The Pennsylvania State University

LionTech Rocket Labs

2018 - 2019 Solium Project

Preliminary Design Report

046 Hammond Building, University Park, PA 16802
November 2nd, 2018

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List of Acronyms

A&R	Avionics and Recovery
AV	Avionics
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
PLA	Polylactic Acid
PPE	Personal Protective Equipment
PSC	Pittsburgh Space Command
PSU	The Pennsylvania State University
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

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1.2 Launch Vehicle Summary

Size and Mass

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" was chosen to give adequate space for the rover, its retention system, and its deployment system. The length of the flight vehicle is 120" to provide enough space for the payload and the necessary avionics and flight systems. The flight vehicle's wet mass weight is 31.2 lbs. The center of pressure is located 94.34" aft of the tip of the nose cone, and the center of gravity is located 76.57" aft of the tip of the nose cone resulting in a static stability margin of 2.96 calibers.

Preliminary Motor Choice and Official Target Altitude

The motor selection is based on the mission performance criteria outlined in the NASA USLI 2018-19 Handbook and preliminarily uses OpenRocket to simulate flight characteristics. Through this motor selection process the Cesaroni L890SS was selected as the motor that will take our vehicle to the target apogee of 5,280 feet.

Recovery System

The recovery system will consist of a removable and fully redundant avionics bay containing Stratologger CF altimeters, power sources, snap connectors, and ejection charges. A dual-deployment parachute system will be utilized containing a 12" Fruity Chutes Classical Ultra drogue parachute deploying at apogee, and a 72" Fruity Chutes Iris Ultra main parachute deploying at 700 ft above ground level. This will guarantee that the flight vehicle drifts less than 2500 ft, and that all body sections impact the ground with less than 75 ft-lbs of kinetic energy.

1.3 Payload Summary

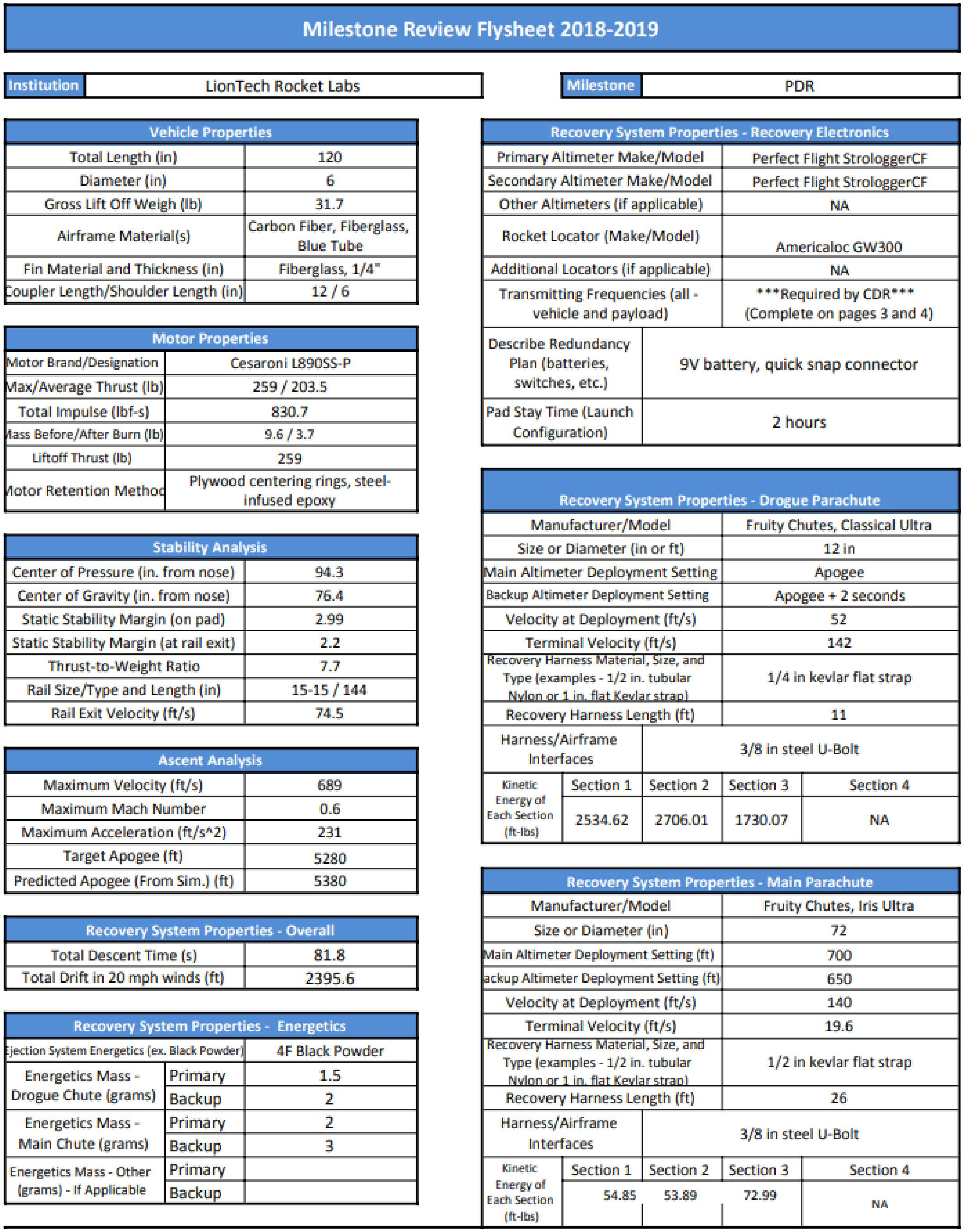
Payload Title

Deployable Rover/Soil Sample Recovery System

Summary of Payload Experiment

The payload criteria section will outline the design decisions for the rover. The section is divided into 2 main parts, mechanical and software/hardware. The rover will be deployed from the launch vehicle's nose cone after landing and then autonomously move at least 10 feet away from all parts of the rocket. After the rover has reached its destination, it will collect a soil sample.

Milestone Review Flysheet



Milestone Review Flysheet 2018-2019

Institution	LionTech Rocket Labs
Milestone	PDR

Vehicle Properties	
Total Length (in)	120
Diameter (in)	6
Gross Lift Off Weigh (lb)	31.7
Airframe Material(s)	Carbon Fiber, Fiberglass, Blue Tube
Fin Material and Thickness (in)	Fiberglass, 1/4"
Coupler Length/Shoulder Length (in)	12 / 6

Motor Properties	
Motor Brand/Designation	Cesaroni L890SS-P
Max/Average Thrust (lb)	259 / 203.5
Total Impulse (lbf-s)	830.7
Mass Before/After Burn (lb)	9.6 / 3.7
Liftoff Thrust (lb)	259
Motor Retention Methoc	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)	2.99
Static Stability Margin (at rail exit)	2.2
Thrust-to-Weight Ratio	7.7
Rail Size/Type and Length (in)	15-15 / 144
Rail Exit Velocity (ft/s)	74.5

Ascent Analysis	
Maximum Velocity (ft/s)	689
Maximum Mach Number	0.6
Maximum Acceleration (ft/s^2)	231
Target Apogee (ft)	5280
Predicted Apogee (From Sim.) (ft)	5380

Recovery System Properties - Overall	
Total Descent Time (s)	81.8
Total Drift in 20 mph winds (ft)	2395.6

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 GW300
Additional Locators (if applicable)	NA
Transmitting Frequencies (all - vehicle and payload)	***Required by CDR*** (Complete on pages 3 and 4)
Describe Redundancy Plan (batteries, switches, etc.)	9V battery, quick snap connector
Pad Stay Time (Launch Configuration)	2 hours

Recovery System Properties - Drogue Parachute				
Manufacturer/Model	Fruity Chutes, Classical Ultra			
Size or Diameter (in or ft)	12 in			
Main Altimeter Deployment Setting	Apogee			
Backup Altimeter Deployment Setting	Apogee + 2 seconds			
Velocity at Deployment (ft/s)	52			
Terminal Velocity (ft/s)	142			
Recovery Harness Material, Size, and Type (examples - 1/2 in. tubular Nylon or 1 in. flat Kevlar strap)	1/4 in kevlar flat strap			
Recovery Harness Length (ft)	11			
Harness/Airframe Interfaces	3/8 in steel U-Bolt			
Kinetic Energy of Each Section (ft-lbs)	Section 1	Section 2	Section 3	Section 4
	2534.62	2706.01	1730.07	NA

Recovery System Properties - Main Parachute				
Manufacturer/Model	Fruity Chutes, Iris Ultra			
Size or Diameter (in)	72			
Main Altimeter Deployment Setting (ft)	700			
ackup Altimeter Deployment Setting (ft)	650			
Velocity at Deployment (ft/s)	140			
Terminal Velocity (ft/s)	19.6			
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)	26			
Harness/Airframe Interfaces	3/8 in steel U-Bolt			
Kinetic Energy of Each Section (ft-lbs)	Section 1	Section 2	Section 3	Section 4
	54.85	53.89	72.99	NA

2. Changes Made Since Proposal

2.1 Changes Made to Vehicle Criteria

Launch Vehicle

The only structural changes made to the flight vehicle since proposal have been the position switch of the main and drogue parachutes and the associated body tube couplers. This moved the center of gravity slightly to the aft of the rocket, lowering the static stability from 3.07 calibers to 2.96 calibers.

Recovery System

The team has reduced the size of the main parachute from 84” to a 72” Fruity Chutes Iris Ultra. The team has also reduced the size of drogue parachute from 24” to a 12” Fruity Chutes Classical Ultra. These changes were made after extensive modeling of the descent characteristics of the flight vehicle after launch. The reduction in main and drogue parachute size decrease the maximum drift distance of the rocket, and allow all sections of the rocket to remain within kinetic energy requirements.

2.2 Changes Made to Payload Criteria

Since proposal, the team has further developed the design for the rover. One of the main mechanisms added to the rover is a rotating payload bay mechanism. The rotational aspect will allow the rover to be oriented in the correct direction to allow it to drive out of the rocket upright upon landing.

Design decisions have also been improved upon for the retaining mechanism which will include a solenoid locking mechanism. The rover will be attached to the inside of the rocket through a 9V powered solenoid that will release the rover when the power is cut off.

2.3 Changes Made to Project Plan

Other than what the subsystems have specified, there are no changes to the project plan.

3. Vehicle Criteria

3.1 Vehicle Design and Justification

Mission Statement and Success Criteria

The mission of the structures team of LTRL for the 2019 NASA Student Launch competition is to build a launch vehicle capable of safely and consistently flying to an altitude of 5,280 feet. This launch vehicle will also be able to hold and successfully deploy a rover payload.

The mission success criteria will be defined by the launch vehicle achieving an altitude within 5% of the target altitude and allowing the rover payload to exit the rocket after landing. This criteria also includes safety standards that require that no team members, launch officials, or spectators be in harm's way at any point during the launch process.

Airframe

In the 2017-2018 competition year, the team built the launch vehicle using carbon fiber wrapped blue tube. For the 2018-2019 competition year, the team has decided to move forward with carbon fiber as the selected material to build the launch vehicle. This decision was made based on a weighted design selection matrix.

The four categories considered were creating carbon fiber tubes using shrink tape, creating carbon fiber tubes using vacuum bagging, purchasing blue tube body tubes, or purchasing glass fiber body tubes. Baking body tubes in an oven or autoclave was not considered due to a lack of necessary tools or sufficient working space.

There are six factors on the material selection matrix that were considered when determining which material would work best for the launch vehicle. A score of 1-5 was assigned to the different factors based on the material's performance in that criteria. A score of one is considered the worst, and a score of five is considered the best. The six factors that were taken into account were strength, cost, workability, material weight, educational value, and safety. Strength was rated on the materials' ability to withstand forces experienced during flight such as thrust forces, impact forces, compressive forces, potential zippering, and buckling. Materials with a higher tensile strength were given a higher score. Cost was determined by the price of the material per linear foot. If a material had a lower cost, it was given a higher score. Workability was scored based on how easy it would be to modify the material to the required dimensions. Material weight is a measure of the material's density. A higher material density received a lower score. Educational value was graded based on how much club members could learn from using the material. Finally, safety was scored based on how hazardous a material is. A safer material received a higher score.

Each of the different criteria were weighted on a scale from zero to one. The factors that the team deemed more important were given a higher weight. The sum of the scores is equal to one. Strength was given a weight of 0.15 to reflect its importance. However, strength did not receive a higher weight because the team has not seen nominal flight conditions lead to catastrophic failure for even the weakest materials. Cost was given a weight of 0.10 to account for the material's important impact on the team's budget. This weight accounts for the possibility that the team needs to rebuild the launch vehicle in the event of a catastrophic launch failure, and needs to replace material as a result. Workability was given a weight of 0.10 to reflect the ease of handling the material under different circumstances. Material weight was given a weight of 0.15 due to its impact on the altitude achieved and the stability of the launch vehicle. Educational value was given a weight of 0.25 because of the importance the club places on educating all the members of the club. Safety was given a weight of 0.25 to account for the hazardousness of all the materials used. Safety risks can be limited if correct steps are taken, but the use of composite materials provides a greater risk to the user.

The scores for the different materials can be found in Table 1 below.

Table 1. 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	0.10	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	4	0.60	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**		**3.55**		**2.35**		**3.25**

Strength

Tensile strength is considered to be the most important factor when determining the strength of a material. The ratings given to the different materials can be found below in Table 2. The launch vehicle will experience multiple forces during its flight. Some examples of these forces are compressive forces during ascent, tensile forces during separation of sections, various shear forces, and an impact force if the parachute deployment is not optimal. Carbon fiber has a high tensile strength as well as a high stiffness. It is three times stiffer than steel or aluminum for a given weight. Glass fiber has a high tensile strength just like carbon fiber, but the stiffness of the material is far lower. Since the launch vehicle is an application where a small amount of flexibility is wanted, glass fiber received a lower score of four. Carbon fiber was given a score of three or five depending on the method used to make the tubes. Shrink tape received a score of a three due to the uneven spread of epoxy throughout the laminate. The team determined that there would be more voids between the matrix and fiber bond than during the vacuum bagging method. The vacuum bagging process to create carbon fiber tubes received a score of five because the epoxy would be more evenly distributed throughout the laminate and any extra epoxy will be wicked out.

Table 2. Material Strength and Stiffness

Material	Tensile Strength [ksi]	Modulus [Msi]
Carbon Fiber	525-655	33-42
Glass Fiber	500-650	10.5-12.4
Blue Tube	560-600	0.55-0.607

Cost

The cost for the composite materials was measured by cost per yard of fabric. The exact cost of carbon fiber could not be determined at this time because it has not been determined how many layers of carbon fiber will be used. More testing is required to determine how many layers of carbon fiber are needed to keep the launch vehicle structurally stable during flight. The prices for all materials can be found below in Table 3.

Table 3. Material Cost Comparison

Material:	Cost/Foot [in $]:
Carbon Fiber	35-58
Glass fiber	55
Blue Tube	18

The cost for carbon fiber was measured using the 3K-Plain Weave variant. The range for the cost per foot comes from the amount of layers the team is deciding to use. Currently, the team is looking at creating body tubes using a range of layers from four-seven. More testing is required to determine what amount of layers will provide a structurally stable rocket that is also as light as possible.

Workability

Glass fiber, carbon fiber created with shrink tape, and carbon fiber created with vacuum bagging were given low scores of three, two and one respectfully. Glass fiber was given a score of three because LTRL would purchase prefabricated tubes for the rocket. This would allow for the tubes to be almost the exact size needed for each section. However, some sanding would still need to be done to correctly fit couplers and bulkheads into the body tubes. Carbon fiber tubes made from using a heat source and shrink tape were given a score of two because the tubes would need to be cut down to get correct dimensions. Also, the tubes would need to be sanded to make flush connections with other sections. Vacuum bagged carbon fiber was given a score of one due to the members’ lack of experience using this technique. Tubes using this technique would also need to be sanded and cut down to correct sizes. Blue tube received a score of five since it can be easily modified to meet the design requirements set by the team.

Weight

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 the supplier's information.

Table 4. Density Discrepancy between OpenRocket and Supplier

	OpenRocket Density (oz/in^3)	Supplier Density (oz/in^3)
Glass Fiber	1.07	1.18
Blue Tube	0.75	0.54
Carbon Fiber	1.03	0.642

For carbon fiber, the team believes that this discrepancy is caused by the specific fabric used. The process at which the tubes are cured will also have an effect on the density of carbon fiber. The team will have to take into account the discrepancies when building the launch vehicle and calculations will have to be done to determine the correct density of carbon fiber.

Educational Value

LTRL has decided to include an educational value category this year as one of the project's main objectives is to involve students in engineering projects, and for those students to learn valuable lessons for their future careers. As the aerospace industry continues to trend towards composite materials, the team decided it would be beneficial to experiment using these materials. For this reason, blue tube received a low score of one since the team has previously used this material in past years, and does not find any additional educational value in using it again. Glass fiber was given a score of two because the prefabricated tubes would be bought and cut down to the correct dimensions. This provides some educational benefit as team members can learn the different properties of glass fiber, but they are unable to learn how this material is made. Since carbon fiber is used throughout the aerospace industry, and only a few members in LTRL have experience using carbon fiber, it received a score of five.

Safety

Blue tube received a score of five as it poses no significant safety hazards. Both carbon fiber and glass fiber received low scores of two and one respectfully because of the difficulties that come with modifying the laminate. Carbon fiber and glass fiber shards are dangerous when inhaled, and can easily be embedded in the skin if proper caution is not taken. Vacuum bagged carbon fiber received a higher safety score than shrink tape carbon fiber because heating the laminate involves the extended application of heat. This requires heat gun which can be a safety hazard if the process is not carefully monitored and controlled.

Final Selection

After all the scores were assigned and weighted, vacuum bagged carbon fiber had the highest score and was selected as a result. The team will test the strength of carbon fiber using different numbers of layers of carbon fiber to determine what the correct amount is to withstand all the forces the launch vehicle is expected to encounter during flight.

Nose Cone

Two different nose cone designs are currently being considered for the flight vehicle. The optimal nose cone will be chosen based on its availability, cost, drag and mass. Currently the two nose cones being considered are ogive or Von Kármán designs. The current nose cone for the flight vehicle is an ogive 4:1 based on its availability, low cost, and mass. A Von Kármán design is being considered due to its low drag. Trade studies that have been done in the past put the ogive design ahead of Von Kármán, but new trade studies need to be done to account for changing availability and cost of a nose cone with a diameter of 6 inches.

Couplers

Couplers will be used in between separation points to hold the flight vehicle together. The coupler materials that were considered were blue tube and glass fiber. The current flight vehicle design uses one blue tube coupler and one glass fiber coupler due to the different forces each coupler will experience. The payload-drogue coupler will be a blue tube coupler because the potential for zippering from drogue parachute deployment is very low during a nominal drogue deployment. The main-booster coupler will be a glass fiber coupler because the chance of a structural failure due to zippering is much higher at main parachute deployment. Each coupler will have a length of 12” with a wall thickness of 0.2”.

Bulkheads

Bulkheads are to be 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”. The current flight vehicle design uses plywood as the material for the bulkheads because of its low cost, availability and low weight. The plywood bulkheads will be fastened to coupler tubes with JB-Weld steel-infused epoxy resin. Glass fiber was also considered as the potential bulkhead material because of its strength. However, glass fiber bulkheads were eliminated because of their higher cost and smaller thickness which would result in weaker epoxy bonds with the body tube.

Motor Retention

Currently, the flight vehicle’s motor will be contained with three centering rings and a motor block. The three centering rings will be epoxied to the motor tube and the body tube at 1”, 11”, and 21” aft of the flight vehicle. The motor block will be epoxied to the body tube at the end of the motor tube 26” aft of the flight vehicle. JB-Weld steel-infused epoxy resin is the epoxy being used to epoxy the centering rings and motor block in. In the current design, the centering rings and motor block are made of ¼” plywood. Glass fiber was also considered but its cost lack of thickness resulting in weaker epoxy bonds resulted in plywood being chosen as the centering ring material. A plywood centering ring motor retention system has been verified through past test and competition flights. The centering ring at 1” aft of the flight vehicle will be cut to accommodate for the fin brackets.

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. G12 Glass Fiber of 3/16” is currently being used as the fin material because its high shear modulus is necessary to resist fin flutter. A dimensioned drawing of the fin is located in Figure 1. While plywood is lighter and costs less, it does not have the strength needed for the forces encountered during flight. The fins will be placed and bolted into fin brackets, which can be easily removed and interchanged.

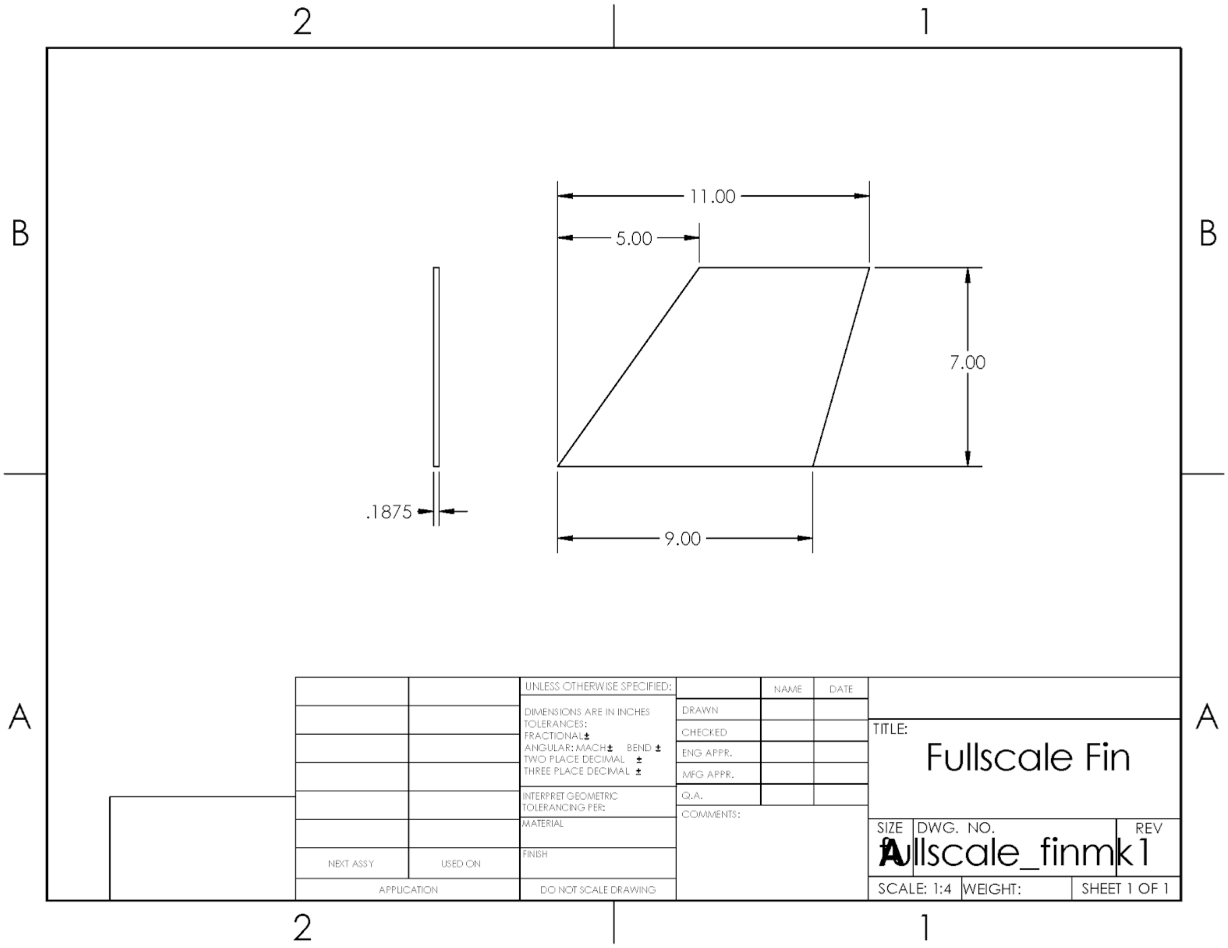


Figure 1. Fin Dimensions

Separation Points

The rocket will separate during flight to release parachutes for descent. Additionally, the nose cone of the rocket will separate from the flight vehicle after it has landed. The current flight vehicle design has two separation points for the parachute. Drogue parachute separation is in between the payload body tube and the drogue body tube, and the main parachute will be deployed in between the booster body tube and the main body tube. These separation points allow for one avionics bay to deploy both parachutes.

The current rover deployment design requires a separation point between the nose cone and the payload body tube. This separation point was chosen to minimize the likelihood that the rover payload would get caught in a shock cord or parachute. The team found that the most feasible way to avoid this failure mode was to use a ground-separation event. This same separation method was used last year, so the team has experience with the complications and possible failure modes associated with this design. Effort will be taken to improve upon last year's design and further ensure the safety of this method.

3.2 Key Design Features

Fin Brackets

The team has decided to use 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. Since fins are often the most common point of structural failure on even nominal landings, this design specifically satisfies Requirement 2.10 since no epoxy or permanent fastening methods are used. The design can be seen in Figure 2.

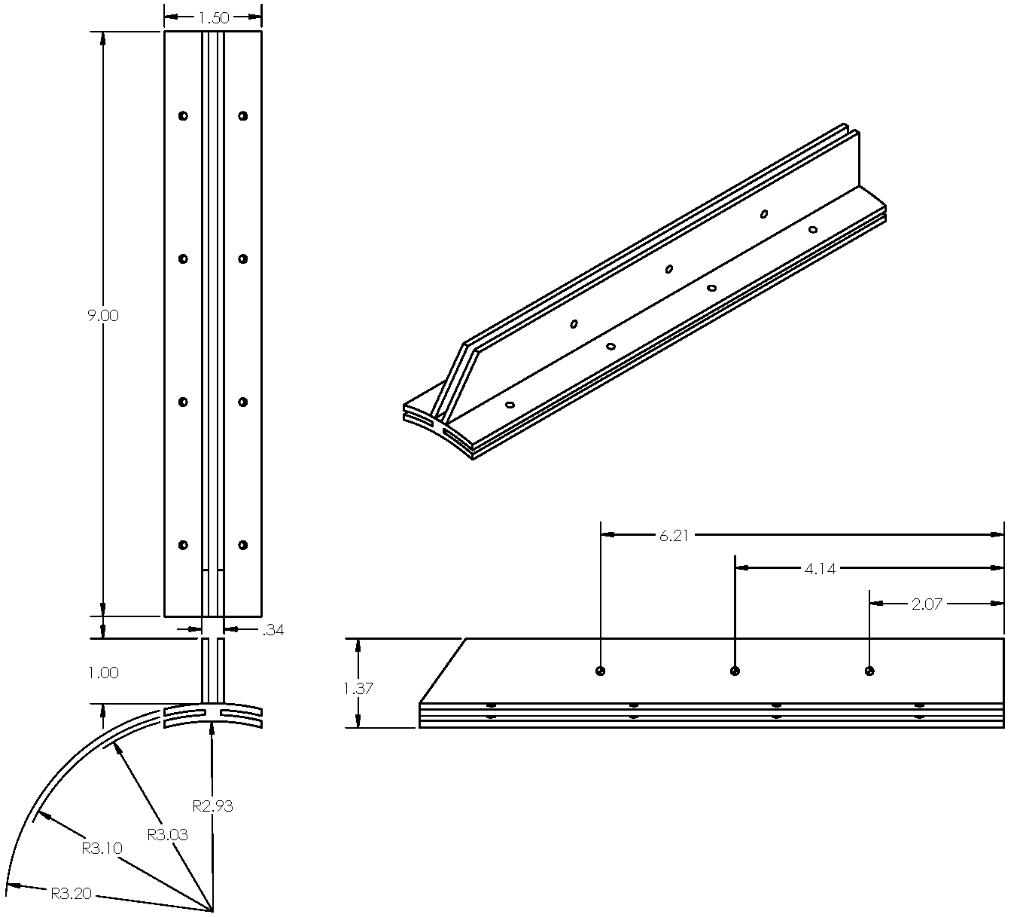


Figure 2. SolidWorks Model of Proposed Fin Brackets

There are holes to employ a screw only retention system. This will allow for LTRL 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 full 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.

Camera Cover

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. For the past two years, the rocket has used a large, cylindrical camera with a diameter of 0.75 in and length of 4 in. This system has not only proven to be aerodynamically inefficient, but the faulty camera has also had multiple recording failures. To prevent this from happening again, a camera system will be built from scratch using a Raspberry Pi. Therefore, the structures team must design a new cover to house this system. To securely seat the camera on the exterior of the rocket, a 3D printed cover will be designed to tightly hold the camera to the body while also providing aerodynamic efficiency.

3.3 Motor Selection

The motor selection is based on the mission performance criteria outlined in the NASA USLI 2018-19 Handbook and preliminarily uses OpenRocket to simulate flight characteristics. Through this motor selection process the Cesaroni L851 was selected as the motor that will take the vehicle to the target apogee of 5,280 ft. The flight profile is detailed in Figure 3.

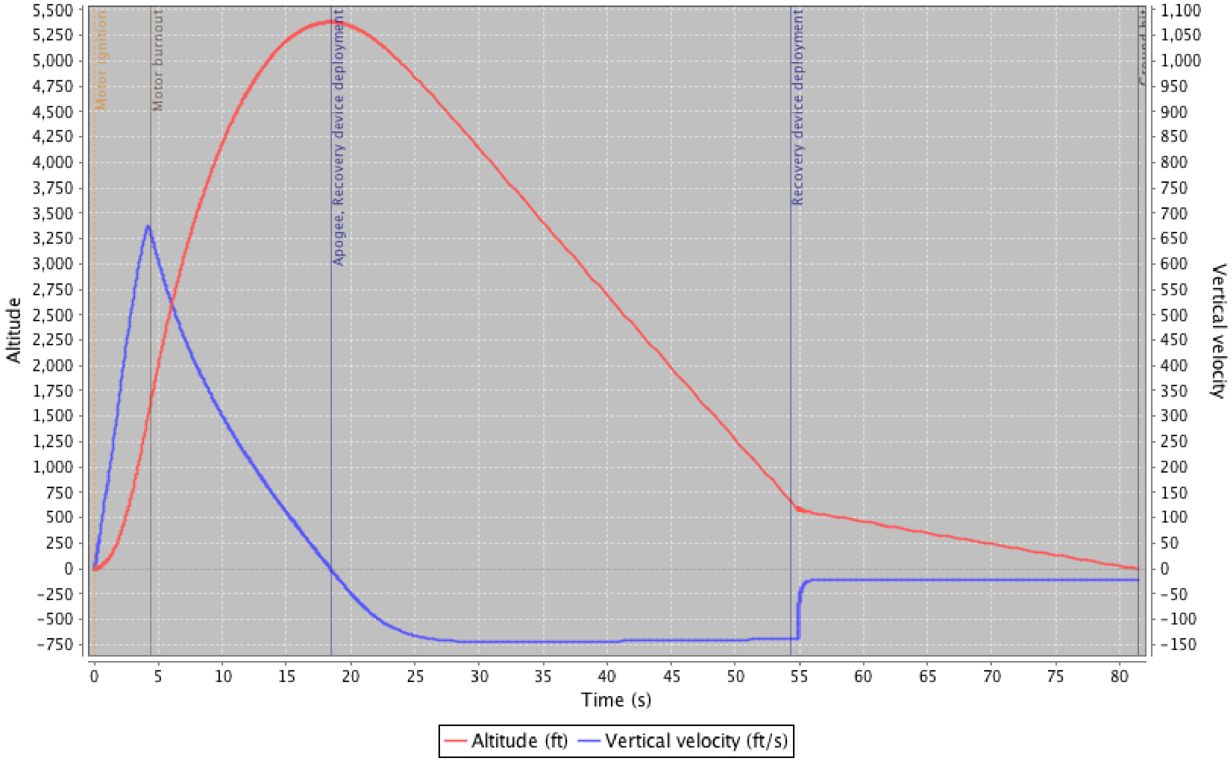


Figure 3. OpenRocket Flight Profile Simulation

The motor selection process was constrained by several factors:

- A 75mm diameter motor, due to the diameter of the rocket.
- Cesaroni or Aerotech brand, due to past experiences with these brands.
- A non-“Skidmark” propellant type, due to competition guidelines.
- A total impulse lower than 1150 lbf*s, due to competition guidelines and member certification restrictions.
- Model is based on a single stage motor and shall not be a hybrid, clustered motor, include forward firing motors, or motor that expels titanium sponges.
- The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.
- The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.

With this model, all motors that fell within the enumerated constants were simulated in OpenRocket. The motor that resulted in a predicted apogee closest to the competition’s target altitude of 5280 feet was the Cesaroni L851 at 5377 feet; therefore it will be designated as the primary motor. In the event that the OpenRocket model is inaccurate regarding the final mass of the rocket, two contingency motors were also selected. The Cesaroni L1720-WT resulted in an apogee of 5487 feet, and the Cesaroni L800 resulted in an apogee of 5563 feet. The club has never experienced the rocket’s total mass being less than the initial estimated mass, so the team doesn’t feel the need to include a motor that achieves an apogee lower than the target altitude. The thrust curves for the various motors are listed in Figure 4, Figure 5, and Figure 6. A more detailed comparison between the motors is listed in Table 5.

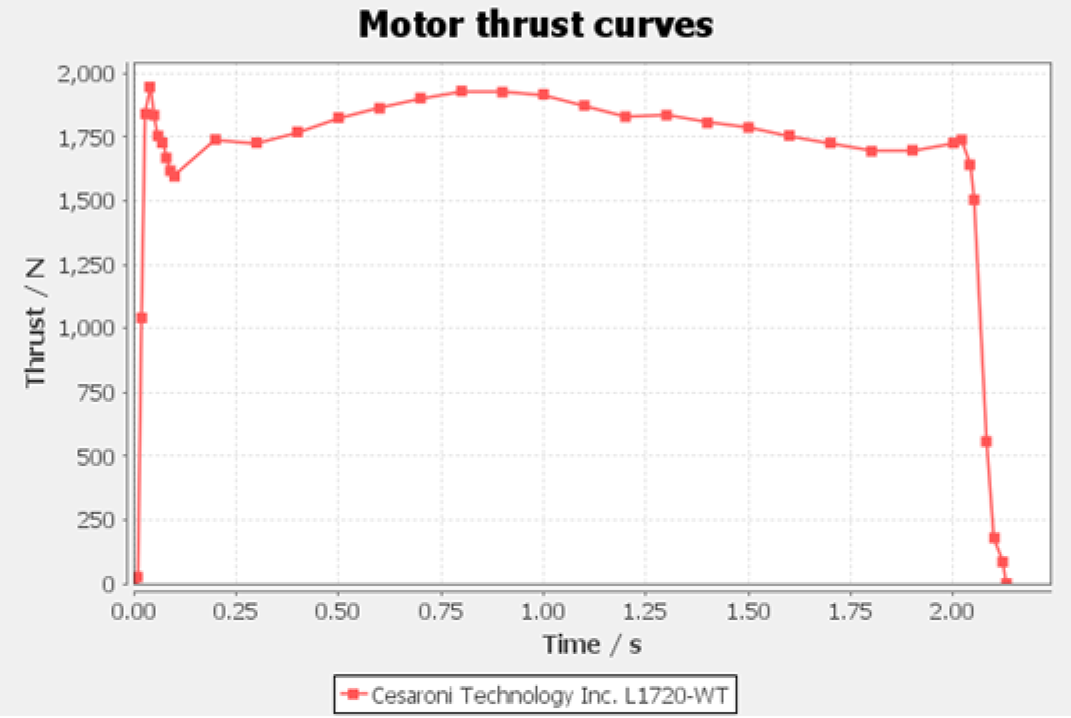


Figure 4. L1720-WT Thrust Curve

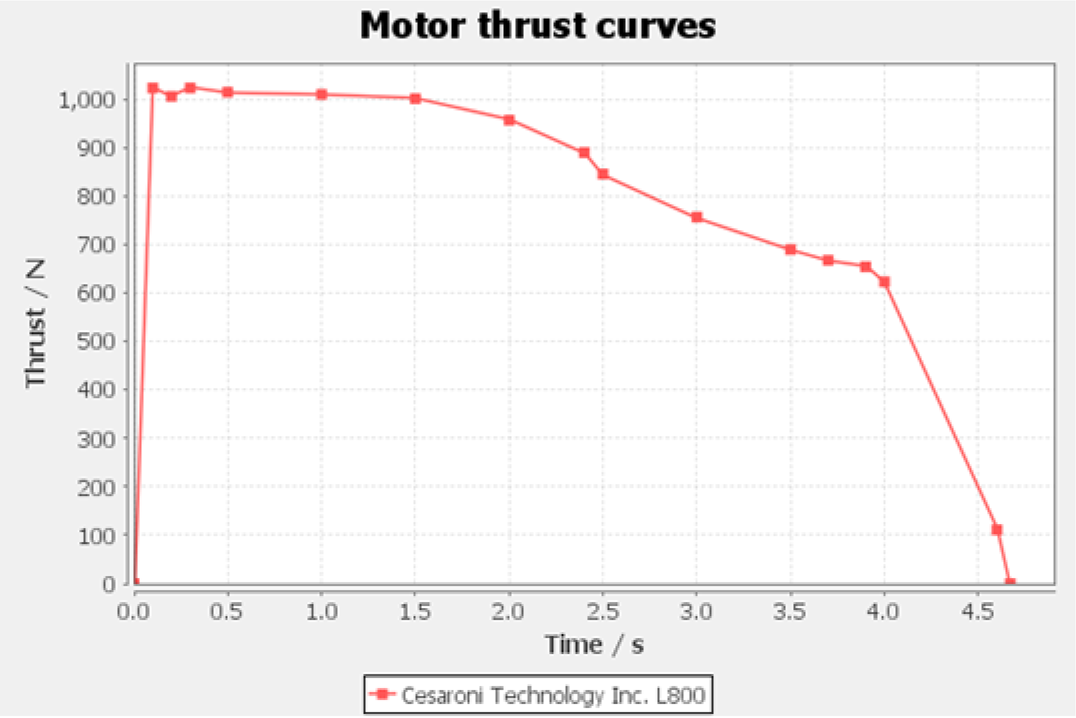


Figure 5. L800 Thrust Curve

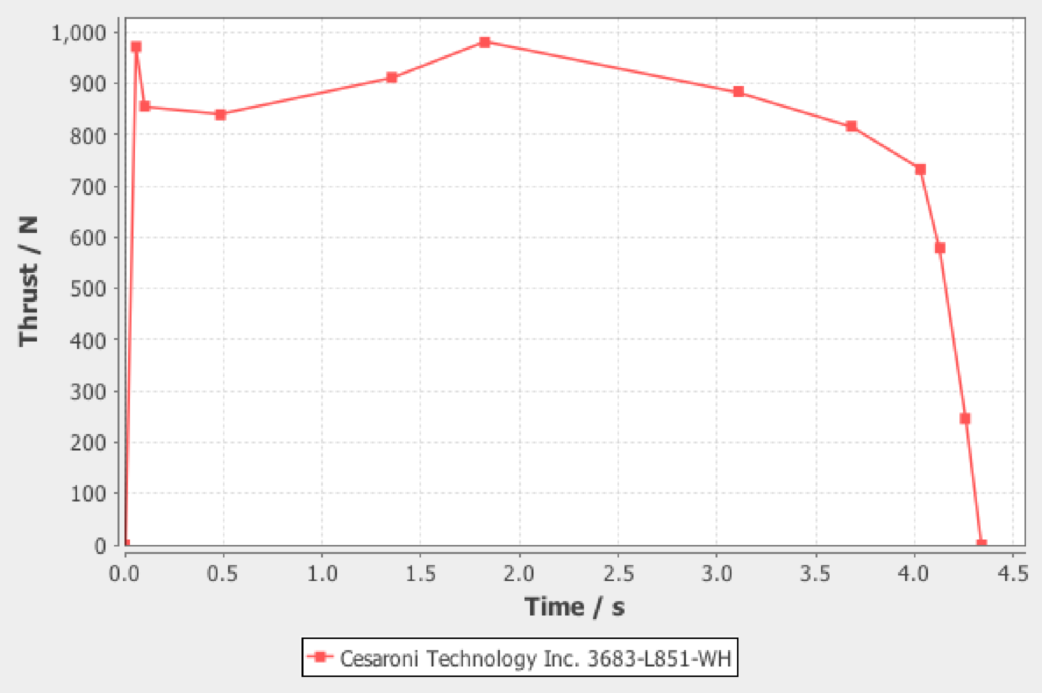


Figure 6. L851 Thrust Curve

Table 5. Motor Characteristics

	Cesaroni L1720	Cesaroni L851	Cesaroni L800
Predicted Apogee	5487 ft	5377 ft	5563 ft
Velocity off the Rail	87.6 ft/s	58.7 ft/s	65.6 ft/s
Thrust to Weight Ratio	13.1	11.7	7.6
Total Impulse	831 lbf*s	827 lbf*s	839 lbf*s
Average Thrust	394 lbf	192 lbf	181 lbf
Maximum Thrust	438 lbf	220 lbf	230 lbf
Burn Time	2.11 s	4.32 s	4.63 s
Liftoff Mass	118 oz	134 oz	124 oz
Burnout Mass	55.9 oz	56.2 oz	60.7 oz
Length	19.1 in	19.1 in	19.1 in
Propellant Grains	3	3	3

Mission Performance Predictions

An OpenRocket model was created to simulate flight and vehicle characteristics. This model was used to calculate the static stability margin, the center of pressure (CP), and the center of gravity (CG). The CP is located 94.34” aft of the tip of the nose cone, and the CG is located 76.57” aft of the tip of the nose cone. The preliminary flight vehicle has a static stability margin of 2.96 calibers. The target apogee of exactly 5,280 feet will be achieved by altering the rocket's mass very slightly via incorporated ballast. Additionally, the team will continue to improve the model of drag calculation and thrust curve for more accurate apogee calculation. Improvements to modeling the rocket's flight will be made via static motor testing at Penn State’s High Pressure Combustion Lab and experimental data from wind tunnel testing using a closed-circuit wind tunnel.

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 1.

$$X_n = 0.466 * L_n \tag{1}$$

X_n is the location of the center of pressure for the fins as measured from the tip, and L_n is the length of the nose cone. The center of pressure of the fins was then calculated using Equation 2.

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

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 3.

$$C_{nf} = 1 + \frac{R}{S + R} * \frac{4N\left(\frac{S}{D}\right)^2}{1 + \sqrt{1 + \left(\frac{2 * Lf}{C_r + C_t}\right)^2}} \tag{3}$$

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 4.

$$X = \frac{C_{nn} * X_n + C_{nf} * X_f}{C_{nn} + C_{nf}} \tag{4}$$

Where C_{nn} is the coefficient for the center of pressure for the nose cone. The center of pressure was calculated to be 90.001 inches aft of the tip.

To calculate the center of gravity, cg, Equation 5 was used.

$$cg = \frac{d_n * m_n + d_p * m_{payload} + d_m * m_m + d_d * m_d + d_b * m_b}{M} \tag{5}$$

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 68.491 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 6.

$$m_a = m_r + m_e - \frac{m_{prop}}{2} \tag{6}$$

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 7.

$$k = \frac{1}{2} * \rho * C_d * A \tag{7}$$

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 8.

$$q_1 = \sqrt{\frac{T - (m_a * g)}{k}} \tag{8}$$

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 9.

$$x_1 = \frac{2 * k * q_1}{m_a} \tag{9}$$

The burnout velocity, v_1, was calculated with Equation 10.

$$v_1 = q_1 * \frac{1 - e^{-x_1 * t}}{1 + e^{-x_1 * t}} \tag{10}$$

Where t is time at motor burnout. Finally, the altitude at which the motor burnout occurs, y_1 was calculated using Equation 11.

$$y_1 = -\frac{m_a}{2 * k} * \ln\left(\frac{T - (m_a * g) - (k * {v_1}^2)}{T - m_a * g}\right) \tag{11}$$

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 12.

$$m_c = m_r + m_e - m_{prop} \tag{12}$$

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 13.

$$q_c = \sqrt{\frac{T - m_c * g}{k}} \tag{13}$$

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 14.

$$x_c = \left(\frac{2 * k * q_c}{m_c}\right) \tag{14}$$

The coast velocity, v_c, was calculated using Equation 15.

$$v_c = q_c * \frac{1 - \mathrm{e}^{-x_c * t}}{1 + e^{-x_c * t}} \tag{15}$$

The coast distance, y_c, was calculated using Equation 16.

$$y_c = \frac{m_c}{2 * k} * \ln\left(\frac{m_c * g + k * v_c^2}{T - m_c * g}\right) \tag{16}$$

Lastly, the flight apogee altitude, PA, was calculated using Equation 17.

$$PA = y_1 + y_c \tag{17}$$

The flight apogee altitude was calculated to be 5540 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 6 and the margin of error between the methods is in Table 7. All margins of error were below 5%.

Table 6. OpenRocket and MATLAB Discrepancies

	OpenRocket	MATLAB
Center of Pressure (inches from tip)	94.34	93.54
Center of Gravity (inches from tip)	76.57	75.89
Static Stability (Calibers)	2.96	2.94
Altitude at Apogee (feet)	5377	5540

Table 7. Margin of Error

	Margin of Error
Center of Pressure	0.85%
Center of Gravity	0.89%
Static Stability	0.68%
Altitude at Apogee	2.94%

The larger discrepancy in the predicted apogee altitudes is likely due to the MATLAB simulation's 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, in the team's experience, OpenRocket has proven to be very accurate in predicting apogee, and values the OpenRocket predictions more as a result. Regardless, the team will continue to improve the MATLAB simulation to account for the various factors listed previously.

3.4 Recovery Subsystem

The recovery system components include the avionics board, avionics bay structure, all-threads, parachutes and harnesses, GPS, charge wells, ejection charges and the shear pins at the separation points of the rocket. The avionics bay will contain electromagnetic shielding to act as a faraday cage to prevent interference with the altimeters. The avionics board will contain two independent sets of altimeters, charges, mechanical switches, initiators, and 9V batteries for power sources. By designing an avionics bay containing a secondary recovery system, the team ensures redundancy in the avionics bay that guarantees parachute deployment at the selected altitudes even with a failure of one system. The secondary redundant altimeter will be on a two-second delay to assure that both ejection charges do not detonate at the same time. This prevents a potential overpressure event which would risk damaging the body of the rocket. The recovery subsystem used decision matrices in order to determine the optimal avionics bay design.

Avionics Bay Design

The avionics bay consists of the avionics board and avionics board retainment. The avionics board is the component that the altimeters, batteries, and wiring are attached to. The avionics board retainment system is the all-thread rods, nuts and bolts that provide the structural support between the avionics board and the surrounding avionics bay bulkheads. The triangular avionics bay design was used by the team two years ago and is pictured in Figure 7.

Figure 7. 2016-2017 Avionics Bay

The avionics bay with door design is similar to the one used in the 2017- 2018 competition. This design is pictured in Figure 8.

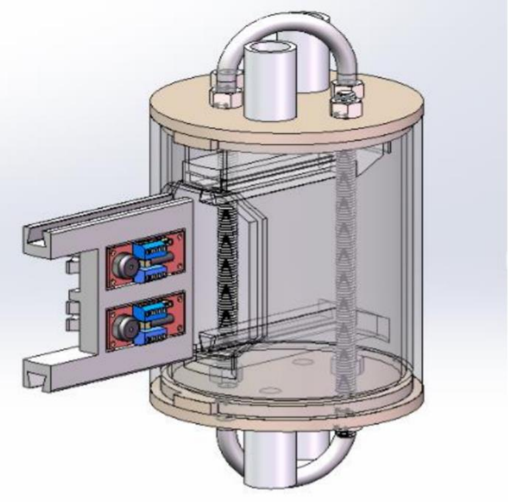


Figure 8. 2017-2018 Avionics Bay

The standard avionics bay design is similar to the one used by club members for their NAR certification flights. This design is pictured in Figure 9.

Figure 9. NAR Certification Flight Avionics Bay

The team has experience with building each of the three candidate designs, and can guarantee that any of the three preliminary designs could complete this year's objectives.

The avionics selected the five selection criteria of accessibility, mass, ease of assembly, precision, and cost to adequately score and rank the three preliminary designs for the avionics bay.

The attribute for accessibility represents the difficulty for the team to access the altimeters and internals of the avionics bay after the rocket is fully constructed. It was given a weight of 0.4 since this is the most important requirement for the design. A score of one means that the entire avionics bay has to be removed from the rocket to access the avionics board wiring. A score of five is given if the entire wiring of the avionics bay can be accessed from the outside of the rocket without having to disassemble any of body sections.

The mass of the avionics bay was given a weight of 0.1 because it is a very important component that is acceptable to be massive. The other factor is that the motor can be picked out after the final design and can be determined with the knowledge of how massive the avionics bay is. A score of five means the mass is less than two ounces, and a score of one means that the avionics bay weighs more than ten ounces.

The ease of assembly attribute represents how easy it is for the avionics bay to be built into the rocket during the designing and construction prior to the competition. This was given a weight of 0.1 because the team has sufficient time during the months leading up to the competition to assemble the rocket. A score of five is given if the avionics bay requires no equipment other than hand tools, and if a team member can build the avionics bay without knowledge of the rest of the rocket. A score of one is given if the avionics bay requires multiple extra power tools as well as specialized knowledge.

The precision attribute for the avionics bay represents tolerance that the avionics bay can be built and flown in. This was given a weight of 0.3 because it is vital that the avionics board containing the electronics is kept stable during flight, and can be assembled in the exact same location after multiple flights. A score of five will be given if the design can be easily manufactured to required tolerances, and can be launched multiple times without having to adjust or tighten any of the non-replaceable components. A score of one is given to the design that will be difficult to manufacture to the required tolerances, and has to be completely disassembled and then reassembled in between launches.

The cost attribute is the amount of time and money that would be required to build the selected design. Cost was given a weight of 0.1 due to all the options having a relatively similar and low cost. Time is considered to be a cost since the printer cannot be used to create other parts while the avionics bay is being printed. However, as long as the total print time is fewer than 15 hours which is considered “overnight”, then the time to print the design is not considered as a cost. Raw material cost is the domination factor for the amount of money to print the designs. All of the designs were priced as being printed from a $20, 1 kg spool of PLA.

The three preliminary design options were scored in Table 8 below.

Table 8. Avionics Bay Design Selection Matrix

Selection Criteria	**Weight**	**Triangular AV Bay**		**AV Bay with Door**		**Standard AV Bay**	
		Score	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**
Accessibility	0.4	2	0.8	5	2	3	1.2
Mass	0.1	3	0.3	1	0.1	4	0.4
Ease of Assembly	0.1	3	0.3	2	0.2	4	0.4
Precision	0.3	3	0.9	4	1.2	3	0.9
Cost	0.1	3	0.3	1	0.1	5	0.5
Total	**1**		**2.6**		**3.6**		**3.4**

The triangular avionics bay design from Table 8 was given a score of two for accessibility because the only way to access the components on launch day is to take out the avionics section of the rocket and reach into the body tube after unscrewing the bolts on the all-thread rods. This proves to be an inefficient use of time, and may prevent the team from relaunching the rocket within the two hour window. The mass of this design was given a score of three because it is estimated to weigh 9.35 ounces. Its ease of assembly was scored at a three due to it being difficult to access the components and the inability to reach both the batteries and the altimeters at the same time when reaching down the body tube. The second difficulty is that the wiring has to be wrapped from top to bottom and can become tangled easily, but this can be mitigated with wiring labeling and attaching the wires to points on the avionics board. The triangular avionics bay was given a three for precision it requires three all-thread rods which can be difficult to line up, which creates issues when positioning the avionics board on the all threads. Finally the cost for this design was given a three because it is estimated to cost $5.12 in materials and can be printed overnight.

The avionics bay with doors was scored a five for accessibility because the design allows the team to access the altimeters and batteries easily by opening the door on the outside of the rocket while it is completely assembled. The mass of this concept is expected to be 20.67 ounces and so was given a one. The ease of assembly scored a two as well because of the difficulty in incorporating the slider and creating a hole in the body tube and coupler of the rocket. This requires structural changes to the body tube as well as the combination of several 3D printed parts for the avionics bay. The precision of the avionics bay with a door scored a four since the slider fits tightly on the rail in the avionics bay and can be easily removed and reinserted at any time. The cost for building this design was given a one because it is estimated to be $11.36 and can be printed overnight. This is the most complicated preliminary avionics bay design and will require more time to design in SolidWorks.

The standard avionics bay scored a three for accessibility because of the need to disassemble part of the rocket to be able to reach down the body tube and access the avionics components. The standard design earned a score of four on mass because it is estimated to weigh 2.82 ounces. This design earned a four for its ease of assembly because it only requires two all-thread rods and is easily incorporated into the rocket. The wiring is all on one side of the board so wire management is simple. The standard avionics bay was given a score of three for precision since the avionics board can slide up and down on the all-threads. The cost attribute received a score of five since it is estimated to cost $1.60 and can be printed within a few hours.

The avionics bay with a door design received the highest weighted score was chosen for this year’s rocket as a result. This design allows for the rocket to be completely assembled before the altimeters are wired to the initiators which allows for more streamlined assembly process. This design is not yet complete, and several components and their locations have not been finalized yet. Two all-thread rods will be installed running through the entire avionics bay, to support in flight loading on the fragile avionics equipment. The location for these all-threads will be in the optimal place to mitigate the stresses. The initiator wire holes going through the bulkheads on either end of the avionics bay have not been designed yet as proper stress calculations must be modeled on the bulkhead. The team does not have knowledge on where the optimal initiator hole location would be, and a FEA SolidWorks simulation needs to be run to determine the best location. The team is planning to evaluate a design that removes excess plastic on the external wall of the avionics bay from solid to colonnaded. This design needs to be tested first, but if chosen, this design will reduce the mass of the avionics bay while retaining sufficient structural integrity.

Avionics Bay Wiring Layout

The interior of the avionics bay is a completely independent system, pictured in Figure 10, with two altimeters that are wired independently of each other. Each Stratologger CF altimeter is wired to a 9 volt battery. The batteries are located on the reverse side of the avionics bay slider. The altimeter is also separately connected to two initiators which will ignite the ejection charge for both the main and drogue parachutes. The ejection charges are located in the charge wells on the outside of the two bulkheads on either end of the avionics bay. The switch connected to each altimeter is called a quick snap connector, these are solid locking connectors and is a physical switch that cannot be engaged before launch, or mechanically agitated to the off position in flight.

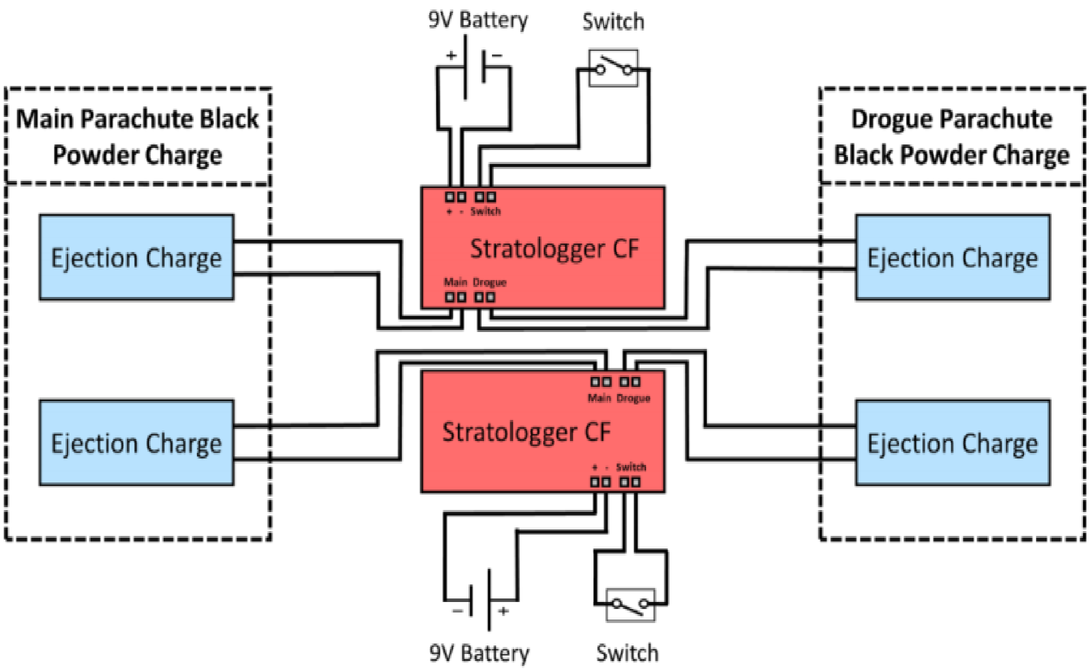


Figure 10. Avionics Bay Wiring Layout

Altimeters

LTRL must use an altimeter which is able to measure and report peak altitude as well as maximum velocity during flight. The altimeter must be able record at least ten samples per second and must store information on altitude, temperature, and battery voltage. This data must be able to be transferred to a computer after measurements are made for calculation. It is important for the altimeter to store data even without power in case of an unforeseen loss of power after landing and during flight in case of a brownout. The altimeter needs to be able to deploy drogue and main parachutes by sending a signal to two initiators at independent events.

The altimeter must also allow for programming of various altitudes for main parachute deployment.

The team used a weighted selection matrix to select an altimeter for the 2018-2019 competition year by comparing five important attributes: cost, size, reliability, accuracy, and programmability.

The cost attribute is the asking price of the altimeter in USD from the manufacturer's website. This attribute is assigned a weight of 0.1 because the team will be able to use the chosen altimeter for subscale launches and certification flights in the future. An altimeter will receive a five in the cost category if the team already owns the altimeter, resulting in zero dollars out of pocket. A score of one will be given, if the altimeter costs more than $125.

Size is given a score of 0.1 since the team would prefer the chosen altimeter to be as small as possible to allow the AV bay to be smaller which would reduce print time and filament costs. A five in the size category will be given to an altimeter that has a footprint of .90 inches cubed or smaller. A score of one will be given to an altimeter that has a footprint of 2 inches cubed or larger.

Reliability is one of the most important attributes for an altimeter as it needs to be able to survive the stresses of flight and the pressure differentials that accompany it. The reliability attribute was given a weight of 0.3. An altimeter will be given a five in reliability if the altimeter is guaranteed by the manufacture to operate through all the conditions that the flight vehicle will face. A score of one will be given to an altimeter that is not operating within warranty period or not guaranteed to survive in flight forces.

Accuracy is imperative for all altimeters to properly deploy the parachutes and to record apogee and was given a weight of 0.2 as a result. The altimeter will receive a score of five if it is accurate past 50,000 feet and accurate to within 0.1%. An altimeter will receive a score of one if it is not accurate past 10,000 feet or accurate to within 1%.

The final attribute that the team is considering when choosing altimeters is ease of programmability. This factor was given a weight of 0.3, as it is one of the most important factors. This high weight was given in order to ensure that both experienced and inexperienced team members can effectively read, understand, interpret data, and program the accompanying software. A score of five was given for programmability if the team would describe the altimeter as user-friendly and easy to operate. A score of one would be given to an altimeter with software and data that the team members cannot easily work with.

The weighted scores for each preliminary design option are shown below in Table 9.

Table 9. Altimeter Selection Matrix

Selection Criteria	Weight	StratoLoggerCF		StratoLogger SL100		Jolly Logic AltimeterThree	
		Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Cost	0.1	5	0.5	5	0.5	2	0.5
Size	0.1	5	0.5	3	0.3	5	0.5
Reliability	0.3	4	1.2	4	1.2	4	1.2
Accuracy	0.2	5	1	5	1	3	0.6
Programmability	0.3	4	1.5	4	1.5	5	1.2
Total	**1**		**4.40**		**4.20**		**4.30**

The StratoLoggerCF and the StratoLogger SL100 both scored a five in the cost category as the club currently has both of these altimeters while the Jolly Logic AltimeterThree scored a 2 in the cost category as it is priced at around $110 on the manufacturer's website.

For the StratoLoggerCF, the footprint is only 2.0”x0.84”x0.5” in length, width, and height respectfully, while the StratoLogger SL100 has a footprint of 2.75”x0.9”x0.5” in length, width, and height. The total area of the StratoLoggerCF is 0.84 inches cubed. When compared to the StratoLogger SL100’s area of 1.2375 inches cubed, the CF model has a 32% smaller footprint. When comparing these two altimeters to the Jolly Logic AltimeterThree, it has a smaller size of 1.93”x.71”x.57”, giving it a footprint of only .74 inches cubed. Compared to the StratoLoggerCF, the Jolly Logic AltimeterThree has a footprint that is nearly 12% smaller. These footprints resulted in the CF and AltimeterThree models achieving a five in the size category due to their very small size while the SL100 achieved a three due to its larger size.

All models of altimeter are roughly of the same reliability, with differences in brownout protection and amount of flight data stored during power loss. The StratoLoggerCF model only has a two second brownout protection period compared to the Stratologger SL100’s three seconds of protection. However, the StratoLoggerCF is able to store more flight data if the power were to be lost during flight. Comparing both to the AltimeterThree, the Jolly Logic version has an integrated rechargeable battery, resulting in much more reliability if the rocket were to lose power in flight. However, the Jolly Logic altimeter can store only one flight. The StratoLoggerCF model is the leading competitor in terms of memory storage as it has the advantage of being able to store multiple flights which prevents the possibility of accidental overwriting of previous flights whose data was not transferred. Since all of these altimeters are guaranteed for three years, the club ranked all three of these altimeters as a four due to small issues that differ between models.

The accuracy of both the StratoLoggerCF and Stratologger SL100 are rated for within 0.1% pressure fluctuations and up to 100,000 feet. However, the AltimeterThree is only rated for up to 29,500 feet reliability and there is no data known for pressure sensitivity. As a result, the AltimeterThree scored a three for accuracy and both Stratologger models scored a five.

Both StratoLogger altimeters use the same software which the team has experience using in the past and were given a score of four for programmability as a result. The AltimeterThree variant allows the data to be sent to a smartphone or other smart device, such as a tablet or a laptop. This prevents issues stemming from software which allows for anybody to use this altimeter and transfer and graph data effectively. As a result, the AltimeterThree was given a score of five for programmability.

The StratoLoggerCF altimeter received the highest weighted score, and was chosen to be the altimeter of choice for the 2018-2019 competition year. This altimeter shows a few advantages over the StratoLogger SL100 model such as smaller size, smaller footprint, and ease of accessibility. This allows the team to be much more conservative in the use of materials. The Jolly Flight altimeter might be smaller and easier to use, but it is more expensive and less accurate.

Electronic Shielding

The electronic shielding, also known as a faraday cage, is employed to shield the electrical components inside of the avionics bay from electronic interference to prevent the accidental ignition of one of the separation charges. In past years, LTRL has constructed a wire mesh cage around the avionics bay. However, this made it difficult to reach in and access the inside of the avionics bay before launch. This mesh caused cuts to members’ hands and was difficult to install. This year, LTRL is using a new design for electronic shielding that combats many of the issues that the wire mesh had created. The avionics bay will be wrapped in aluminum foil in between the outer and inner diameter of the avionics bay’s colonnaded wall to act as the faraday cage. By using aluminum foil, the avionics systems will avoid inadvertent electronic excitation. The aluminum foil wrap is a lightweight option that is easier to install and doesn’t restrict access to the avionics bay.

Separation Charges

The team must select an ejection charge which is compact and able to fit inside the rocket’s main and drogue chambers. The ejection charge also needs to be reliably ignited when in contact with the initiator that receives a signal from the altimeter. The ejection charge must produce a reliable force that can be calculated in order to ensure that the charge detonation will break the shear pins and allow the rocket to separate. The three potential options for ejection charge material are black powder, CO_2, and Pyrodex. These potential ejection methods were scored in a weighted design matrix based on the following selection criteria: volume, cost, ease of use, tolerance, and safety.

The volume selection criteria is a measure of how much space inside the rocket the ejection system will require. The team is limited in space and would prefer to use at little space as possible so this attribute was given a weight of 0.3. A score of five in this category will be given to a charge that requires 5 cubic centimeters of space or less. A score of one will be given if the charge requires more than 20 cubic centimeters of space.

The cost of all explosives charges is relatively small and can be purchased in bulk so this attribute was given a weight of 0.1. A score of five will be given to a charge with a per-launch cost of 10 ¢ or less. A score of one will be given to a charge that costs more than 50 ¢ per launch.

Ease of use is a measure of how easy it is to get the explosive charge installed in the rocket on launch day. This attribute was given a weight of 0.2. A score of five for this attribute will be given to a charge that can installed by one person within two minutes. A score of one will be given if it takes one person more than ten minutes to set it up in the rocket.

Ease of modelling is how well the team can model the behavior of the explosion. This was given a weight of 0.1 since the team can use a factor of safety to ensure proper separation if modelling is variable. A charge will be given a score of one if the team cannot model the event without using multiple correction factors. A score of five will be given to the charge if it can be modelled without using any fudge correction.

The last attribute used to judge potential ejection systems is safety. This attribute is the most important to the team and was given 0.3 weight. This is a measure of how many precautions the team must take when handling the explosives charge. A score a five in this attribute is given to a charge that only requires one extra safety measure. A score of one will be given to a charge that requires many safety measures as well as specialized training for members of the team in handling the material due to its hazardousness nature, and potential danger to team members.

The weighted scores for each preliminary design option are shown below in
Table ***10***.

Table 10. Separation Charges Design Selection Matrix

Selection Criteria	Weight	Black Powder		CO2		Pyrodex	
		Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Volume	0.3	5	1.5	1	0.3	4	1.2
Cost	0.1	5	0.5	1	0.4	5	0.5
Ease of Use	0.2	5	1	3	0.6	3	0.6
Ease of Modelling	0.1	4	0.1	2	0.2	4	0.4
Safety	0.3	1	0.3	5	1.5	2	0.6
Total			**3.40**		**3.00**		**3.30**

Black powder and Pyrodex are similar in density and in many applications can be substituted in a 1:1 ratio. Pyrodex, which is closely compared to 3F black powder, has grains that range in size from .021”-.034” (.05334-.08636 centimeters) in diameter while the grains of 4F powder are only .009”-.020” (.02286-.0508 centimeters) in diameter. Black powder received a five in volume while Pyrodex only received a four due to the extra packing material that would be required to keep it tightly compressed during launch. The CO_2 charge requires 14 cubic centimeters of space for one 12 gram charge which is the smallest size that can be purchased. With the additional hardware required to hold the CO_2 container, this ejection system will take up more than 20 cubic centimeters and received a one as a result.

For cost, both black powder and Pyrodex scored a five, as each material only costs less than 10 cents per charge per flight. The CO_2 cartridge scored a one in this category as well since they have to be purchased in sets, and cost around 70 cents per charge per flight.

For the ease of use attribute, black powder received a five due to it easily being measured and poured into the charge wells. Pyrodex received a three because it requires tight packing of the powder to correctly ignite. The CO_2 option was given a three because the CO_2 container has to be screwed in place and then armed.

For ease of modelling, black powder and Pyrodex were both given scores of 4 because their explosion characteristics can be easily modeled using known laws of physics and a simple idealization of the body tube. There are also many online calculators for amateur rocketry black powder charge sizes to verify the team’s calculations. Additionally, Range Safety Officers have greater experience with black powder charges, and can also additionally verify that the team is using the correct size charges. The CO_2 cartridges were given a two since it is harder to model the pressure distribution from ejection due to the uneven and slow pressure release of the CO_2 cartridge when they are popped.

The MSDS sheets for both black powder and Pyrodex are listed in Appendix C**.** Based on this, the team will give black powder a safety score of one and Pyrodex a two. CO2 cartridges only discharge if punctured which the team will guarantee will not happen. Additionally, the CO_2 tanks contains no handling hazards and received a five as a result.

Black powder received the highest weighted scored, and was chosen to be the separation charge of choice for the 2018-2019 competition rocket. This material showed exceptional performance in volume required, cost, ease of use, and tolerance, despite being an unsafe material. The team will employ fail safe methods to ensure safe handling of the black powder at all times.

Separation Charge Wells

The black powder used to separate the rocket for drogue and main parachute deployment will be contained within a charge well. The purpose of these wells is to contain the explosive charge during launch, and to direct the flow of hot gases away from the avionics bay and towards the separation point. These will be approximately 1” long and 1” in diameter. These charge wells will be epoxied to the bulkheads on either side of the avionics bay. The three preliminary ejection well designs considered were PVC pipe, steel pipe, and 3D printed ejection wells. These designs were evaluated in a weighted selection matrix based on the following selection criteria: ease of manufacturing, cost, strength, and weight.

Ease of manufacturing represents the amount of knowledge, and equipment required to create each black powder well. A score of one means that manufacturing the charge well requires specialized knowledge or equipment. A score of five means that team members with no knowledge of the rocket or access to equipment past hand tools could build this component. This attribute was given a weight of 0.4 since the charge wells are simple components that should not require excessive time to manufacture.

Cost represents the amount money and time that will need to be allocated to produce these parts. A score of one means that the component is more than $10 and will take more than one hour to produce. A score of 5 is given to a component that costs less than $1 and takes less than ten minutes to make. This attribute was assigned a weight of 0.2 due to the necessity of the charge wells to be built quickly and cheaply.

Strength represents the amount of stress the charge wells can undergo without failing. A score of one means that the material has a Young's modulus of less than 1 GPa. A score of five is given if the material has a GPa of greater than 100 GPa. This attribute was assigned a weight of 0.2 since the team does not want to over design these simple components, but still needs them to hold up under pressure.

Weight represents the amount of mass added to the rocket by the charge wells. A score of one is given to a material that will weigh more than 1 pound per foot. A score of five is given to materials with a weight less than 0.1 pound per foot. This attribute was assigned a weight of 0.2 to keep the mass low in the avionics bay.

The weighted scores for each preliminary design option are shown below in Table 11.

Table 11. Separation Charge Wells Design Selection Matrix

Selection Criteria	**Attribute Weight**	**PVC Pipe**		**Steel Pipe**		**3D printed**	
		Score	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**
Ease of Manufacturing	0.4	5	2	4	1.6	2	0.8
Cost	0.2	4	0.8	3	0.6	4	0.8
Strength	0.2	2	0.4	5	1	1	0.2
Weight	0.2	4	0.8	1	0.2	4	.8
Total			**4.0**		**3.4**		**2.6**

The PVC pipe option scored a perfect five in ease of manufacture because the material is easy to cut to proper lengths, and requires only a hand saw and less than ten minutes build. PVC pipe scored a four in cost since it can only be purchased in three foot sections for a few dollars. The material was given a two in strength, because it only has an average Young’s modulus of 58 MPa. With a relatively low weight, at 1.08 grams per milliliter, PVC pipe earned a score of four in weight.

The metal pipe option was given a 4 for ease of manufacturing because it only requires a hand saw to cut, but leaves metal shavings that have to be safely disposed of. This option scored a three for cost since it is $2 per foot and can be purchased from multiple online vendors. This option received a perfect five in strength because it has a Young’s modulus of 200 GPa. Due to its relatively high weight at 8 grams per milliliter, the metal pipe charge well was given a score of one.

The 3D printed option earned a score of two for ease of manufacturing because members must be familiar with modeling software and it takes over an hour to print. This option was given a four for the cost criteria because PLA filament and operating a 3D printer is expensive. This material scored a one in strength due to the inherent flaws in 3D printing, and because PLA filament has a Young's modulus of approximately 40 MPa. The weight of a plastic 3D printed part is comparable to PVC plastic, at 1.3 grams per milliliter, and received a score of four.

PVC pipe received the highest weighted score and the charge wells will be made from PVC pipe as a result. It is low cost, light weight, and all team members have the knowledge on how to create ejection wells from PVC pipe without additional training. LTRL has used this design in the past, and is confident that PVC pipe will hold up to the stresses experienced during black powder ejection and will perform exceptionally.

Recovery Harness

The recovery harnesses is estimated to be 26 feet in length for main and 11 feet in length for drogue. These lengths will ensure that body tubes will not collide with each other after parachute deployment. The elasticity of the harness also ensures that there is low inertial loading on the rocket frame during separation. The recovery harness had been selected to be a ½” Kevlar cord. The cord is secured to the rocket by using ½” quick links, connecting the cord to 3/8” steel U-bolts on the bulkheads. This design has been used for many previous LTRL rockets, and can withstand all the forces acting on the cord during parachute ejection and descent. The main and drogue parachutes will be covered and protected by Nomex blankets to ensure that the black powder charges do not burn them during deployment. The Nomex blankets will be attached to the recovery harness with ½” quick links. A fireball will be connected to the recovery harness to prevent zippering of the body tubes. Figure 11 shows a diagram of the planned descent including positioning of the sections during freefall and the location of the two events not to scale.

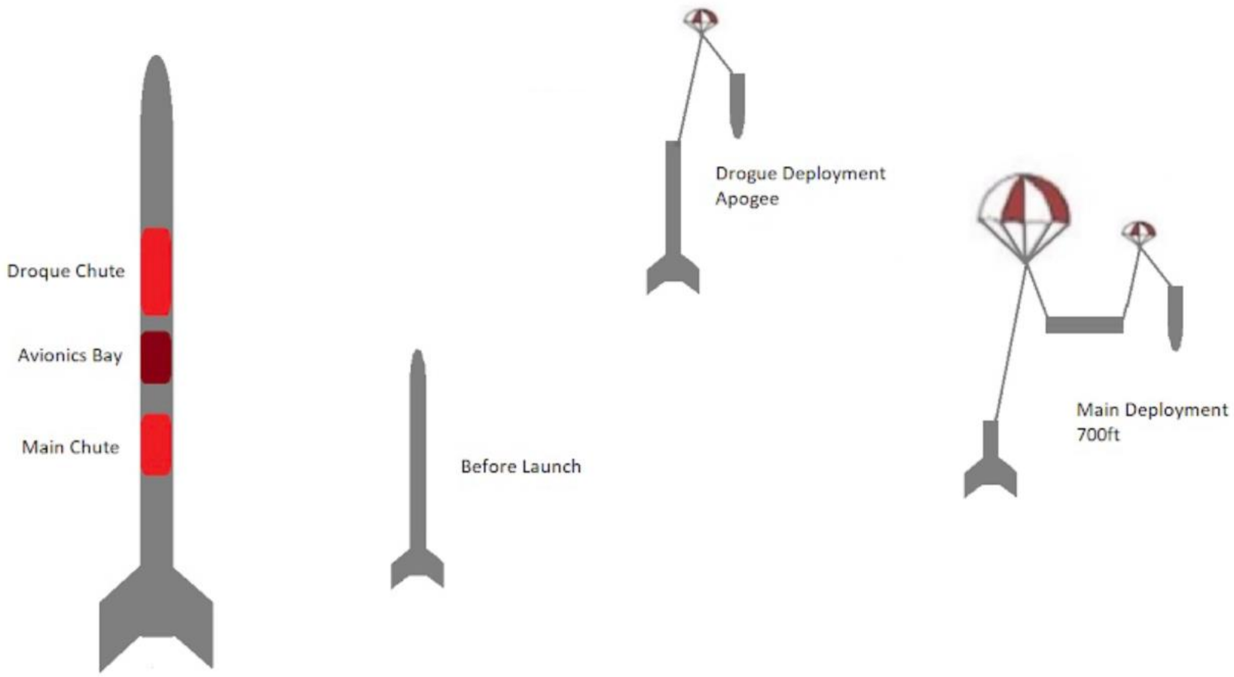


Figure 11. Parachute Deployment Sequence

Black Powder Calculation

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 12 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 12. Black Powder Calculation

	Fullscale Drogue	Fullscale Main	Fullscale Drogue Redundant	Fullscale Main Redundant
4F Black Powder (grams)	1.5	2	2	3
Body tube diameter	6"	6"	6"	6"
Body tube length	8"	8"	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 b.

$$V = \frac{\pi D^2 L}{4} \tag{18}$$

The volume is then substituted into Equation 18 for V where N is the mass of black powder in grams from Table 12**.** P is the pressure in psi that will result from the black powder detonation in the chamber. Equation 18 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.

$$P = \frac{\left(N * \left(\frac{1lbf}{454grams}\right) * 266 \; {}^{in\;lbf}/_{lbm} * 3370^{0}R\right)}{V} \tag{19}$$

The team is using two 56 brand 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. Equation 20 solves for the force required to break the shear pins in lbs. P is the chamber pressure calculated from Equation 19 and A is the cross sectional area of the chamber.

$$F = PA \tag{20}$$

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 13. A factor of safety was then applied to each of the results to account for any unknown factors. The last row in Table 13 has listed the number of shear pins the team plans on using on the flight vehicle for each chamber. The redundant charges must have the same number of shear pins as the other charge in its respective chamber.

Table 13. Shear Pin Calculations

	Fullscale Drogue	Fullscale Main	Fullscale Drogue Redundant	Fullscale 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	3	5	3	5

GPS Unit

The team needs to have a GPS unit contained within the rocket to ensure it will be located after launch. The GPS needs to be able to be tracked remotely from a phone or laptop to within an accuracy of 25 ft. The GPS needs to able to maintain power for at least one day in case the team is not able to locate the rocket right away. It will be mounted securely inside the nose cone of the rocket so the GPS needs to be small enough to fit within that space. This location for the GPS mounting was chosen because it is far away from the payload section, avionics bay, and the motor. The team used a weighted selection matrix to select a GPS for the 2018-2019 competition year by comparing five important attributes: cost, ease of use, size, reliability, and range.

Cost is the price in US dollars of the GPS unit being implemented. Cost was given a weighting of 0.2 because a GPS unit is a large upfront cost, however it is a reusable piece of equipment that will be used in future years. A GPS will be given a score of five if the team already owns the GPS. A GPS will be given a score of one if it costs more than $400.00.

Ease of use is a measure of how easy it is for the team to integrate the GPS into the rocket, and is also a measure of how easy it is for a team member to operate and track the GPS. Ease of use was given a weight of 0.4 because it is vital that the team is able to track the rocket and only has a short window on launch day to correctly set up the GPS. A GPS unit will be given a score of five if it can be set up by one, unskilled team member in less than five minutes. A GPS unit will be given a score of one if it requires one skilled person with training in the operation of the GPS to mount and correctly turn on the GPS system.

Size is based on the volume the GPS takes up in the rocket. This attribute was given a weight of 0.1 since there is extra space inside the rocket for a small device the size of a few cubic inches. A GPS will be given a score of one if it has a volume greater than 10 cubic inches, and a score of five if it has a volume smaller than 1 cubic inch.

Reliability is based on the battery life the manufacturer claims the GPS has as well as the warranty that comes with the GPS. A GPS will be given a score of one if it has a battery life of less than one day or if it does not come with any warranty. A GPS will be given a score of five if it has a battery life of one day and provides a year or longer warranty. This attribute was given a score of 0.2 because the team plans on using this GPS in future years.

Range is the distance that the GPS will be able to be tracked from the launch site. A GPS will be given a score of one if the GPS has a range of under one mile and will be given a score of five if the range is anywhere on earth.

The weighted scores for each preliminary design option are shown below in Table 13.

Table 14. GPS Selection Matrix

Selection Criteria	**Attribute Weight**	Americaloc GL300W		Spy TEC STI GL300		BRB900Tx/Rx	
		Score	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**
Cost	0.2	5	1	4	0.8	2	0.4
Ease of Use	0.4	5	2	4	2	2	0.8
Size	0.1	1	0.2	5	1	5	0.5
Reliability	0.2	5	1	4	0.8	2	0.4
Range	0.1	5	0.5	5	0.5	3	0.3
Total			**4.7**		**4.7**		**2.4**

The Americaloc GPS costs $109.90 and was given a score of four for the cost attribute. The SKY TEC costs $49.90 and was given a score of five. The BRB 9000 costs $309 and so was given a score of two.

For ease of us, the Americaloc GPS was given a score of five since it can be accessed using any tablet or phone with an app without having a wired connection, and can display zones and mark events. Additionally, the Americaloc GPS be placed into a structure within the rocket quickly due to its sturdy rectangular design. The SKY TEC GPS was given a score of five since it can be accessed using any tablet or phone without being wired to it. The SKY TEC can also be placed into the rocket quickly due to its small design. The BRB 9000 must have the ground station wired into a laptop to receive data in real time. This GPS also does not have a sturdy exterior so it must be carefully designed into a safe location in the rocket and received a score of two as a result.

The Americaloc GPS has a volume of 4.3 x 2.6 x 2.6 inches and so was given a score of 1. The SKY TEC has a volume of 2 x 1 x .8 inches and so was given a score of five. The BRB 9000 has a volume of 2.6 x 1 x .5 inches and so was given a score of five for the size attribute.

For reliability, the Americaloc GPS was given a score of five since it has a two week battery life as well as a two year warranty. The SKY TEC GPS was given a score of four since it has a two week battery life, but its warranty needs to be purchased separately. The BRB 9000 has an estimated battery life of three days per charge and does not come with a warranty so was given a score of two.

For the range attribute both the Americaloc and the BRB 9000 have an unlimited range because they are tracked by satellite so they received a score of five. The SKY TEC requires a ground station to be within 15 miles of the large antenna that is attached and so was given a score of three.

After summing up the weighted scores for each preliminary design option, the Americaloc GW300 and the SPY TEC STI tied. The team has decided to use the Americaloc GW300 as the 2018-2019 competition year GPS, because the team has used this model before and members are already familiar it. 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.

Parachute Selection

The team used OpenRocket's flight predictions to determine the best parachute for this year’s rocket. The team also used a MATLAB script as a second mode of verification to verify OpenRocket’s results. 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. The parameters of the parachute’s coefficients of drag are based on experimentally derived values from previous launches. The 12” Fruity Chutes Classical Ultra drogue parachute is estimated to have a coefficient of drag of 1.5, and the 72” Fruity Chutes Iris Ultra main parachute is estimated to have a coefficient of drag of 1.6. Using OpenRocket and MATLAB, the team is able to confirm that these parachutes will land within the landing zone and with a safe amount of kinetic energy. The team’s MATLAB model calculated that the rocket will take 82.6 seconds to descend from apogee to landing. The predicted descent profile from the MATLAB model can be seen in Figure 12. OpenRocket predicts the launch vehicle’s descent time to be 81.6 seconds. This verifies the team’s MATLAB model prediction that the launch vehicle will fulfill requirement 3.10.

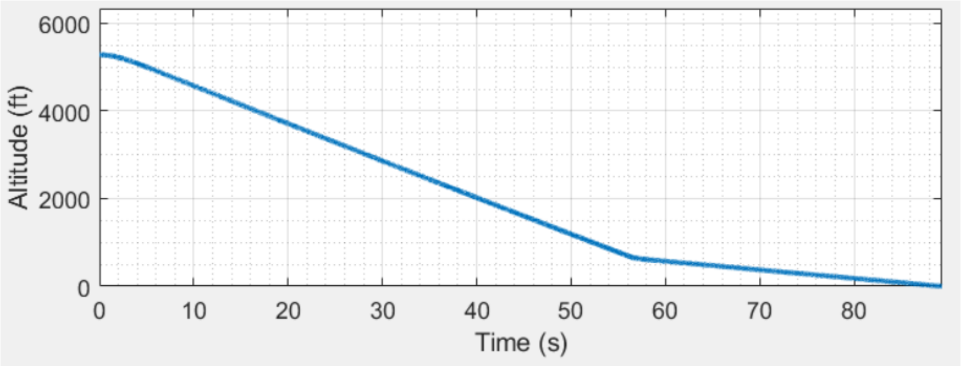


Figure 12. Descent Graph

Landing

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. In Figure 13**,** the distance the rocket drifts from apogee is shown. The MATLAB model does not account for weather cocking during ascent. As a result, launches where there are winds and no launch angle underestimate the rocket's drift distance. OpenRocket predicts a drift distance that is approximately 500 feet shorter than the MATLAB model from apogee to landing in 20 mph wind. This is due to OpenRocket not accounting for body drag once the drogue parachute has deployed. If OpenRocket accounted for this extra drag it would drift further as well as descend slower. This problem explains OpenRocket's faster descent rate and shorter time to landing from apogee.

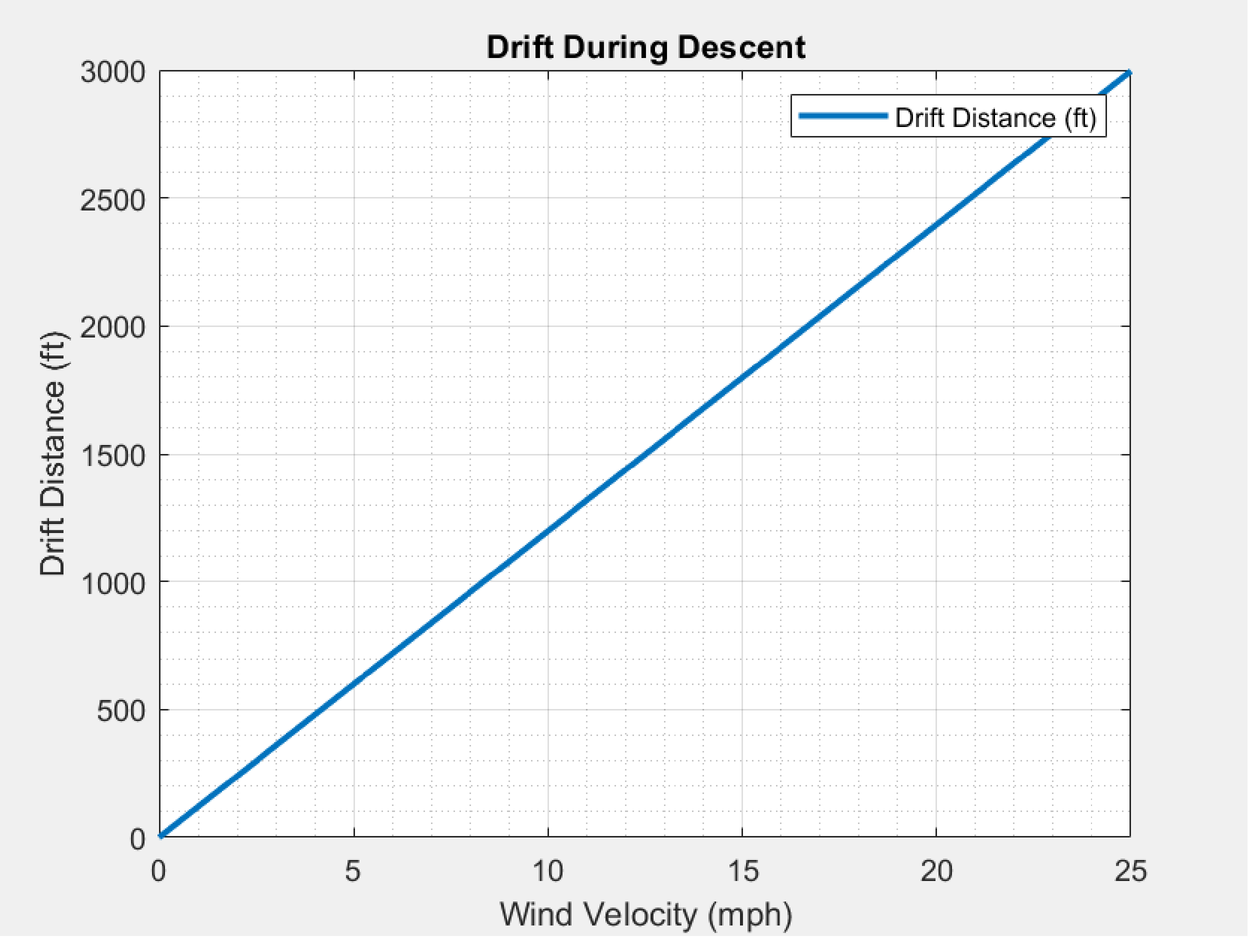


Figure 13. Drift During Descent

Exact drift distances from apogee to landing for wind velocity are given in Table 15.

Table 15. Drift Distance Calculations

Wind velocity	5 mph	10 mph	15 mph	20 mph
Drift distance	598.9 ft	1197.8 ft	1796.7 ft	2395.6 ft

Kinetic Energy

The MATLAB simulations predicted that the landing velocity of the rocket is 21.21 ft/s. Kinetic energy of each body tube section was calculated using equation 21. The function of parachute size versus parachute radius is given in Figure 14**.** The kinetic energy of each section of the rocket at landing is given in Table 16**.**

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

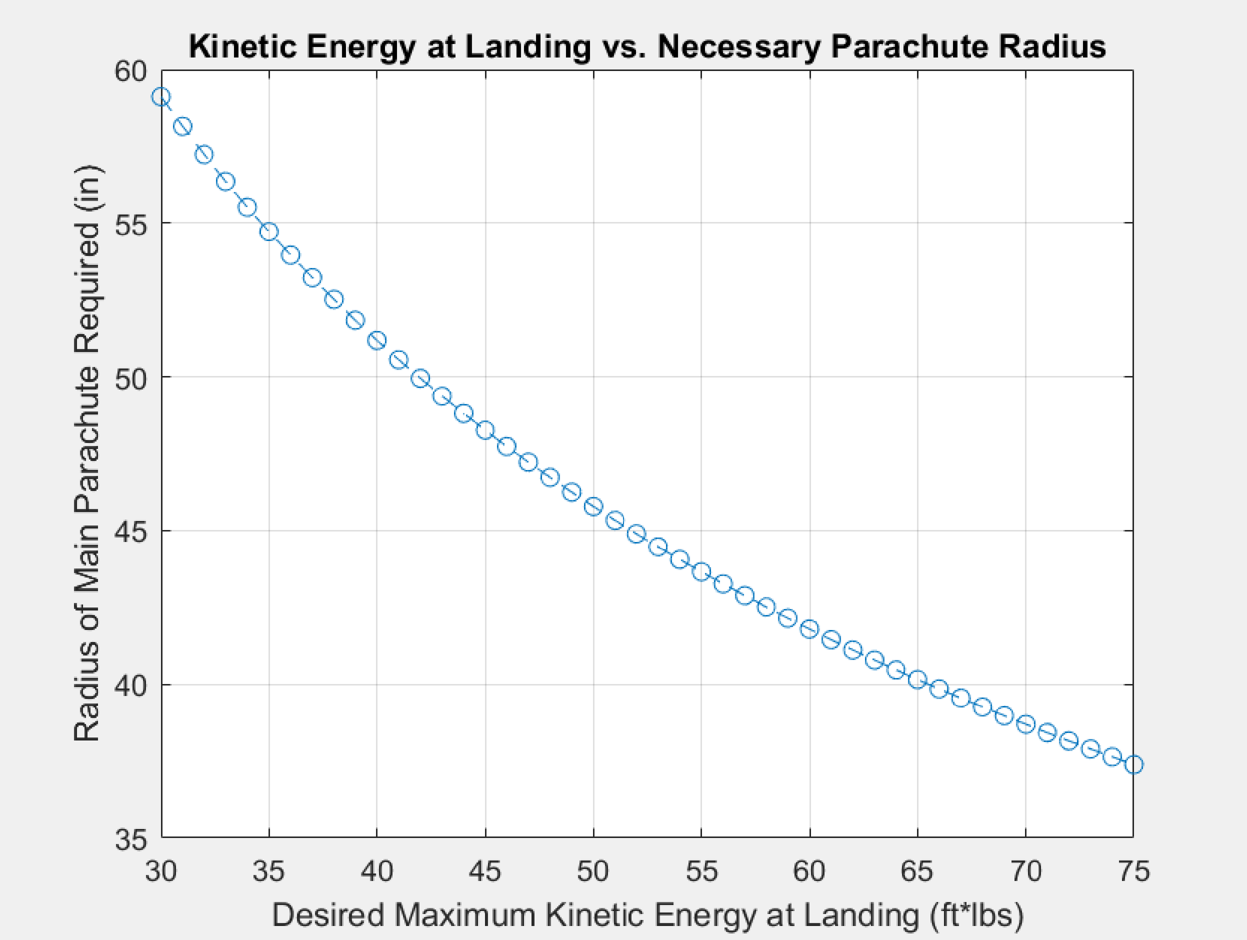


Figure 14. Kinetic Energy at Landing vs. Necessary Parachute Radius

Table 16. Kinetic Energy per Separation

Section	Mass	Kinetic Energy at landing (Matlab)	Kinetic Energy at landing (Openrocket)
Nose	125.5 oz	54.85 ft*lbs	58.78 ft*lbs
Avionics	123.3 oz	53.89 ft*lbs	57.75 ft*lbs
Booster	167.0 oz	72.99 ft*lbs	78.21 ft*lbs

The kinetic energy at landing based on the OpenRocket calculations is higher than the MATLAB calculations and the expected value. This is due to OpenRocket not modelling body drag, and the rocket will actually descend slower due to a higher drag than what OpenRocket models. The MATLAB model's predicted velocity versus time for the flight of the launch vehicle is shown in Figure 15.

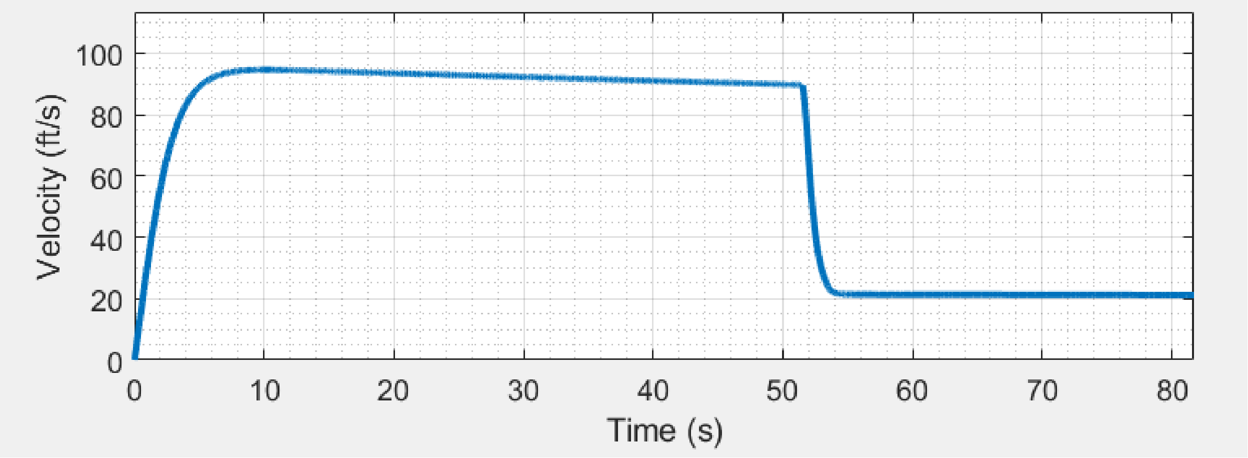


Figure 15. Velocity versus Time for Launch

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.

Statement of Work Requirements

The statement of work requirements for Safety provided by NASA are shown in the requirements verification in section 6.2 below.

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 section 6.1.

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 17 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 17. 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 materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.	Payload and the Structures subsystems will 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 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	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 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

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.	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 18.

Table 18. 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 19.

Table 19. 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 20.

Table 20. 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 21. 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 21. 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. These hazards can be found in Failure Modes and Analysis (FMEA)
Table 25.

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 22.

Launch Vehicle Assembly and Launch Risk Assessment

The hazards found in Table 26 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 27.

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 28.

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 29.

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 24.

Environmental Hazards to Rocket Risk Assessment

The hazards found in Table 23 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.

The checklists will be 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 B: Safety Data 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 22. Lab and Learning Factory Risk Assessment

Lab and Learning Factory Risk Assessment							
Hazard	**Cause**	**Outcome**	**Pre-Mitigation Risk**	**Severity**	**Likelihood**	**Risk**	**Mitigation**
Working with chemical components	Chemical splash or fumes	Possible mild to severe burns or asthma aggravation due to inhalation of fumes.	2-Moderate	2	4	6-Low	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.
High Voltage Shock	Improper use of welding	Severe injury or even death	4-Moderate	1	5	6-Low	All members must have certified training prior to welding. Two certified team members will be present when welding. One to watch for possible to mistakes and one to weld
Using power tools such as saws, sanders, drills, or blades or other machines	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.	5-Moderate	2	4	6-Low	All members using the tool must have knowledge and training with using that tool. If they are using the tool for the first time, 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.
Sanding materials	Improper use of PPE	This could cash a rash, a sore throat, nose, eyes, and possible asthma.	5-Moderate	3	3	6-Low	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.
Metal shards	Using a drill or other cutting equipment to machine metal parts	Metal splinters lodged in the skin or in the eyes.	4-Moderate	2	5	7-Low	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
Use of white lithium grease	Used when installing the motor	Possible skin irritation	5-Moderate	3	4	7-Low	All members will be required to wear gloves and safety glasses when working with hazardous substances.
Burns while soldering	Improper use of the soldering iron	Minor to severe burns	6-Low	4	3	7-Low	All team members will be taught how to properly solder and their first few times will be supervised by an experienced member.

Table 23. Environmental Hazards to Rocket Risk Assessment

Environmental Hazards to Rocket Risk Assessment						
Hazard	**Cause**	**Outcome**	**Severity**	**Likelihood**	**Risk**	**Mitigation**
Extremely cold temperatures.	N/A	Batteries could discharge meaning the rocket will not separate.	1	5	6-Low	All batteries will be checked prior to all launches to ensure they are both in working condition and new.
Trees.	N/A	The rocket may be damaged and the team cannot recover it.	1	4	5-Moderate	Drift calculations will be computed beforehand to ensure that the likelihood is decreased. Additionally, launching during high winds will not be allowed and the team can always change the launch angle if necessary.

Ponds, creeks, and other bodies of water.	N/A	The team could lose the rocket.	1	4	5-Moderate	Launching near any bodies of water should be avoided at all costs. Additionally, drift calculations can be done beforehand to ensure the rocket does not drift near a body of water.
Extremely high temperatures.	N/A	1. Heat could degrade electronics. discharging, or cause an explosion in LiPo batteries. 2. Adhesives could degrade and lead to possible electrical malfunctions.	1	5	6-Low	The team should seek shelter during the heat.

Rain.	N/A	Unable to launch the rocket.	1	4	5-Moderate	The weather will be monitored to ensure cloud cover is not an issue and the team can reschedule a launch if necessary.
High winds.	N/A	The rocket has decreased launch altitude, drifts farther, or the launch could not occur.	1	4	5-Moderate	The weather will be monitored to ensure cloud cover is not an issue and the team can reschedule a launch if necessary. If the winds are deemed ok, the team may still attend the launch and decide at the launch site if the weather is safe.
Low cloud cover.	N/A	Unable to launch the rocket.	2	4	6-Low	The weather will be monitored to ensure cloud cover is not an issue and the team can reschedule a launch if necessary.

Table 24. Hazards to Environment Risk Assessment

Hazards to Environment Risk Assessment							
Hazard	**Cause**	**Outcome**	**Pre-Mitigation Risk**	**Severity**	**Likelihood**	**Risk**	**Mitigation**

Release of hydrogen chloride into the atmosphere.	Burning of composite motors.	Hydrogen chloride gets into the water and disassociates to form hydrochloric acid.	5-Moderate	4	1	5-Moderate	The amount of motors being used this year is small, so the amount of hydrochloric acid would be negligible.
Release of reactive chemicals.	Burning of composite motors.	Reactive chemicals released help contribute to the reduction of the ozone layer.	5-Moderate	4	1	5-Moderate	The release of chemicals into the environment is almost certain, but the overall effects are negligible since the total is so little.
Release of toxic fumes in the air.	Burning of ammonium perchlorate motors.	Biodegradation.	5-Moderate	4	1	5-Moderate	Small amounts will be burned that limit the damage to the environment.
Spray painting.	The rocket will be spray painted.	The water could be contaminated and emissions may be produced.	5-Moderate	2	5	7-Low	All spray-painting operations will be performed in a small location to limit the exposure to the environment and not near any water source.

Harmful substances permeating into the ground or water.	Improper disposal of batteries or chemicals.	Could cause human illness if close to population.	6-Low	4	3	7-Low	Batteries will be disposed of properly and when a spill occurs, proper procedure will be followed to ensure proper disposal.
Use of lead acid battery leakage.	Old or damaged housing to battery	The battery acid will leak into the ground.	6-Low	3	4	7-Low	The batteries being used are new and all manufacturer's instructions will be followed.

4.9 Failure Modes and Analysis (FMEA)

Table 25. Overall Team Risk Assessment

Overall Team Risk Assessment							
Hazard	**Cause**	**Outcome**	**Pre-Mitigation Risk**	**Severity**	**Likelihood**	**Risk**	**Mitigation**
Project falls behind schedule	Major milestones are not met in time	Team cannot compete in Alabama.	4-Moderate	1	5	6-Low	Weekly status meetings, follow project plan and Gantt chart
Project is over budget	Project requires more money than allotted	Team fails to complete the project and cannot compete in Alabama.	4-Moderate	1	5	6-Low	Properly allot resources over time and provide communication with the treasurer, the school, and the subsystems.
Integration Failure	Parts don't fit together properly	The rocket may not be safe for launch.	4-Moderate	2	5	6-Low	Shared online documents and testing of parts and necessary sanding.
Damage during testing	Failure of recovery devices, hard landings, etc	Team falls behind and has to rebuild the rocket entirely.	5-Moderate	2	5	7-Low	Ground testing and testing on all parts along with simulations of the rocket flight
Parts are unavailable	Testing or fabrication parts are not available when needed	Project falls behind and has to make up ground.	5-Moderate	4	3	7-Low	Use non-exotic materials and check for availability. Order parts far in advance or order parts from different places.
Labor leaves/graduates	Seniors graduate or students stop	Loss of leadership and manpower leads to the team	5-Moderate	3	4	7-Low	Recruitment at beginning of each semester along with team building activities.

	attending meetings	falling behind schedule.					
Club loses funding	One or more sources can no longer provide funding	The team may become strapped for resources and money.	5-Moderate	3	4	7-Low	Dedicated members to track expenses and make funding contacts.
Failure to acquire transportation	Transportation to Alabama cannot be acquired	The team cannot secure vans to travel down to Alabama.	5-Moderate	3	4	7-Low	Have a plan to carpool if necessary.
Club loses facilities	Room 46 Hammond no longer available	The club no longer can build the rocket.	6-Low	2	5	7-Low	Maintain clean environment and proper storage of materials along with maintaining a good relationship with the University.
Injury of Team Personnel	Team member become hurt while working on project	A team member could suffer a severe injury that causes long recovery.	6-Low	2	5	7-Low	Identify potential safety hazards. Inform and enforce team safety.
Theft of Equipment	Parts or testing equipment get stolen	Loss of parts and team has to remake those parts.	8-Low	4	5	9-Low	Only subsystem leaders and officers will have card access to the LTRL lab.

Table 26. Launch Vehicle Assembly Risk Management

Launch Vehicle Assembly Risk Assessment							
Hazard	**Cause**	**Effect**	**Pre-Mitigation Risk**	**Likelihood**	**Severity**	**Risk**	**Mitigation**
Nose cone ejection	Early ejection charge due to faulty wiring	Nose cone goes into freefall	4-Moderate	2	3	5-Moderate	Test for continuity and wiring for charges before launch
Airframe/coupler zippering	Zippering due to the shock cord on parachute deployment	Airframe/coupler becomes unusable for future launch, may cause pieces to freefall	5-Moderate	3	4	7-Low	Use shock-absorbers on the shock cord where it contacts the coupler
Premature airframe separation	Drag separation or internal pressure separation	Parachutes deploy early, failure to reach altitude	6-Low	3	4	7-Low	Use analysis models to ensure drag and internal pressure will not cause separation
Airframe buckling	Intense G-forces	Weakens the structural integrity of the airframe, makes it unable to safely launch in the future	5-Moderate	4	4	8-Low	Load test the materials used for the airframe and couplers to ensure the airframe is strong enough to resist buckling
Fin Failure	Fin flutter due to stronger than expected	Fins may break off of the vehicle and go into freefall, also would cause	5-Moderate	4	4	8-Low	Use analysis models to ensure that fin flutter will not cause failure

	forces on the wings	the flight to become unstable					

Table 27. Propulsion Risk Assessment

Propulsion Risk Assessment							
Hazard	**Cause**	**Effect**	**Pre-Mitigation Risk**	**Likelihood**	**Severity**	**Risk**	**Mitigation**
Motor CATOs	Motor components fracture	Destructive damage to rocket	4-Moderate	5	1	6-Low	Inspect motor grains and components prior to installation. Assemble the motor according to the assembly instructions with another observing. Develop an internal checklist. Check for fracture on any motor components after the launch.
Motor does not stay retained	Motor thrust pushes the motor into the rocket	Destructive damage to rocket	4-Moderate	5	1	6-Low	Verify that the motor retention system can handle the motor impulse
Motor does not stay retained	Ejection charges push motor out of the rocket	Motor does not retain in rocket	3-High	5	2	7-Low	Use of active motor retention. Use of lower impulse motor

Motor does not ignite	Motor does not ignite	Rocket remains static	4-Moderate	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.

Table 28. Avionics and Recovery Risk Assessment

Avionics and Recovery Risk Assessment								
Hazard	**Cause**	**Effect**	**Pre-Mitigation Risk**	**Severity**	**Likelihood**	**Risk**	**Mitigation**	**Verification**
Electromagnetic interference triggers altimeter.	Altimeter isn’t properly shielded.	The altimeter prematurely fires the separation charge.	3-High	1	4	5-Moderate	Use a tin foil faraday cage around the avionics bay	Test the faraday cage to prevent electromagnetic interference
Drogue parachute remains inside the body tube during deployment.	The parachute has not been packed correctly, or is impeded by	The flight vehicle engages in ballistic descent.	3-High	1	4	5-Moderate	Ensure the parachute is packed correctly, preventing any obstructions from interfering	Simulate deployment conditions by dropping the body tube with the parachute packed inside.

	a physical obstruction.							
Main parachute remains inside the body tube during deployment.	The parachute has not been packed correctly, or is impeded by a physical obstruction.	The flight vehicle impacts the ground with excessive kinetic energy.	3-High	1	4	5-Moderate	Ensure the parachute is packed correctly, preventing any obstructions from interfering	Simulate deployment conditions by dropping the body tube with the parachute packed inside
The drogue parachute is damaged	Drogue parachute is damaged by separation charge, improper packing	Main deployed at an excessive kinetic energy, cause zippering or other damage	4-Moderate	1	5	6-Low	Ensure the Nomex blanket covers the parachute, that parachute exits the body freely	Ground test the deployment systems before launch
Initiators do not ignite separation charge	Faulty initiator, failed connection to ejection charge	Ejection charge not ignited, Drogue and/or Main parachute don't deploy.	5-Moderate	2	4	6-Low	Completely redundant charge system	Perform ground tests, practice wiring and setting up initiators

Initiator loses contact with separation charge	Faulty connection between ejection charge and initiators	Ejection charge not ignited, Drogue and/or Main parachute don't deploy.	5-Moderate	2	4	6-Low	Completely redundant charge system,compact yet accessible charge well	Perform ground tests, practice wiring and setting up initiators
Main parachute does not unfold after exiting the body	Improper packing, Nomex blanket tangles in shroud lines	The flight vehicle impacts the ground with excessive kinetic energy.	5-Moderate	1	5	6-Low	Ensure Nomex blanket is in its proper place and that parachute is properly folded	Ground test the deployment systems before launch, practice folding parachutes
Drogue parachute does not unfold after exiting the body	Improper packing, Nomex blanket tangles in shroud lines	The flight vehicle engages in ballistic descent.	5-Moderate	1	5	6-Low	Ensure Nomex blanket is in its proper place and that parachute is properly folded	Ground test the deployment systems before launch, practice folding parachutes
Kinetic energy is over maximum landing threshold	Parachutes not deployed properly	Flight vehicle damages itself and payload or surroundings	5-Moderate	1	5	6-Low	Ensure that parachute calculations are correct, parachute is folded correctly	Perform ground tests and double check MATLAB parachute calculations
Altimeter has partial or	Wiring breaks or disconnects	Drogue and/or Main parachute	5-Moderate	2	5	7-Low	Redundant altimeter, Use new	Batteries have at least 9.2V prior to assembly. Both altimeters are

complete loss of power	, Battery has too low of voltage	don't deploy. No altitude measurement					batteries, use strong connections	configured properly. Wire connection point can hold the weight of the altimeter
Altimeter loses connection with initiators.	Initiator wire connection damaged or improperly installed	Ejection charge not ignited, Drogue and/or Main parachute don't deploy.	5-Moderate	2	5	7-Low	Redundant altimeter, Ensure all wire connections are solid and not damaged before launch	Practice wiring avionics bay and perform ground tests
The main parachute is damaged	Main parachute is damaged by separation charge, improper packing	Decent affected, flight vehicle impacts the ground with excessive kinetic energy	5-Moderate	2	5	7-Low	Ensure the Nomex blanket covers the parachute, that parachute exits the body freely	Ground test the deployment systems before launch
Altimeter is damaged during launch	Altimeter is subjected to forces caused by a design error in the AV bay or from being seated improperly.	Drogue and/or Main parachute don't deploy. No altitude measurement	6-Low	2	5	7-Low	Ensure redundant altimeter, confirm structural integrity of avionics bay and all-thread rods	Test avionics bay for structural integrity to prevent potential damage

Flight vehicle lands outside of maximum safe distance	Parachutes deployed too early or cause too much drift	Potential damage to rocket, rocket not recoverable, potential damage to surrounding area	6-Low	2	5	7-Low	Ensure that parachutes deploy at correct altitude	Test drift calculations to ensure that drift isn’t an issue
Main parachute recovery harness becomes tangled in drogue recovery harness	Drift causes interference between body tubes and recovery harness	Potential damages to rocket body or cause turbulent descent	6-Low	3	4	7-Low	Ensure that rocket is weighted in a way to prevent collisions and interference	Perform and test decent model on MATLAB to ensure that cords will not tangle
Altimeter does not properly register altitude.	Altimeter detects jostling of rocket as pressure change, AV bay chamber does not equalize with outside pressure	Altimeter deploys parachute too early or too late	7-Low	3	5	8-Low	Ensure barometer hole allows sufficient pressure equilibrium	Use a pressure chamber to make sure pressure equilibrium is achieved

Main parachute deploys at apogee	Drogue and main are packed in the wrong location, wiring diagram was not followed	Flight vehicle exceeds maximum allowable drift distance	7-Low	3	5	8-Low	Ensure the wiring to the altimeter is correct, label all interchangeable components	Ground test the deployment systems before launch
Body sections collide under parachute descent	Recovery harness cords too short drift causes	Potential damage to rocket or parachutes	7-Low	3	5	8-Low	Ensure that there is enough distance between body tubes after parachute deployment	Perform and test decent model to ensure that collisions aren't an issue

Table 29. Payload Risk Assessment

Payload Risk Assessment								
Failure	**Cause**	**Effect**	**Pre-Mitigation Risk**	**Likelihood**	**Severity**	**Risk**	**Mitigation**	**Verification**
Rover containment system fails during launch	The ejection mechanism deploys prematurely	Nose cone of the rocket separates prematurely during flight - can cause massive instability during launch, and free-falling body sections	3-High	4	1	5-Moderate	Perform thorough rigorous testing on the control software to prevent premature triggering. Double check all wire connections before launch. Verify that there are strong soldering connections.	Tests have been performed to verify the reliability of the control hardware and software.

		pose a serious danger to bystanders on the ground						
Rover containment system fails during launch	Acceleration experienced during launch or landing	Rover becomes unsecured during launch - an unsecured mass can cause instability during flight	4-Moderate	4	2	6-Low	Verify structural integrity of rover housing before launch. Ensure that materials used to construct rover containment mechanism can withstand launch acceleration. Perform extensive testing to ensure reliability.	Test that the rover and payload bay can withstand forces similar to those experienced during flight. This can be accomplished during full scale launch before the competition.
Retainment mechanism fails due to a loose connection	Weak connection points between components of the circuit	The rover will not be secured to the inside of the rocket for the launch	5-Moderate	4	3	7-Low	Extensive testing will be performed to ensure the retainment circuit can withstand vibrations and launch conditions. Connections will be checked on launch day	Testing during full scale launch will verify the connection points are strong enough to withstand launch conditions.
Structural damage to payload bay	Acceleration experienced during launch or landing	A breach in the wall of the body tube would prevent the black powder from creating	6-Low	4	3	7-Low	Check parachute deployment mechanism with A&R subsystem to ensure that the rocket does not land at a high speed.	Verified with A&R subsystem that expected landing speed of the rocket would not damage the payload bay.

		enough pressure to separate the nose cone from the rocket body						
Deployment mechanism fails to activate	Control software malfunction	Rover will be unable to deploy from the rocket	6-Low	4	3	7-Low	Perform rigorous testing on the control software to ensure that initiatior is triggered. Test physical trigger method to ensure it works consistently	Tests have been performed to verify that the signal strength and reliablility between the ground station and rocket are acceptable.
Physical damage to the rover	Acceleration experienced during launch or landing	Rover is damaged during launch or deployment - if damage sustained is severe enough, rover may be unable to operate correctly	5-Moderate	4	4	8-Low	Construct the rover out of materials durable enough to withstand launch forces. Verify before launch that all connections between components are secure.	Test that the rover can withstand forces similar to those experienced during flight. This can be accomplished during full scale test flight.
Deployment mechanism fails to activate	Trigger mechanism becomes physically disconnected/damaged due to acceleration experienced	Rover will be unable to deploy from the rocket	5-Moderate	5	3	8-Low	Double check integrity of physical mount points for the activation trigger and soldered wires between the control board and trigger	Test durability of trigger mechanism

	during launch or landing							
Deployment mechanism fails to activate	Faulty initiator	Rover will be unable to deploy from the rocket	6-Low	5	3	8-Low	Use a multimeter to test the initiator before wiring it into the circuit	Initiator testing has been written into launch procedure
Retainment mechanism fails due to a dead battery	Battery dies during or before launch	The rover will not be secured to the inside of the rocket for the launch	6-Low	5	3	8-Low	Use fresh batteries and minimize the amount of power the retainment circuit actively uses	The sample rate on the Arduino is one sample every 5 seconds. The circuit has been tested to ensure it can operate if sitting on a launch pad for up to 3 hours.

5. Payload Criteria

The objective of the payload is to create an autonomous rover that will be deployed after the rocket lands. After deployment, the rover will drive at least 10 feet away from the rocket and collect a soil sample of at least 10 milliliters.

In order to successfully complete the competition, payload will need to fulfill 3 objectives. First, the team must ensure that the rover is safely secured in the rocket until landing. Second, the rover needs to deploy from the rocket after landing and autonomously drive at least 10 feet away. Finally, the rover must collect a soil sample of a least 10 milliliters.

To complete the 3 objectives stated above the payload team will be broken into 5 branches based on relevance of what needs to be focused on to complete the objectives. The branches are rocket integration, chassis and electronics, drivetrain and wheels, software, and soil sample collection. The engineers in the payload subsystem will alternate between these branches in order to complete the objectives.

5.1 Rocket Integration

The rocket integration subsystem will be responsible for safely securing the rover within the rocket. Similarly, the rover and other electronics within the payload bay must be protected from the black powder charge during the separation of the rocket. The rocket integration subsystem will also ensure that the rover is able to easily exit the rocket after landing.

Last year, the team had issues with the amount of space used by the containment mechanism. The containment system was integrated into the rover, taking up space and complicating the rover itself. To avoid similar challenges, the team has decided to keep the integration and security system separate from the rover. The designs described in Table 30 reflect this decision.

Three different designs are being considered for the integration and retainment of the rover inside the payload bay. The designs are outlined in Table 30 with a brief description of the design.

Table 30. Retention Description, Testing, and Verification

	Description	Testing	Verification
Solenoid Lock	A solenoid lock will be used to keep the rover secured in flight until ready for deployment.	Test circuit reliability under various conditions on the ground.	Test the system during subscale and/or full scale launch. Can also be tested in the lab.
Tether	The rover will be tethered down using a series of wires.	Perform various tests to determine if the system is suitable for launch conditions.	Test the system during subscale and/or full scale launch.

Door	A door will be hinged at the end of the rover shelf and locked into place with a servo to ensure that it does not open during flight.	Perform various tests to determine if the system is suitable for launch conditions.	Test the system during subscale and/or full scale launch.

Keeping the rover secured is essential to protect the safety of the team and everyone in attendance at launches, to avoid damage to the rover body and electronics, and to ensure that the rover does not fall out of the payload bay after rocket separation.

The solenoid lock design is the most viable and current front-runner for rover integration and security. The simplicity of the design is one of the most important features. The software necessary to hold and release the rover is basic, and the addition of a thin metal rod to the rover would be easy. Along with simplicity, there are very few ways the system could fail during flight or after landing. Testing will be required to ensure the battery can last long enough to hold the rover even after sitting on the launch pad for a period of time. Importantly, the solenoid locking mechanism is quick and easy to set up on launch day.

The door design is the second best design for securing the rover. It is simple to set up on launch day and would require little time to secure the rover. The design also does not need any additions to the rover in order to secure it inside the payload bay. The down side of the door design is the locking mechanism could be difficult to construct with a servo and some other small parts. The complexity could also lead to a higher likelihood of the system failing.

The tether design is the least viable design. Tying down the rover could result in tangles and other complications after the rocket lands. Also, the mechanism that would be needed to lock down the wires and then release them would be complicated and difficult to set up on launch day.

The final integration and security design will be attached inside a rotating payload bay to ensure that the rover can drive out of the rocket right-side-up. The rotating payload bay pictured in Figure 16 will be suspended on one end by a screw mounted to the bulkhead and an epoxied faceplate. The bay itself will be nearly flush with the inside of the rocket to maximize space. The rotating bay system will allow for the heavier side to settle to the bottom and make sure that the rover exits the rocket in an upright position. Figure 16 is a 3D printed model of the first prototype for this system.

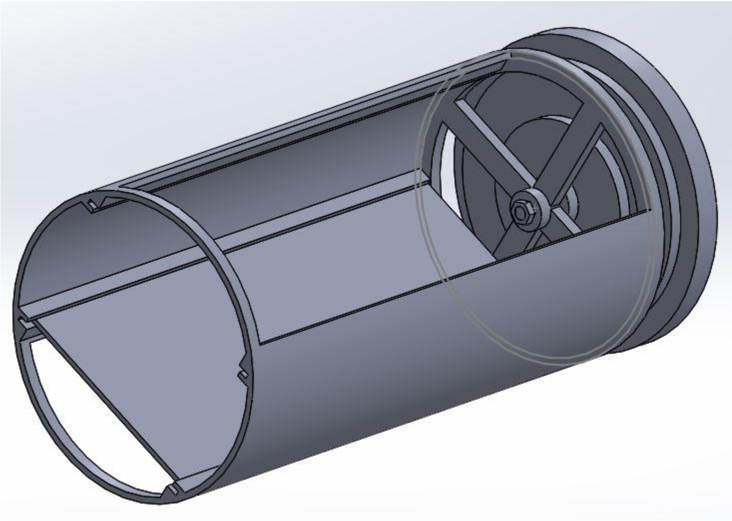


Figure 16. Rotating Payload Bay SolidWorks Model

Figure 17. Payload Bay Prototype

The rover will rest on the shelf depicted in Figure 17 and will be secured using one of the retainment designs above. One of the major challenges the team faced while designing the rover last year was creating a rover that would work regardless of the orientation the rocket landed in. Previous designs sacrificed ground clearance and wheel size. Learning from these mistakes from last year, the team has designed and tested the rotating payload bay to ensure that the rover always exits the rocket upright. The bottom shelf would be weighted so that it always ends up on the bottom, while the top shelf (not depicted in Figure 17) can be used to hold some light electronics for deployment and retainment.

5.2 Chassis and Electronics

The chassis/electronics subsystem will be responsible for creating the frame of the rover and the electronics board that will house all of the electronics. The electronics board is being created to organize the electronic components and ensure they are secure during all aspects of rocket flight and rover deployment. Based on the results from the previous year, it has been decided that a sheet of fiberglass will be used to mount the electronics. The electronics will be mounted to the sheet with 3D printed mounting devices. The isolated housing compartments will be vital in keeping electronics of the rover protected as well as being efficient with the amount of space. The sheet will allow for optimal clearance for the wheels to ensure the rover does not get stuck in the soil. For the electronics, an Arduino Nano will be used to help reduce the amount of space needed for the chassis while having enough pinouts for connecting the soil collector. Table 31 outlines the possible materials for the chassis design as well as the pros and cons of each material.

Table 31. Design Considerations for Rover Chassis

	Description	Test/ Verification	Pros	Cons
3D Printed PLA Plastic	PLA plastic is the material used in the LTRL 3D printer.	Create SolidWorks models of the chassis and use FEA to predict the strength.	Easy to model on a computer and print complicated designs.	PLA plastic can be fragile or heavy depending on infill percentages.
Wood	Maple	Further testing is required to determine how much force will break the wood.	Easy to work with and cost effective.	Not easy to machine into complex shapes.
Fiberglass	A single sheet of ¼ inch fiberglass	Create SolidWorks models of the chassis and use FEA to predict the strength.	High strength.	Dangerous to cut in the lab. Not easy to machine into complex shapes.

Figure 18 is a SolidWorks model of the current design for the rover chassis. The rover's electronics components, which are modeled on top, will be mounted to a fiberglass sheet that has 3D printed mounts attached to the bottom. The decision to use a combination of 3D printed parts and fiberglass is because fiberglass can provide the structural capabilities that are necessary and the 3D printed parts can provide the complexity necessary to mount various components. The mounts shown at the bottom of the figure are for holding dual shaft DC motors that will have axles for the wheels to attach to.

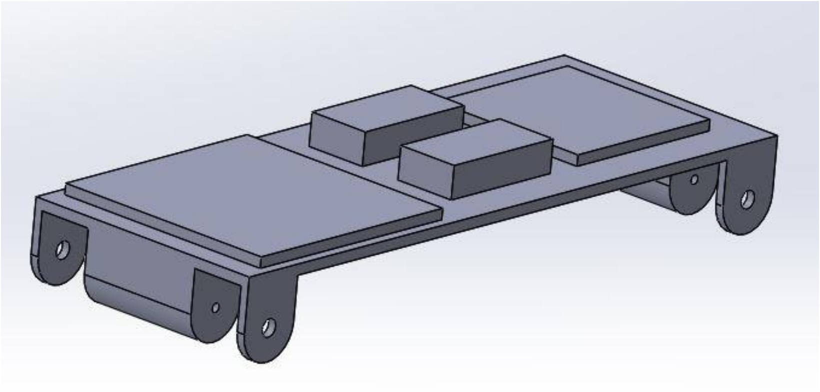


Figure 18. Rover Chassis

5.3 Soil Sample Collection

The soil sample collection subsystem is responsible for designing and manufacturing a system to collect a soil sample of at least 10 milliliters. The system will deploy after the rover has driven 10 feet away from the rocket.

Three designs are being considered for the soil sample collection. In Table 32 the different designs are described briefly. Tests that will be done to determine the best design along with a list of pros and cons of each design.

Table 32. Soil Collection Description, Testing, and Verification

	Description	Testing/Verification
Auger	The auger will be powered by a servo. This will pull the soil up into a container to retain the soil.	Ground tests using soil similar to that at the launch site will determine the effectiveness of the auger.
Wheel	The separate wheel will pull the soil up as it turns. The soil will be directed into a container built onto the rover.	Ground tests using soil similar to that at the launch site will determine the effectiveness of the wheel.
Scoop	A mechanical scoop will dig into the earth and deposit the soil into a container on the rover.	Ground tests using soil similar to that at the launch site will determine the effectiveness of the scoop.

The designs in Table 32 will require testing and multiple design iterations to finalize. The best design must be effective at soil collection and easy to integrate into the rover. Testing for the most effective soil collector will require full scale 3D printed models to ensure the design works effectively. The tests will utilize soil of similar consistency to that at the launch site. Importantly, the final design must integrate onto the design of the rover while staying within the bounds of the payload bay. Models of the soil collection designs will be drawn in SolidWorks to test the ease of integration onto the rover. After a series of tests, the primary design will be chosen for the final rover.

5.4 Software Subsystem

The software subsystem will be responsible for working with the rocket integration, drivetrain, and soil sample collection subsystems to develop the code required to execute their respective tasks.

Table 33 is detailing the necessary software tasks that must be completed by the payload subsystem.

Table 33. Software Tasks

Software Tasks	Description	Testing/Verification
Remotely communicate with the rover to deploy it from launch vehicle.	Establishing communication with a packet radio, programing the rover to release the locking mechanism, and sending an initialization command to make the rover start moving.	Verify via test program that the rover successfully unlocks itself from the locking mechanism and exits the rocket on ground station command.
Ensure that the rover has moved 10 feet from the rocket.	Determine if the rover as reached its target distance using a specified time determined through testing.	Verify via test program that the rover stops after moving for a certain time period on a terrain akin to the launch field.
Collect soil sample.	Once the rover has stopped moving, utilize a servo motor to scoop up soil sample.	Write and run a test program multiple times that causes the rover to collect a soil sample. Measure each test and take the average of the amount of soil.
Maintain orientation.	Using an accelerometer to measure the relative direction of gravity, determine which way the rover is oriented in the rocket. Constantly check orientation in case of flipping.	This system will be tested by placing the rover in the holding mechanism and determining if the orientation is upright.

The rover's processor will be an Arduino Nano microcontroller. An Arduino was chosen over other microcontrollers and portable computing platforms because of the weight and size constraints on the rover. An Arduino Nano is the smallest and lightest platform which is still powerful enough to run the control software for the rover and has enough pins for all necessary electronic components. Additionally, Arduinos are more suitable for servo and motor control. The software will be programmed in C++, using the Arduino's setup and loop functions as main functions of the program. The logic for the rover's software is outlined in Figure 19.

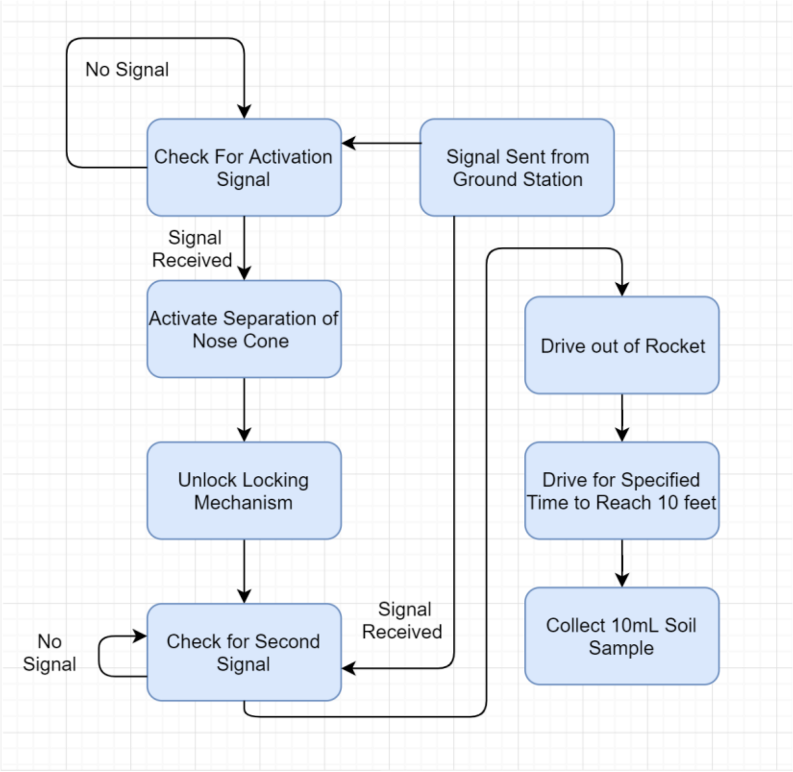


Figure 19. Software Control Logic

Upon receiving the activation signal from the ground station via LoRa RFM9x radio, the control software will trigger the nose cone separation mechanism of black powder. To account for any issues after the separation of the nose cone, the team will be testing delay times until there is no movement of the rocket before moving onto the next step. After a decided delay time, another signal will be sent to unlock the retainment mechanism holding the rover in place. After another delay time, acquired from the process explained above, the rover will drive out of the rocket onto the ground. The rover will then be in a loop to drive for a predetermined amount of time to ensure it reaches the goal of 10 feet. Distance will be determined based on time because the results obtained from last year's distance measurement system were not accurate enough for the desired specifications. It was determined that using GPS is not accurate enough and would present a large margin of error compared to time based methods. After the rover has traveled for the specified time, the rover will stop and use a servo-powered soil collection mechanism to collect the desired 10 milliliter of soil.

5.5 Payload Wheel Design

Last year, the rover's wheel design did not perform well in the soil of Huntsville, Alabama. The wheels were designed and tested only on the terrain at Penn State, which is groomed, hard soil. The grooves for the treads were too shallow to get traction against the loose soil at the launch site. Since the payload competition is very similar to last year's, the new wheel designs are made with the previous wheels' problems in mind. All of the wheel designs focus on getting sufficient traction to effectively drive on the loose soil of the launch site.

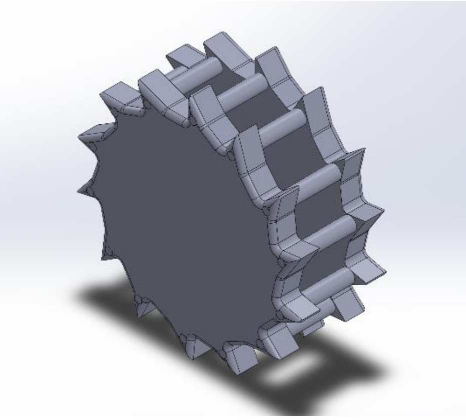


Figure 20. Gear Wheel

The first design, the “gear wheel”, as shown in Figure 20, was the first iteration of the “larger grooves” idea. It included a hollow middle and cut spaces to allow the loose soil to pass through without clogging the spokes. This design included two mirrored plates that connected individual spokes on each tooth of the wheel. Because of its over-complicated nature, this design was taken out of consideration.

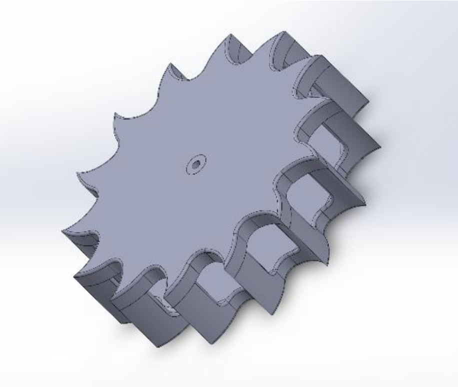


Figure 21. Sun Wheel

The second design was a much less complicated version of the gear wheel, adequately named the sun wheel, as seen in Figure 21. The design was simply two different parts with one half including the spokes and the other as a connecter plate. The sun wheel features curved teeth rather than hard angles but kept the hollowed out center. When printed, however, the design was still too complicated for the printers available. After seeing the final product, the idea for a more rounded, oval edge would eliminate the need for the hollowed out section of the part and reduce the inaccuracies from coming from printing two different parts.

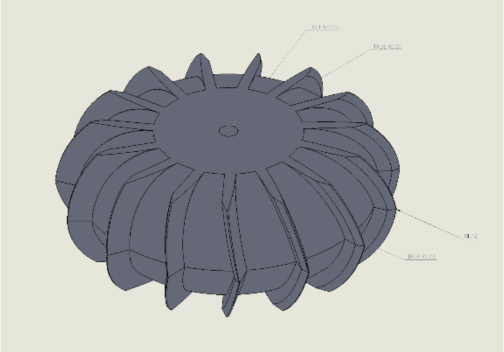


Figure 22. Wheel with Angled Treads

The latest design is named the angled treads wheel, shown by Figure 22, for its slightly askew pinpoints. The overall idea of “more traction” was kept in mind while designing this part as well as the need for accurate simplicity. With the outside diameter of the treads at about 2.3 inches, these wheels will fit properly into the approximate payload area. Although the wheels will be heavier, the increased weight will give the rover more power to push through the soil. The solid nature of the wheel will also prevent soil from getting clogged within the wheel itself. When printed, the single part printed accurate enough to standard with what is needed.

Testing the wheels in soil similar to that of the launch site will be essential for picking the best wheel design for the rover. After the wheels are modeled in SolidWorks, the can then be 3D printed and tested using a basic test rover to determine the best traction in the loose soil. The best design can then be changed if necessary in SolidWorks, printed, and tested again to improve the design. Each design iteration will allow for improvements on the best design. The final wheel design will be tested thoroughly because the wheels were one of the major shortcomings of last year’s design.

6. Project Plan

6.1 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.
1.4.1-.3	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 full scale 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 full scale launch will also be used during full scale 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 full scale 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 vehicle demonstration 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 vehicle demonstration 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

3.1	Demonstration	Drogue parachute will deploy at apogee and main will deploy at 700 ft. This will be demonstrated through sub-scale and full-scale launch, as well as avionics bay setup.
3.1.1	Demonstration	Main parachute will deploy at 700 ft. This will be demonstrated through sub-scale and full-scale 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 any subscale or 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 modeling, in order for each component of the rocket to land within the kinetic energy constraint of 75 ft-lbs. Current parachute selection models have the rocket under the kinetic energy limit.
3.4	Inspection	The recovery system, including all wiring, will be completely independent of any payload retention or deployment mechanisms.

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	Motor ejection will not be used to separate the rocket. The StratologgerCF altimeter will control all the recovery system's ejection charges.
3.8	Inspection	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	The team has created a MATLAB model to predict the highest anticipated drift of the rocket in 20 mph winds when using the selected parachutes. This model will be verified using OpenRocket drift calculations to ensure the launch vehicle does not drift outside of the 2,500 radius.
3.10	Analysis	The team's MATLAB model will predict the descent profile of the launch vehicle. This model will be verified using OpenRocket's descent profile predictions to further ensure the rocket's total descent time will be under 90 seconds.
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	Inspection	All parts of the rocket will be tethered to the rocket with shock cord during its flight.
3.11.2	Testing	The GPS unit will be functional and tested 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 electric interference.
3.12.1	Inspection	The recovery system will be in its own coupler, and will be isolated from all other electronic components as a result.

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.
3.12.4	Testing	The faraday cage and the recovery section being in its own coupler will protect the recovery system from both external and internal interference. Testing before launch will confirm this requirement.

Payload

Requirement	**Method of Verification**	**Verification**
4.2	N/A	Option 1(Deployable Rover)
4.2.1	N/A	No additional experiments.
4.2.2	N/A	No additional experiments.
4.3.1	Analysis	The payload will be designed to fit the requirements set by the launch vehicle.

4.3.2	Test	The team will design various retention mechanisms to ensure that the rover will remain inside the launch vehicle during the entire flight
4.3.3	Test	A communication link between the ground control station and the rover will be established so that the rover can inform the team that the rocket landed, and the team can remotely trigger rover deployment.
4.3.4	Test	The rover will use a drivetrain capable of traversing the launch site terrain and use a combination of two distance measurement techniques to ensure the rover has moved to at least ten feet from all parts of the launch vehicle.
4.3.5	Test	The rover will collect a soil sample of at least 10 millimeters.
4.3.6	Demonstration / Testing	The team will ensure that the compartment holding the soil sample is large enough to transport the sample to the desired location.
4.3.7	Inspection	All batteries used on the rover will be safely secured during flight and incase of impact with the ground.
4.3.8	Inspection	All batteries used on the rover will be brightly colored.

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.

6.2 Team Derived Requirements

Vehicle

Requirement	Justification	Verification
Launch vehicle fins will be removable.	Since the fins are often the first point of impact on the rocket during landing, they often break. Having the fins be removable 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.	The fin brackets for the launch vehicle are designed so that fins can be removed and replaced if needed.
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 so that they are removable from the launch vehicle and can be replaced if needed.
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 our 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 that are 1.5 times the length of 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**
Avionics bay will be accessible once parachutes are packed.	To prevent potential tangling of the parachute and their shroud lines with the recovery harness the avionics bay must be accessible while the parachutes are inside the rocket.	The team has designed the avionics bay with a removable door and slide tray so all avionics can be accessible after all parachutes are packed.
Avionics bay will accessible without having to disconnect sections of the body of the rocket.	The team has had issues with continuity on the launch pad in the past, and requires that it be accessible without having to disassemble the entire avionics bay.	The team has designed the avionics bay with a removable door and slide tray so all avionics can be accessible after body tubes are assembled.
Parachutes will be able to be packed prior to loading of black powder	To ensure minimum time with dangerous energetics inside the rocket during assembly.	Before connecting body sections, black powder will be the last component added to the rocket. This order of assembly will be in the launch day procedures.

The altimeter wiring will be accessible without interacting with the AV bay faraday cage.	To maintain effective electromagnetic shielding around the avionics bay team members will not contact the faraday cage during avionics bay assembly.	The team has designed the avionics bay with a removable door and slide tray so all avionics can be accessible without interacting with the faraday cage.
Altimeters and batteries will be allowed no relative degrees of motion.	Tangling of altimeter and battery wiring must be prevented to ensure proper avionics function	The 3D printed avionics bay contains structural mounts for the altimeters and batteries so that they will not be able to move relative to each other. The altimeter will be screwed into the avionics mount while the battery will be held in by a clip in avionics mount.

Payload

Requirement	Justification	Verification
Provide constant communication with ground station before rover deployment	The team wants to be able to send specific signals to the rover so that it can start driving	Test the range of the communication system to ensure that is it greater than the maximum drift distance of the rocket
Protect electronics during launch and landing	The electronics are vital to meet the objective for the rover	The rover electronics will be protected in 3D printed casings
Correct orientation of the rover upon landing	The rover must be able to exit the payload bay upright	The payload bay will include a rotating mechanism that allows the rover to always remain upright after landing
Avoid becoming stuck when driving away from the rocket	The rover has to be able to move 10 feet from the rocket and recover a soil sample	The rover will be able to continue driving without significantly changing speed

Safely detonate black powder charge to eject nose cone	The rover electronics and connections are essential to the execution of the mission	The nose cone, rover, and launch vehicle will be undamaged after separation
The total mass of the rover will be under 30 oz	To allow extra mass for the rotating mechanism and the other electronics not attached to the rover	Use lightweight materials and minimize the amount of components necessary to complete the mission

Safety

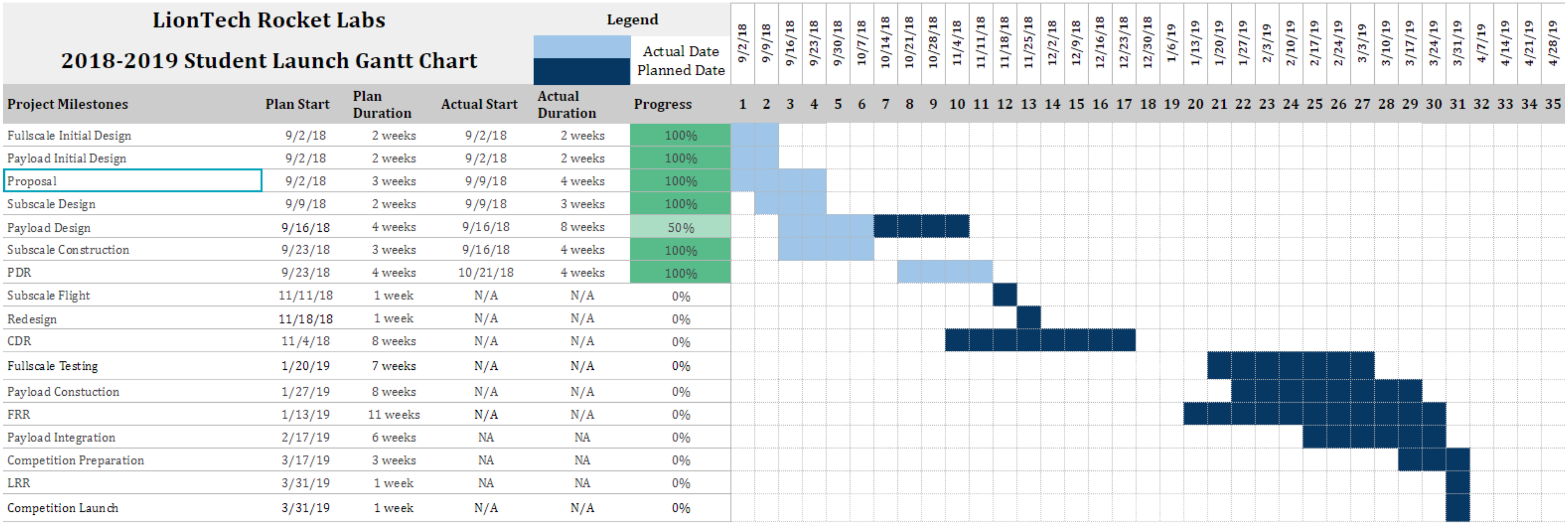
Requirement Number	Requirement	Verification	Justification
Safety 1.1	Provide the team with PPE requirements, SDS, machine instructions, FAA laws, and NAR and TRA regulations.	**Demonstration** The Safety Officer must keep all documents available to all team members in the lab to be accessed at any time.	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.	**Demonstration** 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.	**Demonstration** 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.	**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

	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.		compliance with all rules at any time.

6.3 Gantt Charts

LionTech Rocket Labs Gantt Chart

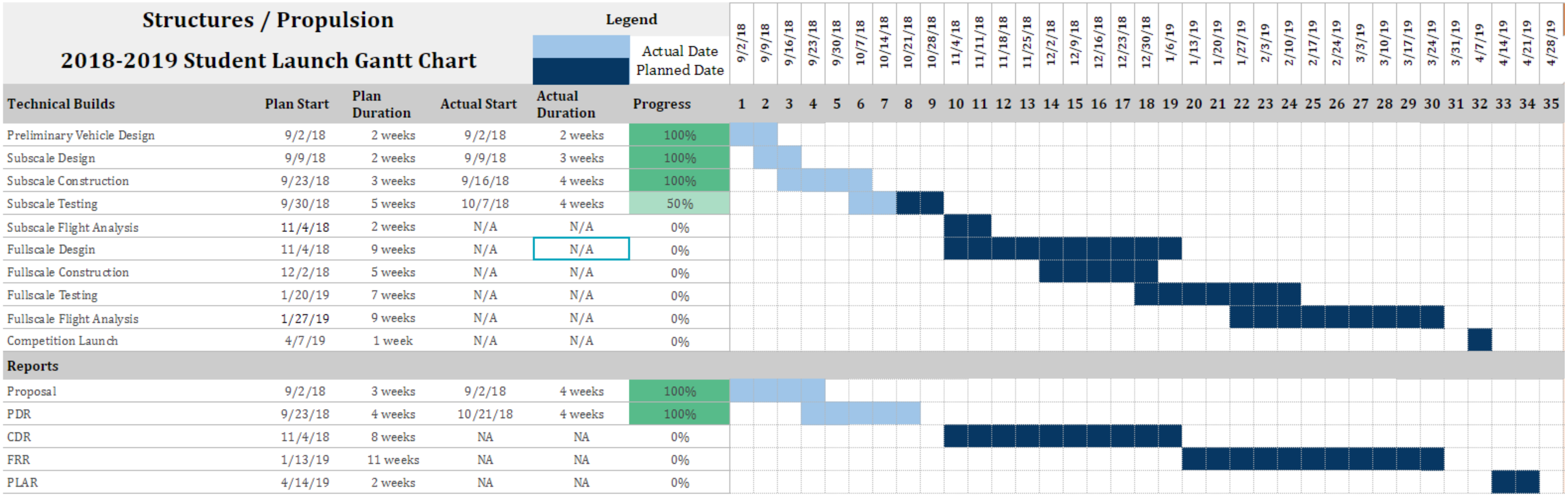


LionTech Rocket Labs

2018-2019 Student Launch Gantt Chart

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	4 weeks	9/16/18	8 weeks	50%
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	11/11/18	1 week	N/A	N/A	0%
Redesign	11/18/18	1 week	N/A	N/A	0%
CDR	11/4/18	8 weeks	N/A	N/A	0%
Fullscale Testing	1/20/19	7 weeks	N/A	N/A	0%
Payload Констuction	1/27/19	8 weeks	N/A	N/A	0%
FRR	1/13/19	11 weeks	N/A	N/A	0%
Payload Integration	2/17/19	6 weeks	NA	NA	0%
Competition Preparation	3/17/19	3 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 / Propulsion

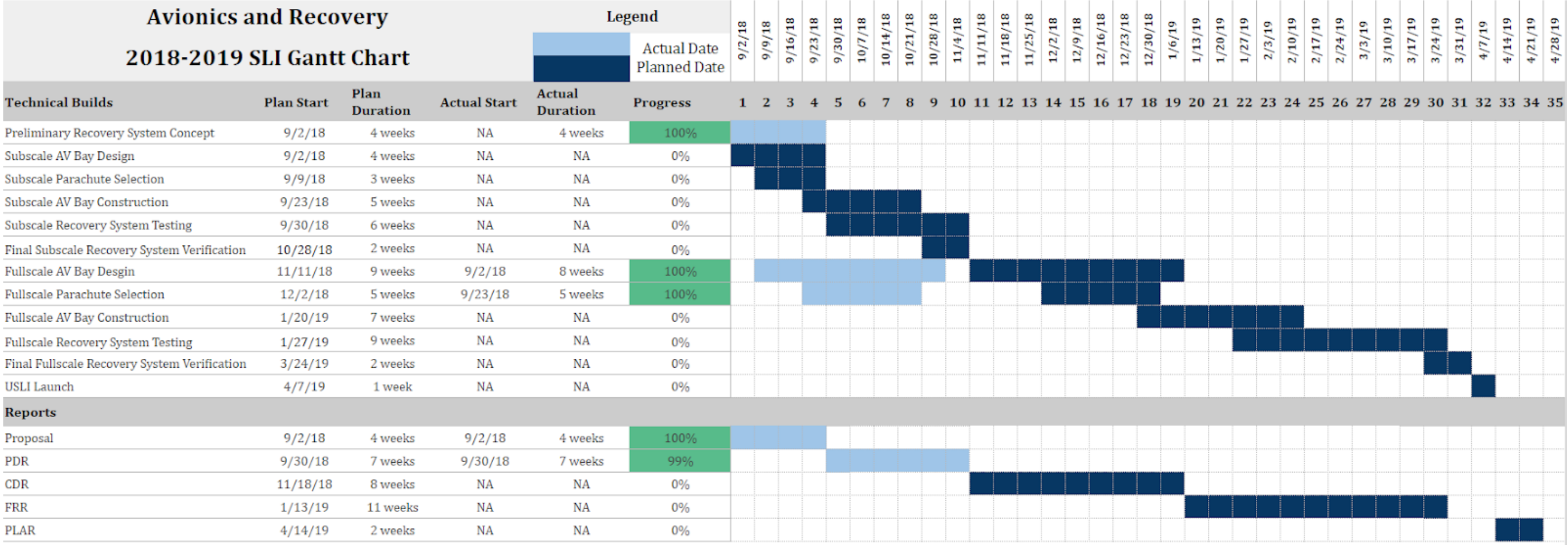
2018-2019 Student Launch Gantt Chart

Legend

▨ Actual Date
■ Planned 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	4/28/19
Technical Builds	**Plan Start**	**Plan Duration**	**Actual Start**	**Actual Duration**	**Progress**	**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**	**35**
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	50%						▨	▨	■	■																										
Subscale Flight Analysis	11/4/18	2 weeks	N/A	N/A	0%										■	■																								
Fullscale Desgin	11/4/18	9 weeks	N/A	N/A	0%										■	■	■	■	■	■	■	■	■	■																
Fullscale Construction	12/2/18	5 weeks	N/A	N/A	0%														■	■	■	■	■																	
Fullscale Testing	1/20/19	7 weeks	N/A	N/A	0%																		■	■	■	■	■	■	■											
Fullscale Flight Analysis	1/27/19	9 weeks	N/A	N/A	0%																						■	■	■	■	■	■	■	■	■					
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	NA	NA	0%										■	■	■	■	■	■	■	■	■	■																
FRR	1/13/19	11 weeks	NA	NA	0%																				■	■	■	■	■	■	■	■	■	■	■					
PLAR	4/14/19	2 weeks	NA	NA	0%																																	■	■	

Avionics and Recovery Gantt Chart



Avionics and Recovery

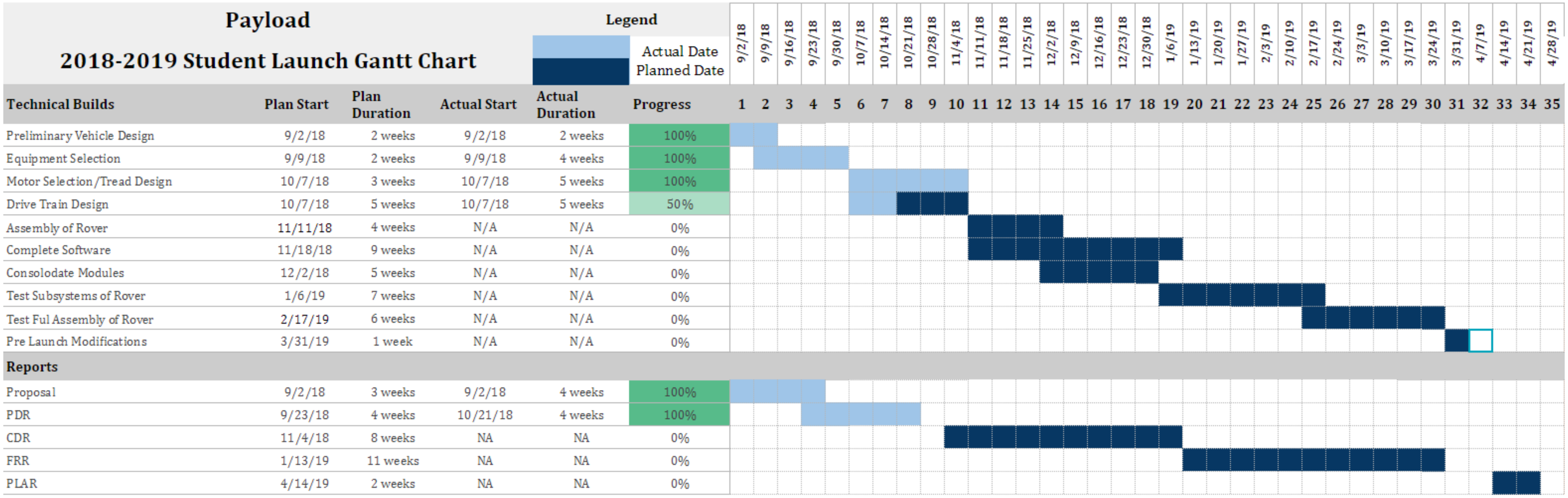
2018-2019 SLI Gantt Chart

Legend

▒ Actual Date
█ Planned Date

Technical Builds	Plan Start	Plan Duration	Actual Start	Actual Duration	Progress	9/2/18 1	9/9/18 2	9/16/18 3	9/23/18 4	9/30/18 5	10/7/18 6	10/14/18 7	10/21/18 8	10/28/18 9	11/4/18 10	11/11/18 11	11/18/18 12	11/25/18 13	12/2/18 14	12/9/18 15	12/16/18 16	12/23/18 17	12/30/18 18	1/6/19 19	1/13/19 20	1/20/19 21	1/27/19 22	2/3/19 23	2/10/19 24	2/17/19 25	2/24/19 26	3/3/19 27	3/10/19 28	3/17/19 29	3/24/19 30	3/31/19 31	4/7/19 32	4/14/19 33	4/21/19 34	4/28/19 35
Preliminary Recovery System Concept	9/2/18	4 weeks	NA	4 weeks	100%	▒	▒	▒	▒																															
Subscale AV Bay Design	9/2/18	4 weeks	NA	NA	0%	█	█	█	█																															
Subscale Parachute Selection	9/9/18	3 weeks	NA	NA	0%		█	█	█																															
Subscale AV Bay Construction	9/23/18	5 weeks	NA	NA	0%				█	█	█	█	█																											
Subscale Recovery System Testing	9/30/18	6 weeks	NA	NA	0%					█	█	█	█	█	█																									
Final Subscale Recovery System Verification	10/28/18	2 weeks	NA	NA	0%									█	█																									
Fullscale AV Bay Desgin	11/11/18	9 weeks	9/2/18	8 weeks	100%		▒	▒	▒	▒	▒	▒	▒	▒		█	█	█	█	█	█	█	█	█																
Fullscale Parachute Selection	12/2/18	5 weeks	9/23/18	5 weeks	100%				▒	▒	▒	▒	▒						█	█	█	█	█																	
Fullscale AV Bay Construction	1/20/19	7 weeks	NA	NA	0%																		█	█	█	█	█	█	█											
Fullscale Recovery System Testing	1/27/19	9 weeks	NA	NA	0%																						█	█	█	█	█	█	█	█	█					
Final Fullscale Recovery System Verification	3/24/19	2 weeks	NA	NA	0%																														█	█				
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	99%					▒	▒	▒	▒	▒	▒																									
CDR	11/18/18	8 weeks	NA	NA	0%											█	█	█	█	█	█	█	█	█																
FRR	1/13/19	11 weeks	NA	NA	0%																				█	█	█	█	█	█	█	█	█	█	█					
PLAR	4/14/19	2 weeks	NA	NA	0%																																	█	█	

Payload Gantt Chart



Payload

2018-2019 Student Launch Gantt Chart

Legend

🟦 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	5 weeks	50%
Assembly of Rover	11/11/18	4 weeks	N/A	N/A	0%
Complete Software	11/18/18	9 weeks	N/A	N/A	0%
Consolodate Modules	12/2/18	5 weeks	N/A	N/A	0%
Test Subsystems of Rover	1/6/19	7 weeks	N/A	N/A	0%
Test Ful Assembly of Rover	2/17/19	6 weeks	N/A	N/A	0%
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	NA	NA	0%
FRR	1/13/19	11 weeks	NA	NA	0%
PLAR	4/14/19	2 weeks	NA	NA	0%

Technical Builds	9/2/18 1	9/9/18 2	9/16/18 3	9/23/18 4	9/30/18 5	10/7/18 6	10/14/18 7	10/21/18 8	10/28/18 9	11/4/18 10	11/11/18 11	11/18/18 12	11/25/18 13	12/2/18 14	12/9/18 15	12/16/18 16	12/23/18 17	12/30/18 18	1/6/19 19	1/13/19 20	1/20/19 21	1/27/19 22	2/3/19 23	2/10/19 24	2/17/19 25	2/24/19 26	3/3/19 27	3/10/19 28	3/17/19 29	3/24/19 30	3/31/19 31	4/7/19 32	4/14/19 33	4/21/19 34	4/28/19 35
Preliminary Vehicle Design	🟦	🟦																																	
Equipment Selection		🟦	🟦	🟦	🟦																														
Motor Selection/Tread Design						🟦	🟦	🟦	🟦	🟦																									
Drive Train Design						🟦	🟦	■	■	■																									
Assembly of Rover											■	■	■	■																					
Complete Software											■	■	■	■	■	■	■	■	■																
Consolodate Modules														■	■	■	■	■																	
Test Subsystems of Rover																			■	■	■	■	■	■	■										
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Pre Launch Modifications																															■				
Reports																																			
Proposal	🟦	🟦	🟦	🟦																															
PDR				🟦	🟦	🟦	🟦	🟦																											
CDR										■	■	■	■	■	■	■	■	■	■																
FRR																				■	■	■	■	■	■	■	■	■	■	■					
PLAR																																	■	■	

6.4 Budget

Table 34 displays the expected costs of the 2018-2019 with the current design plan. This table includes all anticipated costs for the club for the NASA Student Launch competition.

Table 34. 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
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
Avionics and Recovery			
GPS Subscription	1	$65.00	$65.00
Propulsion			
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	$800.00	$4,800.00
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	**$8,000.00**
Outreach			
Miscellaneous Supplies	1	$300.00	$300.00
		Outreach Total	**$300.00**

Table 34 shows the projected line item expenses. The fullscale and subscale sections are broken up by subsystems. Each subsystem has estimates for fullscale as most of these materials have not yet been purchased. Only structures and propulsion are given expenses from subscale because avionics and recovery and payload used equipment from previous years. Travel costs consist mostly of the trip to Alabama as well as fuel costs for getting to and from launches. Outreach costs also contribute to the club's expenditures due to the purchase of miscellaneous supplies needed to host events throughout the academic year.

Table 35 gives the breakdown for the budget by each overall component of the competition.

Table 35. Overall Outflow

Budget	Total Cost
Fullscale	$2,031.85
Subscale	$867.69
Travel	$8,000.00
Outreach	$300.00
Miscellaneous	$500.00
Total	**$11,699.54**

Table 35 shows the total costs from each header of Table 34 to more easily show where the funds are being used. As expected, travel and fullscale are LTRL's most expensive sectors. An additional $500 was added into the budget in case unexpected costs arise.

6.5 Funding

Table 36. 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	$1,000.00
Pennsylvania Space Grant	$2,055.37
The Boeing Company	$500.00
Total	$18,055.37

Table 36 shows the sources of funding that LTRL plans to use during the 2018-2019 academic year. The Penn State College of Engineering has repeatedly supported LTRL and is expected to do so again. The Penn State Department of Aerospace Engineering aerospace engineering consistently supports LTRL's goals and high number of aerospace engineering student members. The Penn State Department of Mechanical Engineering shows support for the mechanical engineering student members of LTRL. University Park Allocations Committee (UPAC) is a Penn State organization that supports the clubs at Penn State. They offer funding to LTRL to cover most of the expenses related to travel and large equipment purchases such as a 3D printer. Club fundraising is represented largely by the club's required dues to become a member.
The Pennsylvania Space Grant offers the club support in recognition of furthering STEM involvement in NASA related fields. Each year the Boeing Company offers funds in support of LTRL's mission.

In order to prevent any unseen expenses from impacting the club's performance LTRL will be pursuing as much additional funding as possible. Additional funds may be available from the Pennsylvania Space Grant if those funds are depleted. The club will be attempting to collaborate with corporate sponsors such as the Boeing Company to acquire additional funding.

Having extra funds available to the club will allow the club to set more goals and expand current goals. Extra funds will allow participation in other projects such as supporting club members to acquire their level 1 and 2 certifications through the National Association of Rocketry. This is important to the club since LTRL needs current members to have proper certifications to launch the subscale and fullscale rocket.

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]
Page 1 of 6

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

Epoxy Hardener SDS

Fibre Glast Developments Corporation

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

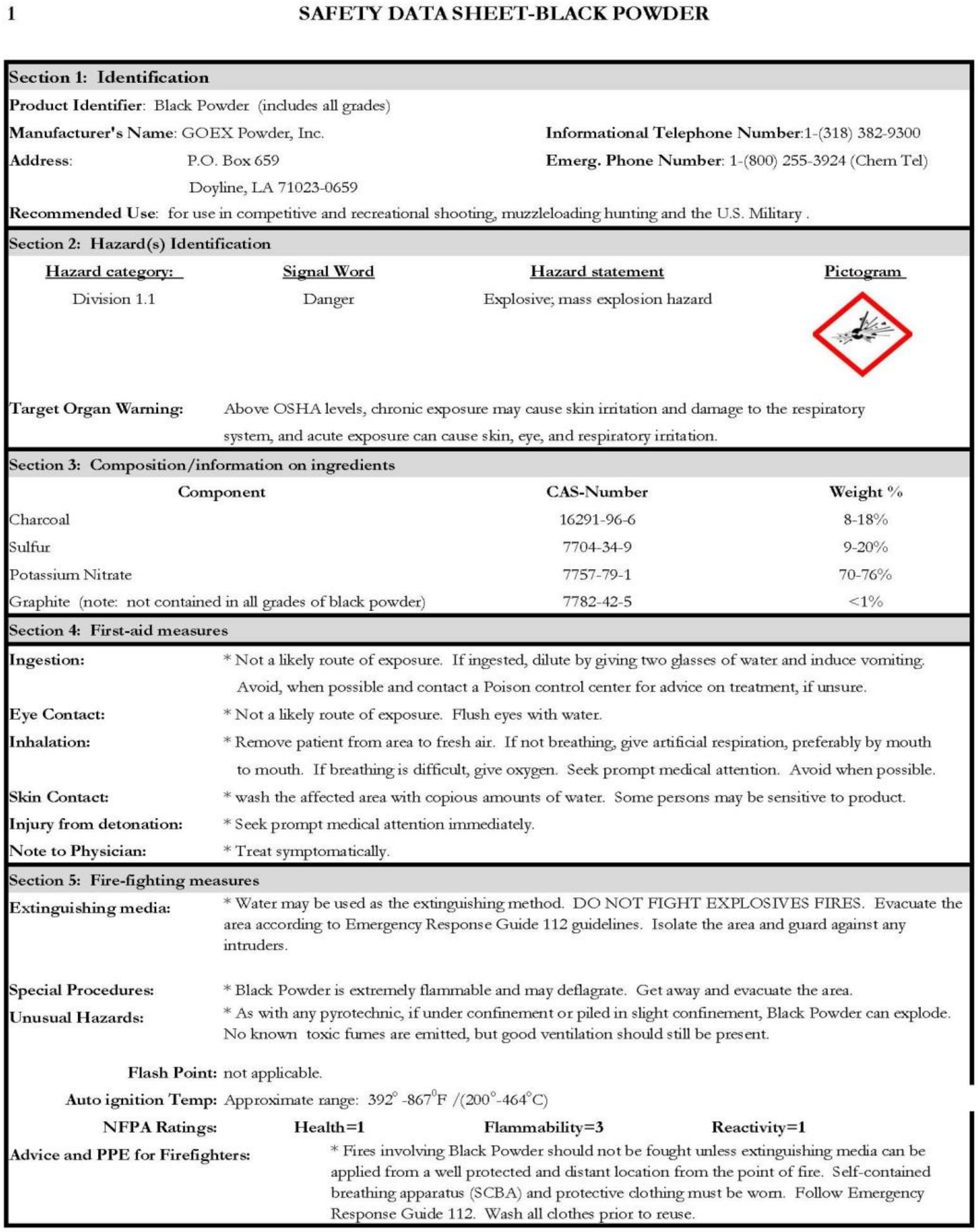
Hazard statements : H318 Causes serious eye damage.
H302+332 Harmful if swallowed, or if inhaled.
H317 May cause an allergic skin reaction.

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]
Page 1 of 6

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
Doyline, LA 71023-0659

Emerg. Phone Number: 1-(800) 255-3924 (Chem Tel)

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°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

Fibre Glast
Developments Corporation

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

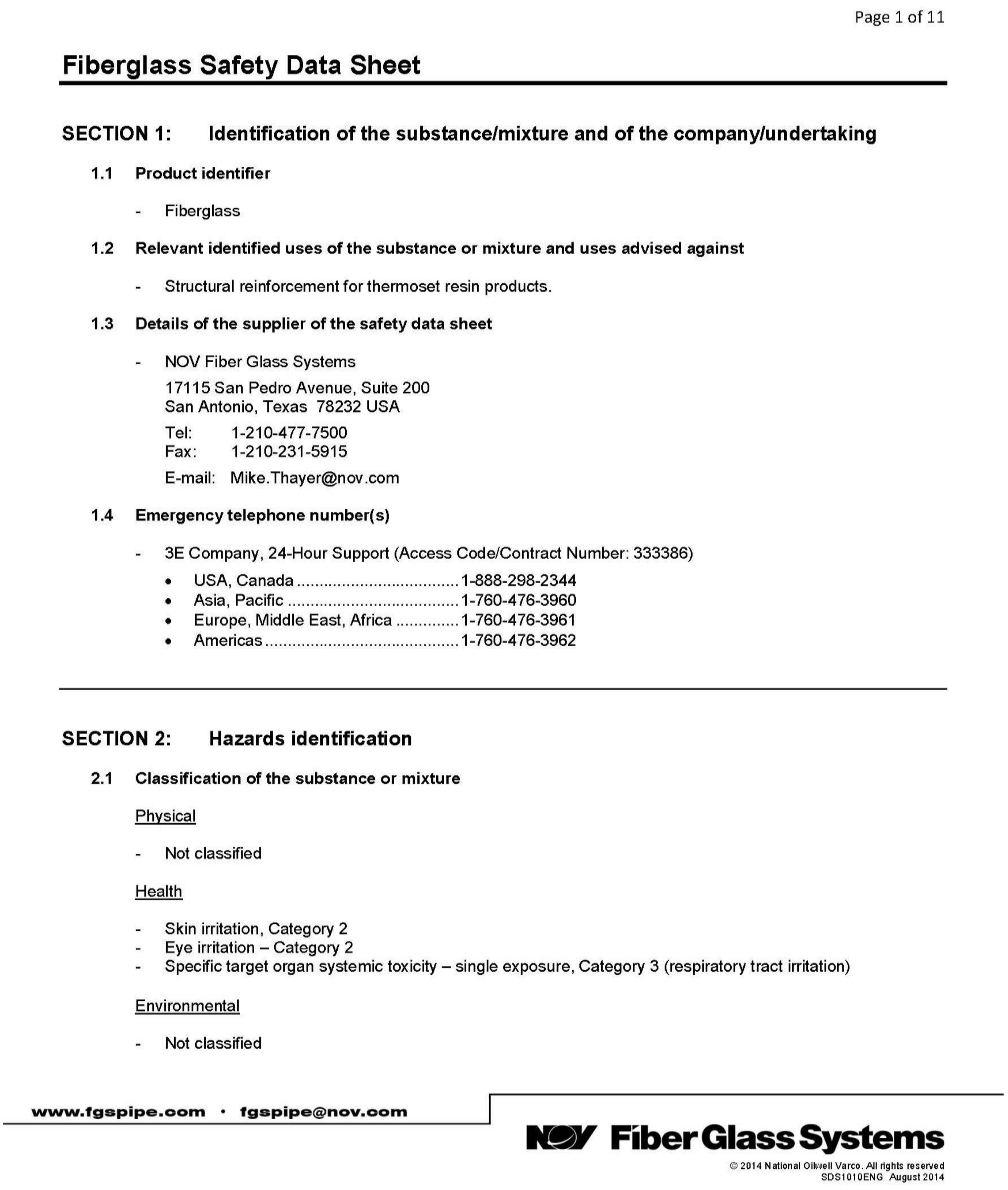
Hazard Statements : USH01 May form combustible dust concentrations in air

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]
Page 1 of 7

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

Fiberglass SDS



Page 1 of 11

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

www.fgspipe.com · fgspipe@nov.com

NOV Fiber Glass Systems

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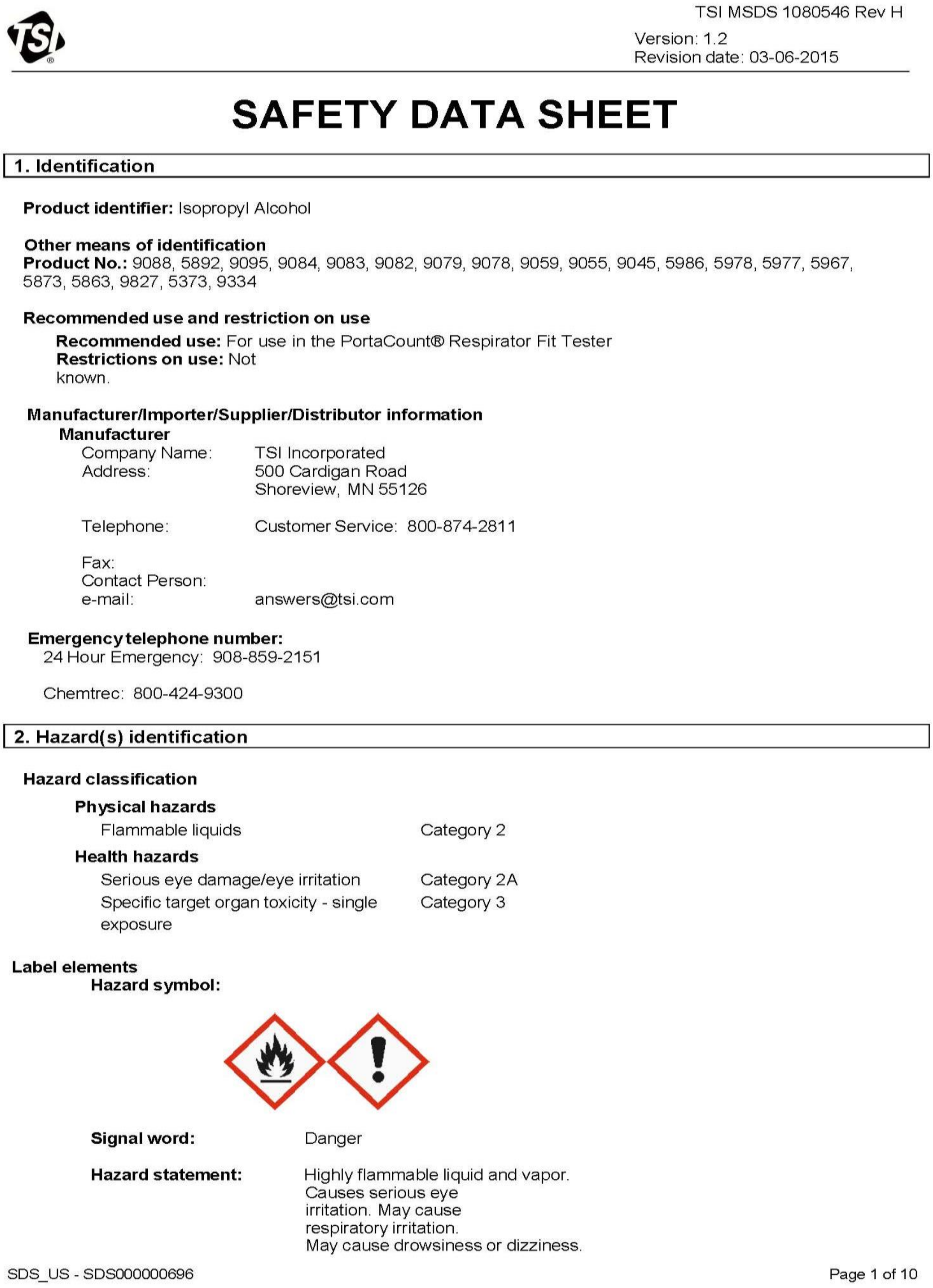
SDS1010ENG August 2014

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

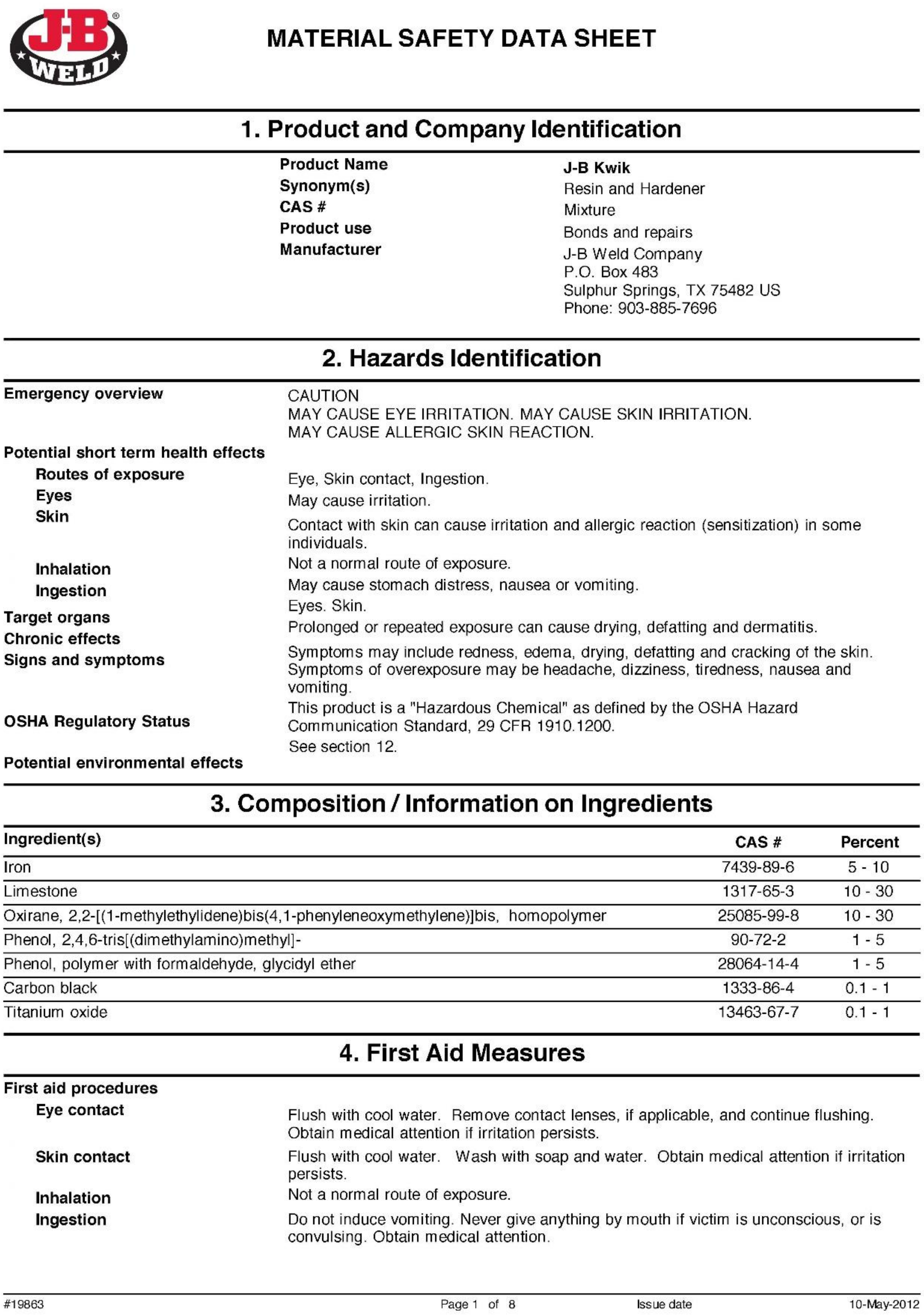
Label elements
Hazard symbol:

Signal word: Danger

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

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

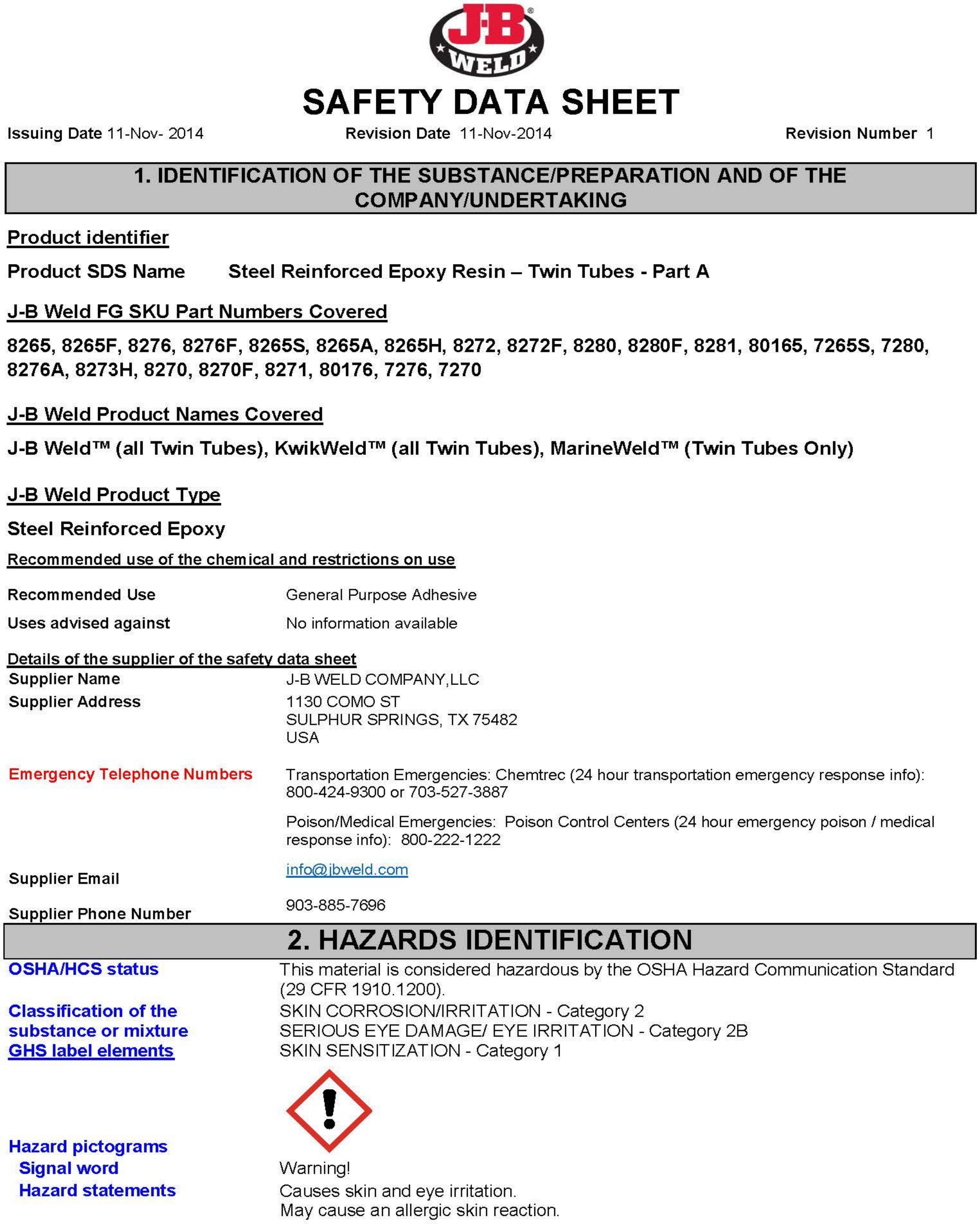
4. First Aid Measures

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.

#19863 Page 1 of 8 Issue date 10-May-2012

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

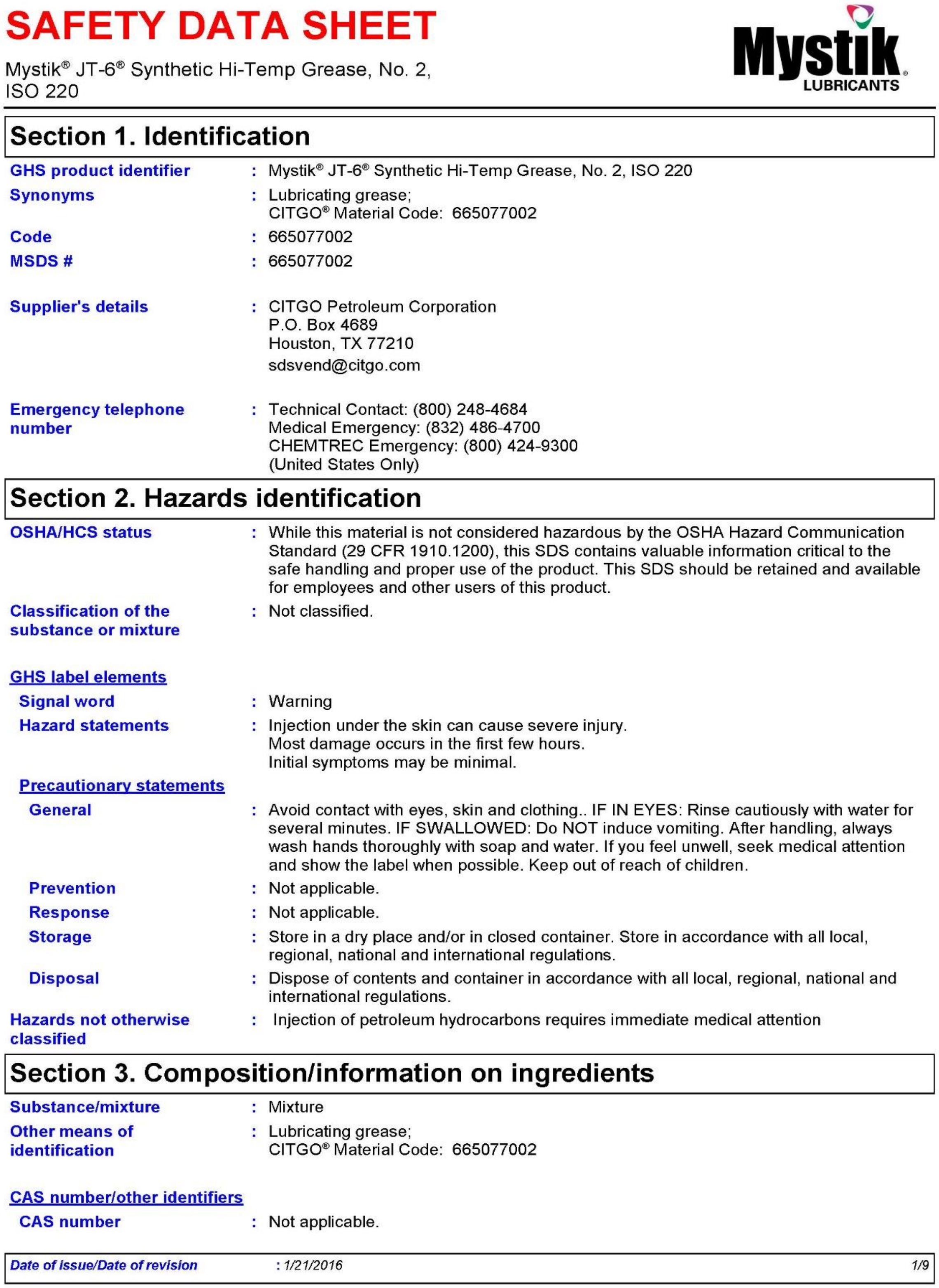
Supplier Name	J-B WELD COMPANY,LLC
Supplier Address	1130 COMO ST SULPHUR SPRINGS, TX 75482 USA
Emergency Telephone Numbers	Transportation Emergencies: Chemtrec (24 hour transportation emergency response info): 800-424-9300 or 703-527-3887 Poison/Medical Emergencies: Poison Control Centers (24 hour emergency 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 SKIN SENSITIZATION - Category 1
GHS label elements	
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 :

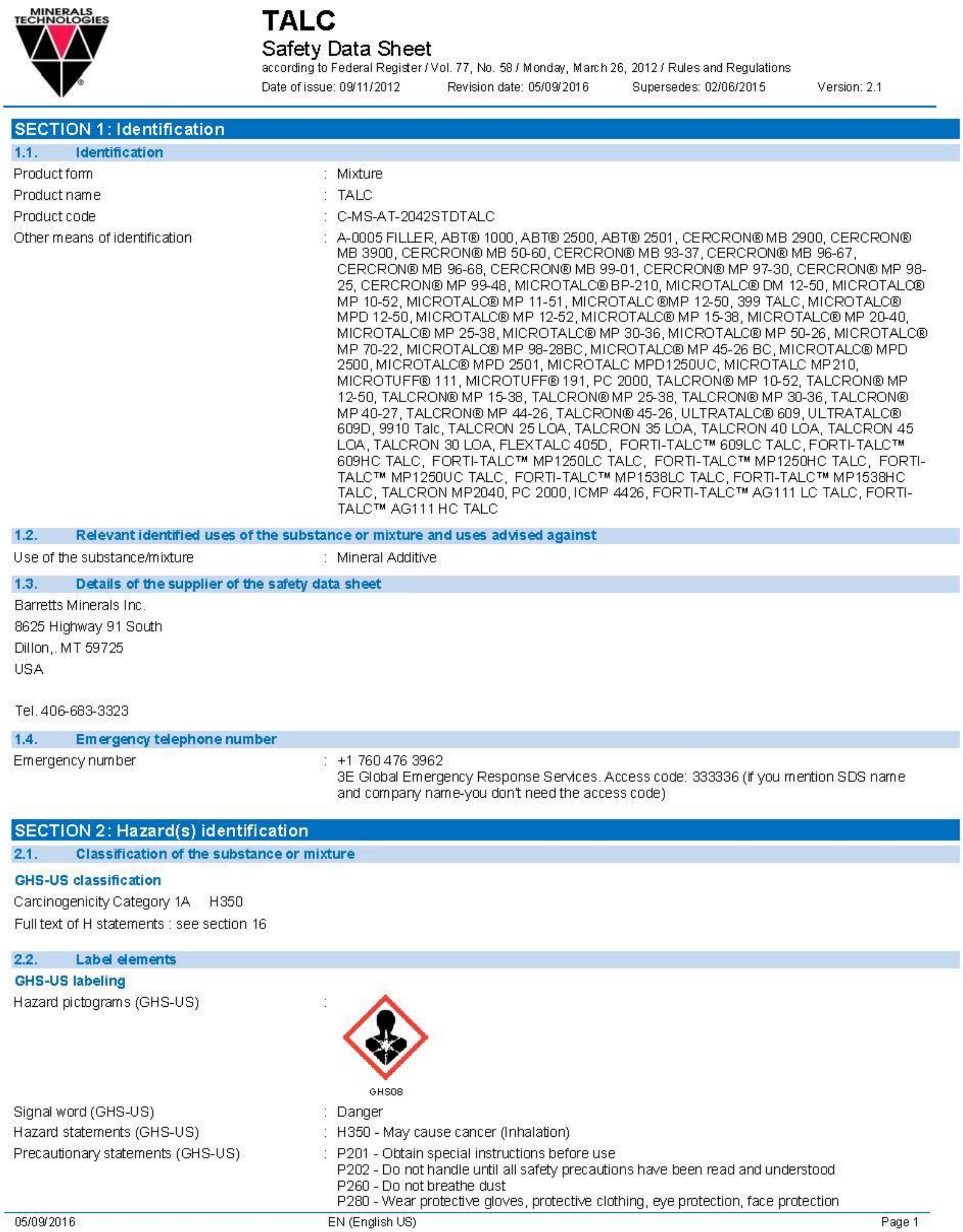
Signal word : Danger

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) :

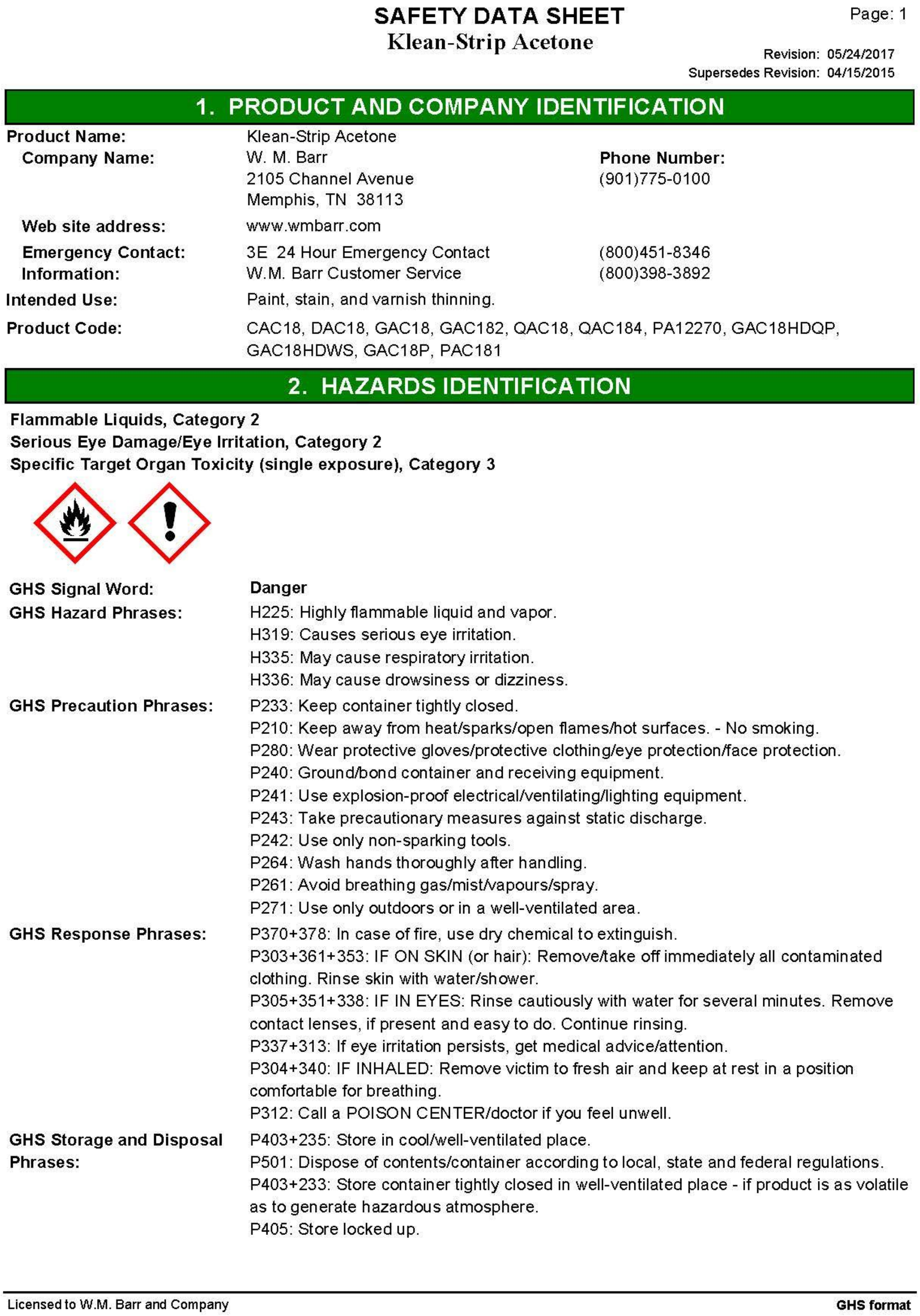
GHS08

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
Klean-Strip Acetone

Page: 1

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.

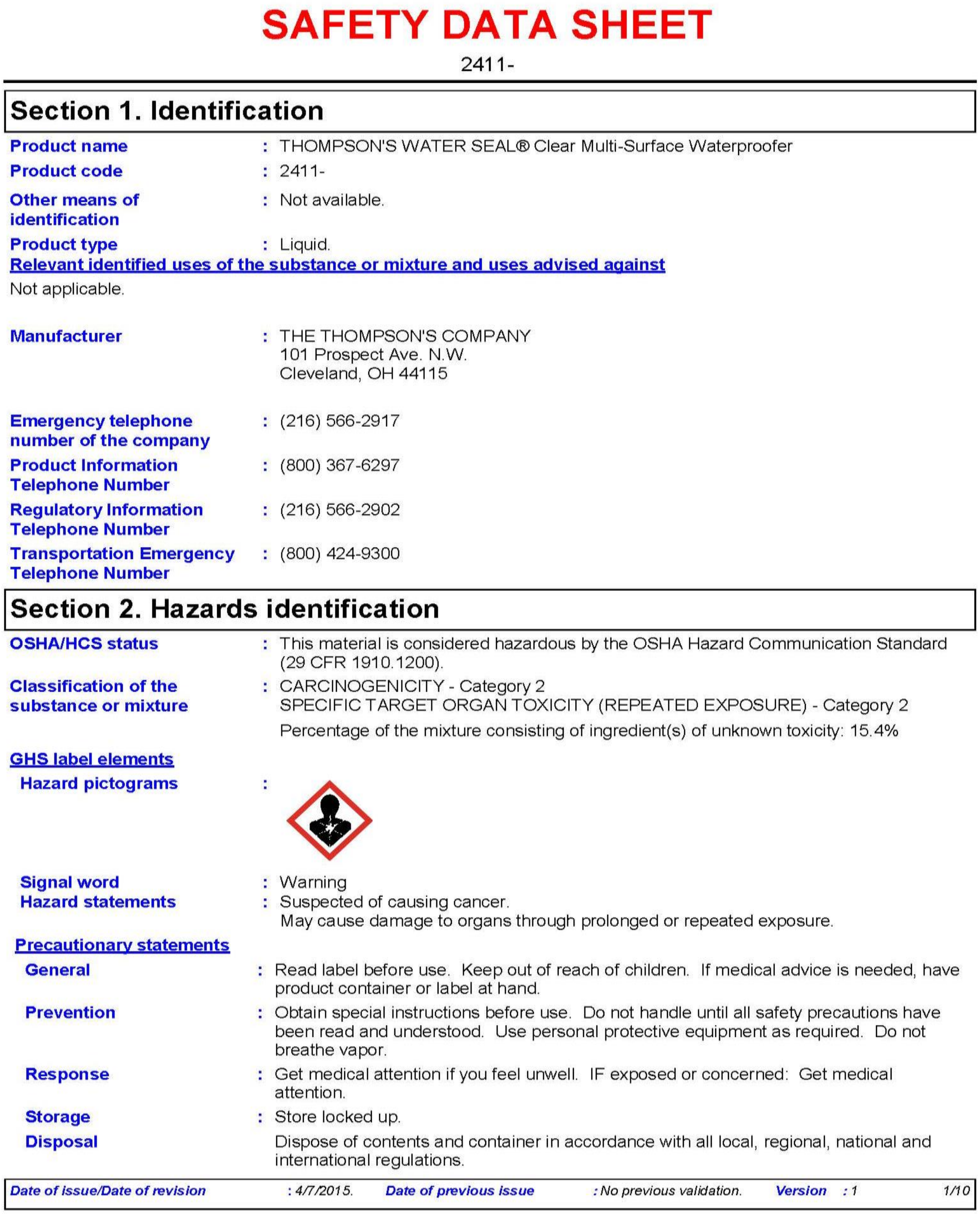
GHS Storage and Disposal Phrases:
P403+235: Store in cool/well-ventilated place.
P501: Dispose of contents/container according to local, state and federal regulations.
P403+233: Store container tightly closed in well-ventilated place - if product is as volatile as to generate hazardous atmosphere.
P405: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

Licensed to W.M. Barr and Company

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.

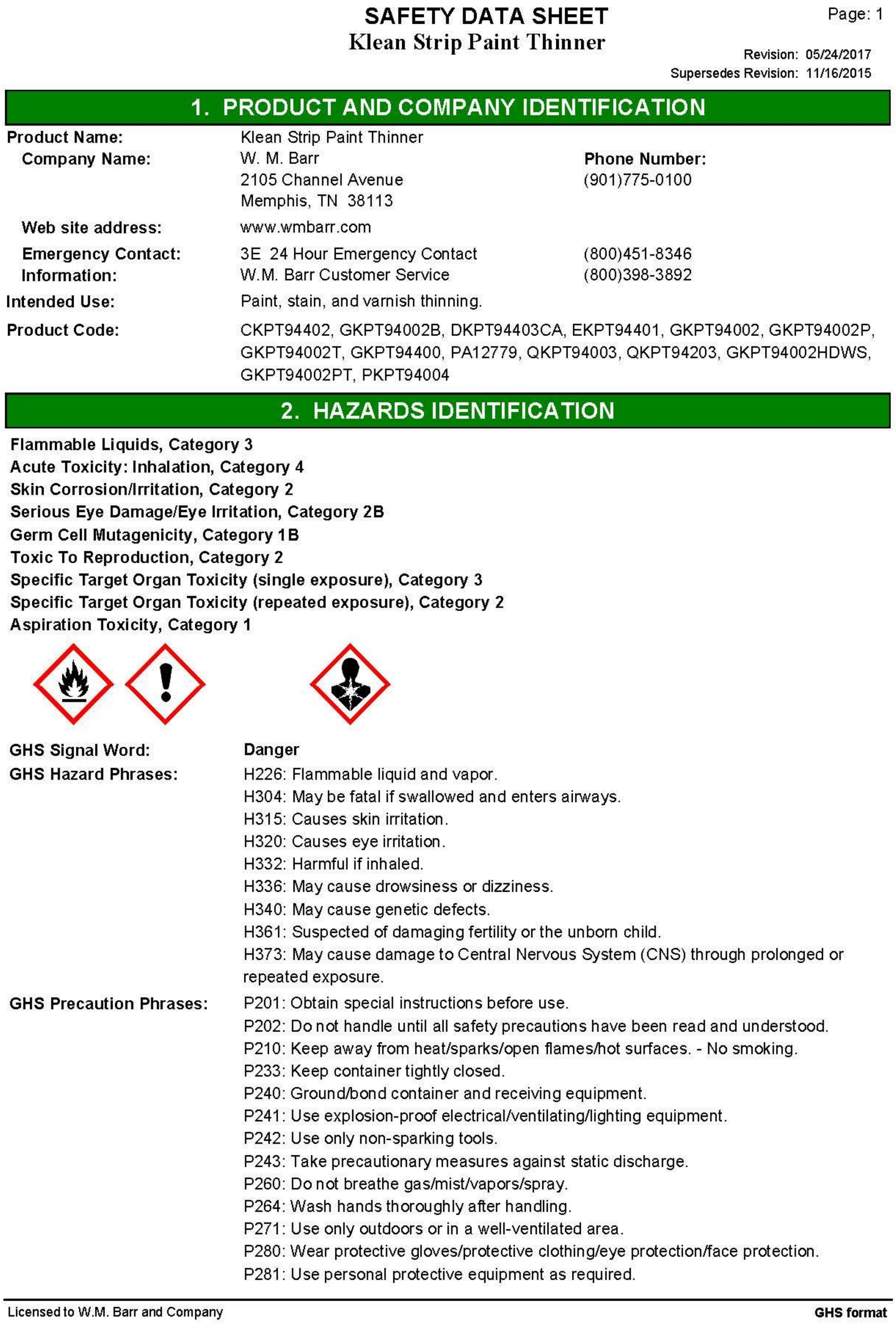
Storage : Store locked up.

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 (800)451-8346
W.M. Barr Customer Service (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.

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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**

Safety Data Sheet

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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:

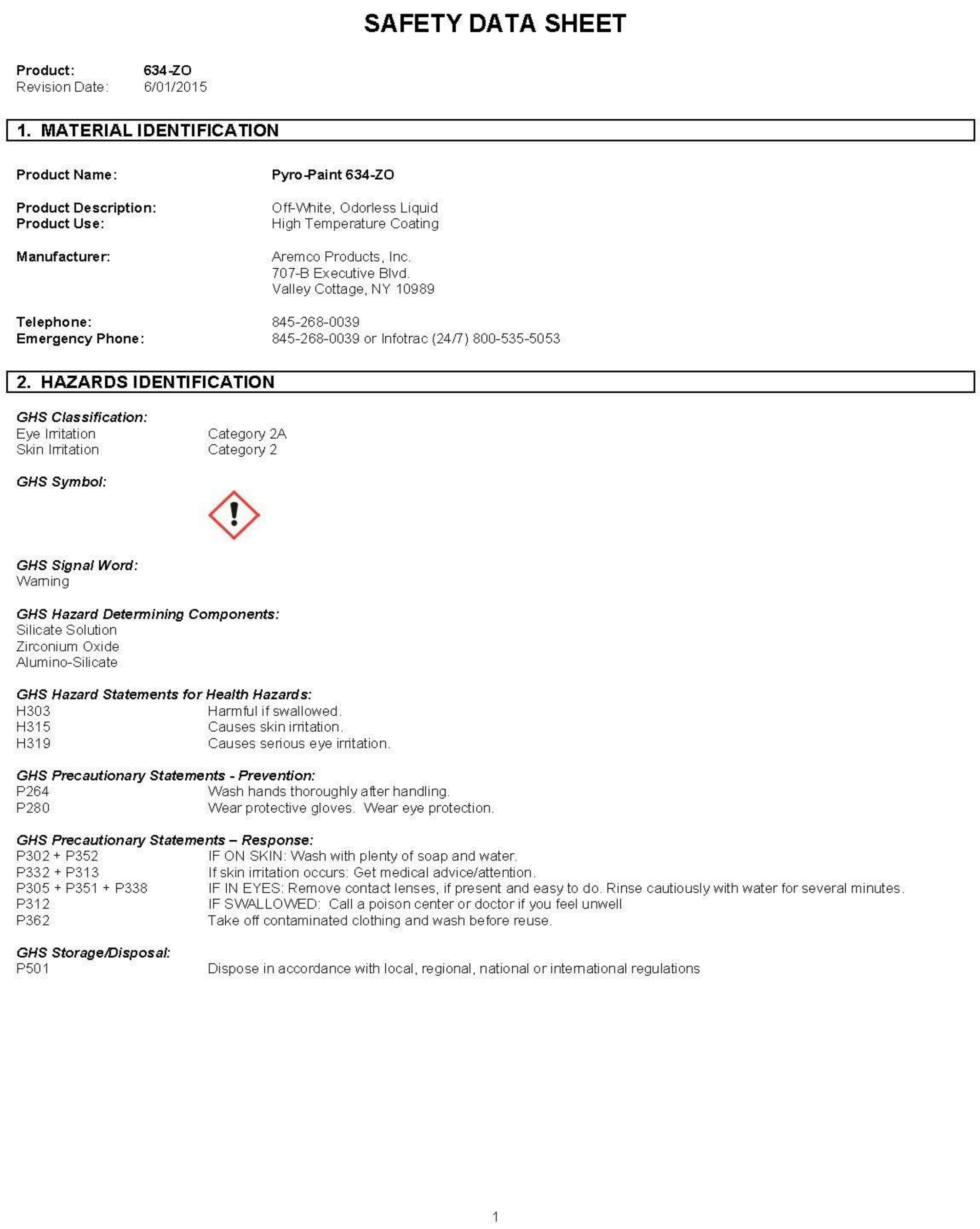
24-2429-9, 24-2440-6

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.

Page 1 **of** 2

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

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 (4,4methylene 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

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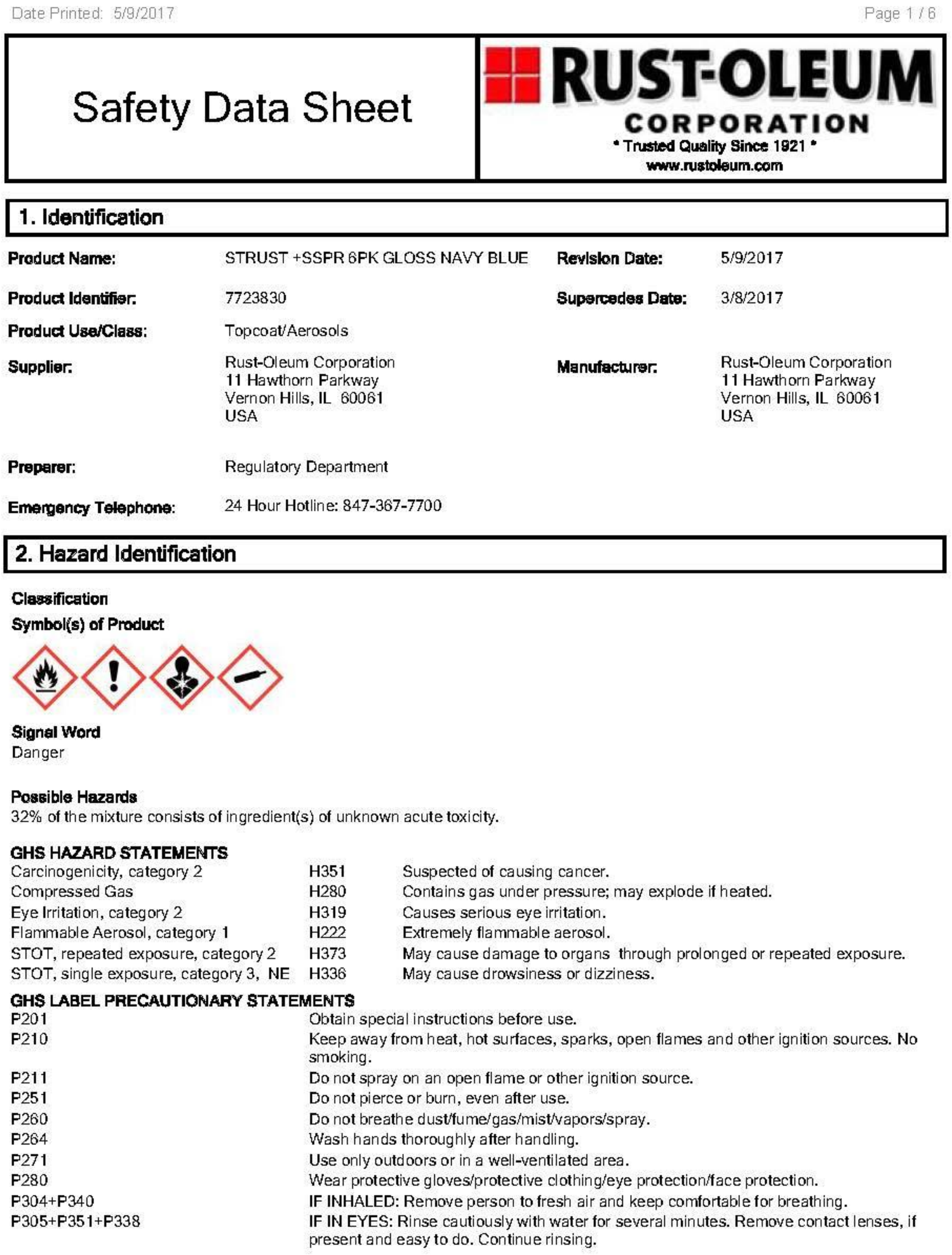
Full SDS:
https://www.vercounty.org/MSDS/EMA/34Dow%20Great%20Stuff%20Spray%20Foam.pdf

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

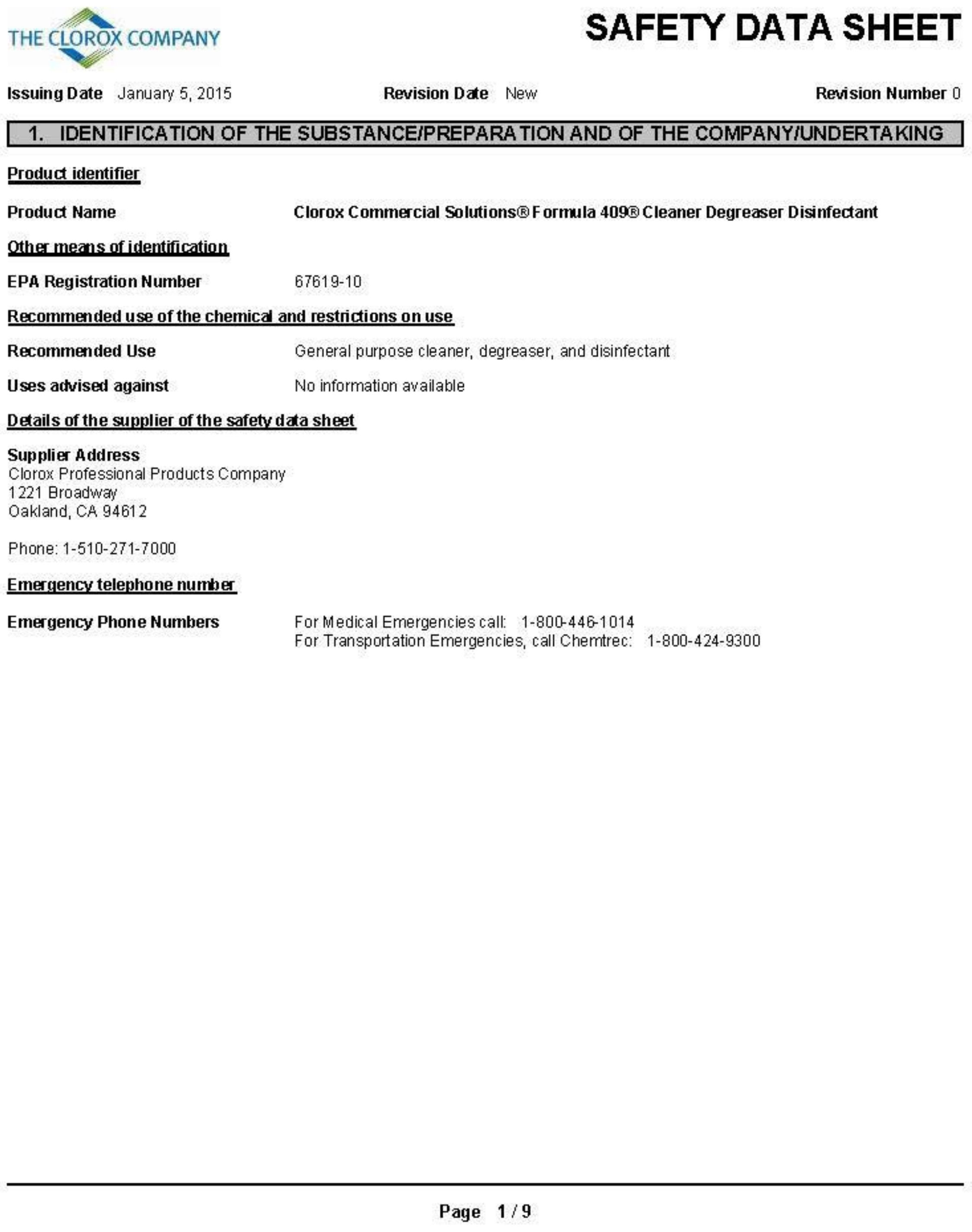
Carcinogenicity, category 2	H351	Suspected of causing cancer.
Compressed Gas	H280	Contains gas under pressure; may explode if heated.
Eye Irritation, category 2	H319	Causes serious eye irritation.
Flammable Aerosol, category 1	H222	Extremely flammable aerosol.
STOT, repeated exposure, category 2	H373	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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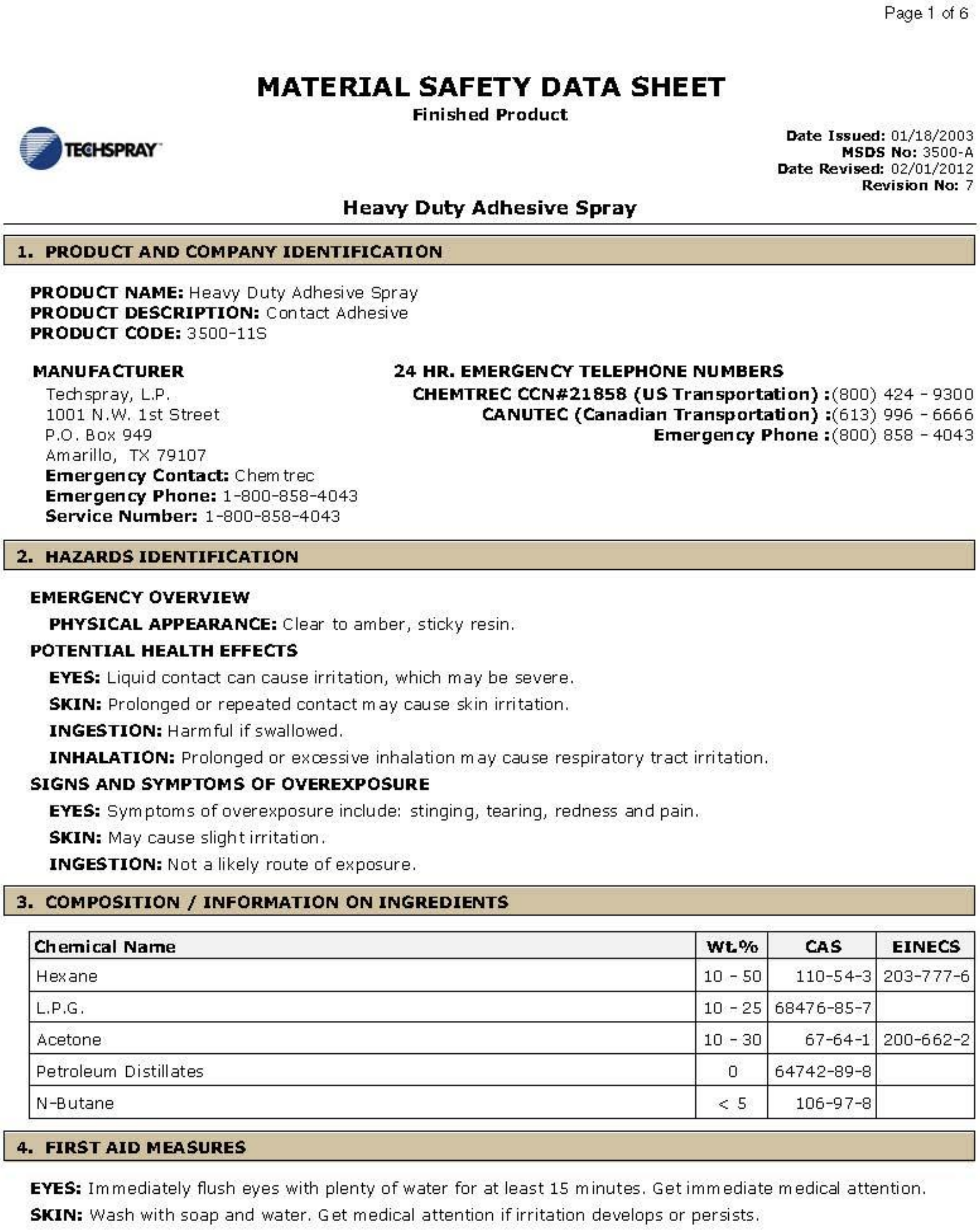
Full SDS: https://www.parish-supply.com/documents/CLO35296-01.pdf

Adhesive Spray SDS



Page 1 of 6

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

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Page 1 of 2

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

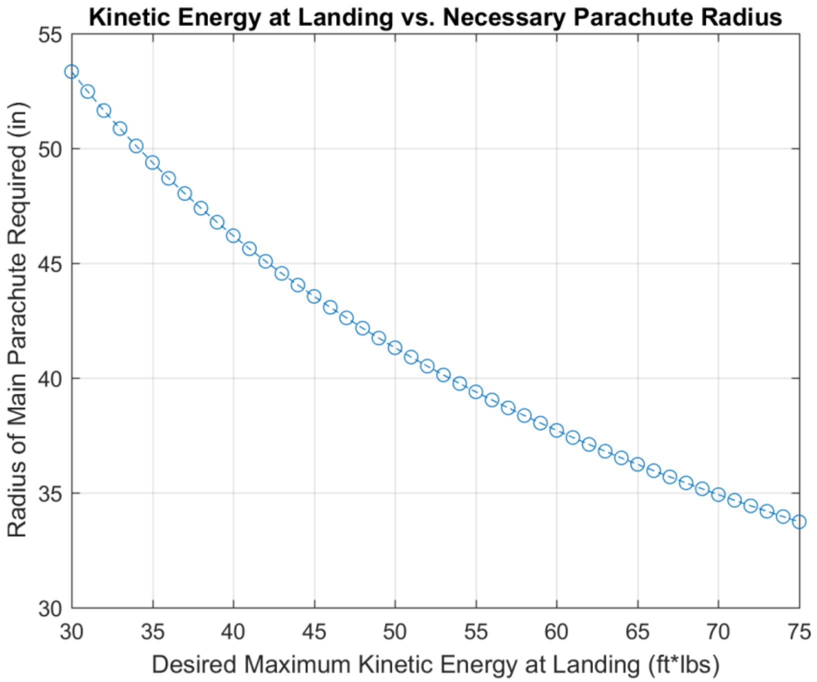
8. Appendix B: Recovery Decent Profile Calculator

```
% 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;
```



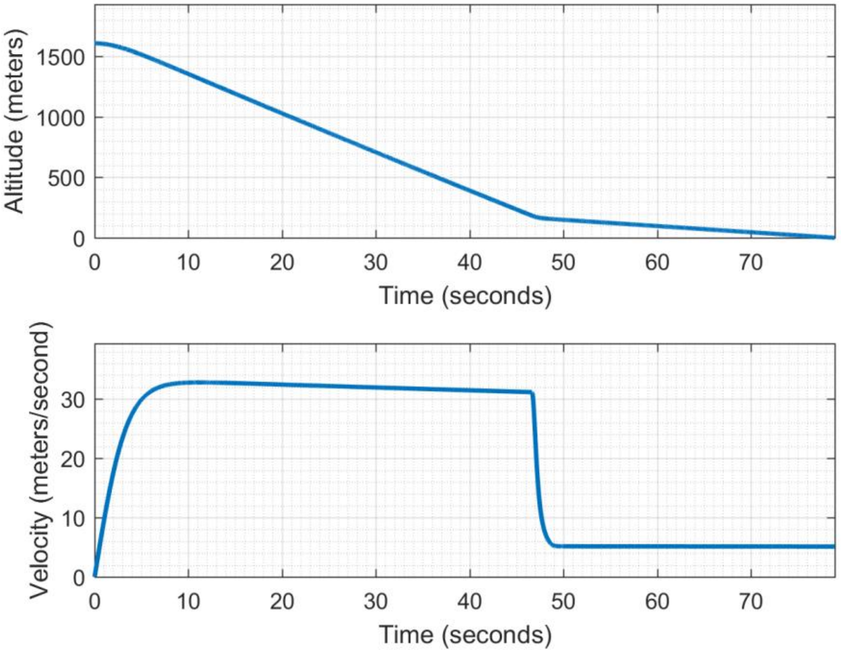
Calculating Force based results

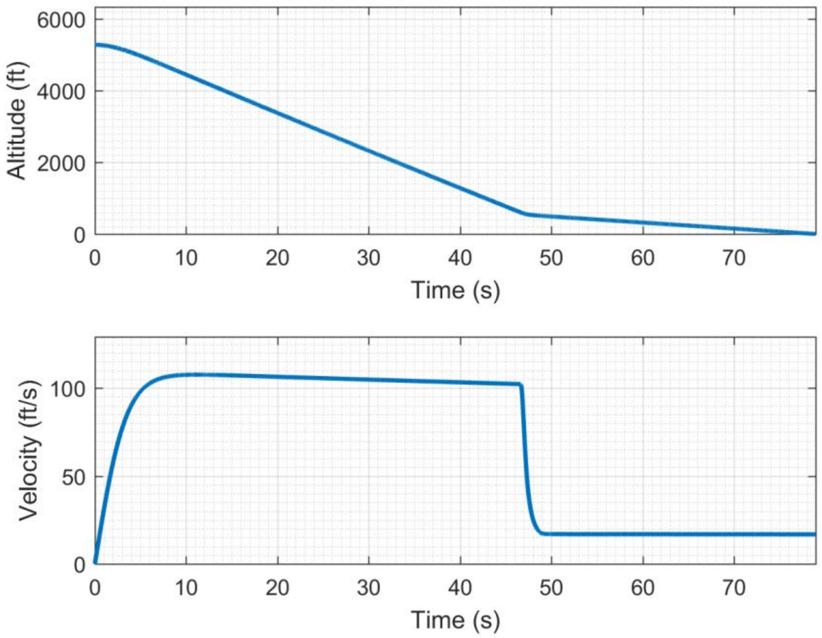
```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Input Begin %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Rd_in = 6; %radius of drogue[in]
Rm_in = 42; %radius of main[in]
Rr_in = 7.5; %simulated radius of "tumbling" rocket parachute[in]

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;
```

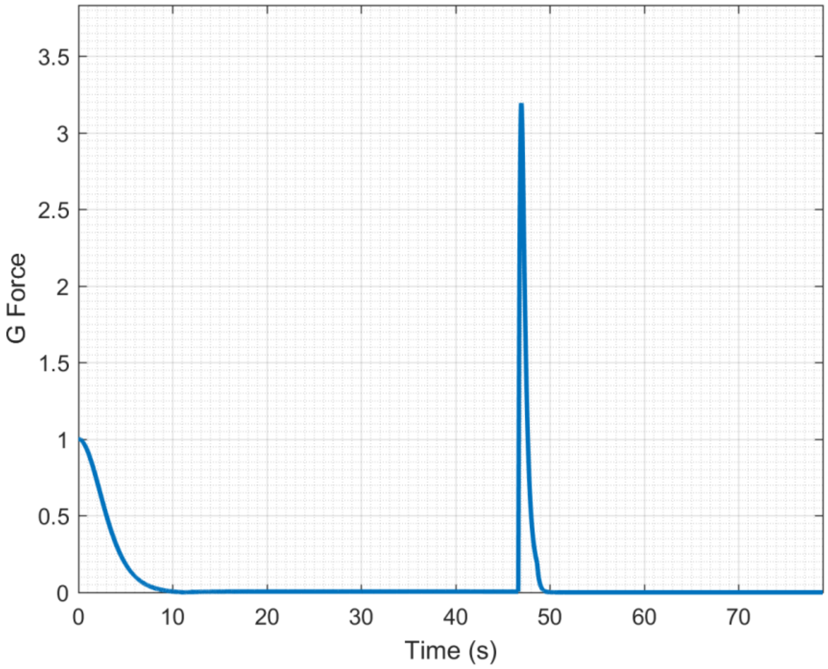
```
altDrogue = 0.3048*altDrogueft;
altMain = 0.3048*altMainft;

% 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]);
```





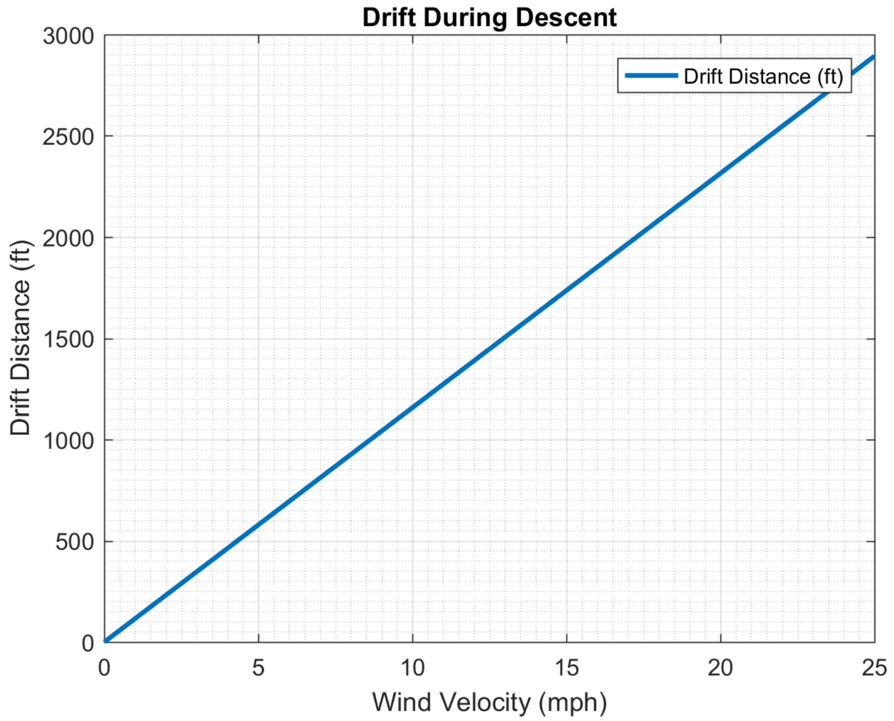


Calculate Drift Distance

```
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
```



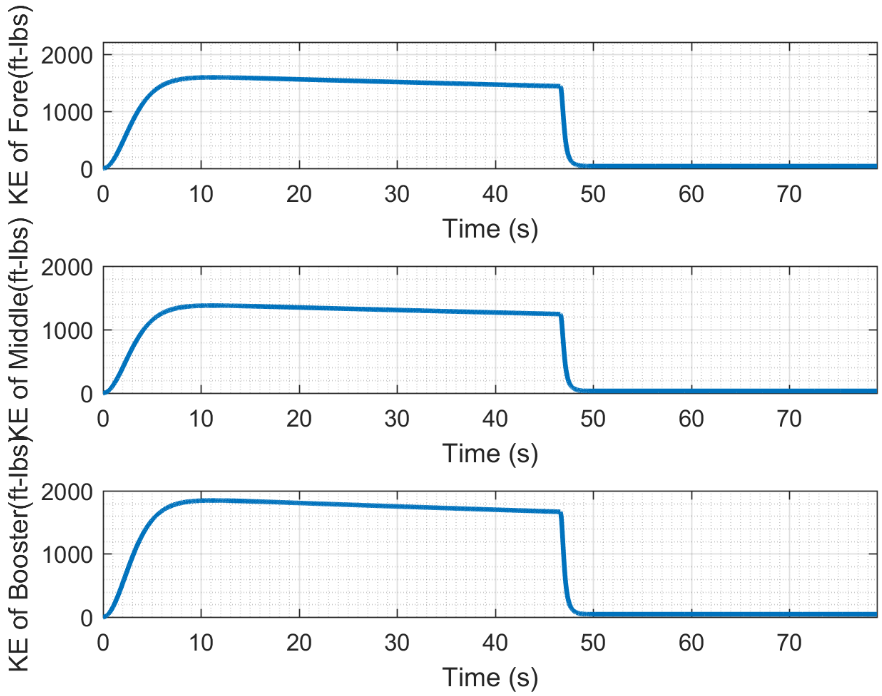
Calculate KE History of each component

```
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
```



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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
```

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