONTAINS BLACK POWDER CHARGES AND NO TEAM MEMBERS SHOULD STAND IN THE LINE OF FIRE OF EACH END OF THE COUPLER.

Payload Systems Lead Sign-off: ____

Safety Officer Sign-off: ____

Ejection Charges

Warning! Only leads should handle the black powder and the initiators.

1. Take orange plastic end protectors off four initiators. The avionics board may need to be all the way out of the avionics bay to access the altimeters.
2. Using wire cutters strip approximately 1/4th inch of the plastic from the ends of the initiator wire. Caution: Before continuing to the next step, make sure the toggle switches are in the off position!
3. Install the newly trimmed ends of the initiators into both the drogue and main ports on the primary and redundant altimeter. Label near the head with a piece of tape the primary drogue and main initiator as well as the redundant drogue and main initiator. Caution: Ensure the mechanical switches are in the off position.
4. Feed the two drogue initiators through the initiator holes in the forward bulkhead.
5. Feed the two main initiators through the initiator holes in the booster side bulkhead.
6. Place the initiator heads into the blast caps and secure them with electrical tape. Caution: The initiators must be secure to ensure proper detonation.
7. **Required PPE: Latex gloves and safety glasses.** Locate the primary drogue and main black powder charge as well as the redundant drogue and main black powder charge. Caution: To avoid spilling black powder have a different team member hold the avionics coupler at approximately a 45 degree angle to the team member pouring the black powder.
8. Place the primary main black powder charge into the blast cap with the primary main initiator.
9. Pack the blast cap with shredded newspaper and cover it with electrical tape.
10. Repeat Step 7 for the primary drogue black powder charge as well as the redundant drogue and main black powder charge. Caution: The black powder must be tightly secured so that it does not leak or ignite incorrectly.

Warning! Handle the coupler carefully so as to not displace any of the tape of black powder.

DANGER! THE COUPLER NOW CONTAINS BLACK POWDER CHARGES AND NO TEAM MEMBERS SHOULD STAND IN THE LINE OF FIRE OF EACH END OF THE COUPLER.

A&R Lead Sign-off: ____

Safety Officer Sign-off: ____

Avionics Board Assembly

1. Attach the battery connectors to two 9V batteries. An avionics lead will confirm these batteries are new.
2. Place the batteries in the battery slots on the avionics board.
3. Locate the primary altimeter and redundant altimeter and make sure they are properly labeled.
4. Screw the four corners of the two Stratologger CF altimeters into the four altimeter port holes on the avionics board.
5. Install the battery connector wires into the altimeter power supply ports labeled “Battery.” Note that the black wire is negative and should be screwed into the port with the black tab. Tug on each wire to ensure that the connection is secure. Caution: The altimeters will not turn on if the batteries are installed incorrectly.
6. Install the mechanical switches into the mechanical switch holes on the avionics board.
7. Connect the leads on the mechanical switches to the switch ports labeled “switch” on the altimeters. Place the switches if not already so in the off position.
8. Check that the avionics board has two altimeters, two switches and two batteries installed. Additionally, the altimeter should have the battery connector wires and switch wires installed.

A&R Lead Sign-off: ____

Main Section

This section has an 84” Fruity Chutes Iris Ultra as the main parachute.

1. Connect one quicklink to each the end of the 27 ft shock cord labeled “av-bay to main.”
2. Lay the folded parachute out next to the shock cord 2/3rd of the way up the shock cord from the booster section.
3. Run the parachute shroud lines under the shock cord and then loop them over the parachute.
4. Pull the shroud lines tight, this will tie the parachute to the shock cord.
5. Connect the third quicklink to the fire blanket and the other end to the knot where the parachute connects to the shock cord.
6. Cover the parachute and shroud lines with the fire blanket. Warning! The Nomex blanket must completely cover the side of the parachute facing the charges, or the parachute could be burned and damaged.
7. Making sure the shock cord runs through the main body tube, attach the quicklink on the end closest to the parachute the U-bolt in the AV Bay.
8. Attach the quicklink on the end furthest from the parachute the U-bolt in the main-booster coupler.
9. Insert the shock cord into the main body tube, followed by the main parachute. Note: If the parachute sticks, talcum powder will help it to slide in easily. Caution: A sticky parachute will not deploy easily and might cause a recovery failure.
10. Insert the forward end of the main body tube over the avionics bay coupler.
11. Align the depth markings and the registration marks on the forward end of the main body tube with the matching markings on the aft end of the drogue body tube.

12. Screw in six (6) half inch #6 screws into the six (6) screw holes to attach the avionics bay to the main body tube.
13. Insert the main-booster coupler into the aft end of the drogue body tube. Caution: Verify that the shock cord is entirely enclosed within the airframe, if the shock cord catches or snags on any hardware, it could result in a recovery failure.
14. Align the depth markings and the registration marks on the main body tube with the matching markings on the booster section.
15. Insert three (3) 2-56 shear pins into the shear pin holes to connect the main-booster coupler and the main body tube attachment point.

Structures Lead Sign-off: ____

A&R Lead Sign-off: ____

Booster Section

1. Attach the down body camera system to the motor stop in the booster section.
2. Pull the camera through the dedicated slot in the booster body tube.
3. Fasten the camera to the camera cover outside the airframe.
4. Ensure that the camera cover is properly secured to the booster body tube by checking all screws between the booster body tube and the camera cover.
5. Insert the forward section of the booster body tube over the main-booster coupler.
6. Align the depth markings and the registration marks on the aft end of the drogue body tube with the matching markings on the forward end of the booster body tube.
7. Screw in six (6) half inch #6 screws into the six (6) screw holes to attach the booster body tube to the main-booster coupler.
8. Ensure that the fin brackets are properly secure by checking all screws between the body tube and fin bracket as well as the screws between the fins and the fin brackets.
9. Insert the completely assembled motor into the motor tube. Push the motor into the motor tube until the aft end of the motor casing is flush with the aft end of the motor retainer. Warning! The motor is categorized as a high explosive and should only be handled by subsystem leads.
10. Screw the motor retainer ring onto the motor retainer. Note: These threads are very well-fitting and should not require *any* force to fasten.
11. Verify that the motor is securely fastened to the motor tube with a brief shake test.

Structures Lead Sign-off: ____

Safety Officer Sign-off: ____

Transportation to Launcher

1. Assemble the launch team, which consists of the Flight Systems Lead, Payload Systems Lead, Propulsion Lead, and the Safety Officer to carry the rocket to the launcher and set

it up. Warning! All team members must leave their cell phones in the launch preparation area after this step. Electromagnetic signals from the devices may cause the avionics to prematurely detonate the parachutes' black powder charges, causing serious harm to team members or even bystanders.

2. Make sure all members of the team have a firm grasp on the rocket, and lift the rocket to a comfortable carrying height. Make sure the rocket stays as close to horizontal as possible at all points during transportation.

3. Walk the rocket out to the launcher, ensuring that no people are too near or directly in line with either end of the rocket. Caution: Standing in-line with the either end of the rocket increases the likelihood a team member or bystander will sustain an injury in the event of an explosive failure.

Flight Systems Lead Sign-off: ____

Setup on the Pad

1. Have a member or two of the launch team bring the launch rail from vertical to horizontal and hold it in that position.
2. Align the rocket's rail buttons so that they are pointed directly down towards the ground.
3. Slide the aft rail button into the launch rail so that the weight of the rocket is resting on the rail buttons. Make sure the rocket is not "hanging" off the rail only attached at the rail buttons.
4. Slide the aft rail button towards the flame deflector at the base of the launch rail, minimizing twisting of the rocket relative to the launch rail and scraping of the rocket airframe against the leading edge of the launch rail.
5. Once the forward rail button is securely inserted into the launch rail, slide the rocket towards the flame deflector until it makes contact.
6. Several members of the team should then push the launch rail into a vertical position while the rest of the team stabilizes the rocket on the rail to prevent twisting relative to the rail.
7. Once the launch rail is in a vertical position, lock the rail into this position with a bolt or screw.
8. Verify that:
    a. The rocket is secured to the launch rail.
    b. The launch rail is secured in the upright position.
9. Flip the primary altimeter continuity switch to the "on" position.
10. Audibly verify that the sequence of beeps is first two for the setting. Then six, ten, and ten again for main deployment altitude. Then the previous apogee will beep out in four numbers and finally the voltage will be the last two sets of beeps, this should be at least 9.0. Note: If a different series of beeps or a wailing sound emits flip the switches off and then on again. If the problem persists consult the user manual for the Stratologger CF altimeters.
11. Audibly verify that the primary altimeter has continuity through the initiators in both the main and drogue charges by listening for three consecutive beeps.
12. Flip the secondary altimeter continuity switch to the "on" position.
13. Audibly verify that the sequence of beeps is first two for the setting. Then five, ten, and ten again for redundant main deployment altitude. Then the previous apogee will beep out in four numbers and finally the voltage will be the last two sets of beeps, this should

be at least 9.0. Note: If a different series of beeps or a wailing sound emits flip the switches off and then on again. If the problem persists consult the user manual for the Stratologger CF altimeters.

14. Audibly verify that the secondary altimeter has continuity through the initiators in both the main and drogue charges by listening for three consecutive beeps.
15. Take the AV Bay Panel and have another team member hold it over the AV Bay access port.
16. Screw all four #6 screws into the four corners of the Panel, securing it in place for flight.
17. Flip the payload systems power switch to the “on” position.
18. Take the Payload Bay Panel and have another team member hold it over the Payload Bay access port.
19. Screw all four #6 screws into the four corners of the Panel, securing it in place for flight.
20. Flip the camera system power switch to the “on” position.

Flight Systems Lead Sign-off: ____

Payload Systems Lead Sign-off: ____

Initiator Installation

Warning! The initiators are harmful explosives if not handled properly. After initially separating the initiator leads, do not allow them to come into contact with each other at any point.

1. Verify with the A&R lead that the altimeter is correctly and completely initialized.
2. If the rocket’s nozzle is resting on the flame deflector, proceed to Step 3. Otherwise, proceed to Step 4.
3. Have several team members raise the rocket a few inches vertically so that it no longer rests on the flame deflector and ensure that the team members can hold the rocket in this position for as long as it takes to install the initiator.
4. Thread the initiator through the pre-cut hole in the wall of the nozzle cap. For now, ignore the nozzle cap but make sure it does not slide off the initiator wire.
5. Insert the end of initiator that contains the charge into the nozzle of the rocket and continue to slide the initiator upwards through the propellant grains.
6. When you feel the initiator contact the aft end of the smoke charge, stop feeding the initiator into the motor.
7. Secure the initiator wire to the nozzle with tape, making sure the initiator stays in contact with the aft end of the FSD.
8. Secure the nozzle cap over the end of the nozzle, again making sure not to pull the initiator wire any further out of the motor.
9. Separate the initiator wire leads as far apart as possible without damaging the wire.
10. Take one alligator clip from the power supply extension and connect it to one lead on the initiator wire.
11. Secure this connected wire to the launcher a safe distance from the second lead.
12. Take the second alligator clip from the power supply extension and connect it to the remaining lead on the initiator wire.
13. Secure this second wire to the launcher a safe distance from the first wire.

Propulsion Lead Sign-off: ____

Safety Officer Sign-off: ____

Post-Flight Deployment Operation

Rover Deployment and Operation

Warning! Approach the rocket with caution because parts might be hot from the ejection charges, or ejection charges might still be live.

1. Open MATLAB and load the ground station controls system.
2. Send a signal to the rocket to deploy the black powder charge.
3. Once the rocket has settled from separation, send a signal to the rocket to unlock the rover from the containment mechanism.
4. Once the rover has been successfully been released, send a drive signal for the rover to begin its driving sequence.

Payload Systems Lead Sign-off: ____

Rocket Retrieval and Recovery Harness Inspection

Warning! Approach the rocket with caution because parts might be hot from the ejection charges, or ejection charges might still be live.

1. Check to see that all charges have properly deployed. If not, notify the RSO, and maintain muzzle awareness on both ends of the rocket while an A&R lead disconnects the altimeters.
2. Disconnect any shock cords necessary in order to safely remove the rocket from the range or field to the launch preparation area.
3. Disassemble the recovery harness by detaching all of the quicklinks from the bulkhead eyebolts, parachutes and shock cords.
4. Wrap the shock cords to be stored.
5. Lay out parachutes and inspect them for any damage. Warning! Damaged parachutes must be replaced.
6. After inspection, fold and wrap the parachutes for storage, separating out and labeling any damaged parachutes.
7. Place all quicklinks, shock cords, fireballs and parachutes in their respective places to be transferred to the lab and stored.

A&R Lead Sign-off: ____

Post Flight Avionics Inspection

1. Unscrew the avionics bay door.
2. Disconnect the secure wire connectors to turn the altimeters off.
3. Remove the avionics sled from the avionics coupler.
4. Unscrew all of the wire terminals of the two altimeters and remove the wires. Caution: Properly dispose of burnt initiators.
5. Unscrew the altimeters and place them into the A&R box.
6. Remove the batteries and place them into the A&R box.
7. Place the avionics sled back into the rocket for ease of transportation.
8. Screw the door back onto the rocket.
9. At a computer, plug the altimeters in and extract the data. Compare the actual flight data to the estimated data from computer simulations. IF there are any discrepancies, the flight model must be adjusted. The flight data should be stored on the computer for future reference.

A&R Lead Sign-off: ____

5. Payload Criteria

5.1 Payload Design and Testing

Changes from CDR

The method for loading the black powder into the payload bay on launch day was changed to improve safety. The previous method for loading the black powder required it to be loaded before inserting the rotating payload bay into the payload section. The new method is to load the black powder into the payload bay through the external payload door after the payload section has been fully assembled. This reduces the amount of time that black powder is being handled and reduces the amount of time that the payload team needs the payload section and drogue coupler during launch day assembly. Figure 52 shows the black powder loading method for the payload section.

Figure 52. Payload Black Powder Charge Assembly with Door

New motors were selected for the rover because the motors selected in CDR did not provide enough torque to allow the rover to overcome small obstacles. The new high torque motors provide 1 kg*cm of torque when operating on a 6V power source. Two of these high torque motors have been selected to replace the previous motors. The rover will only operate on front wheel drive because powering four motors would require more battery space than is available.

Because new motors were selected, the design for the 3D printed motor mounts was changed. The new design holds two single motors and holds them in place with a cover as shown in Figure 53. During testing, the wiring attached to the motors came loose because of delicate leads. Wire clips were added to the motor mounts so that the wiring would not come loose from the motors while adjusting the positions of the wires.

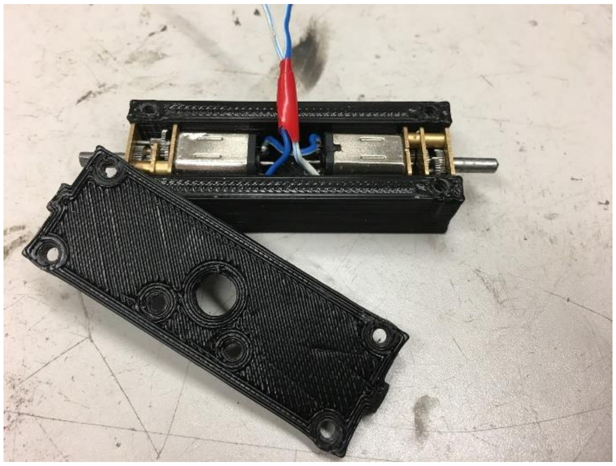


Figure 53. New Motor Mounts for High Torque DC Motors

Another adjustment made because of the new motors was the attachment point for the wheel and the axle mount. Previously, the single dual shaft motor on the front wheels took up 2.5 cm of space while the new motors take up almost 10 cm of space. To compensate for this extra horizontal space, the axle attachment connects to the inside wall of the outer face of the wheel as shown in Figure 54.

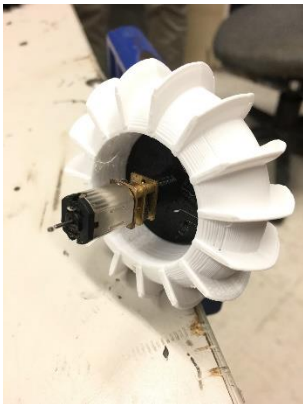


Figure 54. Axle Mount Attachment for High Torque Motors

5.2 Unique Features of the Payload

Rotating Payload Bay

The rotating payload bay is a feature of the payload design that ensures that the rover will be in the correct driving orientation post flight regardless of how the launch vehicle lands. This feature allows the rover to have the maximum amount of clearance underneath. Large clearance was an important initial design criteria because the rover has to be able to clear obstacles that are large relative to its own size.

Figure 55 shows the payload bay as it would appear inside the launch vehicle. The nut and bolt mechanism acts as an axle for the payload bay to rotate around. The masses of the shelves and the solenoid create moments about the rotation axis which causes the payload bay to always be oriented with the rover facing upright.

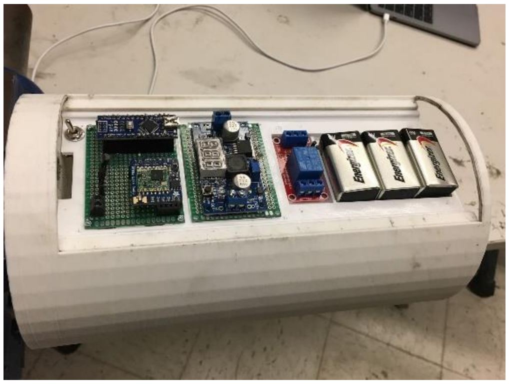


Figure 55. Rotating Payload Bay Top View

3D Printed Electronics Shelf

The 3D printed electronics shelf is a feature that allows the payload electronics to be mounted to an easily constructed, custom made board. The electronics on the shelf include the nose cone deployment and solenoid locking mechanisms. The reason for including these as a separate component of the payload is so that the rover is independent of the deployment and release mechanisms. This design allows for there to be more space and less mass on the rover. The electronics board also features a switch that can be accessed from the outside of the rocket. This feature allows for the deployment and solenoid mechanisms to be turned on while the rocket is on the launch rail. The switch minimizes the amount of time handling a live charge, allows for disarmament on the launch pad, and saves battery life for the deployment electronics.

Figure 56 shows the electronics shelf with all of the deployment electronics mounted. The board was constructed from PLA with LTRL's Taz 6 3D printer. The reason for choosing 3D printing as the construction method is because it allows for more unique geometries that would be difficult and expensive to machine. Additionally, 3D printing also allows for more rapid prototyping.

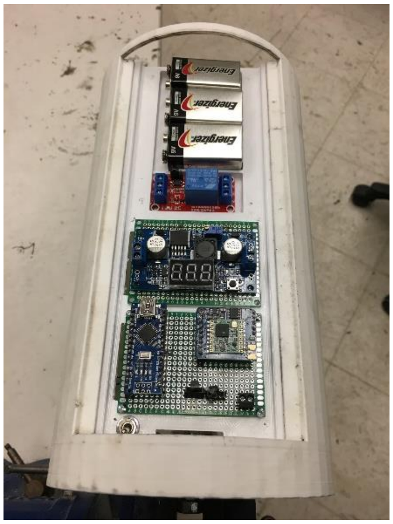


Figure 56.Electronics for Payload Deployment

External Switch and Payload Door

To make the payload as safe as possible on launch day, the payload section includes an external door that is used to load, arm, and disarm the black powder charge for nose cone separation. The door contains 4 screws which, when removed, give access to the blast cap and mechanical switch. Being able to load the black powder charge from outside the rocket is safer because it limits the amount of time the payload team is working on the payload section with a live charge. With this setup, loading black powder is the last step before screwing on the door in for the payload assembly procedure. Additionally, the deployment electronics can be easily disarmed by the mechanical switch at any time during the launch procedures.

Figure 57 shows the door with access to the blast cap and mechanical switch. Because the shelves rotate with the payload bay, the switch is always able to be accessed by rotating the payload bay manually if it is not in the correct orientation on the launch pad.

Figure 57. External Access to the Payload Bay Switch

3D Printed Rover

The 3D printed rover is a unique electronic and structural component of the payload. The rover is 3D printed with PLA because it allows for the rover to take on a unique geometry that would not be possible to machine with standard techniques and materials. The reason for the unique geometry of the rover is so that it can maximize clearance while optimizing the amount of space for electronics and wheels. One of the electronic features on the rover includes a radio module independent of the deployment electronics. Because the deployment and solenoid electronics are independent of the rover, the rover needs to include a way to communicate with the ground station. Another electronic feature of the payload is the high torque motors. These motors provide 1 kg*cm torque when operating at 6V of power which is enough to only need front wheel drive. Front wheel drive reduces mass and wiring complexities by not needing four motors with additional pins on the Arduino.

Figure 58 shows an image of the rover. In addition to the unique geometry of the rover body, another design decision was made to optimize space in the horizontal direction. The motors were placed into the wheels and mounted to the outside face of the wheel as shown in Figure 54. Mounting the motors on the outside of the wheel allows for a more efficient use of the horizontal space in the payload bay and allows for 2 single shaft motors to be mounted next to each other without sacrificing wheel width.

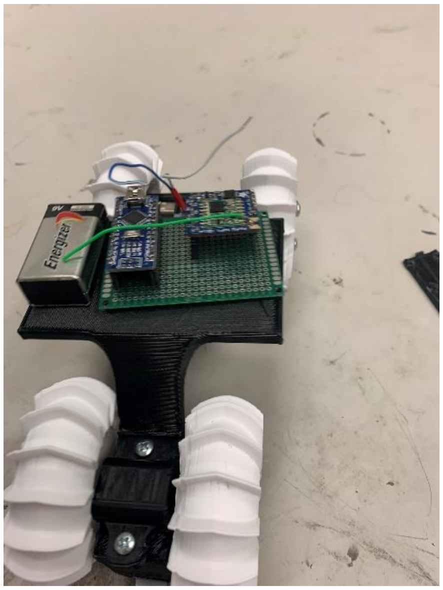


Figure 58. Assembled Rover Back View

Solenoid Locking and Retaining Mechanism

The solenoid locking mechanism is a fail safe way to retain the rover during flight. A 3D printed key was made using polycarbonate because of it high tensile strength. The solenoid key is mounted to the back plate of the payload bay and is oriented so that the unpowered position holds the rover in place. The lock portion of the system is located on the back of the rover. To release the rover, the ground station sends a signal to the launch vehicle that tells the Arduino to power the solenoid which then rotates to unlock the rover. The rover is then able to drive out of the launch vehicle as long as the solenoid remains powered.

Figure 59 shows an image of the solenoid locking mechanism as it is integrated into the payload bay.

Figure 59. Solenoid Locking Mechanism for Rover Retainment

Ground Station Communication System

The ground station communications system is the mechanism for which the payload team is able to talk to the launch vehicle and the rover. A custom ground station GUI was coded in MATLAB to allow for easily adjustable parameters and for limiting the amount of soldered components on the ground station. The GUI has three buttons which initiate nose cone deployment, unlock the rover, and initiate the rover's driving sequence. The communication system does this by sending unique signals on unique radio frequencies.

Figure 60 shows an image of the ground station electronics and the MATLAB GUI. The communication system features an Arduino Nano and a LoRa RFM95x radio module.

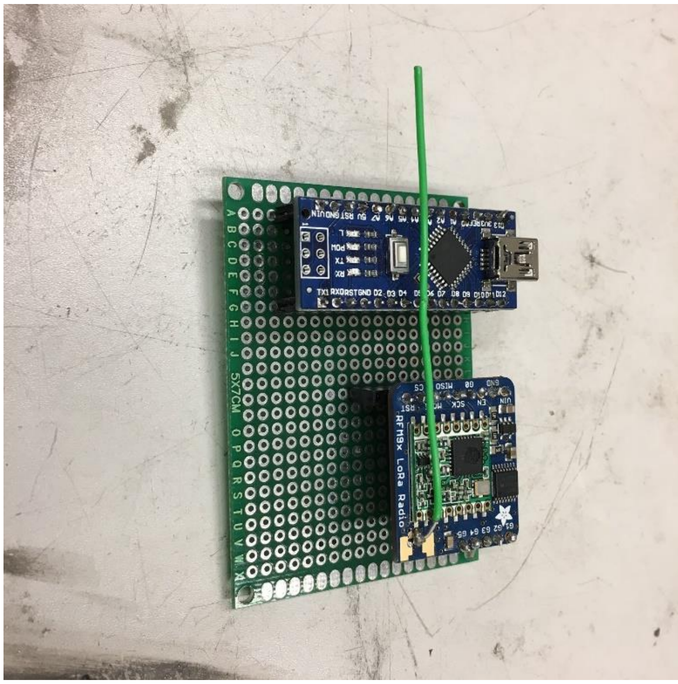


Figure 60. Ground Station Control for Payload System

5.3 Flight Reliability Confidence

The payload team believes that the payload will perform as expected on launch day because of successful ground tests and a successful full scale test flight. For the mission to be successful, the rover and nose cone will be retained through launch and descent, the ground station will separate the nose cone after the launch vehicle has landed, the ground station will unlock the rover from the payload bay, the rover will drive 10 feet from the launch vehicle, and will finally recover the 10 mL soil sample.

During full scale test flight, the design for the retention mechanism and nose cone retainment were verified. The retention mechanism worked correctly as the rover was not disconnected from the solenoid lock during flight. Additionally, the nose cone was successfully secured to the rocket throughout flight by 8 shear pins.

Despite a ground station failure on full scale test flight, multiple ground tests have verified that the electronics for deployment will work as expected after a successful launch. Additionally, the deployment electronics and retainment electronics successfully withstood the accelerations of launch. These results lead the team to believe that the deployment system will work as expected on launch day.

The team also believes that the rover will operate as expected on launch day. Despite the rover not being able to drive during full scale test flight, lab testing has verified that the rover will be capable of driving after being released from the launch vehicle. The electronics from the rover are independent of those on the deployment and retainment system, therefore the team believes the success or failure of the rover will not affect the success of the other aspects of the payload.

Multiple lab tests have verified that the soil sample recovery system will work as expected on launch day. Testing and integrating the of the soil sample recovery system leads the team to believe that it will successfully recover at least 10 mL of soil and remain sealed properly on launch day.

5.4 Payload Demonstration of Flight

Date of Flight: February 9th 2019

Successful flight criteria are determined by the NASA and some of the team derived requirements. Meeting all of these requirements would demonstrate a successful flight. Flight criteria include retaining the rover during flight, deploying the autonomous rover from the launch vehicle, the autonomous rover driving 10 feet, and collecting a 10 mL soil sample. Other qualifications for a successful flight include the successful operation of the communications system and the rover having the correct orientation upon landing.

The rover was successfully retained during flight by the solenoid locking mechanism because it was not displaced during the post flight analysis. However, because the ground station software failed on launch day, there was no way to verify that the solenoid would have unlocked the rover until it was returned to Penn State for further testing. The solenoid locking mechanism did successfully operate post flight when this additional test was conducted.

The ground station failed on launch day because the ground station was not operating on the correct computer. Due to a long wait time between arrival at the launch site and recovery of the rocket, the normal ground station computer’s battery died and a different computer was used. The ground station was unable to connect with the rocket and the nose cone was not deployed.

The rotating payload bay was successful because the rover had the correct orientation after landing. All of the electronics on board the rocket were unharmed post flight.

5.5 Construction

The first element of the payload to be constructed was the rotating payload bay shown before in Figure 55. The team began with this project to ensure that the rover would be able to exit the rocket in an upright position regardless of the landing orientation. The rotating bay was first 3D printed on a small scale as a proof-of-concept, then printed at the full scale size using PLA plastic. The rotating payload bay was designed to hold removable shelves with the necessary electronics for both retainment during launch and the deployment after landing. To ensure the retainment mechanism was able to hold the rover within the payload bay, the mount was built into the back wall of the rotating bay. Similarly, the blast cap was built directly into the rotating bay.

The second element constructed was the wheels for the rover. The wheels were created to the constraints of the rotating payload bay. The wheels were constructed using 3D printed PLA plastic. Printing the wheels early was important for testing and integration purposes. To attach the wheels to the motors, axle mounts were also 3D printed. These mounts allow for the wheels to be changed if damaged or modified without the need to buy new permanently attach new wheels shown in Figure 54.

After finalizing construction of the rotating payload bay, the electronics shelf, shown in Figure 56 was designed and 3D printed using PLA plastic to exactly fit the needed retainment and deployment electronics. The needed electronics boards, batteries, switch, and other components were measured and the shelf was built around each part. This allows for secure attachments to ensure all components do not move during any phase of the launch. The shelf also works as a counterweight to help rotate the payload bay to the correct orientation upon landing.

Once the electronics shelf was 3D printed, the retainment mechanism was constructed. A rotary solenoid was mounted onto the back of the rotating payload bay and an attachment piece was 3D printed using polycarbonate to attach to the rover. The attachment key piece is screwed into the solenoid and extends outward to the lock on the rover. The key piece assembled with the rotary solenoid is shown mounted in Figure 59.

The rover was 3D printed using PLA plastic. The chassis was constructed to hold two motors, an axle, the solenoid lock, and the electronics necessary for its function. The rover’s motors will be inserted into the designated area and secured using the cap. The axle will be inserted in a similar fashion. The elevated section will hold the rover’s electronics including the Arduino, batteries, and communications system. The elevated section was changed from earlier models to add more space between the wheels while also increasing the clearance above the ground.

Before the rover and electronics boards were printed, the electronics need for operation of the rover, retainment mechanism, and deployment were temporarily put together and tested to ensure proper function. After the rover and electronics boards were 3D printed, the electronics were then installed onto their respective spots. Because both models were made to exactly fit the needed electronics, the assembly required only securing the pieces and soldering the parts together.

The soil sample recover system was 3D printed using PLA plastic. It will be attached to the bottom side of the rover along with the appropriate electronic components. The system was be printed so that tolerances will allow for a tight seal upon recovery of the 10 mL soil sample.

6. Project Plan

6.1 Structures Testing

One test will be to determine the amount of layers of carbon fiber needed for the launch vehicle. To determine this, the team considered the max q condition. The max q condition is the point when an aerospace vehicle reaches its maximum dynamic pressure during its flight. This is a significant factor as it is proportional to the structural load the launch vehicle can handle. The team considered using the Cesaroni L851 motor when calculating the dynamic pressure of the launch vehicle. The dynamic pressure equation is represented by:

$$q = \frac{1}{2}\rho v^2 \tag{22}$$

Where q is the dynamic pressure, ρ is the local air density, and v is the velocity of the launch vehicle.

The team considered two different points when calculating the dynamic pressure. The first was at ground level in Alabama. The height of Alabama above sea-level is 636 feet. This height was denoted as ground-level. The team also used the velocity of the launch vehicle as it leaves the rail, which is 58.7 feet/s. To determine the pressure at ground-level, the following equation was used:

$$P_h = P_0 e^{\frac{-Mgh}{RT}} \tag{23}$$

P_h is the pressure at ground-level, P_0 is the average pressure at sea-level, M is the molar mass of Earth's air, g is Earth's gravitational acceleration, h is the height above sea-level, R is the universal gas constant, and T is the temperature. To determine the temperature the launch vehicle will most likely encounter on launch day, the team looked at past average temperatures in Alabama during the month of April. After looking at the different averages over the years, the team decided to use 72 degrees Fahrenheit.

After determining the pressure at ground-level, the team calculated the density of air utilizing:

$$\rho = \frac{P_h}{rT} \tag{24}$$

Where ρ is the local air density and r is the specific gas constant.

Plugging in the calculated local air density and the velocity of the launch vehicle, the dynamic pressure yielded was 125.683 $lb * ft^2$.

This value seemed fairly small, so the team decided to determine the dynamic pressure at the point of the launch vehicle's maximum velocity. The team chose this position since the launch vehicle will not be reaching a height further than a mile above ground-level, so velocity will have the largest impact.

This point was found to be when the launch vehicle was 2146 feet above sea-level, which is 1510 feet above ground-level. The velocity of the launch vehicle at this point is 674 feet/s. Using

Equations 1, 2 and 3, the dynamic pressure exerted on the launch vehicle was found to be 15859.2 lbft2. This value seemed to be fairly high, but the team decided to use it and move forward with calculating the amount of layers of carbon fiber needed.

Since the dynamic pressure is proportional to the maximum stress the launch vehicle will encounter, the following equation can be used:

$$\sigma = \frac{F}{A} \tag{25}$$

Where σ is the maximum stress or dynamic pressure, F is the force exerted on the launch vehicle, and A is the area the force is exerted on. Because the dynamic pressure is exerted on the whole launch vehicle, the total area was utilized. To determine the amount of layers needed, the area of a cylinder with an outer radius denoted as X and an area of a cone were used. These can be found in Equation 26 and Equation 27 respectively:

$$A_h = 2\pi(X + r)(h + X - r) \tag{26}$$

Equation 26 denotes the area of a hollow cylinder, where X is the outer diameter, r is the inner diameter, and h is height of the cylinder. Equation 27 (below) denotes the area of a cone:

$$A_c = \pi r(r + \sqrt{h^2 + r^2}) \tag{27}$$

Where r is the radius on the base of the cone and h is the height of the cone.

The areas calculated in Equations 26 and 27 were then added together and plugged into A found in Equation 25.

The force was determined through using Newton's Second Law:

$$F = ma \tag{28}$$

Where m is the mass of the launch vehicle at the point where the dynamic pressure was calculated, and a is the acceleration of the launch vehicle at the same point.

Using 3K Carbon Fiber Plain Weave thickness of 0.012 inches and solving for X, it was determined that the amount of layers needed was 6.4. The team will test the structural integrity of the launch vehicle using six and seven layers to determine how each act provided the forces the team believes the launch vehicle will encounter during flight.

One of these forces the airframe will have to resist is zippering during deployment of the main parachute. The zippering force of the shock cord will be due to the force of drag caused by main parachute:

$$F_D = \frac{1}{2}\rho v^2 S C_d \quad (29)$$

Where FD is the force of drag, ρ is the air density, v is the velocity, S is the surface area, and Cd is the coefficient of drag. A successful test is defined by obtaining a tensile strength value that is higher than the force that the shock cord will exhibit on the airframe during main parachute deployment. The exact procedure for tensile testing of the airframe can be found in Appendix D: Tensile Test Procedure.

Another test the structures team will take part in is to determine if PLA will be a good substitute for bulkheads instead of plywood. PLA and plywood have relatively the same tensile strength, but PLA has a higher flexural modulus. The weight of PLA can be similar, heavier, or lighter than plywood depending on the infill percentage used during the print. The cost of PLA and plywood are also very similar. Because of the similarities that team found between the two materials, it was determined that a tensile test was needed to conclude whether or not PLA would be a sufficient alternative to plywood.

The bulkheads are an important component of the launch vehicle because they hold the avionics bay in place, so they cannot fail during flight under any circumstance. The bulkheads support forces from the parachute and body tube of the launch vehicle. To determine if PLA will be a sufficient alternative, the team will run a SolidWorks FEA simulation. The team will compare these results to simulations run using plywood and previous knowledge of how plywood bulkheads held up during the duration of the flight.

The structures team will also manufacture a test piece and place a bulkhead made out of PLA into the body tube using epoxy. The team will then provide relatively the same amount of force the bulkheads will encounter during the duration of the flight to determine if the PLA bulkhead will fail or not under these loads.

6.2 Avionics and Recovery Testing

Avionics Board Altimeter Test

The purpose of this test is to confirm the accuracy of the primary and redundant PerfectFlite StratoLoggerCF Altimeters the team is using in the rocket. PerfectFlite StratoLoggerCF Altimeters record pressure through the use of a barometer and turn this into altitude and velocity data. This testing procedure determines the accuracy and operability of the barometer on the altimeter for measuring elevation. The second purpose is to confirm that drogue and main deployment events are occurring where they are expected.

The team placed the altimeter to be tested into a cylindrical pressure vessel designed to maintain near vacuum pressure for extended periods of time. A vacuum pump and a pressure gauge are attached to a cylindrical pressure vessel to control the internal pressure to that similar to what the rocket will experience in flight.

The altimeter is wired up following the launch procedures except with a solid wire instead of an initiator on the end. After confirming continuity beeps, it is placed inside of the pressure chamber and sealed in. The vacuum pump was on to simulate an altimeter undergoing an ascent of a rocket launch by decreasing the pressure inside the vessel. The pressure vessel was then let to equalize with the atmosphere at a rate similar to drogue descent. The maximum pressure that was simulated is then recorded through the attached pressure gauge.

The pressure gauge is compared to a pressure altitude chart to determine the effective altitude the altimeter experienced. The altitude vs time chart is then compared to this value to make sure they are the same. The team performed the test and confirmed the accuracy of both altimeters.

Parachute Test

The purpose of this test is to gather accurate data on the coefficients of drag on several of the team's parachutes. Currently the team must estimate the drag on the parachutes based on previous years launches. This is inaccurate since the team also does not know the drag on the rocket body.

The test will take place outside on an open road that has no traffic and low ambient wind speeds. The team will measure the ambient wind speeds and use a car to accurately record its speed. Then each parachute will be attached to a standard spring scale force cage with a digital reading, which will be held by a team member.

The car will be put in cruise control at speeds in 5 mph increments and the parachute will be held in the free stream out of the wake of the car. The car is then driven down the road at the target speed while one person reads the force on the gauge and records that specified speed. This will be repeated multiple times for each parachute to gather accurate results.

The coefficient of drag can then be calculated using the standard drag equation for each parachute. This will be put in table in the team's MATLAB script and run against the results from previous year's flights. If the results or similar to the altimeter data from previous years, the test will be considered a success and that data will be used for the next years launch.

6.3 Payload Testing

Initiator Circuit

To verify that the Arduino could light the initiator.

The method for testing the initiator was to prototype the system in the lab on breadboards and then assemble it to flight standards for ground testing and a full scale test launch. The schematic was assembled on the breadboard for the circuit that was designed in CDR. Code was written and uploaded to the Arduino that would output a voltage to the D5 pin after a 5 second delay. Once the circuit was verified to be working as expected, the communication system was integrated to verify that a signal could be sent from the ground station to the initiator circuit. The full system was then soldered together and placed into the rocket for ground testing. For the ground test, the communication system operated as expected. The communication was then placed into the rocket for the full scale test flight. Due to technical issues on the ground station, the system was not able to operate after the landing. Without any alterations to the system, a second ground test was conducted post flight with the ground station operating correctly.

The tests for the initiator deployment system have been successful and the team believes that the system will operate correctly on launch day. Despite the unsuccessful deployment on launch day, the team still believes the system will work because the exact same system was tested 3 days later during a ground test. The reason for failure on launch day was because the computer the ground station normally operates on had died and the ground station was operating on an unfamiliar system with COM ports that it did not recognize. Because this issue is easily fixed by ensuring that the correct computer is charged and available on launch day, the team believes that the initiator will deploy.

One lesson learned from these tests was to use the same computer that had been used for all lab and ground station testing. In case of the issue of a computer running out of battery in the future, additional tests will be conducted in the lab to verify that the ground station can operate on other computers if necessary.

Communication Systems

To test that the rocket systems and ground station can communicate with each other.

The method for testing the communications system was to prototype the electronics in the lab and assemble it to flight ready standards for ground testing and full scale test flight. The radios were wired on breadboards according to the design chosen in CDR. Test code was written and uploaded to the transmitter circuit to verify that the transmitter could send signals. Test code was written and uploaded to the receiver circuit to verify that the receiver could accept the signals that the transmitter was sending. Once communication was established, the ground station GUI was written in MATLAB to begin testing connection between MATLAB and Arduino. Each of the components of the on board electronics were then tested with the communications system. Testing was done to determine if the communications system could send a signal from the MATLAB GUI and detonate the black powder charge. Then, tests were done to determine if the MATLAB GUI could send the signal to the solenoid lock to release the rover. Finally, the team tested the MATLAB GUI with the rover to initiate the driving sequence. Once all of these systems were tested independently, they were tested as whole to verify that they would work correctly sequentially.

The results of these tests were successful and the team believes that the system will operate as expected on launch day.

Rotating Payload Bay

To verify that the payload bay will adjust to the correct orientation when the entire payload system is assembled inside the payload section.

The method for verifying that the payload bay would remain upright after launch was performing lab tests and flying it during full scale test launch. The rotating bay was placed inside the rocket fully assembled with weights inside of it to simulate the weight of the rover. The payload section was rotated to various orientations to see if the payload bay would correct itself. The system then flew in the full scale test launch.

The results of these tests were successful and are expected to work on launch day. The lab tests performed as expected and the payload bay was oriented upright post full scale test flight.

Retention Mechanism

To verify the rover can be held in place during flight and during nose cone separation.

The method for testing the retention mechanism was to fly it during full scale test launch. There were no lab tests that could easily simulate the accelerations that the rover would be experiencing in flight.

The results of this test were successful because the rover was securely attached to the retention mechanism after the full scale test flight. These results lead the team to believe that the retention mechanism will work correctly on launch day.

Motor Testing for the Rover

To verify that the selected motors are able to move the rover at the expected weight.

The method for testing the rover’s driving capability was to drive it in soil that is expected for the terrain in Huntsville, Alabama. The tests were conducted in a patch of dirt outside of the LTRL lab.

The results of this test were initially unsuccessful with 2 dual shaft DC motors. The motors selected in CDR did not provide enough torque to move the rover in the dirt. The design was changed to use 2 single shaft high torque motors. The results of these tests were successful and the rover was able to move.

One of the lessons learned from these tests was to verify torque ratings on motors before following through with further design. If this issue had been discovered earlier, less time would have been spent developing mounts for the initial motors and the team would not have had to go through redesigning mounts.

Nose Cone Separation

To verify the black powder charge was enough to separate the nose cone and to verify the communication system worked through carbon fiber body tube at the necessary distance.

The method for testing the nose cone separation was to conduct ground tests that verify the black powder charge could successfully separate the nose cone from the body tube. The team took the payload section of the rocket to a designated location on campus to conduct the test.

The initial results of this test were unsuccessful. The nose cone did not separate from the body tube on the first ground test because of a leak in the payload section door. To make this system more airtight, the structures team built another door that fits the cutout better and the payload team created a cover for the blast cap that blocks the pressurization from the door. Conducting tests with these parameters changed resulted in a successful deployment of the nose cone.

One of the lessons learned from the nose cone separation tests was the significance of having an airtight seal in the payload section when pressurizing it to break shear pins. When the door was not sealed well, the easiest way for the gas to escape was to escape through the door. This taught the team that improvements needed to be made to the door so that it would not be the easiest way for the gas to escape.

6.4 Requirements Verification

General Requirements

Requirement	Method of Verification	Verification
1.1	Demonstration	The team will design, build, test the entirety of the rocket and its payload as well as write all milestone reports. Additionally, the team's mentor, Justin Hess who is accredited with a NAR HPR Level 2 certification, will handle motor assembly, ejection charges, and electric matches.
1.2	Demonstration	The team will follow a strict project plan based on each subsystem's Gantt charts and well as the team's overall Gantt chart. Additionally, the team will outreach to local schools, and create all risk mitigation tables, checklists, budget tables.
1.3	Demonstration	The team only has one foreign national member, Wilson Chiang, who's contact information has been submitted prior to PDR.
1.4.	Demonstration	The rocket will decide all team members that are going to Alabama for the competition by the CDR milestone. Additionally, the team mentor and adult educator have already been identified by the team.
1.5	Demonstration	The team has a dedicated Outreach Chair who will be responsible for the team's contribution to educating 200 participants in STEM related material.
1.6	Demonstration	The team has identified its only social media account (Instagram) to NASA student launch representative.
1.7	Demonstration	The team will email milestone deliverables by the specified deadlines.

1.8	Demonstration	All milestone deliverables will be in PDF format.
1.9	Demonstration	The team will include an appropriate table of contents in each milestone report.
1.10	Demonstration	The team will include correct page numbers at the bottom of every page for milestone reports.
1.11	Demonstration	The team will be given access to conference rooms will teleconference abilities through Pennsylvania State's SEDTAPP department.
1.12	Demonstration	The launch vehicle will use 15-15 rail buttons so it can be successfully launched from the provided launch rails.
1.13	Demonstration	The team has already identified its team mentor, Justin Hess, who fulfills are mentor requirements stated.

Vehicle Requirements

Requirement	Method of Verification	Verification
2.1	Analysis	Data from the altimeters used during flight will verify that the rocket reaches an apogee of 5,280 ft. altitude with the payload in it.
2.2	N/A	The declared target altitude goal is 5,280 ft. and will not be changed after this report is published.
2.3	Inspection	The AV bay will contain an altimeter that is built by a certified company that will record the official apogee of the launch vehicle.
2.4	Inspection	Each altimeter will be armed by connecting two connection points through mechanical means on the exterior of the flight vehicle prior to launch.
2.5	Inspection	Each altimeter will be wired to a commercially available 9 volt battery that is secured to the avionics bay.
2.6	Testing	The avionics switch will be secured via a robust mechanical linkage so that it will remain in the ON position during flight without possibility of the switch disarming.
2.7	Demonstration / Inspection	The rocket will be launched on launch day and inspected afterwards to confirm that no damage was done and the vehicle is able to launch again.
2.8	Demonstration	The rocket is designed with only four independent sections. The four sections are the payload body tube, main body tube, drogue body tube, and the booster body tube.
2.8.1	Demonstration	The rocket is designed with airframe couplers and shoulders that are no shorter than 10 in. in length which is 1.67 times larger than the 6” diameter of the airframe.

2.8.2	Demonstration	The nose cone shoulder is 5.5" in length which is ½ the diameter of the rocket. Additionally, the nose cone will be separated during flight.
2.9	Demonstration	The rocket's propulsion system contains one solid rocket motor and no additional stages.
2.10	Demonstration / Testing	The team will keep a timer during all fullscale test launches to ensure that the build time does not take longer than 2 hours. The rocket will be designed with assembly timing in mind, extensive launch day procedures will be written and followed to ensure timeliness on launch day.
2.11	Demonstration / Testing	The launch vehicle is designed so that all components such as avionics can remain functional for an extended period of time after the vehicle is in launch-ready configuration. Testing can be done on test launch days to assure the functionality of the components after a certain amount of time.
2.12	Testing	Tests will be performed on a fullscale primary motor prior to the fullscale test launch to demonstrate that the motor can be ignited with a 12-volt direct current firing system. These tests will be part of the larger test goal to gather operational and performance characteristics of the primary fullscale motor before the fullscale test launch.
2.13	Demonstration	All electronics will be contained within the launch vehicle with the exception of the initiator required to light the motor upon launch.
2.14	Demonstration	The motor used for competition launch will be from a trusted manufacturer (Cesaroni or Aerotech), using NAR approved APCP propellant.
2.14.1	Analysis	In-depth mass analysis of the rocket using OpenRocket and SolidWorks will be performed to ensure mass estimates are accurate by CDR. After this analysis, a proper motor will be selected.

2.14.2	N/A	The final flight vehicle motor will not be changed after CDR.
2.15.1 - 3	N/A	The final flight vehicle will not contain any custom pressure devices.
2.16	Analysis	Analysis will be conducted via OpenRocket and MATLAB models to simulate the flight profile of the vehicle, and the associated motor selection process will be limited to motors approved by the aforementioned bodies.
2.17	Analysis	Stability will be calculated with various programs to ensure that the vehicle's stability is over 2.0 calibers off the rail.
2.18	Analysis	Launch velocity will be calculated with various programs to ensure that the vehicle's velocity off the rail is at least 52 fps.
2.19	Demonstration	A launch vehicle exactly 50% the size of the fullscale rocket will be designed and launched to accurately imitate the fullscale rocket's main design features and aerodynamics.
2.19.1	Demonstration	All major design features such as airframe material, avionics bay design, fin brackets, and camera cover will be included in the subscale launch vehicle.
2.19.2	Demonstration	The avionics bay will be designed to include an altimeter that will record the altitude the launch rocket reaches.
2.19.3	N/A	The subscale rocket will be a newly constructed rocket, designed and built specifically for this year's project.
2.19.4	Demonstration / Analysis	The subscale rocket will be successfully launched and recovered before CDR, altimeter data from the flight will be provided to prove a successful flight.

2.20	Demonstration	The team will launch the rocket as soon as the design is finalized to make sure each system is working properly and can be fixed if failure occurs.
2.20.1	Inspection / Analysis	After the rocket is launched, the team will inspect each system to confirm that it functioned properly. The structural integrity of the vehicle will be inspected to ensure that no part of the rocket suffered severe damages during flight, and flight data will be analyzed to ensure that recovery systems were deployed at their correct altitudes, and to determine if drift calculations were correct.
2.20.1.1	Analysis	After the rocket is recovered the team will analyze the altimeter data and compare it to the mission performance predictions calculated before the launch. Flight characteristics that will be analyzed include deployment altitudes, drift distance, and landing velocity.
2.20.1.2	N/A	The fullscale rocket will be a newly constructed rocket, designed and built specifically for this year's project.
2.20.1.3	Demonstration	Appropriate ballast will be added to each section to simulate missing payload mass.
2.20.1.3.1	Demonstration	If the payload is not ready for a fullscale test launch, it will not be flown, but it should be thoroughly tested regardless.
2.20.1.3.2	Demonstration	The simulated payload mass will be placed in a calculated area to best simulate the missing payload mass.
2.20.1.4	Demonstration	The vehicle will account for the payload's potential changes to the rocket's external surface or energy during fullscale test launches to ensure accurate flight data. The camera system that will be used for footage during launch day will be active during fullscale test launches.

2.20.1.5	Analysis	If the fullscale motor is not flown during the fullscale test flight, analysis will be performed via OpenRocket and MATLAB with the motor used during the flight to verify that major flight characteristics such as maximum velocity, maximum acceleration, and maximum altitude are as close to originally predicted as possible.
2.20.1.6	Demonstration	All ballast that will be used in the rocket for fullscale launch will also be used during fullscale test launches. The ballast needed for launch day will be confirmed by the time fullscale test launches to ensure that the ballast is an accurate representation for launch day's rocket.
2.20.1.7	Inspection	Between the fullscale test flight and Student Launch competition, the final flight vehicle will not be modified in any way.
2.20.1.8	Demonstration / Analysis	The fullscale rocket will be successfully launched and recovered before FRR, altimeter data from the flight will be provided to prove a successful flight.
2.20.1.9	Demonstration	LTRL will strictly follow its Gantt charts and own deadlines to ensure that the fullscale rocket can be launched prior to March 6th.
2.20.2	Inspection / Analysis	After the rocket is launched, the team will inspect each payload system to confirm that it functioned properly. The structural integrity of the payload will be inspected to ensure that no part of the system suffered severe damages during flight and that the retention system functioned as intended.
2.20.2.1	Demonstration / Analysis	The retention system will be flown in its final configuration during the payload demonstration flight and the results of the flight will be analyzed after recovery to ensure that the system functioned properly.
2.20.2.2	N/A	The payload flown will be the final, active version.

2.20.2.3	Demonstration	The team is planning on flying the final, active version of the payload on the fullscale fullscale test flight. If the team cannot carry out that plan, the team is prepared to fly the separate fullscale Payload Demonstration Flight.
2.20.2.4	Demonstration	The team has allowed for the inclusion of a fullscale payload demonstration flight in the project plan if the original plan of flying the payload on the fullscale test flight cannot be met.
2.21	N/A	An FRR-Addendum will be completed by the team if either of the original fullscale demonstration flights fails.
2.21.1	Demonstration	The team has planned for a possible fullscale demonstration re-flight and allowed time in the schedule for an FRR-Addendum to be competed.
2.21.2	Demonstration	The team will complete the competition launch with an accurate payload mass simulation if the Payload Demonstration Flight cannot be successfully completed by FRR.
2.21.3	Demonstration	The team will be prepared to present a petition to the NASA RSO and Review Panel to prove the safety of the payload design if a Payload Demonstration Flight cannot be successfully completed by FRR.
2.22	Demonstration	The rocket will be designed so that all possible protuberances such as the camera cover will be located aft of the burnout center of gravity.
2.23	Demonstration	Each section of the rocket will have the appropriate contact information located in an easy-to-access location.
2.24.1	Demonstration	The rocket will be designed so that no forward canards are necessary to the vehicle's flight or payload.

2.24.2	Demonstration	It will be demonstrated through launch vehicle design specifications and test launches that the launch vehicle does not include or utilize forward firing motors.
2.24.3	Analysis	Analysis will be conducted via OpenRocket and MATLAB models to simulate the flight profile of the vehicle, and the associated motor selection process will be limited to motors that do not expel titanium sponges.
2.24.4	Analysis	Analysis will be conducted via OpenRocket and MATLAB models to simulate the flight profile of the vehicle, and the associated motor selection process will be limited to APCP solid-fuel motors that are not of the hybrid design.
2.24.5	Analysis	Analysis will be conducted via OpenRocket and MATLAB models to simulate the flight profile of the vehicle, and the associated motor selection process will be limited to a single motor that is not clustered.
2.24.6	Demonstration	The motor tube and motor will be attached to the airframe of the launch vehicle with plywood centering rings that will be epoxied between the airframe and the motor tube.
2.24.7	Analysis	Analysis will be conducted via OpenRocket and MATLAB models to simulate the flight profile of the vehicle, and the associated motor selection process will be limited to motors that do not accelerate the vehicle past Mach 1 at any point during the flight. This will primarily be achieved by ensuring that motors with higher average thrust values are not included in the selection process.
2.24.8	Demonstration	The rocket's weight and potential ballast will be calculated carefully so that a ballast no more than 10% of the rocket's weight is needed. The mass of the rocket will be thoroughly fleshed out by CDR so that there will be no mass issues after design changes cannot be made.

2.24.9	N/A	The team will limit design choices of transmitters to those that do not exceed 250 mW of power.
2.24.10	Demonstration	The team will design the vehicle with this requirement in mind, use of metal in the construction of the rocket will be limited to the motor casing and various parts of the recovery system.

Recovery System Requirements

Requirement	Method of Verification	Verification
3.1	Demonstration	Drogue parachute will deploy at apogee and main will deploy at 600 ft. This will be demonstrated through subscale and fullscale launch.
3.1.1	Demonstration	Main parachute will deploy at 600 ft. This will be demonstrated through subscale and fullscale launch.
3.1.2	Demonstration	Drogue parachute will deploy at apogee, and the redundant altimeter will be set to a two second delay to ensure drogue deployment.
3.2	Testing	LTRL will ground test ejection charges prior to the first subscale and fullscale launch. Ground tests will be performed before each initial launch to demonstrate successful ground ejection test.
3.3	Analysis	Both parachutes will be correctly sized, based on MATLAB and OpenRocket modeling, in order for each component of the rocket to land within the kinetic energy constraint of 75 ft-lbs.
3.4	Inspection	The recovery system, including all wiring, will be completely independent of any payload retention, deployment or vehicle wiring.
3.5	Inspection	All avionics systems will be powered by new, commercially available 9V batteries.
3.6	Inspection	The recovery system will contain two redundant altimeters with corresponding independent charges, power supplies, and switches to ensure a fully redundant recovery system. The selected StratologgerCF altimeters are commercially available.

3.7	Inspection	The StratologgerCF altimeter will control all the recovery system's ejection charges.
3.8	Demonstration	Removable shear pins will be installed for both the main body tube and the drogue body tube to be broken by ejection charges during parachute deployment.
3.9	Analysis	Using a MATLAB and OpenRocket simulation the drift distance will be confirmed to be less than 2500 ft in up to 20 mph winds.
3.10	Analysis	Using a MATLAB and OpenRocket simulation the descent time will be confirmed to be less than 90 seconds after apogee.
3.11	Inspection	There will be a working and tested GPS unit installed in the nose cone of the rocket which will constantly send the position of the rocket to the team.
3.11.1	Demonstration	All sections of the rocket will be tethered to each other through a recovery harness at all times.
3.11.2	Testing	The GPS unit will be functional and tested prior to launch on launch day. There will be a spare GPS unit in case of any electronic failures before the launch.
3.12	Inspection	The avionics bay containing all avionics electronics will be contained in a faraday cage so that it is electronically shielded from any electromagnetic interference.
3.12.1	Demonstration	The recovery system will be in its own coupler, and will be isolated from all other electronic components.
3.12.2	Testing	The faraday cage will protect the recovery system from any internal or external interference. Testing before launch will confirm this requirement.

3.12.3	Testing	The faraday cage will protect the recovery system from any internal or external interference. Testing before launch will confirm this requirement.

Payload

Requirement	Identification	Associated Plan
4.3.1	Demonstration	A custom rover has been designed with 3D printed parts and custom electronics. The rover is deployed from the internal structure of the launch vehicle by separating the nose cone with a black powder charge.
4.3.2	Testing, Demonstration	A locking mechanism was developed using a rotating solenoid that will rotate only when a signal to do so is sent to the onboard receiver. If there is any communication or electronics failure on board, the rover will remain in the locked position and will not be able to exit the launch vehicle, making the system fail safe.
4.3.3	Demonstration	Ground station control and communication systems were developed that remotely ignite a black powder charge using a unique radio signal. These systems were verified by two ground tests and a full scale test launch.
4.3.4	Inspection, Testing, Demonstration	A rover was developed that can drive using two single shaft motors and is programmed to recover a soil sample after traveling for 60 seconds. Testing has determined that waiting 60 seconds is the best way to verify that the rover is at least 10 feet away from the launch vehicle. Ground tests have been conducted to verify the rover's driving capability.
4.3.5	Inspection, Testing, Demonstration	A scooping mechanism that rotates using a servo has been developed. The storage well created holds the minimum of 10 milliliters. After soil has been collected, tests will be performed to determine the total retention volume of substrate.

4.3.6	Demonstration, Testing	The scooping mechanism will be 3D printed to fit the tolerances of the designated compartment for the soil sample. Testing will verify that the soil sample is closed and secured within the given space.
4.3.7	Demonstration, Testing, Analysis	The batteries have been securely attached to the rover and the shelves of the rotating payload bay. A custom mount was developed in SolidWorks, FEA tested, and printed using a Lulzbot Taz 6 3D printer.
4.3.8	Demonstration	Bright pink tape will be used to identify the batteries easily.

Safety

Requirement Number	Requirement	Verification
5.1	Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.	**Demonstration:** Comprehensive checklists will be created prior to all launches and will require a lead or executive member relevant to that task to sign off after the completion of that task. The checklists will be updated after each launch and will be finalized and printed in the report prior to FRR.
5.2	Each team must identify a student safety officer who will be responsible for all items in section 5.3.	**Demonstration:** Ben Akhtar is the Safety Officer for the 2018-2019 season.
5.3	The role and responsibilities of each safety officer will include, but not limited to: Safety 5.3.1.- Safety 5.3.4.	**Demonstration:** Ben Akhtar will make sure all of these responsibilities are upheld and all rules are followed throughout the year through procedures, documents, and verification.

5.3.1	Monitor team activities with an emphasis on Safety during: design, construction, assembly, and ground testing of vehicle and payload, subscale and fullscale launch tests, launch day, recovery activities, and educational engagement activities.	**Demonstration:** Leads will hold meetings every two weeks to review the design and construction progress. Additionally, all constructing, testing, launching, and educational activities that may have any hazards involved will have a review of all safety requirements and necessary steps to mitigate the risk as much as possible.

6.5 Team Derived Requirements

Vehicle

Requirement	Justification	Verification
Launch vehicle fins will be removable.	The fins are often the first point of impact on the rocket during landing and often break as a result. Having removable fins means that if they break, the team can replace them on launch day to aid in satisfying Requirement 2.10. Additionally, the team will not have to create a whole new booster tube every time the fins break as would be the case if the fins were epoxied to the motor tube and booster body tube.	The fin brackets for the launch vehicle are manufactured as a separate component than the booster body tube and are fastened to the body tube in a modular fashion with bolts.
Launch fin brackets will be removable.	Since the fins are often the first point of impact on the rocket during landing, the associated hardware often breaks. Having removable fin brackets means that if they break, the team can replace them on launch day to aid in satisfying Requirement 2.10. Additionally, the team will not have to create a whole new booster tube every time the fins brackets break.	The fin brackets for the launch vehicle are designed as a separate component than the booster body tube and are fastened to the body tube in a modular fashion with bolts.

Camera will be housed in the launch vehicle with aerodynamics in mind.	Getting down-body footage of the rocket in flight is a crucial aspect of the post-flight analysis process.	The team will design an aerodynamic cover to minimize the effect of the external camera. A 3D printed camera cover will be screwed into the rocket so that the camera can film without disturbing aerodynamics.
Maintain a circular profile after laying up the carbon fiber body tubes	During the wrapping process, the carbon fiber layup curing and the vacuum pulled on the tubes will lead to stress on the mandrel. With standard aluminum mandrels this is not an issue, but the hollow phenolic mandrels may deform and cause the carbon fiber layups to be deformed as well.	The team will test different methods of wrapping the mandrel with carbon fiber to ensure that the mandrel will not warp after wrapping and compressing. Bulkheads will be epoxied into the hollow mandrel at certain spots to help reduce stress experienced by the body tube.
Flush cuts between separation points to ensure structural integrity	Non-flat cuts at the ends of body tubes can lead to “wobble” in the rocket under axial loads. This causes an unsafe and inefficient flight path.	The team will test different methods of cutting the body tube to ensure straight cuts and a flush body tube sections.

Cut screws so that they will not interfere with parachute deployment	Screws fastening airframe sections together will be cut to length so they do not protrude into the body tube sections holding parachutes and shock cord. Screws that protrude into these sections can lacerate parachutes and tangle shock cords. This could potentially prevent a safe recovery of the vehicle.	Screws will be measured and cut to a length that remains long enough to maintain structural integrity but short enough so that they do not interfere with parachute deployment.
Coupler length is 1.5 times the diameter of the rocket to ensure structural integrity	Coupler length can have a significant impact on the dynamic stability of the vehicle. The team believes that exceeding Requirement 2.8.1 by 50% will help improve the dynamic stability of the rocket. The team has struggled with dynamic stability in the past.	The team will purchase couplers with a length that is at least 1.5 times the diameter and measure couplers to verify length.

Rocket is designed to optimize assembly efficiency on launch day	While adherence to requirement 2.10 ensures the rocket will be assembled in under two hours on launch day, the team believes even more efficient procedures can be developed for use on launch day.	When finalizing the design of the rocket, separation points will be picked so that each respective subsystem can work on their section of the rocket without having to wait for other subsystems. Additionally, launch day procedures will be created and strictly followed on launch day to ensure quick assembly of the rocket.
Camera can start recording after it is fastened into the rocket.	Since down body footage of the rocket in flight is such a crucial aspect of post-flight analysis, it is essential that the memory card in the camera system does not run out of space while sitting on the pad so that the fight can be successfully recorded.	The 3D-printed camera housing system will be modified so that an external recording button can be threaded through the rocket and accessed from the outside of the rocket after full assembly.
Reduce motor assembly time on launch day to 15 minutes.	While the team takes every precaution to ensure the safe handling of hazardous material, the longer the material is being worked with, the greater the chance of an accident occurring.	Create and follow a very detailed checklist for motor assembly on launch day.

Recovery

Requirement	Justification	Verification
Altimeters and their wiring will be accessible without having to unpack the parachutes.	To ensure the assembly time on launch day is under two hours. In the event of an issue with the avionics bay, such as a lack of continuity with the altimeters, having easy access to the altimeters will additionally limit time loss and inefficiency.	The avionics board is removable while the parachutes are in the rocket.
Altimeters and their wiring will be accessible without having to disconnect sections of the rocket.	To allow for the arming of the altimeters to be the last action before the launch of the rocket the team must be able to have the entire rocket assembled.	The avionics board containing the altimeters and their wiring is a separate removable component from and body section of the rocket.
Altimeter circuit will be able to be armed while altimeters are inside of the rocket.	To prevent any damage to the avionics circuit prior to launch the switches will be accessible without having to move or adjust any flight hardware.	The switches will be located on the outward facing side of the avionics board so that the altimeters will remain on the internal side of the avionics board while manipulating the switches.
Altimeter circuit will be able to be disconnected while on the pad without removing the altimeters from the rocket.	If the rocket undergoes a malfunction on the pad the first switches need to be able to be flipped off without having to touch any of the avionics circuitry.	The switches will be located on the outward facing side of the avionics board so that the altimeters will remain on the internal side of the avionics board while manipulating the switches.
Altimeters and batteries will be allowed no relative degrees of motion.	To prevent the connecting wires from tangling or disconnecting the altimeters and batteries need to be motionless on the ground and during flight.	The altimeters and batteries will be attached to the same avionics board to restrict any motion both on the ground and in flight.

Altimeters and switches will be allowed no relative degrees of motion.	To prevent the connecting wires from tangling or disconnecting the altimeters and switches need to be motionless on the ground and during flight.	The altimeters and switches will be attached to the same avionics board to restrict any motion both on the ground and in flight.
Altimeters and their wiring will be accessible without interacting with the avionics bay faraday cage.	To prevent any damage to the faraday cage or breaking the circuit the faraday cage will be isolated from the avionics system during installment.	The faraday cage will be inserted into a slotted channel in the avionics bay to prevent it being touched when accessing the avionics circuitry.
All load-bearing hardware in the recovery system shall be independent of the components attached to the altimeters and their wiring.	The team does not want stresses from in-flight forces transmitted through the sensitive electronics. They are not built to handle high loads and could be disrupted or damaged.	The team will use two all-threads that will run through the avionics bay and connect to the bulkheads on either end. SolidWorks simulations will be run to ensure the design has the loads transmitted through them. The electronics will also be placed on the avionics board which will rest within the avionics bay and only friction fit to it.
The detonation of primary and redundant ejection charges will not occur at the same time.	To prevent overpressurization of the parachute chambers which could cause structural damage the redundant altimeter will trigger separation events after the primary altimeter.	The redundant altimeter will be set to deploy drogue 2 seconds after apogee and main 100ft lower. There will be a ground test before launch to confirm that the redundant altimeter is not firing at the same time as the primary altimeter.
The detonation of drogue ejection charge will not produce enough force to break the shear pins in the main section.	Main parachute must deploy after drogue is deployed so the main section shear pins cannot break during drogue separation event.	Several black powder calculations measurements were made and a factor of safety was taken into consideration. There will be a ground test prior to launch to confirm that drogue does not break main shear pins.
No avionics components will be in the same section the ejection charges pressurize.	The avionics electronics are sensitive and may not handle the pressures required to deploy the parachutes.	The parachute chambers will be separated from the avionics bay chamber by a bulkhead that only has holes drilled in it large enough for the initiators to fit through.

Parachutes will be made of fire resistant material.	Burned parachutes cannot provide the same drag as a fully functioning parachute. They will cause the rocket to descend and drift in unpredictable and unsafe ways.	Both parachutes and their shroud lines are made of nylon and will be wrapped in a Nomex fire blanket when packed inside the parachute chambers. These will be examined after a ground test prior to launch.
Shock cords will be made of fire resistant material.	Burned shock cords may break causing the rocket to split into multiple sections, some of which may fall in a ballistic descent hitting the ground at unsafe speeds.	Shock cords will be half inch thick Kevlar. These will be examined after a ground test prior to launch.
The inside of the section of body tube where a parachute resides will have no protrusions.	Protrusions may prevent the parachutes from exiting the rocket body or damaging the parachute upon exit. Any damage will cause the rocket to descend and drift in unpredictable and likely unsafe ways.	Protrusions inside the parachute chambers will be filed or sanded down. After a ground test the parachutes will be examined for damage.
Avionics bay must be attached to the avionics coupler section.	The forces from the recovery harness are transferred from one bulkhead to the other through the all-thread rods and do not attach to the avionics body tube sections, preventing any forces from directly being applied to the avionics board.	The avionics bay was epoxied to the avionics coupler with JB Weld.
During descent none of the body tube sections will collide with each other.	If both the drogue and main parachutes are connected the same distance from where the shock cord attaches to the body tube sections the two body tubes could collide with each other after the deployment of both parachutes.	The shock cord for the main parachute has a length of 27 feet, and the parachute will be attached 2/3rds of the way up it. The shock cord for the drogue parachute has a length of 24 feet and the parachute is attached 2/3rds the way down it.
The GPS used for the recovery of the rocket after launch must be located	Exposing the GPS to the hot gases and pressure changes from the ejection charges risks damaging the GPS, making it difficult to locate the rocket after its launch.	The GPS will be located in the nose cone of the rocket to ensure it is as far away from the avionics bay as possible.

where it is least likely to be damaged.		
The all-thread rods must not accidently complete any circuit within the avionics bay.	Exposed metal in the avionics bay provides a possible way for the ejection charges to ignite prematurely if exposed wires connected to the altimeters make contact with the metal all-thread rods.	Plastic shrink tubing is placed on the portion of the all-thread rods located inside the avionics bay with as few gaps between the shrink tubing pieces to ensure as much metal is covered as possible.
The GPS located in the rocket must be able to maintain power for at least one day.	If the team is unable to recover the rocket right after launch and the GPS loses power it will be difficult to determine where the rocket is located.	The GPS the team decided to use for the recovery of the rocket is the Americaloc GL300W which has a battery life of two weeks.
The detonation charges will not have sufficient force to destroy the charge wells in which they occur in.	Destruction or damage to the charge wells creates unnecessary shrapnel that may damage the parachute.	Several black powder calculations measurements were made and a factor of safety was taken into consideration. There will be a ground test prior to launch to confirm that drogue does not break any charge wells.
The initiator wire will remain in contact with the black powder throughout the flight to ensure detonation.	If the initiator wire is not ensured to remain in contact with the black powder, then there is the potential for the initiation spark to not detonate the black powder causing a failure of the ejection system.	Cellulose parachute wadding will be used to pack down the black powder to the bottom of the charge well and the initiator wire will be secured into place to ensure constant contact. A piece of masking tape will be placed on top of the charge well adding a second layer of security.
The avionics bay door will be securely attached to the rocket.	If the door to the avionics bay is not securely attached to the rocket it could detach during launch which poses the risk of the avionics bay falling out of the rocket.	The avionics bay door will be attached to the rocket using four corner screws that penetrate through the avionics bay and and into the avionics coupler, securing not only the door but all avionics components together.

Putty and tape will be used to seal the holes drilled in the avionics bay.	Leaving the holes uncovered would allow hot gases to enter the avionics bay when the ejection charges fire. This would cause a pressure change in the avionics bay, messing with the altimeters. The decreased pressure may not have enough force to break the shear pins.	The team will inspect the avionics bay for black powder residue after conducting a ground test.

Payload

Requirement	Justification	Verification
Rover mass will be kept under 30 oz.	The rover must be kept to a low mass because the motors are only powerful enough to move a rover under 30 oz. Additionally, this will help the launch vehicle meet the expected altitude requirement.	Lightweight materials, primarily PLA plastic with low infill density have been used. Only necessary amounts of wire and required sensors and electronics for the mission have been used. The containment electronics have been designed to be external to the rover body.
Total payload mass will be kept under 50 oz.	This mass has been agreed upon by both the payload and structures subsystems to be the maximum allotted mass for the payload section of the rocket. Meeting this requirement, will allow the rocket to reach its target altitude.	To minimize the amount of wasted mass in the payload section, lightweight materials including PLA plastic have been used. Additionally, infill densities have been optimized to avoid any unnecessary mass.
Upon landing, the rover will be in its proper orientation	The rover must exit the vehicle upright so that clearances can be maximized. Previous design attempted to design a rover capable of driving regardless of its landing orientation but this restricted the amount of clearance the rover could have in loose soil.	A rotating containment mechanism using gravity to move to the correct orientation has been created. Communications electronics are to be used as counterweight to pull the shelves to their correct orientations.

Keep rover and rocket communications electronics independent.	This will minimize the chance of failure due to a short circuit and keep the electronics relatively simple to solder and integrate.	Separate communications systems for the rover and containment mechanism have been created. The rocket features its communications system on the shelf that will be controlling the initiator and solenoid. The rover has a communications system which listens for the drive signal and only controls driving and soil sample recovery.

Safety

Requirement Number	Requirement	Verification	Justification
Safety 1.1	Provide the team with PPE requirements, SDS, machine instructions, FAA laws, and NAR and TRA regulations.	**<u>Demonstration</u>** The Safety Officer must keep all documents available to all team members in the lab to be accessed at any time.	To ensure the team is able to protect themselves from harmful particles and can easily access important rules and regulation if they have any questions.
Safety 1.2	Require and confirm that all team members have completed the Lab Safety and Hazards Awareness training course provided by Penn State.	**<u>Demonstration</u>** The Safety Officer will collect physical copies of the completed quizzes in the lab, displaying the member has completed and passed in the course. Additionally, the Safety Officer will keep a electronic database of every person who has and has not completed their safety training.	To ensure that all team members have completed necessary safety training and are ready to participate in a potentially hazardous environment. Also, to ensure the Safety Officer knows who is not allowed in the lab if they have not completed the proper safety training.
Safety 1.3	Identify safety violations and take appropriate action to correct them.	**<u>Demonstration</u>** Team members that violate the safety requirements set forth by NASA, the University, the NRA, the Safety Officer, or any other relevant governing body shall not be allowed to work in the lab or attend launches until they meet with the Safety Officer and agree to comply with all rules and regulations.	To ensure proper safety techniques are followed and that all rules are rigidly followed. This creates a safe environment for the team to work in.

Safety 1.4	Participate in preparations of testing and the testing to ensure that risks are mitigated.	**Demonstration** The Safety Officer must approve and sign off on each testing procedure before it occurs.	The Safety Officer must understand the risks of the testing so as to adequately assess whether or not it is safe to conduct. This ensures safety for all team members and creates a safety-first attitude.
Safety 1.5	Enforce proper use of PPE during manufacturing, construction, testing, and launch of the rocket.	**Inspection** The Safety Officer will oversee these processes. If the Safety Officer cannot attend and supervise, a lead or executive member that is qualified will supervise in the Safety Officer's absence.	To ensure all team members remain safe during all phases of the competition and reduce the severity or likelihood of being harmed.
Safety 1.6	Create a Safety manual throughout the season that will be completed by the end of this season and be implemented next year. The Safety manual will include NAR and TRA rules and regulations along with FAA, federal, state, and local regulations relevant to LTRL. Additionally, it will include any PPE requirements and other requirements to work in the lab as determined by the Safety Officer and the team. Finally, it will include all SDS for materials stored in the lab or used by the team.	**Demonstration** The Safety Officer will work with other members of the team to effectively create a safety manual throughout the year and will give updates at each leads meeting.	To proper store and file all necessary rules and regulations regarding the USLI competition and have easy access to the documents. Additionally, to ensure members have access to any policies at all times and the team can verify if they are in compliance with all rules at any time.

6.6 Gantt Charts

LionTech Rocket Labs Gantt Chart

Student Launch Gantt Chart

CLUB NAME Liontech Rocket Labs

DATE 3/3/19

LionTech Rocket Labs

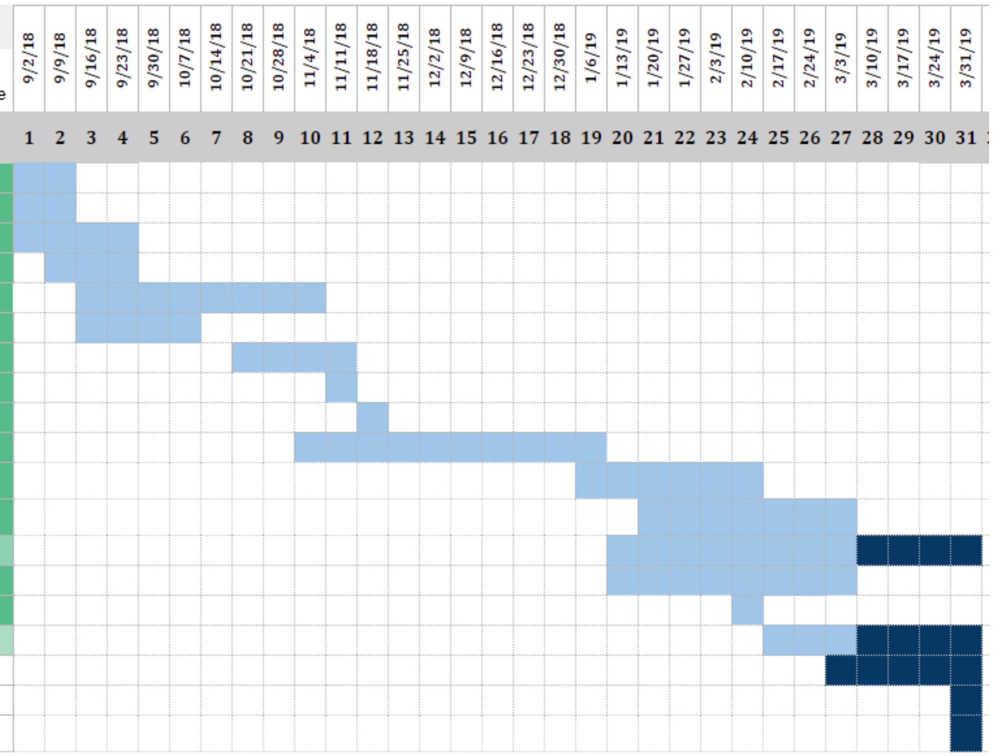
2018-2019 Student Launch Gantt Chart

Legend

Actual Date

Planned Date

Project Milestones	Plan Start	Plan Duration	Actual Start	Actual Duration	Progress
Fullscale Initial Design	9/2/18	2 weeks	9/2/18	2 weeks	100%
Payload Initial Design	9/2/18	2 weeks	9/2/18	2 weeks	100%
Proposal	9/2/18	3 weeks	9/9/18	4 weeks	100%
Subscale Design	9/9/18	2 weeks	9/9/18	3 weeks	100%
Payload Design	9/16/18	8 weeks	9/16/18	8 weeks	100%
Subscale Construction	9/23/18	3 weeks	9/16/18	4 weeks	100%
PDR	9/23/18	4 weeks	10/21/18	4 weeks	100%
Subscale Flight	11/4/18	1 week	11/4/18	1 week	100%
Redesign	11/5/18	1 week	11/5/18	1 week	100%
CDR	11/4/18	8 weeks	11/4/18	8 weeks	100%
Fullscale Construction	1/5/19	5 weeks	1/5/19	6 weeks	100%
Fullscale Testing	1/20/19	7 weeks	1/20/19	7 weeks	100%
Payload Constuction	1/12/19	12 weeks	1/12/19	8 weeks	67%
FRR	1/13/19	8 weeks	1/13/19	8 weeks	100%
Vehicle Demonstration Launch	2/10/19	1 week	2/10/19	1 week	100%
Payload Integration	2/17/19	6 weeks	2/17/19	3 weeks	50%
Competition Preparation	3/3/19	5 weeks	NA	NA	0%
LRR	3/31/19	1 week	NA	NA	0%
Competition Launch	3/31/19	1 week	N/A	N/A	0%



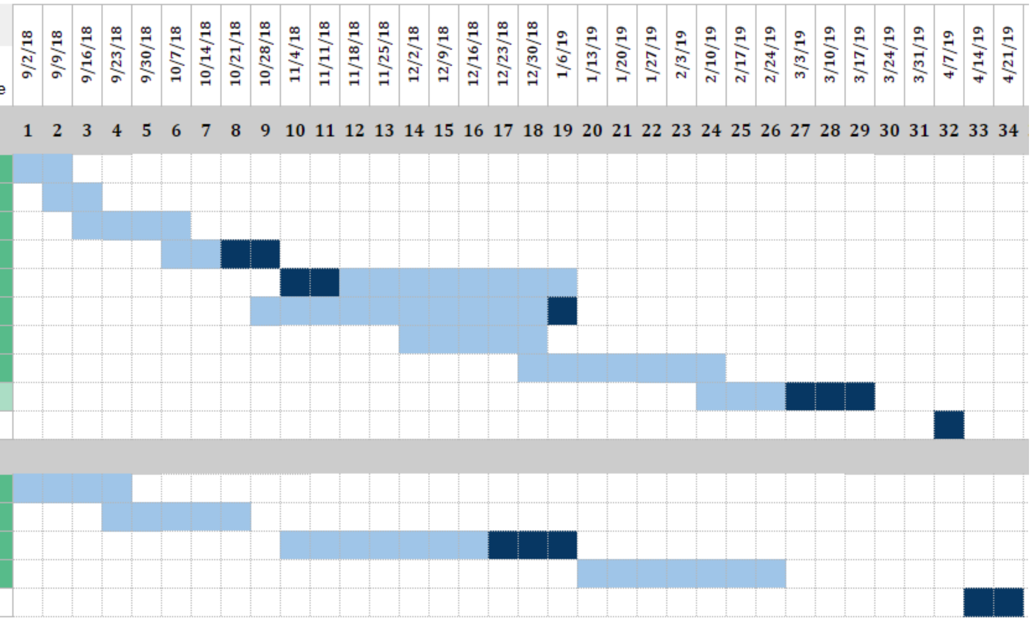
Structures and Propulsion Gantt Chart

Structures 2018-2019		**CLUB NAME**	Liontech Rocket Labs
Student Launch Gantt Chart		**DATE**	1/11/19

Structures / Propulsion
2018-2019 Student Launch Gantt Chart

Legend
- Actual Date (light blue)
- Planned Date (dark blue)

Technical Builds	Plan Start	Plan Duration	Actual Start	Actual Duration	Progress
Preliminary Vehicle Design	9/2/18	2 weeks	9/2/18	2 weeks	100%
Subscale Design	9/9/18	2 weeks	9/9/18	3 weeks	100%
Subscale Construction	9/23/18	3 weeks	9/16/18	4 weeks	100%
Subscale Testing	9/30/18	5 weeks	10/7/18	4 weeks	100%
Subscale Flight Analysis	11/4/18	2 weeks	11/4/18	4 weeks	100%
Fullscale Desgin	11/4/18	9 weeks	11/4/18	8 weeks	100%
Fullscale Construction	12/2/18	5 weeks	12/2/18	5 weeks	100%
Fullscale Testing	12/30/18	7 weeks	12/30/18	7 weeks	100%
Fullscale Flight Analysis	2/10/19	6 weeks	2/10/19	3 weeks	50%
Competition Launch	4/7/19	1 week	N/A	N/A	0%
Reports					
Proposal	9/2/18	3 weeks	9/2/18	4 weeks	100%
PDR	9/23/18	4 weeks	10/21/18	4 weeks	100%
CDR	11/4/18	8 weeks	11/4/18	7 weeks	100%
FRR	1/13/19	7 weeks	1/13/19	7 weeks	100%
PLAR	4/14/19	2 weeks	NA	NA	0%



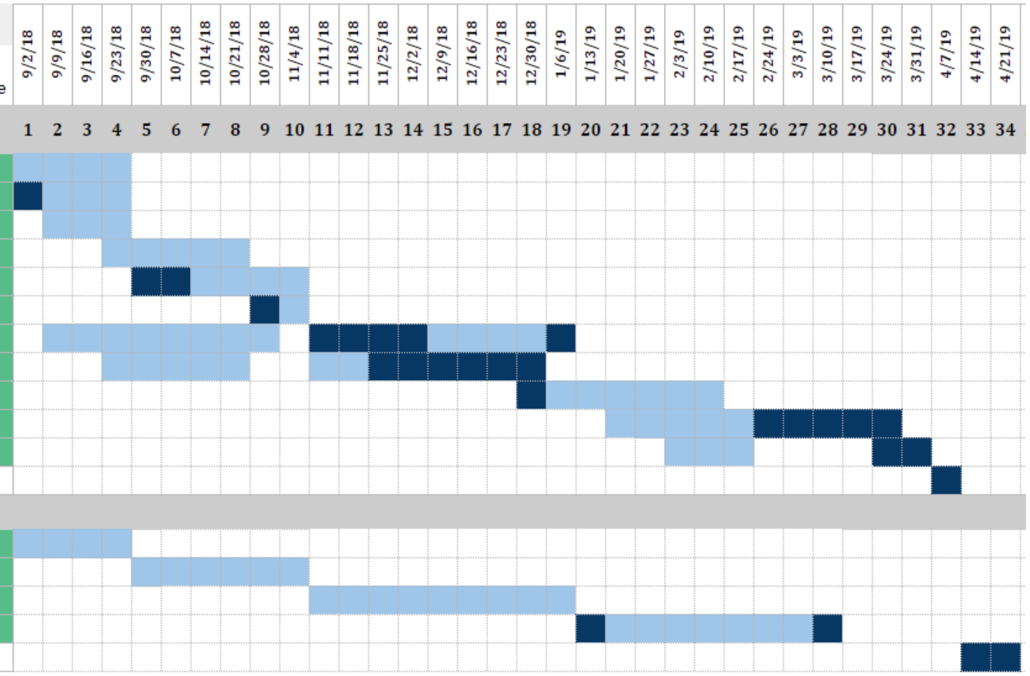
Avionics and Recovery Gantt Chart

Avionics & Recovery 2018-2019		**CLUB NAME**	Liontech Rocket Labs
USLI Gantt Chart		**DATE**	10/21/18

Avionics and Recovery 2018-2019 SLI Gantt Chart

Legend: Actual Date (light blue); Planned Date (dark blue)

Technical Builds	Plan Start	Plan Duration	Actual Start	Actual Duration	Progress
Preliminary Recovery System Concept	9/2/18	4 weeks	9/2/18	4 weeks	100%
Subscale AV Bay Design	9/2/18	4 weeks	9/9/18	3 weeks	100%
Subscale Parachute Selection	9/9/18	3 weeks	9/9/18	3 weeks	100%
Subscale AV Bay Construction	9/23/18	5 weeks	9/23/18	5 weeks	100%
Subscale Recovery System Testing	9/30/18	6 weeks	10/14/18	4 weeks	100%
Final Subscale Recovery System Verification	10/28/18	2 weeks	11/4/18	1 week	100%
Fullscale AV Bay Desgin	11/11/18	9 weeks	9/2/18	12 weeks	100%
Fullscale Parachute Selection	12/2/18	5 weeks	9/23/18	7 weeks	100%
Fullscale AV Bay Construction	12/30/18	7 weeks	1/6/19	6 weeks	100%
Fullscale Recovery System Testing	1/27/19	9 weeks	2/13/19	5 weeks	100%
Final Fullscale Recovery System Verification	3/24/19	2 weeks	2/27/19	3 weeks	100%
USLI Launch	4/7/19	1 week	NA	NA	0%
Reports					
Proposal	9/2/18	4 weeks	9/2/18	4 weeks	100%
PDR	9/30/18	7 weeks	9/30/18	7 weeks	100%
CDR	11/18/18	8 weeks	11/18/18	8 weeks	100%
FRR	1/13/19	11 weeks	NA	NA	99%
PLAR	4/14/19	2 weeks	NA	NA	0%



Payload Gantt Chart

Payload 2018-2019		**CLUB NAME**	Liontech Rocket Labs
Student Launch Gantt Chart		**DATE**	1/11/19

Payload

2018-2019 Student Launch Gantt Chart

Legend: Actual Working Weeks | Actual Date Planned Date

Technical Builds	Plan Start	Plan Duration	Actual Start	Actual Duration	Progress
Preliminary Vehicle Design	9/2/18	2 weeks	9/2/18	2 weeks	100%
Equipment Selection	9/9/18	2 weeks	9/9/18	4 weeks	100%
Motor Selection/Tread Design	10/7/18	3 weeks	10/7/18	5 weeks	100%
Drive Train Design	10/7/18	5 weeks	10/7/18	8 weeks	100%
Assembly of Rover	11/18/18	4 weeks	11/25/18	5 weeks	100%
Complete Software	11/18/18	9 weeks	11/18/18	8 weeks	100%
Consolodate Modules	12/9/18	6 weeks	12/16/18	6 weeks	100%
Test Subsystems of Rover	1/6/19	7 weeks	1/6/19	8 weeks	100%
Test Ful Assembly of Rover	2/17/19	6 weeks	2/17/19	N/A	75%
Pre Launch Modifications	3/31/19	1 week	N/A	N/A	0%
Reports					
Proposal	9/2/18	3 weeks	9/2/18	4 weeks	100%
PDR	9/23/18	4 weeks	10/21/18	4 weeks	100%
CDR	11/4/18	8 weeks	11/11/18	10 weeks	100%
FRR	1/13/19	11 weeks	1/13/19	8 weeks	100%
PLAR	4/14/19	2 weeks	NA	NA	0%

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Date	9/2/18	9/9/18	9/16/18	9/23/18	9/30/18	10/7/18	10/14/18	10/21/18	10/28/18	11/4/18	11/11/18	11/18/18	11/25/18	12/2/18	12/9/18	12/16/18	12/23/18	12/30/18	1/6/19	1/13/19	1/20/19	1/27/19	2/3/19	2/10/19	2/17/19	2/24/19	3/3/19	3/10/19	3/17/19	3/24/19	3/31/19	4/7/19	4/14/19	4/21/19

6.7 Budget

Table 26 displays the expected costs of the 2018-2019 with the updated design. This table includes every individual item that has been purchased so far and all of the projected costs.

Table 26. Expected Outflow for 2018-2019

Fullscale			
Payload	Quantity	Per item	Total
Radio	1	$58.22	$58.22
Soldering Iron and Soldering wire	1		
Stainless Steel Tubing	1		
Dual Shaft Motor	1	$7.62	$7.62
DC Motors	3	$13.02	$39.06
Steel #2-56 x ¼” Phillips Head Machine Screws	1	$2.15	$2.35
Steel #2-56 x 3/8” Phillips Head Machine Screws	1	$2.35	$2.35
LoRa RFM9x Radio	1	$19.00	$19.00
Miscellaneous	1	$100.00	$100.00
Structures			
6.0” Fiberglass 4:1 Ogive Nosecone	1	$149.95	$149.95
6.0” Fiberglass Coupler	1	$69.13	$69.13
6.0” Blue Tube Couplers	2	$19.95	$39.90
3K Plain Weave Carbon Fiber Wrapping	2	$249.95	$499.90
Low Temperature Release Film	2	$14.95	$29.90
Vacuum tubing	1	$1.55	$1.55
Vacuum Connectors	1	$5.25	$5.25
2 Quart Resin Trap	1	$129.95	$129.95
1.5” Rail Buttons	1	$4.65	$4.65
Center Rings 75mm to 6.00”	3	$13.55	$40.65

3.0” Fiberglass Motor Tube	1	$50.00	$50.00
Plywood Bulkheads	11	$8.93	$98.23
3.0” G12 Coupler	1	$15.00	$15.00
6.0” Body Tube Full Length Coupler	1	$66.95	$66.95
Pimoroni LiPo SHIM	1	$9.95	$9.95
Lithium Ion Battery Pack	1	$19.95	$19.95
LiPo Charging Board for USB	1	$6.95	$6.95
UPS Shipping	1	$10.15	$10.15
Lithium Ion Battery (4400 mAh)	1	$19.95	$19.95
64GB Micro-SD Card	1	$13.99	$13.99
Red Oak Sheet of Lumber	2	$12.49	$24.98
18-8 Stainless #6 x ½” Phillips Head Wood Screws	2	$4.33	$8.66
18-8 Stainless #6 x ¾” Phillips Head Wood Screws	1	$5.45	$5.45
18-8 Stainless #6-32 x 1" Phillips Head Wood Screws	1	$6.62	$6.62
Steel #2-56 Hex Nuts	2	$1.00	$2.00
18-8 Stainless #6-32 Hex Nuts	1	$3.40	$3.40
Avionics and Recovery			
GPS Subscription	1	$65.00	$65.00
9V Battery Clips	3	$5.39	$16.17
Toggle Switch with Blue Cover	3	$2.95	$8.85
Mini Toggle Switch	10	$0.95	$9.50
Propulsion			
Aero Pack 75mm Retainer	1	$53.74	$53.74
L-Class Motor	2	$300.00	$600.00
		Fullscale Total	**$2031.85**
Subscale			

Structures			
75mm Blue Tube Full Length Coupler	1	$31.95	$31.95
Coupler Bulkhead Disk 75mm	5	$3.83	$19.15
PVA Release Form	1	$10.75	$10.75
60 Minute Pot Life Hardener	1	$44.95	$44.95
Receipt Paper	1	$19.99	$19.99
Plastic Scrapers	1	$2.99	$2.99
Vacuum Connector	1	$4.95	$4.95
Vacuum Tubing	3	$1.45	$4.35
Plumber's Tape	1	$3.95	$3.95
Nylon Bagging Film	1	$24.95	$24.95
Low Temperature Release Film	1	$29.95	$29.95
Breather and Bleeder Cloth	1	$24.95	$24.95
Nylon Release Peel Ply	1	$39.95	$39.95
Sealant Tape (581-A)	1	$10.95	$10.95
75mm Blue Tube Coupler	1	$9.95	$9.95
Carbon Fiber Fabric (530-C)	1	$249.95	$249.95
Centering Rings 54mm to 75mm	3	$7.30	$21.90
Tube Bulkhead Disk 75mm	6	$3.83	$22.98
Coupler Bulkhead Disk 75mm	5	$3.83	$19.15
Aeropak 54mm Retainer - L	1	$31.03	$31.03
Coupler Bulkhead Disk 6.0	5	$8.93	$44.65
75mm Blue Tube Coupler	2	$10.65	$21.30
Shipping Expenses	1	$100	$100
Propulsion			

Cesaroni J293BS	1	$73.00	$73.00
		Subscale Total	**$867.69**
Travel			
Expected Hotel Costs - 2 Queen Bed Suites	6	$500.00	$3,000.00
Hotel Tax	1	$550.00	$550.00
Minivan Car Rentals	5	$400.00	$2,000.00
Fuel Costs - Alabama Trip	5	$140.00	$700.00
Fuel Costs - Fullscale	1	$400.00	$400.00
Fuel Costs - Subscale Launch	1	$100.00	$100.00
		Travel Total	**$6,750.00**
Outreach			
Miscellaneous Supplies	1	$300.00	$300.00
		Outreach Total	**$300.00**
		Final Total	**10,949.54**

In Table 26, the expected costs are broken up by fullscale, subscale, travel, outreach, and miscellaneous supplies and equipment. Fullscale and subscale are both broken up by subsystems. Subscale only lists purchased items from structures and propulsion because they are the only subsystems that bought new materials, as payload and avionics and recovery used equipment from the lab. Fullscale is a combination between purchased items and expected costs of items. Since the fullscale rocket is still being worked on, the subtotal for fullscale is not yet finalized. Travel continues to be the most expensive subsection. The estimates are becoming more accurate since the Alabama trip is approaching and this gives the club the opportunity to find specific estimates for the actual dates of the trip. Outreach costs contribute to the club's budget as miscellaneous supplies is necessary to host certain outreach events. Miscellaneous supplies and equipment are expenditures that are common use items in the lab. Most of these items are shared amongst subsystems, so these costs are noted under this header. Table 27 gives an overall outlook on where the club's funds are going for the 2018-2019 school year.

Table 27. Overall Outflow

Budget	Total Cost
Fullscale	$2,353.78
Subscale	$867.69
Travel	$6,750.00
Outreach	$300.00
Miscellaneous	$500.00
Total	**$10,771.47**

Table 27 shows the total cost of each subsection from Table 26. This gives a better viewpoint of where the club's funds are going. The outflow shown in Table 27 can also be seen in chart form in Figure 61. Travel and fullscale continue to be the most expensive. Since the club tries to take as many students to Alabama as possible, a large amount of transportation and housing is necessary. Fullscale is also costly due to the large sized rocket and having proper equipment and materials to ensure the success of the rocket.

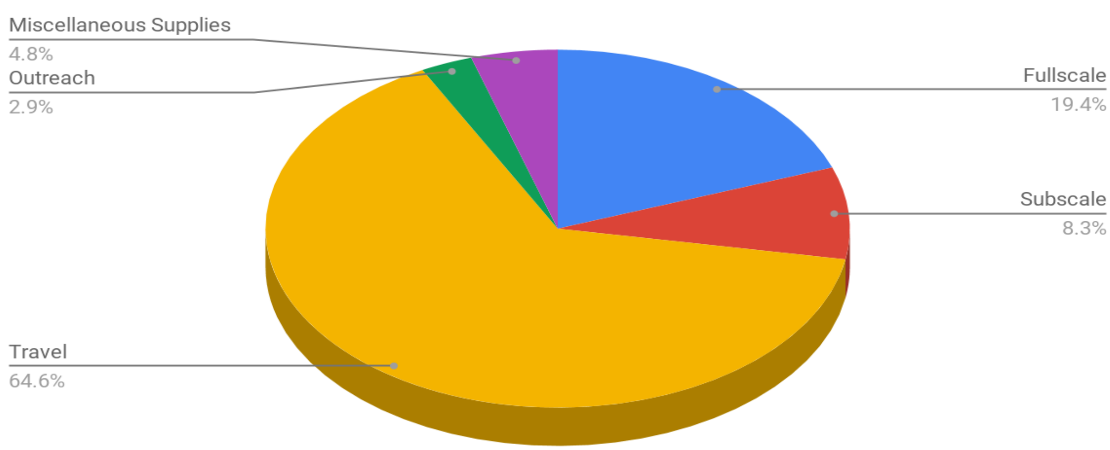


Figure 61. Expected Outflow

6.8 Funding

Table 28. Expected Inflow for 2018-2019

Source of Funds	Received Funds
Penn State College of Engineering	$1,000.00
Penn State Aerospace Engineering Department	$2,000.00
Penn State Mechanical Engineering Department	$1,500.00
University Park Allocations Committee (UPAC)	$10,000.00
Club Fundraising	$1,250.00
Pennsylvania Space Grant	$2,000.00
The Boeing Company	$500.00
Northrop Grumman	$200.00
Total	$18,450.00

Table 28 shows the club's current funding plan. The club believes to have ample funding needed in order to complete our mission. The College of Engineering has donated to the club $1,000.00. Penn State's Aerospace Engineering Department has promised to give the club the club monetary donation of $2,000.00 as well as the continued donation of giving the club lab space. The PSU Mechanical and Nuclear Engineering Department has donated $1,500.00 to LTRL. The club expects to get $10,000.00 in funding from University Park Allocations Committee (UPAC). $5,000.00 will go towards equipment purchases and $5,000.00 will go towards travel funds. UPAC is a university sponsored club that helps other organizations financially. Club fundraising accounts for the money the club itself brought about. This is mainly through dues as well as any other fundraising opportunities that may come about. The club has raised $1,250.00 so far by collecting dues. The Boeing Company has continued their sponsorship in giving $500.00 to LTRL. Additionally, this year, the Student Launch sponsor, Northrop Grumman has promised to give $200.00 to each SLI team. In order to better visualize the club's funding, the chart shown in Figure 62 displays the expected inflow.

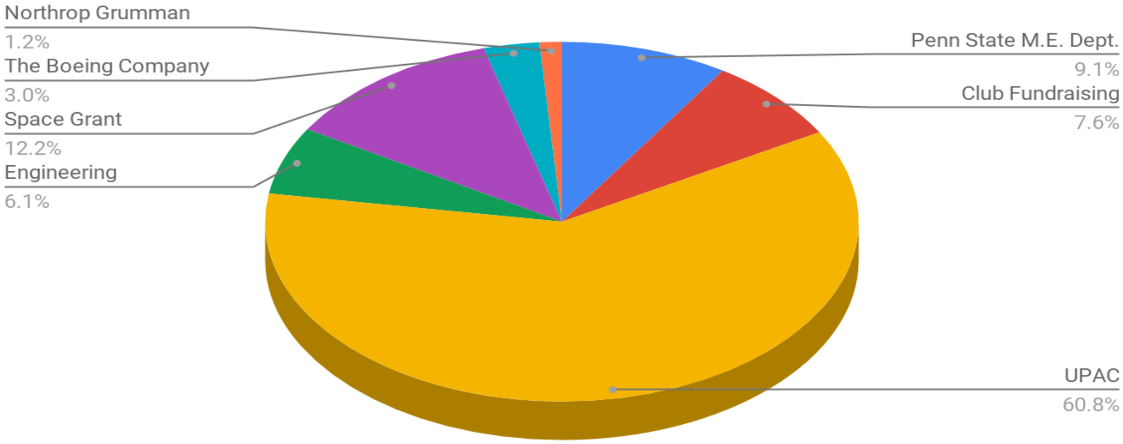


Figure 62. Expected Inflow

7. Appendix A: MSDS Sheets

Fibre Glast Developments Corporation

GHS SAFETY DATA SHEET (SDS)

SECTION 1 - PRODUCT AND COMPANY IDENTIFICATION

PRODUCT: Part #2000 System 2000 Epoxy Resin

FIBRE GLAST DEVELOPMENTS CORP.
385 CARR DRIVE
BROOKVILLE, OH 45309

TELEPHONE: (937) 833-5200
FAX: (937) 833-6555
FOR CHEMICAL EMERGENCY
CALL (801) 629-0667 24 HRS.

RECOMMENDED USE: Industrial Epoxy Resin supplied exclusively for workplace use.

SECTION 2 – HAZARDS IDENTIFICATION

GHS CLASSIFICATION

Eye Irritation	: Category 2B
Acute Toxicity (Oral)	: Category 5
Skin Irritation	: Category 2
Skin Sensitizer	: Category 1
Respiratory Irritation	: STOT SE3

GHS Label Element
Hazard pictogram :

Signal Word : Warning

Hazard statements :
H320 Causes eye irritation.
H303 May be harmful if swallowed.
H315 Causes skin irritation.
H317 May cause an allergic skin reaction.

PDCT-SDS-00130 [Version 1.01]
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Full SDS: https://s3.amazonaws.com/cdn.fibreglast.com/downloads/PDCT-SDS-00130.pdf

Epoxy Hardener SDS

GHS SAFETY DATA SHEET (SDS)

SECTION 1 - PRODUCT AND COMPANY IDENTIFICATION

PRODUCT: Part #2060 Epoxy Hardener

FIBRE GLAST DEVELOPMENTS CORP.
385 CARR DRIVE
BROOKVILLE, OH 45309

TELEPHONE: (937) 833-5200
FAX: (937) 833-6555
FOR CHEMICAL EMERGENCY
CALL (801) 629-0667 24 HRS.

RECOMMENDED USE: Industrial Curing Agent supplied exclusively for workplace use.

SECTION 2 – HAZARDS IDENTIFICATION

GHS CLASSIFICATION

Eye Damage	: Category 1
Acute Toxicity (Oral and Inhalation)	: Category 4
Skin Sensitizer	: Category 1

GHS Label Element
Hazard pictograms :

Signal Word	: Danger
Hazard statements	: H318 Causes serious eye damage. H302+332 Harmful if swallowed, or if inhaled. H317 May cause an allergic skin reaction.
Precautionary statements	: P202 Do not handle until all safety precautions have been read/understood. P261 Avoid breathing dust/fume/gas/mist/vapours/spray. P270 Do not eat, drink or smoke when using this product. P281 Use personal protective equipment as required. P285 In case of inadequate ventilation wear respiratory protection. P273 Avoid release to the environment.

PDCT-SDS-00132 [Version 1.02]
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Full SDS: https://s3.amazonaws.com/cdn.fibreglast.com/downloads/PDCT-SDS-00132.pdf

Black Powder SDS

1 **SAFETY DATA SHEET-BLACK POWDER**

Section 1: Identification

Product Identifier: Black Powder (includes all grades)

Manufacturer's Name: GOEX Powder, Inc. **Informational Telephone Number**:1-(318) 382-9300

Address: P.O. Box 659 **Emerg. Phone Number**: 1-(800) 255-3924 (Chem Tel)

Doyline, LA 71023-0659

Recommended Use: for use in competitive and recreational shooting, muzzleloading hunting and the U.S. Military .

Section 2: Hazard(s) Identification

Hazard category:	Signal Word	Hazard statement	Pictogram
Division 1.1	Danger	Explosive; mass explosion hazard	

Target Organ Warning: Above OSHA levels, chronic exposure may cause skin irritation and damage to the respiratory system, and acute exposure can cause skin, eye, and respiratory irritation.

Section 3: Composition/information on ingredients

Component	CAS-Number	Weight %
Charcoal	16291-96-6	8-18%
Sulfur	7704-34-9	9-20%
Potassium Nitrate	7757-79-1	70-76%
Graphite (note: not contained in all grades of black powder)	7782-42-5	<1%

Section 4: First-aid measures

Ingestion: * Not a likely route of exposure. If ingested, dilute by giving two glasses of water and induce vomiting. Avoid, when possible and contact a Poison control center for advice on treatment, if unsure.

Eye Contact: * Not a likely route of exposure. Flush eyes with water.

Inhalation: * Remove patient from area to fresh air. If not breathing, give artificial respiration, preferably by mouth to mouth. If breathing is difficult, give oxygen. Seek prompt medical attention. Avoid when possible.

Skin Contact: * wash the affected area with copious amounts of water. Some persons may be sensitive to product.

Injury from detonation: * Seek prompt medical attention immediately.

Note to Physician: * Treat symptomatically.

Section 5: Fire-fighting measures

Extinguishing media: * Water may be used as the extinguishing method. DO NOT FIGHT EXPLOSIVES FIRES. Evacuate the area according to Emergency Response Guide 112 guidelines. Isolate the area and guard against any intruders.

Special Procedures: * Black Powder is extremely flammable and may deflagrate. Get away and evacuate the area.

Unusual Hazards: * As with any pyrotechnic, if under confinement or piled in slight confinement, Black Powder can explode. No known toxic fumes are emitted, but good ventilation should still be present.

Flash Point: not applicable.

Auto ignition Temp: Approximate range: 392° -867^{0}F /(200°-464°C)

NFPA Ratings: **Health=1** **Flammability=3** **Reactivity=1**

Advice and PPE for Firefighters: * Fires involving Black Powder should not be fought unless extinguishing media can be applied from a well protected and distant location from the point of fire. Self-contained breathing apparatus (SCBA) and protective clothing must be worn. Follow Emergency Response Guide 112. Wash all clothes prior to reuse.

Full SDS: https://goexpowder.com/wp-content/uploads/2018/05/sds-sheets-goex-black-powder.pdf

Carbon Fiber SDS

GHS SAFETY DATA SHEET (SDS)

SECTION 1 - PRODUCT AND COMPANY IDENTIFICATION

PRODUCT: Part #530 – 3K Plain Weave Carbon Fiber Fabric

FIBRE GLAST DEVELOPMENTS CORP.
385 Carr Drive
BROOKVILLE, OH 45309

TELEPHONE: (937) 833-5200
FAX: (937) 833-6555
FOR CHEMICAL EMERGENCY
CALL (801) 629-0667 24 HRS.

RECOMMENDED USE: Standard Composite Manufacturing

SECTION 2 – HAZARDS IDENTIFICATION

Classification of the substance or mixture

OSHA Regulatory Status : This Product is Not Hazardous under the OSHA Hazard Communication Standard.
Physical Hazards : Combustible Dust – USH01
Health Hazards : Not Classified
Environmental Hazards : Not Classified

Physicochemical : Physical: Carbon fiber contained in some products is electrically conductive.

Label elements

Signal Word : Warning

Hazard Statements : USH01 May form combustible dust concentrations in air

Other hazards
Warning! This may cause mild, temporary mechanical eye and skin irritation. Vapor or fumes evolved during use and/or heating or curing the product may cause respiratory tract and eye irritation. Dust or particulates from machining, grinding or sawing the cured product may cause skin, eye and upper respiratory tract irritation, allergic skin reaction and possible sensitization.

PDCT-SDS-00074 [Version 1.01]
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Full SDS: https://s3.amazonaws.com/cdn.fibreglast.com/downloads/PDCT-SDS-00074.pdf

Fiberglass SDS

Fiberglass Safety Data Sheet

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1 Product identifier

- Fiberglass

1.2 Relevant identified uses of the substance or mixture and uses advised against

- Structural reinforcement for thermoset resin products.

1.3 Details of the supplier of the safety data sheet

- NOV Fiber Glass Systems
  17115 San Pedro Avenue, Suite 200
  San Antonio, Texas 78232 USA
  Tel: 1-210-477-7500
  Fax: 1-210-231-5915
  E-mail: Mike.Thayer@nov.com

1.4 Emergency telephone number(s)

- 3E Company, 24-Hour Support (Access Code/Contract Number: 333386)
  - USA, Canada 1-888-298-2344
  - Asia, Pacific 1-760-476-3960
  - Europe, Middle East, Africa 1-760-476-3961
  - Americas 1-760-476-3962

SECTION 2: Hazards identification

2.1 Classification of the substance or mixture

Physical

- Not classified

Health

- Skin irritation, Category 2
- Eye irritation – Category 2
- Specific target organ systemic toxicity – single exposure, Category 3 (respiratory tract irritation)

Environmental

- Not classified

Full SDS: http://www.nov.com/docHandler.aspx?puid=UvdNvuUs3oL35C

Isopropyl Alcohol SDS

TSI MSDS 1080546 Rev H

Version: 1.2
Revision date: 03-06-2015

SAFETY DATA SHEET

1. Identification

Product identifier: Isopropyl Alcohol

Other means of identification
Product No.: 9088, 5892, 9095, 9084, 9083, 9082, 9079, 9078, 9059, 9055, 9045, 5986, 5978, 5977, 5967, 5873, 5863, 9827, 5373, 9334

Recommended use and restriction on use
Recommended use: For use in the PortaCount® Respirator Fit Tester
Restrictions on use: Not known.

Manufacturer/Importer/Supplier/Distributor information
Manufacturer

Company Name:	TSI Incorporated
Address:	500 Cardigan Road Shoreview, MN 55126
Telephone:	Customer Service: 800-874-2811
Fax:	
Contact Person:	
e-mail:	answers@tsi.com

Emergency telephone number:
24 Hour Emergency: 908-859-2151

Chemtrec: 800-424-9300

2. Hazard(s) identification

Hazard classification

Physical hazards

Flammable liquids	Category 2

Health hazards

Serious eye damage/eye irritation	Category 2A
Specific target organ toxicity - single exposure	Category 3

Label elements
Hazard symbol:

Signal word: Danger

Hazard statement: Highly flammable liquid and vapor. Causes serious eye irritation. May cause respiratory irritation. May cause drowsiness or dizziness.

SDS_US - SDS000000696 Page 1 of 10

Full SDS: http://www.tsi.com/uploadedFiles/_Site_Root/Products/Literature/MSDS/1080546-MSDS-Isopropyl-Alcohol-TSI.pdf

J-B Kwik SDS

MATERIAL SAFETY DATA SHEET

1. Product and Company Identification

Product Name	**J-B Kwik**
Synonym(s)	Resin and Hardener
CAS #	Mixture
Product use	Bonds and repairs
Manufacturer	J-B Weld Company P.O. Box 483 Sulphur Springs, TX 75482 US Phone: 903-885-7696

2. Hazards Identification

Emergency overview
CAUTION
MAY CAUSE EYE IRRITATION. MAY CAUSE SKIN IRRITATION.
MAY CAUSE ALLERGIC SKIN REACTION.

Potential short term health effects

- **Routes of exposure**: Eye, Skin contact, Ingestion.
- **Eyes**: May cause irritation.
- **Skin**: Contact with skin can cause irritation and allergic reaction (sensitization) in some individuals.
- **Inhalation**: Not a normal route of exposure.
- **Ingestion**: May cause stomach distress, nausea or vomiting.

Target organs: Eyes. Skin.

Chronic effects: Prolonged or repeated exposure can cause drying, defatting and dermatitis.

Signs and symptoms: Symptoms may include redness, edema, drying, defatting and cracking of the skin. Symptoms of overexposure may be headache, dizziness, tiredness, nausea and vomiting.

OSHA Regulatory Status: This product is a "Hazardous Chemical" as defined by the OSHA Hazard Communication Standard, 29 CFR 1910.1200.

Potential environmental effects: See section 12.

3. Composition / Information on Ingredients

Ingredient(s)	CAS #	Percent
Iron	7439-89-6	5 - 10
Limestone	1317-65-3	10 - 30
Oxirane, 2,2-[(1-methylethylidene)bis(4,1-phenyleneoxymethylene)]bis, homopolymer	25085-99-8	10 - 30
Phenol, 2,4,6-tris[(dimethylamino)methyl]-	90-72-2	1 - 5
Phenol, polymer with formaldehyde, glycidyl ether	28064-14-4	1 - 5
Carbon black	1333-86-4	0.1 - 1
Titanium oxide	13463-67-7	0.1 - 1

4. First Aid Measures

First aid procedures

- **Eye contact**: Flush with cool water. Remove contact lenses, if applicable, and continue flushing. Obtain medical attention if irritation persists.
- **Skin contact**: Flush with cool water. Wash with soap and water. Obtain medical attention if irritation persists.
- **Inhalation**: Not a normal route of exposure.
- **Ingestion**: Do not induce vomiting. Never give anything by mouth if victim is unconscious, or is convulsing. Obtain medical attention.

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Full SDS: https://cdn.shopify.com/s/files/1/0411/5921/files/J-B-Weld-MSDS-KwikWeld.pdf?1921

J-B Steel Reinforced Epoxy Resin SDS

SAFETY DATA SHEET

Issuing Date 11-Nov- 2014 **Revision Date** 11-Nov-2014 **Revision Number** 1

1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND OF THE COMPANY/UNDERTAKING

Product identifier

Product SDS Name **Steel Reinforced Epoxy Resin – Twin Tubes - Part A**

J-B Weld FG SKU Part Numbers Covered

8265, 8265F, 8276, 8276F, 8265S, 8265A, 8265H, 8272, 8272F, 8280, 8280F, 8281, 80165, 7265S, 7280, 8276A, 8273H, 8270, 8270F, 8271, 80176, 7276, 7270

J-B Weld Product Names Covered

J-B Weld™ (all Twin Tubes), KwikWeld™ (all Twin Tubes), MarineWeld™ (Twin Tubes Only)

J-B Weld Product Type

Steel Reinforced Epoxy

Recommended use of the chemical and restrictions on use

Recommended Use	General Purpose Adhesive
Uses advised against	No information available

Details of the supplier of the safety data sheet

Supplier Name	J-B WELD COMPANY,LLC
Supplier Address	1130 COMO ST SULPHUR SPRINGS, TX 75482 USA
Emergency Telephone Numbers	Transportation Emergencies: Chemtrec (24 hour transportation emergency response info): 800-424-9300 or 703-527-3887 Poison/Medical Emergencies: Poison Control Centers (24 hour emergency poison / medical response info): 800-222-1222
Supplier Email	info@jbweld.com
Supplier Phone Number	903-885-7696

2. HAZARDS IDENTIFICATION

OSHA/HCS status	This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).
Classification of the substance or mixture	SKIN CORROSION/IRRITATION - Category 2 SERIOUS EYE DAMAGE/ EYE IRRITATION - Category 2B
GHS label elements	SKIN SENSITIZATION - Category 1

Hazard pictograms	
Signal word	Warning!
Hazard statements	Causes skin and eye irritation. May cause an allergic skin reaction.

Full SDS:
https://cdn.shopify.com/s/files/1/0411/5921/files/Steel_Reinforced_Epoxy_Twin_Tubes.pdf?785811878289892783

Synthetic Hi-Temp Grease, No.2 SDS

SAFETY DATA SHEET

Mystik® JT-6® Synthetic Hi-Temp Grease, No. 2, ISO 220

Mystik LUBRICANTS

Section 1. Identification

GHS product identifier	:	Mystik® JT-6® Synthetic Hi-Temp Grease, No. 2, ISO 220
Synonyms	:	Lubricating grease; CITGO® Material Code: 665077002
Code	:	665077002
MSDS #	:	665077002
Supplier's details	:	CITGO Petroleum Corporation P.O. Box 4689 Houston, TX 77210 sdsvend@citgo.com
Emergency telephone number	:	Technical Contact: (800) 248-4684 Medical Emergency: (832) 486-4700 CHEMTREC Emergency: (800) 424-9300 (United States Only)

Section 2. Hazards identification

OSHA/HCS status	:	While this material is not considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200), this SDS contains valuable information critical to the safe handling and proper use of the product. This SDS should be retained and available for employees and other users of this product.
Classification of the substance or mixture	:	Not classified.
GHS label elements		
Signal word	:	Warning
Hazard statements	:	Injection under the skin can cause severe injury. Most damage occurs in the first few hours. Initial symptoms may be minimal.
Precautionary statements		
General	:	Avoid contact with eyes, skin and clothing.. IF IN EYES: Rinse cautiously with water for several minutes. IF SWALLOWED: Do NOT induce vomiting. After handling, always wash hands thoroughly with soap and water. If you feel unwell, seek medical attention and show the label when possible. Keep out of reach of children.
Prevention	:	Not applicable.
Response	:	Not applicable.
Storage	:	Store in a dry place and/or in closed container. Store in accordance with all local, regional, national and international regulations.
Disposal	:	Dispose of contents and container in accordance with all local, regional, national and international regulations.
Hazards not otherwise classified	:	Injection of petroleum hydrocarbons requires immediate medical attention

Section 3. Composition/information on ingredients

Substance/mixture	:	Mixture
Other means of identification	:	Lubricating grease; CITGO® Material Code: 665077002
CAS number/other identifiers		
CAS number	:	Not applicable.

Date of issue/Date of revision : *1/21/2016* *1/9*

Full SDS: http://docs.mystiklubes.com/msds_pi/665077002.pdf

Spray Paint SDS

SAFETY DATA SHEET

51601

Section 1. Identification

Product name : KRYLON® ColorMaster™ with Covermax™ Technology Paint + Primer Gloss Black

Product code : 51601

Other means of identification : Not available.

Product type : Aerosol.

Relevant identified uses of the substance or mixture and uses advised against

Paint or paint related material.

Manufacturer : Krylon Products Group
101 W. Prospect Avenue
Cleveland, OH 44115

Emergency telephone number of the company : US / Canada: (216) 566-2917
Mexico: SETIQ 01-800-00-214-00 / (52) 55-5559-1588 24 hours / 365 days a year

Product Information Telephone Number : US / Canada: (800) 457-9566
Mexico: Not Available

Regulatory Information Telephone Number : US / Canada: (216) 566-2902
Mexico: Not Available

Transportation Emergency Telephone Number : US / Canada: (216) 566-2917
Mexico: SETIQ 01-800-00-214-00 / (52) 55-5559-1588 24 hours / 365 days a year

Section 2. Hazards identification

OSHA/HCS status : This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Classification of the substance or mixture : FLAMMABLE AEROSOLS - Category 1
GASES UNDER PRESSURE - Compressed gas
SKIN CORROSION/IRRITATION - Category 2
SERIOUS EYE DAMAGE/ EYE IRRITATION - Category 2A
CARCINOGENICITY - Category 2
SPECIFIC TARGET ORGAN TOXICITY (SINGLE EXPOSURE) (Respiratory tract irritation) - Category 3
SPECIFIC TARGET ORGAN TOXICITY (SINGLE EXPOSURE) (Narcotic effects) - Category 3
SPECIFIC TARGET ORGAN TOXICITY (REPEATED EXPOSURE) - Category 2
ASPIRATION HAZARD - Category 1

Percentage of the mixture consisting of ingredient(s) of unknown oral toxicity: 39.3%
Percentage of the mixture consisting of ingredient(s) of unknown dermal toxicity: 70.8%
Percentage of the mixture consisting of ingredient(s) of unknown inhalation toxicity: 72.2%

GHS label elements

Hazard pictograms :

Signal word : Danger

Date of issue/Date of revision : 10/26/2018 *Date of previous issue* : 10/12/2018 *Version* : 11 1/17

51601 KRYLON® ColorMaster™ with Covermax™ Technology Paint + Primer Gloss Black **SHW-85-NA-GHS-US**

Full SDS: https://www.krylon.com/document/SDS/en/US/724504016014

Talcum Powder Resin SDS

MINERALS TECHNOLOGIES

TALC

Safety Data Sheet

according to Federal Register / Vol. 77, No. 58 / Monday, March 26, 2012 / Rules and Regulations

Date of issue: 09/11/2012 Revision date: 05/09/2016 Supersedes: 02/06/2015 Version: 2.1

SECTION 1: Identification

1.1. Identification

Product form	:	Mixture
Product name	:	TALC
Product code	:	C-MS-AT-2042STDTALC
Other means of identification	:	A-0005 FILLER, ABT® 1000, ABT® 2500, ABT® 2501, CERCRON® MB 2900, CERCRON® MB 3900, CERCRON® MB 50-60, CERCRON® MB 93-37, CERCRON® MB 96-67, CERCRON® MB 96-68, CERCRON® MB 99-01, CERCRON® MP 97-30, CERCRON® MP 98-25, CERCRON® MP 99-48, MICROTALC® BP-210, MICROTALC® DM 12-50, MICROTALC® MP 10-52, MICROTALC® MP 11-51, MICROTALC ®MP 12-50, 399 TALC, MICROTALC® MPD 12-50, MICROTALC® MP 12-52, MICROTALC® MP 15-38, MICROTALC® MP 20-40, MICROTALC® MP 25-38, MICROTALC® MP 30-36, MICROTALC® MP 50-26, MICROTALC® MP 70-22, MICROTALC® MP 98-28BC, MICROTALC® MP 45-26 BC, MICROTALC® MPD 2500, MICROTALC® MPD 2501, MICROTALC MPD1250UC, MICROTALC MP210, MICROTUFF® 111, MICROTUFF® 191, PC 2000, TALCRON® MP 10-52, TALCRON® MP 12-50, TALCRON® MP 15-38, TALCRON® MP 25-38, TALCRON® MP 30-36, TALCRON® MP 40-27, TALCRON® MP 44-26, TALCRON® 45-26, ULTRATALC® 609, ULTRATALC® 609D, 9910 Talc, TALCRON 25 LOA, TALCRON 35 LOA, TALCRON 40 LOA, TALCRON 45 LOA, TALCRON 30 LOA, FLEXTALC 405D, FORTI-TALC™ 609LC TALC, FORTI-TALC™ 609HC TALC, FORTI-TALC™ MP1250LC TALC, FORTI-TALC™ MP1250HC TALC, FORTI-TALC™ MP1250UC TALC, FORTI-TALC™ MP1538LC TALC, FORTI-TALC™ MP1538HC TALC, TALCRON MP2040, PC 2000, ICMP 4426, FORTI-TALC™ AG111 LC TALC, FORTI-TALC™ AG111 HC TALC

1.2. Relevant identified uses of the substance or mixture and uses advised against

Use of the substance/mixture : Mineral Additive

1.3. Details of the supplier of the safety data sheet

Barretts Minerals Inc.
8625 Highway 91 South
Dillon,. MT 59725
USA

Tel. 406-683-3323

1.4. Emergency telephone number

Emergency number : +1 760 476 3962
3E Global Emergency Response Services. Access code: 333336 (if you mention SDS name and company name-you don't need the access code)

SECTION 2: Hazard(s) identification

2.1. Classification of the substance or mixture

GHS-US classification

Carcinogenicity Category 1A H350

Full text of H statements : see section 16

2.2. Label elements

GHS-US labeling

Hazard pictograms (GHS-US) :

GHS08

Signal word (GHS-US)	:	Danger
Hazard statements (GHS-US)	:	H350 - May cause cancer (Inhalation)
Precautionary statements (GHS-US)	:	P201 - Obtain special instructions before use P202 - Do not handle until all safety precautions have been read and understood P260 - Do not breathe dust P280 - Wear protective gloves, protective clothing, eye protection, face protection

05/09/2016 EN (English US) Page 1

Full SDS:
https://www.mineralstech.com/docs/defaultsource/company/talc.pdf?sfvrsn=47ea573b_2

Acetone SDS

SAFETY DATA SHEET

Page: 1

Klean-Strip Acetone

Revision: 05/24/2017
Supersedes Revision: 04/15/2015

1. PRODUCT AND COMPANY IDENTIFICATION

Product Name:	Klean-Strip Acetone	
Company Name:	W. M. Barr 2105 Channel Avenue Memphis, TN 38113	**Phone Number:** (901)775-0100
Web site address:	www.wmbarr.com	
Emergency Contact:	3E 24 Hour Emergency Contact	(800)451-8346
Information:	W.M. Barr Customer Service	(800)398-3892
Intended Use:	Paint, stain, and varnish thinning.	
Product Code:	CAC18, DAC18, GAC18, GAC182, QAC18, QAC184, PA12270, GAC18HDQP, GAC18HDWS, GAC18P, PAC181	

2. HAZARDS IDENTIFICATION

Flammable Liquids, Category 2
Serious Eye Damage/Eye Irritation, Category 2
Specific Target Organ Toxicity (single exposure), Category 3

GHS Signal Word: **Danger**

GHS Hazard Phrases:
H225: Highly flammable liquid and vapor.
H319: Causes serious eye irritation.
H335: May cause respiratory irritation.
H336: May cause drowsiness or dizziness.

GHS Precaution Phrases:
P233: Keep container tightly closed.
P210: Keep away from heat/sparks/open flames/hot surfaces. - No smoking.
P280: Wear protective gloves/protective clothing/eye protection/face protection.
P240: Ground/bond container and receiving equipment.
P241: Use explosion-proof electrical/ventilating/lighting equipment.
P243: Take precautionary measures against static discharge.
P242: Use only non-sparking tools.
P264: Wash hands thoroughly after handling.
P261: Avoid breathing gas/mist/vapours/spray.
P271: Use only outdoors or in a well-ventilated area.

GHS Response Phrases:
P370+378: In case of fire, use dry chemical to extinguish.
P303+361+353: IF ON SKIN (or hair): Remove/take off immediately all contaminated clothing. Rinse skin with water/shower.
P305+351+338: IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P337+313: If eye irritation persists, get medical advice/attention.
P304+340: IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing.
P312: Call a POISON CENTER/doctor if you feel unwell.

GHS Storage and Disposal Phrases:
P403+235: Store in cool/well-ventilated place.
P501: Dispose of contents/container according to local, state and federal regulations.
P403+233: Store container tightly closed in well-ventilated place - if product is as volatile as to generate hazardous atmosphere.
P405: Store locked up.

 GHS format

Full SDS: http://www.kleanstrip.com/uploads/documents/GAC18_SDS-LL34.pdf

Water Seal SDS

SAFETY DATA SHEET

2411-

Section 1. Identification

Product name	: THOMPSON'S WATER SEAL® Clear Multi-Surface Waterproofer
Product code	: 2411-
Other means of identification	: Not available.
Product type	: Liquid.

Relevant identified uses of the substance or mixture and uses advised against

Not applicable.

Manufacturer	: THE THOMPSON'S COMPANY 101 Prospect Ave. N.W. Cleveland, OH 44115
Emergency telephone number of the company	: (216) 566-2917
Product Information Telephone Number	: (800) 367-6297
Regulatory Information Telephone Number	: (216) 566-2902
Transportation Emergency Telephone Number	: (800) 424-9300

Section 2. Hazards identification

OSHA/HCS status	: This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).
Classification of the substance or mixture	: CARCINOGENICITY - Category 2 SPECIFIC TARGET ORGAN TOXICITY (REPEATED EXPOSURE) - Category 2 Percentage of the mixture consisting of ingredient(s) of unknown toxicity: 15.4%

GHS label elements

Hazard pictograms :

Signal word	: Warning
Hazard statements	: Suspected of causing cancer. May cause damage to organs through prolonged or repeated exposure.

Precautionary statements

General	: Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand.
Prevention	: Obtain special instructions before use. Do not handle until all safety precautions have been read and understood. Use personal protective equipment as required. Do not breathe vapor.
Response	: Get medical attention if you feel unwell. IF exposed or concerned: Get medical attention.
Storage	: Store locked up.
Disposal	Dispose of contents and container in accordance with all local, regional, national and international regulations.

Date of issue/Date of revision : 4/7/2015. *Date of previous issue* : No previous validation. *Version* : 1 1/10

Full SDS: http://archpdfs.lps.org/Chemicals/Thompsons-Water-Seal.pdf

Paint Thinner SDS

SAFETY DATA SHEET
Klean Strip Paint Thinner

Page: 1

Revision: 05/24/2017
Supersedes Revision: 11/16/2015

1. PRODUCT AND COMPANY IDENTIFICATION

Product Name:	Klean Strip Paint Thinner	
Company Name:	W. M. Barr 2105 Channel Avenue Memphis, TN 38113	**Phone Number:** (901)775-0100
Web site address:	www.wmbarr.com	
Emergency Contact: Information:	3E 24 Hour Emergency Contact W.M. Barr Customer Service	(800)451-8346 (800)398-3892
Intended Use:	Paint, stain, and varnish thinning.	
Product Code:	CKPT94402, GKPT94002B, DKPT94403CA, EKPT94401, GKPT94002, GKPT94002P, GKPT94002T, GKPT94400, PA12779, QKPT94003, QKPT94203, GKPT94002HDWS, GKPT94002PT, PKPT94004	

2. HAZARDS IDENTIFICATION

Flammable Liquids, Category 3
Acute Toxicity: Inhalation, Category 4
Skin Corrosion/Irritation, Category 2
Serious Eye Damage/Eye Irritation, Category 2B
Germ Cell Mutagenicity, Category 1B
Toxic To Reproduction, Category 2
Specific Target Organ Toxicity (single exposure), Category 3
Specific Target Organ Toxicity (repeated exposure), Category 2
Aspiration Toxicity, Category 1

GHS Signal Word: **Danger**

GHS Hazard Phrases:
H226: Flammable liquid and vapor.
H304: May be fatal if swallowed and enters airways.
H315: Causes skin irritation.
H320: Causes eye irritation.
H332: Harmful if inhaled.
H336: May cause drowsiness or dizziness.
H340: May cause genetic defects.
H361: Suspected of damaging fertility or the unborn child.
H373: May cause damage to Central Nervous System (CNS) through prolonged or repeated exposure.

GHS Precaution Phrases:
P201: Obtain special instructions before use.
P202: Do not handle until all safety precautions have been read and understood.
P210: Keep away from heat/sparks/open flames/hot surfaces. - No smoking.
P233: Keep container tightly closed.
P240: Ground/bond container and receiving equipment.
P241: Use explosion-proof electrical/ventilating/lighting equipment.
P242: Use only non-sparking tools.
P243: Take precautionary measures against static discharge.
P260: Do not breathe gas/mist/vapors/spray.
P264: Wash hands thoroughly after handling.
P271: Use only outdoors or in a well-ventilated area.
P280: Wear protective gloves/protective clothing/eye protection/face protection.
P281: Use personal protective equipment as required.

Licensed to W.M. Barr and Company **GHS format**

Full SDS: http://www.kleanstrip.com/uploads/documents/GKPT94002_SDS-GL42E.pdf

Fiberglass Resin SDS

Bondo® Fiberglass Resin Kit, P.N. 401, 401C, 402, 402M, 402C, 402ES, 402T, 402Z, 404, 404C, 404Z 01/12/18

3M

Safety Data Sheet

Document Group:	24-2437-2	**Version Number:**	7.01
Issue Date:	01/12/18	**Supercedes Date:**	09/04/15

Product identifier
Bondo® Fiberglass Resin Kit, P.N. 401, 401C, 402, 402M, 402C, 402ES, 402T, 402Z, 404, 404C, 404Z

ID Number(s):

60-4550-4826-8, 60-4550-5662-6, 60-4550-5663-4, 60-4550-5664-2, 60-4550-5665-9, 60-4550-5666-7, 60-4550-5667-5, 60-4550-6602-1, 60-4550-6603-9, 60-4550-6605-4, 60-4550-6742-5, 60-4550-7373-8, 60-4550-7374-6, 60-4550-7375-3, 60-4550-7376-1, 60-4550-7377-9, 60-4550-8100-4, 60-4550-8101-2, 60-4550-8102-0, 60-4550-8287-9, 60-4550-8288-7, 60-4550-8297-8, 60-4550-8298-6, 60-4550-8299-4, 60-4550-8325-7, 60-4550-8326-5, 60-4550-8327-3, 70-0080-0014-6, 70-0080-0015-3, 70-0080-0016-1, 70-0080-0148-2, 70-0080-0149-0, 70-0080-0150-8, 70-0080-0151-6, 70-0080-0152-4, 70-0080-0153-2

Recommended use
Automotive, Repairing Auto Body

Supplier's details

MANUFACTURER:	3M
DIVISION:	Automotive Aftermarket
ADDRESS:	3M Center, St. Paul, MN 55144-1000, USA
Telephone:	1-888-3M HELPS (1-888-364-3577)

Emergency telephone number
1-800-364-3577 or (651) 737-6501 (24 hours)

This product is a kit or a multipart product which consists of multiple, independently packaged components. A Safety Data Sheet (SDS), Article Information Sheet (AIS), or Article Information Letter (AIL) for each of these components is included. Please do not separate the component documents from this cover page. The document numbers for components of this product are:

24-2429-9, 24-2440-6

DISCLAIMER: The information in this Safety Data Sheet (SDS) is believed to be correct as of the date issued.3MMAKES NO WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR COURSE OF PERFORMANCE OR USAGE OF TRADE.User is responsible for determining whether the3Mproduct is fit for a particular purpose and suitable for user's method of use or application.Given the variety of factors that can affect the use and application of a3Mproduct, some of which are uniquely within the user's knowledge and control,it is essential that the user evaluate the3Mproduct to determine whether it is fit for a particular purpose and suitable for user's method of use or application.

Full SDS:
https://multimedia.3m.com/mws/mediawebserver?mwsId=SSSSSuUn_zu8l00xM8tvNxm1Mv70k17zHvu9lxtD7SSSSSS--

Pyro-Paint SDS

SAFETY DATA SHEET

Product: **634-ZO**
Revision Date: 6/01/2015

1. MATERIAL IDENTIFICATION

Product Name:	**Pyro-Paint 634-ZO**
Product Description:	Off-White, Odorless Liquid
Product Use:	High Temperature Coating
Manufacturer:	Aremco Products, Inc. 707-B Executive Blvd. Valley Cottage, NY 10989
Telephone:	845-268-0039
Emergency Phone:	845-268-0039 or Infotrac (24/7) 800-535-5053

2. HAZARDS IDENTIFICATION

GHS Classification:

Eye Irritation	Category 2A
Skin Irritation	Category 2

GHS Symbol:

GHS Signal Word:
Warning

GHS Hazard Determining Components:
Silicate Solution
Zirconium Oxide
Alumino-Silicate

GHS Hazard Statements for Health Hazards:

H303	Harmful if swallowed.
H315	Causes skin irritation.
H319	Causes serious eye irritation.

GHS Precautionary Statements - Prevention:

P264	Wash hands thoroughly after handling.
P280	Wear protective gloves. Wear eye protection.

GHS Precautionary Statements – Response:

P302 + P352	IF ON SKIN: Wash with plenty of soap and water.
P332 + P313	If skin irritation occurs: Get medical advice/attention.
P305 + P351 + P338	IF IN EYES: Remove contact lenses, if present and easy to do. Rinse cautiously with water for several minutes.
P312	IF SWALLOWED: Call a poison center or doctor if you feel unwell
P362	Take off contaminated clothing and wash before reuse.

GHS Storage/Disposal:

P501	Dispose in accordance with local, regional, national or international regulations

1

Full SDS: https://www.audec.co.jp/products/pdf/msds_bond107.pdf

WD-40 SDS

Safety Data Sheet

1 - Identification

Product Name: WD-40 Multi-Use Product Aerosol ***NOT FOR SALE IN CALIFORNIA*** **Product Use: Lubricant, Penetrant, Drives Out Moisture, Removes and Protects Surfaces From Corrosion** **Restrictions on Use: None identified** **SDS Date Of Preparation: 07/20/2014**	**Manufacturer: WD-40 Company** **Address: 1061 Cudahy Place (92110)** **P.O. Box 80607** **San Diego, California, USA** **92138 –0607** **Telephone:** **Emergency only: 1-888-324-7596 (PROSAR)** **Information: 1-888-324-7596** **Chemical Spills: 1-800-424-9300 (Chemtrec)** **1-703-527-3887 (International Calls)**

2 – Hazards Identification

Hazcom 2012/GHS Classification:
Flammable Aerosol Category 1
Gas Under Pressure: Compressed Gas
Aspiration Toxicity Category 1

Note: This product is a consumer product and is labeled in accordance with the US Consumer Product Safety Commission regulations which take precedence over OSHA Hazard Communication labeling. The actual container label will not include the label elements below. The labeling below applies to industrial/professional products.

Label Elements:

DANGER!
Extremely Flammable Aerosol.
Contains gas under pressure; may explode if heated.
May be fatal if swallowed and enters airways.

Prevention
Keep away from heat, sparks, open flames, hot surfaces – No smoking.
Do not spray on an open flame or other ignition source.
Pressurized container: Do not pierce or burn, even after use.

Response
IF SWALLOWED: Immediately call a POISON CENTER or physician. Do NOT induce vomiting.

Storage
Store locked up.
Protect from sunlight. Do not expose to temperatures exceeding 50°C/122°F. Store in a well-ventilated place.

Disposal
Dispose of contents and container in accordance with local and national regulations.

3 - Composition/Information on Ingredients

Ingredient	CAS #	Weight Percent	US Hazcom 2012/ GHS Classification
Aliphatic Hydrocarbon	64742-47-8	45-50	Flammable Liquid Category 3

Page 1 of 5

Full SDS: https://www.wd40company.com/files/pdf/sds/mup/wd-40-multi-use-product-aerosol-sds-us-ghs-7-20-14.pdf

Great Stuff Gaps and Cracks SDS

GREAT STUFF* Gaps and Cracks
GMID 277059

MATERIAL SAFETY DATA SHEET

1) PRODUCT AND COMPANY IDENTIFICATION

THE DOW CHEMICAL COMPANY
Midland Michigan 48674
USA

24-Hour Emergency Phone Number: 989-636-4400
Customer Service: 800-366-4740

PRODUCT NAME : GREAT STUFF* Gaps and Cracks
MATERIAL TYPE : One component system
ISSUE DATE : 04/26/2007
REVISION DATE : 01/25/2007

2) COMPOSITION/INFORMATION ON INGREDIENTS

Ingredient	CAS Number	%
Prepolymer of MDI and Polyether polyol	mixture	40-70, 60-100 %
Polymethylene polyphenyl Isocyanate containing approx. 40-50 % MDI (4,4 methylene bisphenyl isocyanate) CAS# 101-68-8	9016-87-9	5-10,10-30 %
Liquified Petroleum Mixture containing Isobutane (CAS#75-28-5), propane (CAS# 74-98-6) and dimethyl ether (CAS# 115-10-6)	mixture	10-30%

3) HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW
Sprayed or heated material harmful if inhaled. May cause allergic skin reaction. May cause allergic respiratory reaction and lung injury. Avoid temperatures above 105F (41C). Toxic flammable gases and heat are released under decomposition conditions. Toxic fumes may be released in fire situations. Reacts slowly with water, releasing carbon dioxide, which can cause pressure buildup and rupture of closed containers. Elevated temperatures accelerate this process.

EYE
May cause moderate eye irritation. May cause very slight transient (temporary) corneal injury.

SKIN
Prolonged or repeated exposure may cause slight skin irritation. May cause allergic skin reaction in susceptible individuals. Animal studies have shown that skin contact with isocyanates may play a role in respiratory sensitization. May stain skin. A single prolonged exposure is not likely to result in the material being absorbed in harmful amounts.

INGESTION
Single dose oral toxicity is considered to be low. No hazards anticipated from swallowing small amounts incidental to normal handling operations.

INHALATION
At room temperature, vapors are minimal due to low vapor pressure. However, certain operations may generate vapor or aerosol concentrations sufficient to cause irritation or other adverse effects. Such operations include those in which the material is heated, sprayed or otherwise mechanically dispersed such as drumming, venting or

"*" or (R) Indicates a Trademark of The Dow Chemical Company   Page 1 of 8

Full SDS:
https://www.vercounty.org/MSDS/EMA/34Dow%20Great%20Stuff%20Spray%20Foam.pdf

Gloss Protective Enamel SDS

Date Printed: 5/9/2017 Page 1 / 6

Safety Data Sheet

RUST-OLEUM CORPORATION
• Trusted Quality Since 1921 •
www.rustoleum.com

1. Identification

Product Name:	STRUST +SSPR 6PK GLOSS NAVY BLUE	**Revision Date:**	5/9/2017
Product Identifier:	7723830	**Supercedes Date:**	3/8/2017
Product Use/Class:	Topcoat/Aerosols		
Supplier:	Rust-Oleum Corporation 11 Hawthorn Parkway Vernon Hills, IL 60061 USA	**Manufacturer:**	Rust-Oleum Corporation 11 Hawthorn Parkway Vernon Hills, IL 60061 USA
Preparer:	Regulatory Department		
Emergency Telephone:	24 Hour Hotline: 847-367-7700		

2. Hazard Identification

Classification

Symbol(s) of Product

Signal Word
Danger

Possible Hazards
32% of the mixture consists of ingredient(s) of unknown acute toxicity.

GHS HAZARD STATEMENTS

Carcinogenicity, category 2	H351	Suspected of causing cancer.
Compressed Gas	H280	Contains gas under pressure; may explode if heated.
Eye Irritation, category 2	H319	Causes serious eye irritation.
Flammable Aerosol, category 1	H222	Extremely flammable aerosol.
STOT, repeated exposure, category 2	H373	May cause damage to organs through prolonged or repeated exposure.
STOT, single exposure, category 3, NE	H336	May cause drowsiness or dizziness.

GHS LABEL PRECAUTIONARY STATEMENTS

P201	Obtain special instructions before use.
P210	Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.
P211	Do not spray on an open flame or other ignition source.
P251	Do not pierce or burn, even after use.
P260	Do not breathe dust/fume/gas/mist/vapors/spray.
P264	Wash hands thoroughly after handling.
P271	Use only outdoors or in a well-ventilated area.
P280	Wear protective gloves/protective clothing/eye protection/face protection.
P304+P340	IF INHALED: Remove person to fresh air and keep comfortable for breathing.
P305+P351+P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.

Full SDS: https://www.rustoleum.com/MSDS/ENGLISH/7723830.pdf

Cleaner Degreaser Disinfectant SDS

THE CLOROX COMPANY

SAFETY DATA SHEET

Issuing Date January 5, 2015 **Revision Date** New **Revision Number** 0

1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND OF THE COMPANY/UNDERTAKING

Product identifier

Product Name **Clorox Commercial Solutions® Formula 409® Cleaner Degreaser Disinfectant**

Other means of identification

EPA Registration Number 67619-10

Recommended use of the chemical and restrictions on use

Recommended Use General purpose cleaner, degreaser, and disinfectant

Uses advised against No information available

Details of the supplier of the safety data sheet

Supplier Address
Clorox Professional Products Company
1221 Broadway
Oakland, CA 94612

Phone: 1-510-271-7000

Emergency telephone number

Emergency Phone Numbers For Medical Emergencies call: 1-800-446-1014
For Transportation Emergencies, call Chemtrec: 1-800-424-9300

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Full SDS: https://www.parish-supply.com/documents/CLO35296-01.pdf

Adhesive Spray SDS

MATERIAL SAFETY DATA SHEET

Finished Product

TECHSPRAY

Date Issued: 01/18/2003
MSDS No: 3500-A
Date Revised: 02/01/2012
Revision No: 7

Heavy Duty Adhesive Spray

1. PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: Heavy Duty Adhesive Spray
PRODUCT DESCRIPTION: Contact Adhesive
PRODUCT CODE: 3500-11S

MANUFACTURER
Techspray, L.P.
1001 N.W. 1st Street
P.O. Box 949
Amarillo, TX 79107
Emergency Contact: Chemtrec
Emergency Phone: 1-800-858-4043
Service Number: 1-800-858-4043

24 HR. EMERGENCY TELEPHONE NUMBERS
CHEMTREC CCN#21858 (US Transportation) :(800) 424 - 9300
CANUTEC (Canadian Transportation) :(613) 996 - 6666
Emergency Phone :(800) 858 - 4043

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW
PHYSICAL APPEARANCE: Clear to amber, sticky resin.

POTENTIAL HEALTH EFFECTS
EYES: Liquid contact can cause irritation, which may be severe.
SKIN: Prolonged or repeated contact may cause skin irritation.
INGESTION: Harmful if swallowed.
INHALATION: Prolonged or excessive inhalation may cause respiratory tract irritation.

SIGNS AND SYMPTOMS OF OVEREXPOSURE
EYES: Symptoms of overexposure include: stinging, tearing, redness and pain.
SKIN: May cause slight irritation.
INGESTION: Not a likely route of exposure.

3. COMPOSITION / INFORMATION ON INGREDIENTS

Chemical Name	Wt.%	CAS	EINECS
Hexane	10 - 50	110-54-3	203-777-6
L.P.G.	10 - 25	68476-85-7	
Acetone	10 - 30	67-64-1	200-662-2
Petroleum Distillates	0	64742-89-8	
N-Butane	< 5	106-97-8	

4. FIRST AID MEASURES

EYES: Immediately flush eyes with plenty of water for at least 15 minutes. Get immediate medical attention.
SKIN: Wash with soap and water. Get medical attention if irritation develops or persists.

Full SDS: https://www.techspray.com/content/msds/3500_US_ENG_SDS.pdf

All Purpose Putty SDS

Bondo® All-Purpose Putty, 20052, 20054, 30054, 31252, 31254 03/19/15

3M

Safety Data Sheet

Document Group:	30-8055-3	**Version Number:**	2.00
Issue Date:	03/19/15	**Supercedes Date:**	06/22/12

Product identifier
Bondo® All-Purpose Putty, 20052, 20054, 30054, 31252, 31254

ID Number(s):

41-0003-7991-1, 41-0003-7992-9, 60-4550-6801-9, 60-4550-6802-7, 60-4550-6829-0, 60-4550-8112-9, 60-4550-8113-7

Recommended use
Putty/Filler used for home repairs.

Supplier's details

MANUFACTURER:	3M
DIVISION:	Automotive Aftermarket
ADDRESS:	3M Center, St. Paul, MN 55144-1000, USA
Telephone:	1-888-3M HELPS (1-888-364-3577)

Emergency telephone number
1-800-364-3577 or (651) 737-6501 (24 hours)

This product is a kit or a multipart product which consists of multiple, independently packaged components. A Safety Data Sheet (SDS), Article Information Sheet (AIS), or Article Information Letter (AIL) for each of these components is included. Please do not separate the component documents from this cover page. The document numbers for components of this product are:

30-8057-9, 29-5993-0

DISCLAIMER: The information in this Safety Data Sheet (SDS) is believed to be correct as of the date issued. 3M MAKES NO WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR COURSE OF PERFORMANCE OR USAGE OF TRADE. User is responsible for determining whether the 3M product is fit for a particular purpose and suitable for user's method of use or application. Given the variety of factors that can affect the use and application of a 3M product, some of which are uniquely within the user's knowledge and control, it is essential that the user evaluate the 3M product to determine whether it is fit for a particular purpose and suitable for user's method of use or application.

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Page 1 of 2

Full SDS:
https://multimedia.3m.com/mws/mediawebserver?mwsId=SSSSSuUn_zu8l00xmxtel8_9mv70k17zHvu9lxtD7SSSSSS--

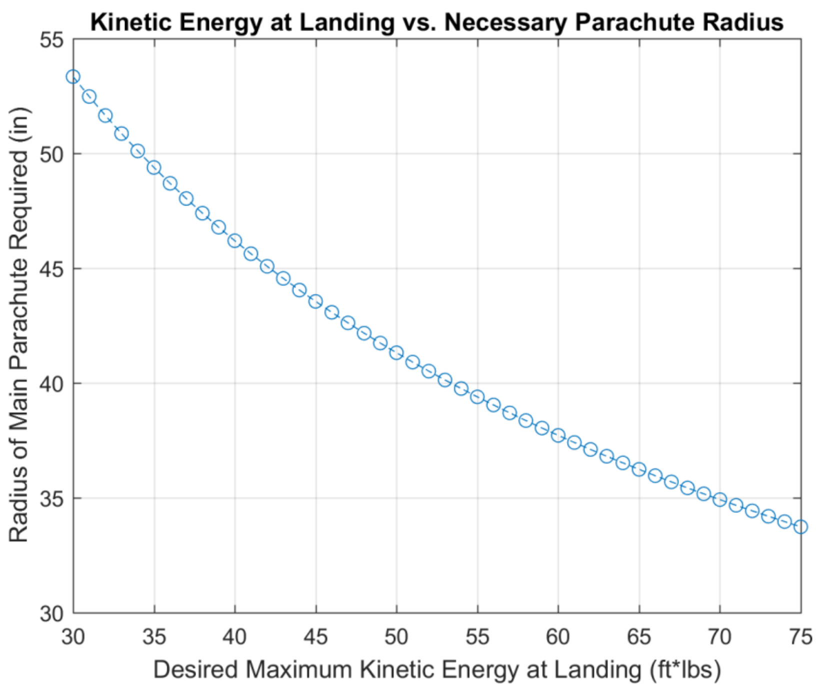
8. Appendix B: Recovery Decent Profile Calculator

```
% RECOVERY DESCENT PROFILE CALCULATOR (RDPC)
% WRITTEN BY EVAN KERR
% PENN STATE LION TECH ROCKET LABS
% AVIONICS AND RECOVERY LEAD
% LATEST UPDATE: 4/20/2017
```

Calculate necessary area of Parachute to meet certain KE on landing

```
clc, clear, close all
%Gravitational acceleration, units: m/s^2
g = 9.81;
%Density in kg/m^3
rho = 1.225;
%Kinetic Energy Limit in ft-lbs
keMax = 75;

%%%%%%%%%%%%%%%%%%%%%%%%% Input Begin %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Coefficient of drag of drogue, main, and tumbling rocket respectively
Cdd = 1.5;
Cdm = 2.2;
Cdr = 1.0;

%These should be in kg
mass(1) = 4.030; %For the fore
mass(2) = 3.478; %For the avionics bay (model minus chord, chutes, and copter)
mass(3) = 4.660; %For the booster
mass(4) = 0.953; %Main parachute
mass(5) = 0.502; %Drogue parachute
%%%%%%%%%%%%%%%%%%%%%%%%%%% Input End %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

maxMass = max(mass);
totMass = sum(mass);

radiusMainM = ones(1,10);
keMatFtLbs = (30:1:75);
keMatJoule = keMatFtLbs*1.3358;

for i = 1:length(keMatJoule)
    radiusMainM(i) = sqrt((maxMass*totMass*g)/(Cdm*keMatJoule(i)*rho*pi));
end

radiusMainFt = 3.281*radiusMainM;
radiusMainIn = radiusMainFt * 12;
```

```
figure(1);
plot(keMatFtLbs,radiusMainIn,'--o')
title('Kinetic Energy at Landing vs. Necessary Parachute Radius');
xlabel('Desired Maximum Kinetic Energy at Landing (ft*lbs)');
ylabel('Radius of Main Parachute Required (in)');
grid on;
```



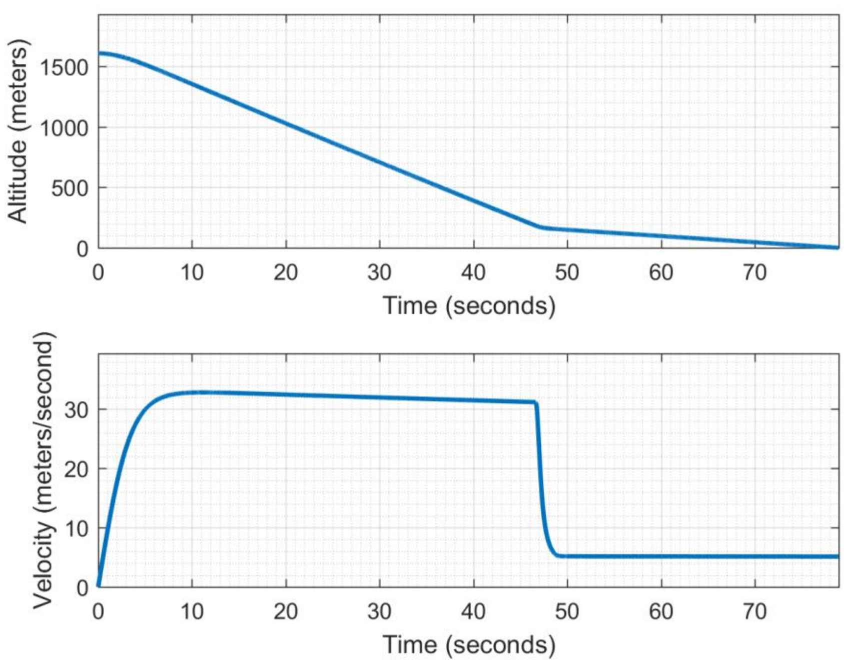
Calculating Force based results

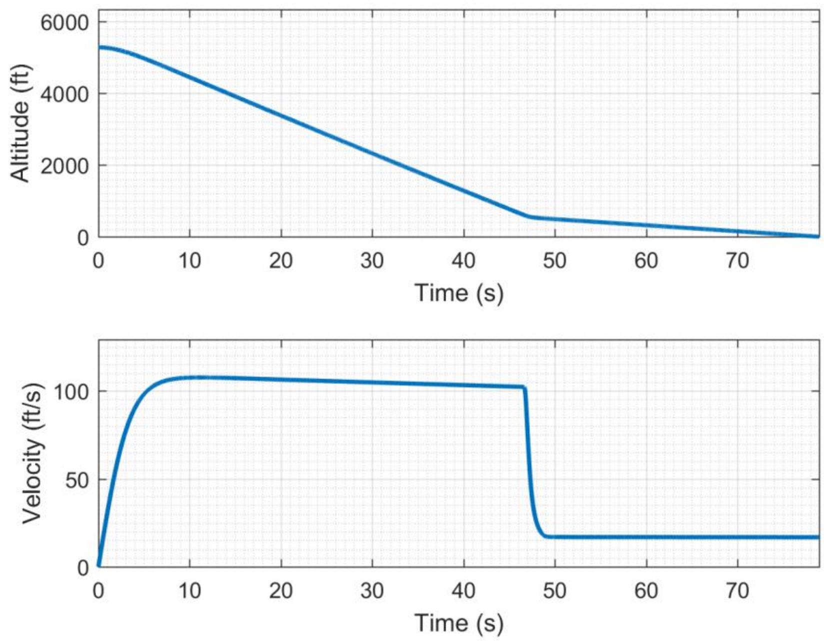
```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Input Begin %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Rd_in = 6; %radius of drogue[in]
Rm_in = 42; %radius of main[in]
Rr_in = 7.5; %simulated radius of "tumbling" rocket parachute[in]

apogeeft = 5280; %apogee altitude above ground level [ft]
altDrogueft = apogeeft-1; %altitude above ground level of drogue deployment[ft]
altMainft = 600; %altitude above ground level of main parachute deployment[ft]

altLaunchSite = 183; % Altitiude above sea level of the launch site in meters
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Input End %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

Rd = 0.0254*Rd_in; %radius of drogue[m]
Rm = 0.0254*Rm_in; %radius of main[m]
Rr = 0.0254*Rr_in; %simulated radius of "tumbling" rocket parachute[m]

apogee = 0.3048*apogeeft;
```

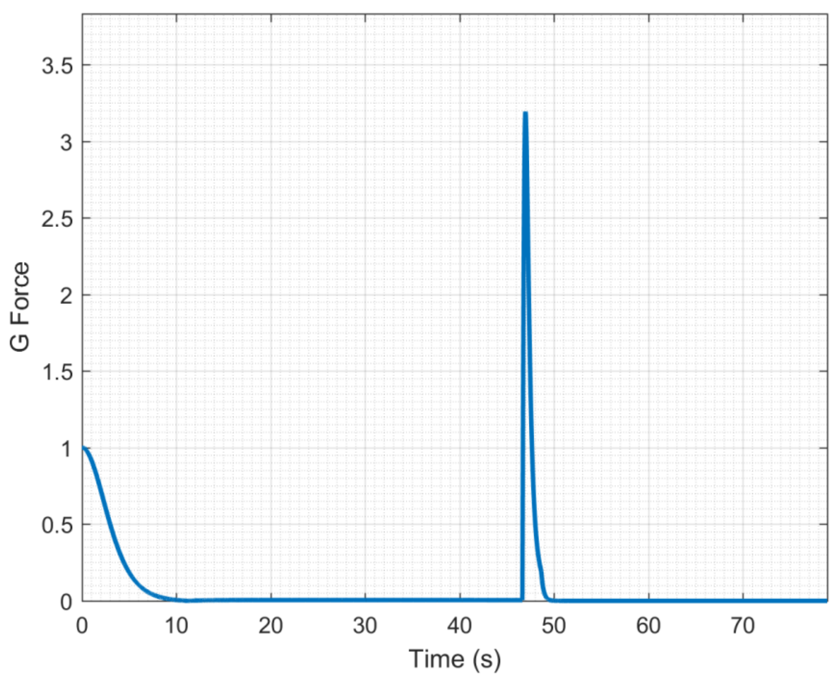
```
altDrogue = 0.3048*altDrogueft;
altMain = 0.3048*altMainft;

% Declare Constants
h = apogee+altLaunchSite; % Initial altitude of the rocket above sea level
h_matrix(1) = h;
time(1) = 0;
dt = 0.01;
v(1) = 0;
a(1) = g;
i = 1; % Counter variable
Temp = 2; % Temperature in Celcius at ground level.
Weight = totMass*g;

% Deployment time and counter initialization for the main and drogue
% parachutes
Kd_dep = 0; % Drogue deployment factor, or how many iterations have run since the drogue was deployed.
Td_dep = 0.25; % Drogue deployment time (how long it takes) in seconds
Td_dep_elapsed = 0;  % Time elapsed since drogue deployment
Km_dep = 0; % Main deployment factor, or how many iterations have run since the main was deployed
Tm_dep = 2;
Tm_dep_elapsed = 0;

%Drag Calculation
while(h >= altLaunchSite) % Although we are integrating over time, the check is whether the height is still above ground level.
  rho_new = rhocalcestSI(h,Temp); % Calculate the density at the given altitude and temperature
  Dragr(i) = .5*Cdr*rho_new*v(i)^2*pi*Rr^2; % Drag of the rocket body
  Dragd(i) = .5*Cdd*rho_new*v(i)^2*pi*Rd^2; % Drag of the drogue parachute
  Dragm(i) = .5*Cdm*rho_new*v(i)^2*pi*Rm^2; % Drag of the main parachute

    if h > (altDrogue + altLaunchSite)% Determines which state of descent the rocket is in and adjusts accordingly by adding the drags
      Drag = Dragr(i); % If the drogue has yet to deploy, the drag of the rocket is the only factor
    elseif h > (altMain + altLaunchSite)
      Kd_dep = Kd_dep + 1; % Increment drogue deployment factor
      Td_dep_elapsed = Kd_dep*dt; % Use the drogue deployment factor to calculate time since drogue deployed
      Drag = Dragr(i) + Dragd(i); % Calculate drage when drogue fully deployed

      % This loop only runs right after chute deployment and models
      % the chute as opening in a linear matter
      if Td_dep_elapsed < Td_dep
        Drag = Dragr(i) + (Td_dep_elapsed/Td_dep)*Dragd(i);
      end
    else
      Km_dep = Km_dep + 1;
      Tm_dep_elapsed = Km_dep*dt;
      Drag = Dragr(i) + Dragd(i) + Dragm(i);
```

```
            if Tm_dep_elapsed < Tm_dep
                Drag = Dragr(i) + Dragd(i) + (Tm_dep_elapsed/Tm_dep)*Dragm(i);
            end
        end
    i = i + 1; % Increment i, the current index value
    a(i) = (-Drag+Weight)/totMass;
    v(i) = v(i-1)+a(i)*dt;
    delh(i) = v(i)*dt;
    h = h-delh(i);
    h_matrix(i) = h;

    time(i) = time(i-1) + dt;
end

figure(2);
ax11 = subplot(2,1,1);
title('Descent Profile In SI Units');

plot(time,h_matrix-altLaunchSite,'LineWidth',2)
ylabel('Altitude (meters)');
xlabel('Time (seconds)');
grid on;
grid minor;
axis([0 max(time) 0 max(h_matrix-altLaunchSite)*1.2]);

ax21 = subplot(2,1,2);
plot(time,v,'LineWidth',2);
ylabel('Velocity (meters/second)');
xlabel('Time (seconds)');
grid on;
grid minor;
axis([0 max(time) 0 max(v)*1.2]);
linkaxes([ax11 ax21],'x');

figure(3)
ax12 = subplot(2,1,1);
title('Descent Profile in English Units');

plot(time,(h_matrix-altLaunchSite)*3.281,'LineWidth',2);
ylabel('Altitude (ft)');
xlabel('Time (s)');
grid on;
grid minor;
axis([0 max(time) 0 max(h_matrix-altLaunchSite)*3.281*1.2]);
```

```
ax22 = subplot(2,1,2);
plot(time,v*3.281,'LineWidth',2);
ylabel('Velocity (ft/s)');
xlabel('Time (s)');
grid on;
grid minor;
axis([0 max(time) 0 max(v)*3.281*1.2]);
linkaxes([ax12 ax22],'x');

figure(4)
title('G Forces vs Time');
plot(time,abs(a/g),'LineWidth',2);
ylabel('G Force');
xlabel('Time (s)');
grid on;
grid minor;
axis([0 max(time) 0 max(abs(a/g))*1.2]);
```





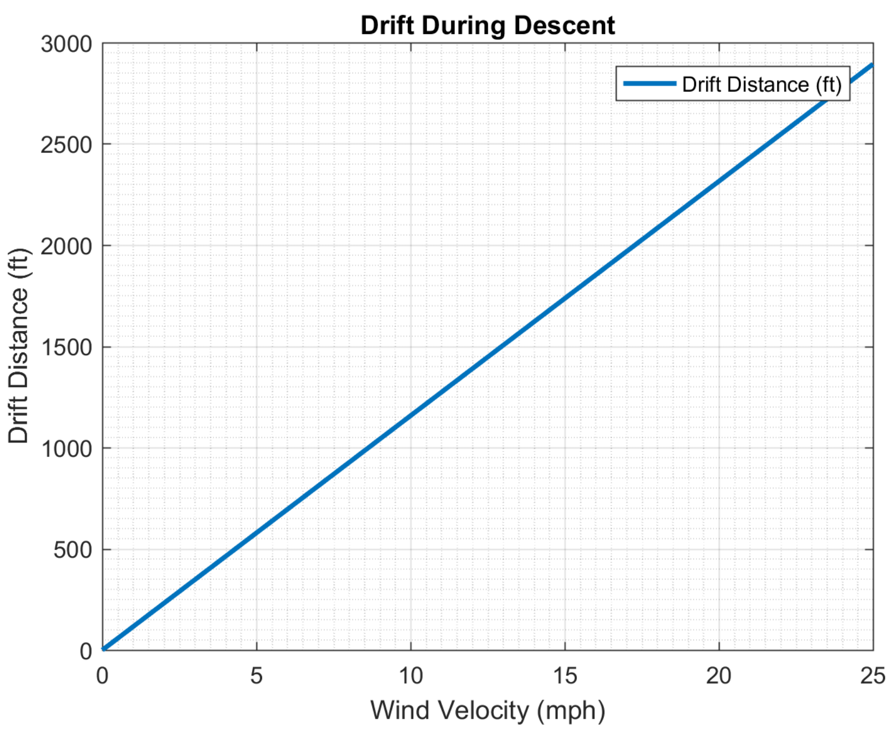


Calculate Drift Distance

```
Windmph = 0:1:25; % Velocity of wind[mph]
Windfps = 1.467*Windmph;
Windmps = Windfps*0.3048;

% Calculate drift distance in metric and standard
descentTime = max(time);
```

```
driftDistM = Windmps*descentTime;
driftDistFt = Windfps*descentTime;

% Plot drift distance
figure(5)
plot(Windmph,driftDistFt,'LineWidth', 2);
ylabel('Drift Distance (ft)');
xlabel('Wind Velocity (mph)');
grid on;
grid minor;
title('Drift During Descent');
legend('Drift Distance (ft)');

% Output max drift distance
fprintf('The drift distance at a wind velocity of 25 mph is %6.1f ft\n\n', max(driftDistFt));
```

The drift distance at a wind velocity of 25 mph is 2894.0 ft



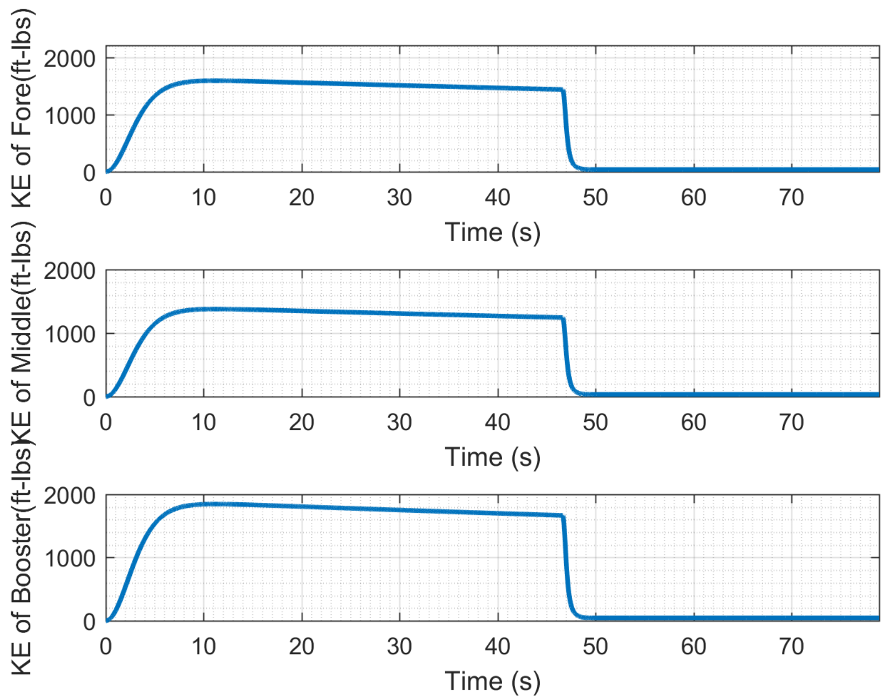
Calculate KE History of each component

```
KEforeSI_mat = (1/2)*v.^2*mass(1);
KEavSI_mat = (1/2)*v.^2*mass(2);
KEboostSI_mat = (1/2)*v.^2*mass(3);

maxKE_SI = max([max(KEforeSI_mat),max(KEavSI_mat),max(KEboostSI_mat)]);
```

```
KEforeST_mat = KEforeSI_mat*0.7376;
KEavST_mat = KEavSI_mat*0.7376;
KEboostST_mat = KEboostSI_mat*0.7376;

maxKE_ST = max([max(KEforeST_mat),max(KEavST_mat),max(KEboostST_mat)]);

% Calculate the KE of each component in Joules at landing
KEforeSI = KEforeSI_mat(end);
KEavSI = KEavSI_mat(end);
KEboostSI = KEboostSI_mat(end);

maxLandingKE_SI = max([KEforeSI,KEavSI,KEboostSI]);

% Calculate the KE of each component in Ft-lbs at landing
KEforeST = KEforeST_mat(end);
KEavST = KEavST_mat(end);
KEboostST = KEboostST_mat(end);

maxLandingKE_ST = max([KEforeST,KEavST,KEboostST]);

figure(6)
ax13 = subplot(3,1,1);
title('Kinetic Energy of Each Component vs. Altitude');

plot(time,KEforeST_mat,'LineWidth',2);
ylabel('KE of Fore(ft-lbs)');
xlabel('Time (s)');
grid on;
grid minor;
axis([0 max(time) 0 maxKE_ST*1.2]);

ax23 = subplot(3,1,2);
plot(time,KEavST_mat,'LineWidth',2);
ylabel('KE of Middle(ft-lbs)');
xlabel('Time (s)');
grid on;
grid minor;
linkaxes([ax13 ax23],'x');

ax33 = subplot(3,1,3);
plot(time,KEboostST_mat,'LineWidth',2);
ylabel('KE of Booster(ft-lbs)');
xlabel('Time (s)');
grid on;
grid minor;
linkaxes([ax23 ax33],'x');
```

```
vf = v(end); %Find final landing velocity

% Print Results
fprintf('The kinetic energy of the nosecone section is %4.2f ft*lbs\n', KEforeST);
fprintf('The kinetic energy of the avionics bay section is %4.2f ft*lbs\n', KEavST);
fprintf('The kinetic energy of the booster section is %4.2f ft*lbs\n\n', KEboostST);

fprintf('The velocity at landing is %4.2f m/s or %4.2f ft/s \n', v(end),v(end) * 3.281);
```

```
The kinetic energy of the nosecone section is 38.96 ft*lbs
The kinetic energy of the avionics bay section is 33.63 ft*lbs
The kinetic energy of the booster section is 45.05 ft*lbs

The velocity at landing is 5.12 m/s or 16.80 ft/s
```



[Published with MATLAB® R2016a](#)

9. Appendix C: Verification of OpenRocket Flight Calculations

```
clc
clear

%CONSTANTS -------------------------------

%Center of Pressure
Ln  = 0.5499;      %length of nosecone [m]
Cnn = 2;           %coeficient of drag for nosecone
Xb  = 2.616;       %length from tip to fin root chord [m]
Xr  = 0.127;       %length from fin root leading edge to fin tip leading edge [m]
Cr  = 0.2032;      %fin root chord length [m]
Ct  = 0.102;       %fin tip chord length [m]
S   = 0.1778;      %fin semispan [m]
N   = 3;           %number of fins
Lf  = 0.19356;     %length of the fin mid-chord line [m]

%Center of Gravity
dn  = 0.4258;      %distance of the nose CG to nose tip [m]
mn  = 1.607;       %mass of the nose [kg]
dp  = 0.8766;      %distance of the payload CG to nose tip [m]
mpayload  = 2.379;  %mass of payload [kg]
dm  = 1.5316;      %distance of the main CG to nose tip [m]
mm  = 4.848;       %mass of main [kg]
dd  = 1.9379;      %distance of the drogue CG to the nose top [m]
md  = 0.907;       %mass of drogue [kg]
db  = 2.563;       %distance of the booster CG to nose tip [m]
mb  = 6.065;       %mass of the booster (with motor) [kg]
M   = mn + mpayload + mm + md + mb;   %mass of the rocket (with motor) [kg]

%Apogee
mr  = 11.964;      %mass of rocket (no motor) [kg]
me  = 3.5635;      %mass of motor [kg]
mprop  = 1.582;    %mass of propellant [kg]
rho = 1.225;       %density of air [kg/m^3]
Cd  = 0.55;        %drag coefficient
D   = 0.1397;      %diameter of body tube [m]
R   = D/2;         %radius of body tube [m]
g   = 9.81;        %gravity constant [m/s^2]
T   = 1405;        %average thrust of motor [N]
t   = 3.63;        %motor burnout time [s]

%CALCULATIONS ------------------------------------
```

```
%Center of Pressure
Xn  = 0.466 * Ln;   %CP location for fins, from tip [m]
Xf  = Xb + ((Xr*(Cr + 2*Ct))/(3*(Cr + Ct))) + (1/6)*((Cr + Ct) - ((Cr*Ct)/(Cr+Ct)));    %CP location of fins, from tip [m]
Cnf = (1+R/(S+R))*(4*N*(S/D)^2/(1+sqrt(1+(2*Lf/(Cr+Ct))^2)));   %CP of fins, from tip [m]
X   = ((Cnn*Xn + Cnf*Xf)/(Cnn+Cnf));    %CP location of rocket from tip [m]

%Center of Gravity
cg = (dn*mn + dp*mpayload + dm*mm + dd*md + db*mb)/M; %CG location of rocket from tip [m]

%Static Stability Calculation
stab = (X - cg) / D;    %static stability margin [calibers]

%Apogee

%Burn Calculations
ma  = mr + me - (mprop/2); %(average) burn mass [kg]
A   = pi*(R^2);        %cross-sectional area of rocket [m^2]
k   = (1/2)*rho*Cd*A;   %aerodynamic drag coefficient [kg/m]
q1  = sqrt((T - (ma*g))/k); %burnout velocity coefficient [m/s]
x1  = (2*k*q1)/ma;      %burnout velocity decay coefficient [1/s]
v1  = q1*((1-exp(-x1*t))/(1+exp(-x1*t)));   %burnout velocity [m/s]
y1  = (-ma/(2*k))*log((T - (ma*g) - (k*v1*v1))/(T-ma*g));   %burnout altitude [m]

%Coast Calculation
mc  = mr + me - mprop;     %coast mass [kg]
qc  = sqrt((T-mc*g)/k); %coast velocity coefficient [m/s]
xc  = ((2*k*qc)/mc);    %coast velocity decay coefficient [1/s]
vc  = qc*((1-exp(-xc*t))/(1+exp(-xc*t)));   %coast velocity [m/s]
yc  = (mc/(2*k))*log((mc*g + k*(vc^2))/(T-mc*g));  %coast distance [m]

%Total Calculation
PA  = y1 + abs(yc);     %apogee [m]

%PRINT VALUES

fprintf('Center of Pressure: %2.4f inches \n', X*39.37);    %print CP [in]
fprintf('Center of Gravity: %2.4f inches \n', cg*39.37);    %print CG [in]
fprintf('Static Stability Margin: %2.4f calibers \n', stab);   %print static stability margin [calibers]
fprintf('Apogee: %2.4f feet \n', PA*3.281);              %print aprogee [ft]
```

Attempt to execute SCRIPT fullscale_simulations as a function:
C:\Users\Evan\Downloads\fullscale_simulations.m

Published with MATLAB® R2016a

10. Appendix D: Tensile Test Procedure

Carbon Fiber Airframe Testing Procedure

Objective:
Determine the tensile load that can be applied to the tube made from 6 layers and 7 layers of carbon fiber. Using these results and predicted loads experience during flight, a safety factor can be obtained to validate the design choice.

Necessary Equipment:

- Sample of 2, 6-inch diameter tubes made from 6 layers and 7 layers of carbon fiber
- 2 Aluminum blocks machined to fit the interior of each body tube and contains 4 threaded holes for machined screws
- 2 Aluminum rods machined to fit through the blocks. These rods are used as attachment points for the tensile equipment
- Minimum of 8 machine screws
- Tensile loading equipment (to be determined by equipment faculty/provider)
- Carbon Fiber Airframe Testing Procedure Document

Assembly

For reliable results, proper assembly of testing equipment is imperative. The assembly procedure shall go as follows:

1. Prepare each tube section for testing; this includes cutting the tube to necessary length (as required by testing equipment or faculty), drilling 4 holes on each end of the tube and ensure alignment of those holes with the aluminum block
2. Align one end of the tube with an aluminum block and secure it using 4 machined screws.
3. **(Important)** Check that the aluminum is aligned perpendicularly to the tube. *Misalignment will disturb testing results as the load will no longer be purely tensile.
4. Feed aluminum rod through the aluminum block with the stop on the interior of the tube; clamp the block once fed through so it cannot fall into the tube.
5. Feed second aluminum rod into second aluminum rod, again with the stop on the side of the block to the interior of the tube. Again clamp the rod so it won't slide out of the block.
6. Align the other end of the tube with the second block-and-rod assembly.
7. **(Important)** Check that the aluminum is aligned perpendicularly to the tube. *Misalignment will disturb testing results as the load will no longer be purely tensile.
8. If alignment is true, this assembly is ready to load into the testing equipment. Load the assembly into the testing equipment by attaching each end of the rod to the testing grips (or similar mechanism depending on tensile equipment).
9. Run the experiment
10. Record the load at failure in the table below.
11. Repeat steps 1-10 for the remaining configurations

Results:

Configuration	Load at failure
6 layers of carbon fiber	
7 layers of carbon fiber	

Success of results:

The test can be deemed successful if all of the following are true:

a. Results are realistic
b. A trend can be examined (i.e. load at failure for 7 layers is higher than 6 layers)
c. Failure is at the screw holes as expected

Validation of design

Determine the safety factor of fullscale design using the failure strength and expected maximum load experienced during flight.