The Pennsylvania State University

LionTech Rocket Labs

2017-2018 USLI Project Nimbus

Preliminary Design Report

046 Hammond Building, University Park, PA 16802
November 03, 2017

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List of Acronyms

A&R	Avionics and Recovery
CFD	Computational Fluid Dynamics
EIT	Electronic and Information Technology
FAA	Federal Aviation Administration
FEA	Finite Element Analysis
EHS	Environmental Health and Safety
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
PPE	Personal Protective Equipment
PSC	Pittsburgh Space Command
PSU	The Pennsylvania State University
RSO	Range Safety Officer
SDS	Safety Datasheet
STEM	Science Technology Engineering and Mathematics
STTR	Small Business Technology Transfer
TRA	Tripoli Rocket Association
UPAC	University Park Allocation Committee
USLI	University Student Launch Initiative

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1. Summary of Report

1.1 Team Summary

Team Name and Address

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1.2 Launch Vehicle Summary

Size and Mass

The launch vehicle was designed to incorporate a rover payload while minimizing weight and providing sufficient strength. A diameter of 5.5 inches was chosen to give sufficient space for the payload. The length of the launch vehicle was determined to be 112 inches to provide enough space for payload and recovery systems. The dry weight of the final flight vehicle will be 26.56 pounds, while the wet mass, which includes the motor and casing, will be 34.25 pounds. An OpenRocket rendering of the final flight vehicle is shown in Figure 1.

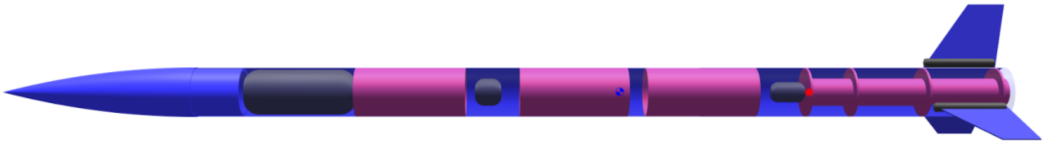


Figure 1. OpenRocket Rendering of Fullscale

Motor Choice

The motor selection process is based on the mission performance criteria outlined in the NASA USLI 2017-18 Handbook and preliminarily uses OpenRocket to simulate flight characteristics. Through this motor selection process the Cesaroni L995 was selected.

Recovery System

The avionics bay will be fully redundant, consisting of two independent Stratologger CF altimeters with corresponding independent power sources switches, and charges. The redundant altimeter will be at a one-second delay so that the body of the rocket is not overwhelmed when the ejection charges detonate. The rocket will have a dual-deployment parachute recovery where the drogue parachute will deploy at apogee and the main parachute will deploy at 600 ft above ground level (AGL). The drogue parachute will be a 12” Fruity Chutes Classical Elliptical and the main parachute will be an 84” Fruity Chutes Iris Ultra Compact. These parachutes guarantee that the rocket will land within the NASA kinetic energy requirement of 75 ft-lbs.

1.3 Payload Summary

The payload challenge chosen this year is build a remotely deployable autonomous rover. The rover will be deployed from the launch vehicle and then autonomously move at least 5 feet away from all parts of the rocket. After the rover has reached its destination, it will deploy a set of foldable solar panels.

Milestone Review Flysheet 2017-2018

Institution	Pennsylvannia State University	**Milestone**	PDR

Vehicle Properties

Total Length (in)	112
Diameter (in)	5.56
Gross Lift Off Weigh (lb.)	34.25
Airframe Material(s)	Carbon Fiber Wrapped Blue Tube
Fin Material and Thickness (in)	G10 FR4 Fiberglass 3/16
Coupler Length/Shoulder Length(s) (in)	0.53

Stability Analysis

Center of Pressure (in from nose)	89.9
Center of Gravity (in from nose)	68.8
Static Stability Margin (on pad)	3.84
Static Stability Margin (at rail exit)	2.87
Thrust-to-Weight Ratio	8.2
Rail Size/Type and Length (in)	1.5/144
Rail Exit Velocity (ft/s)	74.3

Recovery System Properties

Drogue Parachute

Manufacturer/Model	Fruity Chutes Eliptical
Size/Diameter (in or ft)	14" Diameter
Altitude at Deployment (ft)	5280
Velocity at Deployment (ft/s)	-
Terminal Velocity (ft/s)	102
Recovery Harness Material	Kevlar
Recovery Harness Size/Thickness (in)	0.5
Recovery Harness Length (ft)	30
Harness/Airframe Interfaces	3/8" Steel U-Bolt

Kinetic Energy of Each Section (Ft-lbs)	Nose/Payload	Avionics Bay	Booster
	1142	1245	1668

Recovery Electronics

Altimeter(s)/Timer(s) (Make/Model)	Stratologger Cf
Redundancy Plan and Backup Deployment Settings	Single level redundancy for drogue and main event
Pad Stay Time (Launch Configuration)	2 hours

Motor Properties

Motor Brand/Designation	Cerseroni/ L995
Max/Average Thrust (lb.)	316/224
Total Impulse (lbf-s)	814
Mass Before/After Burn (lb.)	392 oz/ 271 oz
Liftoff Thrust (lb.)	258
Motor Retention Method	Aluminum casing/Plywood centering rings

Ascent Analysis

Maximum Velocity (ft/s)	632
Maximum Mach Number	0.57
Maximum Acceleration (ft/s^2)	244
Predicted Apogee (From Sim.) (ft)	5264

Recovery System Properties

Main Parachute

Manufacturer/Model	Fruity Chute Iris Ultra
Size/Diameter (in or ft)	84" Diameter
Altitude at Deployment (ft)	600
Velocity at Deployment (ft/s)	102
Terminal Velocity (ft/s)	16.8
Recovery Harness Material	Kevlar
Recovery Harness Size/Thickness (in)	0.5
Recovery Harness Length (ft)	40
Harness/Airframe Interfaces	3/8" Steel U-Bolt

Kinetic Energy of Each Section (Ft-lbs)	Nose/Payload	Avionics Bay	Booster
	38.96	33.63	44.05

Recovery Electronics

Rocket Locators (Make/Model)	SPYTEC STI GL300	
Transmitting Frequencies (all - vehicle and payload)	***Required by CDR***	
jection System Energetics (ex. Black Powder	Black Powder	
Energetics Mass - Drogue Chute (grams)	Primary	5
	Backup	5
Energetics Mass - Main Chute (grams)	Primary	4
	Backup	4
Energetics Masses - Other (grams) - If Applicable	Primary	N/A
	Backup	N/A

2. Changes made since Proposal

2.1 Changes made to Vehicle Criteria

Since proposal, the team has selected Rocket B as the design option. This means that there will not be a second avionics bay in the nose cone with its own parachute and recovery harness. Instead, the separation of the nose cone will occur on the ground. The main parachute deployment height has changed from 700 ft AGL to 600 ft AGL. The initial parachute estimates have changed as the masses of the rocket sections have been more accurately determined. The new drogue parachute will be a 12” drogue parachute and the updated main parachute size is 84”. An in-depth explanation of the calculations that lead to these choices is included in Section 3.3.

Additionally, a downward facing camera has been added. This is to allow high quality video to be recorded for additional post flight data. A camera cover has been added to protect the camera during flight. This is to reduce drag generated from the external camera. The primary motor was changed from a Cesaroni L800 to a Cesaroni L995. This occurred due to changes in the overall length and predicted mass of the rocket as more accurate estimations were acquired. The L995 provides less impulse than the L800 and was chosen due to its ability to carry the final flight vehicle to the target altitude.

2.2 Changes made to Payload Criteria

Since proposal, the team has further developed the design for the rover. The rover will be powered by rechargeable lithium polymer batteries instead of disposable 9-volt batteries. The use of rechargeable batteries instead of 9V batteries will allow for significant cost savings during testing. The lithium polymer battery pack can simply be recharged instead of having to buy fresh batteries for every component and software test. The rover will use an accelerometer to measure total distance travelled instead of a GPS sensor. Commercially available GPS sensors are not precise enough to measure distances on a small scale such as a rover travelling 5 feet. However, commercially available accelerometers are accurate enough to measure distances travelled on this scale.

3. Vehicle Criteria

3.1 Vehicle Design and Justification

Airframe Design

Blue tube wrapped in carbon fiber was selected as the material for the airframe for this year's launch vehicle. This decision was made based on the scores given in a weighted design matrix.

Seven factors were considered when selecting the material for the airframe. A score of 1-5 (one being the worst and five being the best) was assigned for each factor based on its performance in that specific criteria. The seven criteria considered for airframe selection were strength, cost, workability, weight, appearance, legacy, and hazardousness. Strength was rated based on each material's ability to withstand forces throughout flight. Material that can withstand higher forces received a higher score. The cost criteria score was determined based on each material's price per foot. The cheaper the material, the higher the score. The easier it is to cut, sand, and modify a material, the higher its workability score. Weight was given a score dependent on each material's impact on the total mass of the rocket. The lighter the material, the higher the score. Appearance was graded based on each material's overall look and ability to be painted over. This category was included to account for the rocket's overall presentation value during the rocket fair in Alabama. The better the material looks, the higher the score. Legacy was graded based on club members' previous experience working with the selected material. Thorough experience and knowledge of the material receives a higher grade. Hazardousness was graded based on safety concerns that were associated with working each material. A safer material received a higher score.

Each factor was weighted in importance on a scale from 0-1 where all the weights of all the factors sum to one. Strength was given a rating of 0.25 due its significant effect on the durability of the flight vehicle. The rocket must sufficiently withstand potential zippering, impact forces, thrust forces, buckling, and denting to ensure success in its launch, deployment, and landing. Cost was given a rating of 0.15 to account for its importance on staying on the yearly budget. The cost of the airframe is especially important when considering potential failures where body tube would need to be replaced. Workability was given a weight of 0.1 to reflect the ease of handling the material while considering factors such as types of tools needed. The weight (mass) category was given a large weight of 0.25, to reflect its importance on the flight of the rocket. Weight directly affects the altitude and the stability of the rocket which are critical to mission success. Weight of the material is especially important when considering potential mass creep occurring from discrepancies between manufacturer and actual parts and the variable mass added from epoxy when rolling carbon fiber. The appearance of the rocket is given a relatively low weight of 0.05 due to its lack of impact on the actual flight of the vehicle. However, this category should be accounted for due to the appearance category of the competition. Legacy was given a weight of 0.1 due to importance when constructing the rocket. Knowledge and experience with the material yields better results but is not essential. Hazardousness was assigned a weight of 0.1 due to its importance in providing a safe work environment for members. However, for most materials careful planning and use of proper safety precautions can limit the overall hazardousness of a material.

The scores for each weighted category are shown in Table 1.

Table 1. Airframe material selection matrix

		Fiberglass		Blue Tube		Carbon Fiber		Carbon Fiber Wrapped Blue Tube	
Attributes	**Weight**	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Strength	0.25	4	1	1	0.25	5	1.25	5	1.25
Cost	0.15	2	0.3	5	0.75	1	0.15	3	0.525
Workability	0.1	2	0.2	3.5	0.35	1	0.1	3	0.3
Weight	0.25	1	0.25	4	1	5	1.25	4	1
Appearance	0.05	5	0.25	3	0.15	5	0.25	5	0.25
Legacy	0.1	5	0.5	5	0.5	1	0.1	2	0.2
Hazardousness	0.1	1	0.1	5	0.5	1	0.1	2	0.2
Total			**2.6**		**3.5**		**3.2**		**3.725**

The scores for each category are justified below.

Strength

Yield strength is determined to be the primary factor when discussing strength. The ratings for yield strength for each material are show below in Table 2. The launch vehicle will undergo several types of stresses during flight. Examples of those are, but not limited to, compressive loads throughout ascent, tensile loads during charge deployment and drift, and various shear forces. Carbon fiber has a clear strength advantage with its high yield strength and impact resistance over fiberglass and blue tube and received a five as a result. Fiberglass is significantly stronger than blue tube and the score of a four reflected this. Blue tube performs the worst out of all three materials and received a one as a result. It is assumed that blue tube wrapped in carbon fiber would have similar strength measurements as regular carbon fiber tubes.

Table 2. Material strength comparison

	Yield Strength (KSI)
Fiberglass (G70)	30
Blue Tube	5.07
Carbon Fiber	610-700

Cost

The cost for each material was measured by dollars per foot for 5.5 in. diameter and approximately ⅛ in. thickness body tube is shown in Table 3. To properly quantify the scores for each material, a scale was created to determine at what price each score should be awarded. A total cost of less than 20 dollars per foot was awarded the best score of 5, with the remaining scores decreased by 1 for every increase of 10 dollars per foot. Therefore, a 4 would be awarded for a cost per foot between $20-$30, a 3 for cost between $30-$40, etc. Finally, anything over 50 dollars per foot would result in a score 1.

Table 3. Material Cost Comparison

	Cost ($ / ft)
Fiberglass	43.75
Blue Tube	14.25
Carbon Fiber Tube (5.26 Diameter)	165.40
Carbon Fiber Wrapped Blue Tube	14.25 (blue tube) + 18.42 (carbon fiber) = 32.67

Workability

Fiberglass and carbon fiber were given relatively low ratings of two and one respectfully due to the difficulty of cutting and sanding these materials to desired dimensions. A major impact in this score is the difficulty to find machine shops that allow the cutting of these materials due to Penn State safety restrictions. In contrast, blue tube can be cut in any machine shop on campus. For carbon fiber wrapped blue tube, the body can cut before the carbon fiber is put on the body tube to avoid these restrictions. An ongoing goal of the club is to attempt to find workshops that will allow cutting of carbon fiber wrapping or fiberglass to ensure more precise cuts at key separation points. Since blue tube is easier to cut and sand without major health concerns such as those of fiberglass and carbon fiber and received a higher score as a result.

Weight

The estimated density of blue tube wrapped in carbon fiber was calculated to be .878 oz/in^3 using subscale's measured weight and thickness. There are discrepancies between the density given by the manufacturer's website and the density given by OpenRocket for many of the materials that have been used by LTRL. Those discrepancies were extremely noticeable throughout assembly of the previous year's rocket and preventative measures will be made to mitigate this issue for all future competition participation. This includes extensive weighing of full scale parts upon receiving them to validate mass properties. OpenRocket was deemed acceptable for estimating mass of the rocket after those modifications to density were made. The densities used in OpenRocket are shown in Table 4.

Table 4. Density Discrepancy between manufacturer and OpenRocket

	OpenRocket Density (oz / in^3)	Website Density (oz / in^3)
Fiberglass (1)	1.07	.974
Blue Tube (2)	.751	.146
Carbon Fiber (5)	1.03	.23

Appearance

Fiberglass, carbon fiber, and blue tube wrapped in carbon fiber all received a score of five due to their sleek and finished appearance and their ability to be painted over. Blue tube only received a three due to its coarse and unfinished appearance once painted.

Legacy

Both fiberglass and blue tube received a five for legacy due to the LTRL members having multiple years of experience working with each of these materials. Members are comfortable working with these materials and understand the limitations of each material. LTRL has no prior experience with carbon fiber and the material received a one in this category as a result. Blue tube wrapped in carbon fiber received a two. This score was originally a one in proposal, but after using the material in construction of subscale, this score was increased to a two. This score is still much lower than fiberglass and blue tube because LTRL has yet to wrap carbon fiber on fullscale blue tube parts, and has yet to experience potential issues that might occur as a result.

Hazardousness

Blue tube received a score of five since it poses no problematic safety hazards. Both carbon fiber and fiberglass received a score of one for hazardousness due to the known safety concerns when handling these materials. Carbon fiber and fiberglass shards are known to be cancerous when inhaled and get lodged in skin. As a result, when working with both materials, safety glasses and respirator masks must be worn as well as covering any exposed skin. Blue tube wrapped in carbon fiber received a better score than regular carbon fiber since cutting and sanding the material can be done before carbon fiber is applied, but still received a relatively low score of two since all the previous risk hazards mentioned are in effect once the blue tube is wrapped in carbon fiber.

Final Selection

After the scores were weighted and added up, blue tube wrapped in carbon fiber had the highest score and was selected as a result. Subscale rocket was wrapped with two layers with carbon fiber weaving. The team will test the strength of the body tube while it is wrapped in one layer, two layers, and three layers of carbon fiber weaving to determine how many layers are needed for ensure sufficient structural integrity.

Nose Cone Design

Several nose cone shapes will be evaluated for full scale application. A 4:1 ogive is often considered due to its availability, cost, and length relative to the length of the frame. The Von Karman nose cone was also considered because it has the lowest drag coefficients of all nose cones. Trade studies will be conducted prior to CDR about the effectiveness of each type of nose cone while considering the aerodynamic drag and weight for a 5.5-inch diameter.

Bulkheads

Bulkheads will be used for attachment points of the parachutes and to contain the avionics bay within a coupler. ¼” plywood will be used for attachment point bulkheads due to their cheap cost but reliable strength. Fiberglass bulkheads were also considered because of their superior strength but it was determined that the drawback of the extra cost and mass of fiberglass bulkheads outweighed the benefit of their strength.

Separation Points

Separation points are where the rocket will separate during flight to deploy parachutes and the rover payload. There will be three separation points: two for parachute deployment and one for rover deployment. The separation point for drogue parachute is located between the booster and avionics bay sections. The separation point for main parachute will be located between the avionics bay and payload body tube sections. These separation points were chosen so that one avionics bay would be sufficient for both drogue and main deployment. Attachment point strength was another huge factor, in which couplers were used to secure the attachment points. This allows for the force during deployment to be easily transferred to the body tube, which is preferred over relying upon the shear strength of epoxy to hold a bulkhead in place. Finally, the separation points chosen allows for the parachutes to be pushed out of the body tube to further ensure proper separation and parachute deployment.

The separation point for payload is still being decided since the rover's exact location within the payload body tube has not been determined. The two possible separation points for rover deployment are separation between the nose cone shoulder and the payload body tube or separation between the nose cone shoulder and the nose cone itself. Separation between the nose cone and nose cone shoulder would provide payload with the option of placing the rover and its door mechanism right at the edge of the nose cone shoulder. This would provide the rover with easier access out of the rocket, however, this configuration further limits an already small volume that the CO_2 canisters require. Alternatively, separation between the nose cone shoulder and the payload body tube would increase the volume that will be pressurized by the CO_2 canisters and reduce the violent explosion that was observed with subscale testing. Further testing will be conducted by payload to determine which configuration best fits their needs depending on the force required and the durability of the rover.

An added benefit to the sectioning scheme that has been chosen is that each subsystem will have a dedicated section of the rocket to work on during launch day while being independent of the other subsystems. This will increase the efficiency of each subsystem and reduce assembly time on launch day.

Centering Rings

There will be three centering rings epoxied to the motor tube and to the body of the rocket to keep the motor tube in place. The three centering rings will be located 1 inch, 9 inches, and 17 inches from the aft of the motor tube. The inner edge of the centering rings will be epoxied onto the motor tube using JB-Weld and the outer edge of the centering rings will be then be epoxied onto the body of the rocket to keep the motor tube in place. These motor rings will be made from plywood and laser cut to meet exact dimensions. Fiberglass centering rings were also considered but have a smaller thickness than plywood and a smaller surface area for epoxy to be applied as a result. The lowermost centering ring will be laser cut to accommodate the application of the improved fin retention system.

Fins

The fins of the launch vehicle were designed to move the center of pressure towards the aft end of the flight vehicle and increase the stability of the rocket. The fins will be made from 3/16th inch fiberglass due to its strength and resistance to fin flutter. Fin flutter calculations will be performed prior to CDR once accurate mass data has been acquired for the fullscale parts. The fins will once again be removable using bolts attaching the fins to the 3D printed fin brackets.

3.1.2 Key design features

Fin Retention

One of last year's key design features was the application of 3D printed fin brackets. The goal of that design was to create a system in which fins could be easily replaced if broken during landing. That design relied upon epoxy to attach the brackets to the airframe during flight. To improve upon this design, it was decided to remove the epoxy entirely from this system and employ screw-only retention to improve removability and assembly. The new design will include sections both on the exterior and interior of the body tube to provide extra structural integrity by using bolts to compress the body tube, effectively locking the brackets in place. The body tube will be cut straight from the end to allow the full brackets to be inserted and laid flush to the bottom of the body tube. Figure 2 contains an image of the brackets attached to that tube. This design requires the need to slide the fin brackets onto the body tube using pre-cut slots from the bottom of the rocket. To ensure a proper fit, the bottom centering ring will be laser cut to ensure equidistant placement of the three fins. Eight bolts will be placed equally along the length of the fin bracket and threaded through both the tube and the plastic to ensure reliability. The fins will be fastened via nuts and bolts through the top section of the brackets. A conic rho fillet was chosen to decrease stress concentrations throughout the length of the bracket. This fillet also allows the screws to be aligned perpendicular to the body tube to maximize contact.

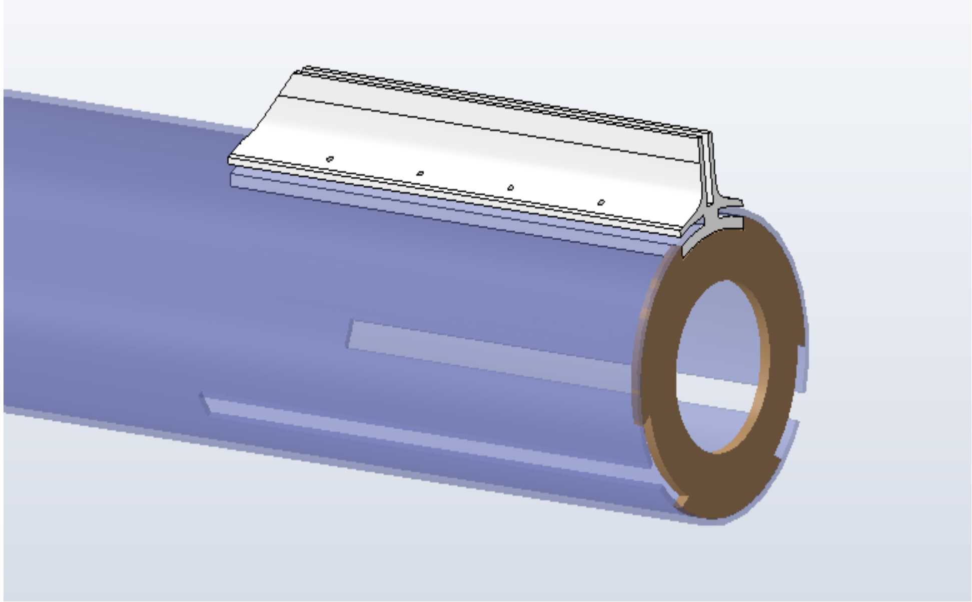


Figure 2. SolidWorks Rendering of proposed fin brackets

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. The exterior portion of the camera is cylindrical with a diameter of 0.75 in and length of 4 in. To securely seat the larger camera on the exterior of the rocket, a 3D printed cover was designed to tightly hold the camera to the body while also providing aerodynamic efficiency. The design has again been improved from last year's much bulkier design. Figure 3 shows the more spatially efficient design for this year's competition.

Figure 3. Refined camera cover design on subscale rocket (3" body tube)

3.2 Motor Selection

The motor selection process was constrained by several factors:

- A 75mm diameter, due to the diameter of the rocket body
- Cesaroni or Aerotech brand, due to past experiences with a variety of 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

The OpenRocket model used to simulate the flight profile included additional mass to compensate for the inevitable increase in total rocket mass due to miscellaneous hardware such as screws, bolts, and epoxy. The model also included ballast equal to exactly 10% of the rocket's total mass. With this model, all motors that fell within the enumerated constraints 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 L995 at 5263 feet, and 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 Aerotech L1150 resulted in an apogee of 5003 feet, and the Cesaroni L1720 resulted in an apogee of 5512 feet. This variation both above and below the target altitude allows the club mobility in case mass changes as fullscale parts are ordered and weighed.

All three motors are available from the supplier, and an extra motor will be acquired to perform motor testing before the fullscale test launch. The thrust curves of the three motors are shown in Figure 4, Figure 5, and Figure 6 respectively.

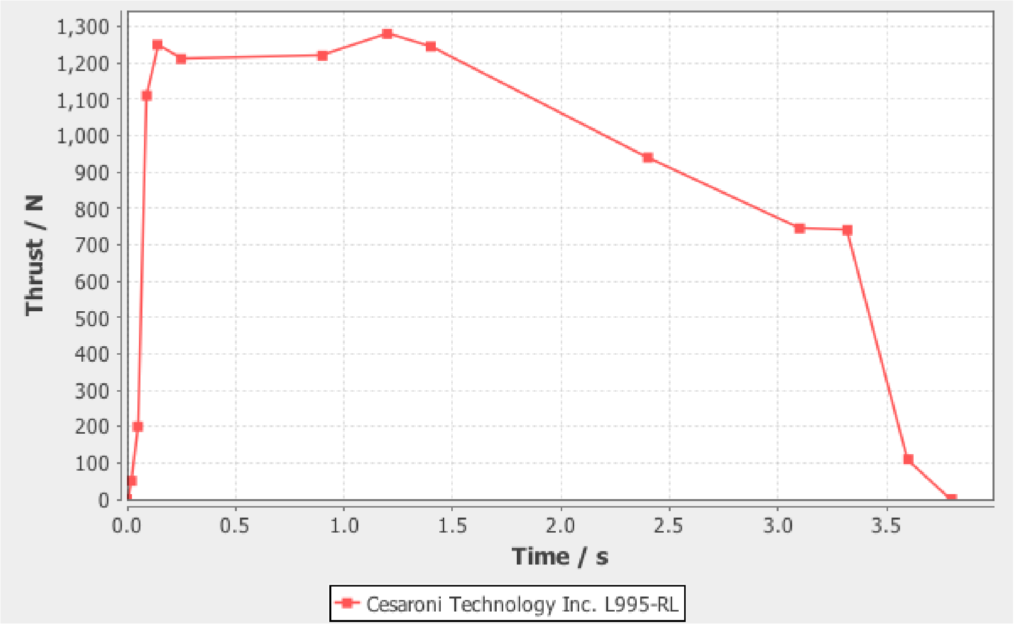


Figure 4. Cerseroni L-995 Thrust curve

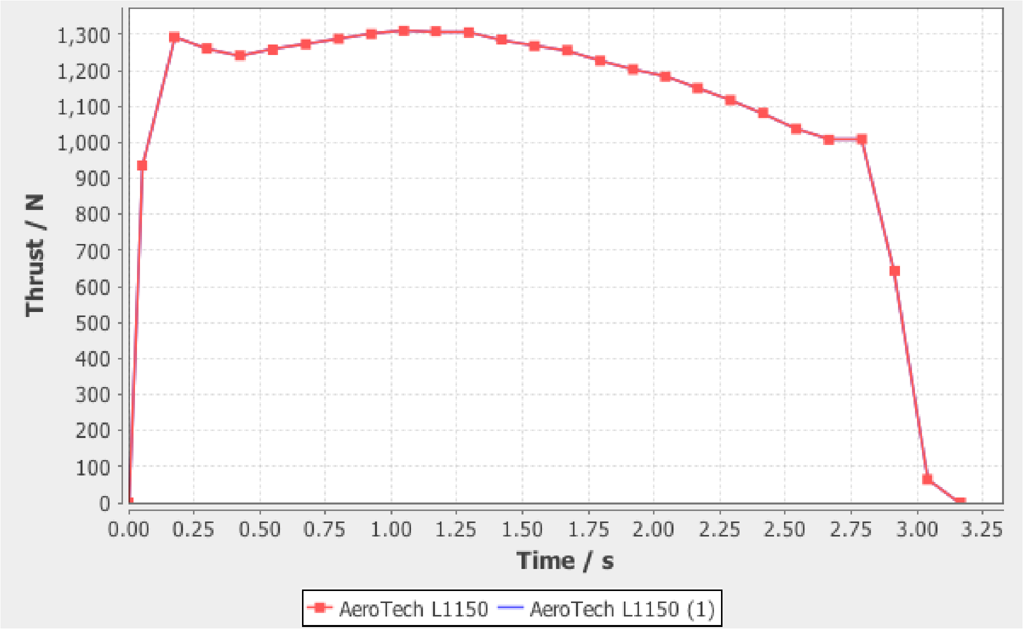


Figure 5. AeroTech L1170 Thrust curve

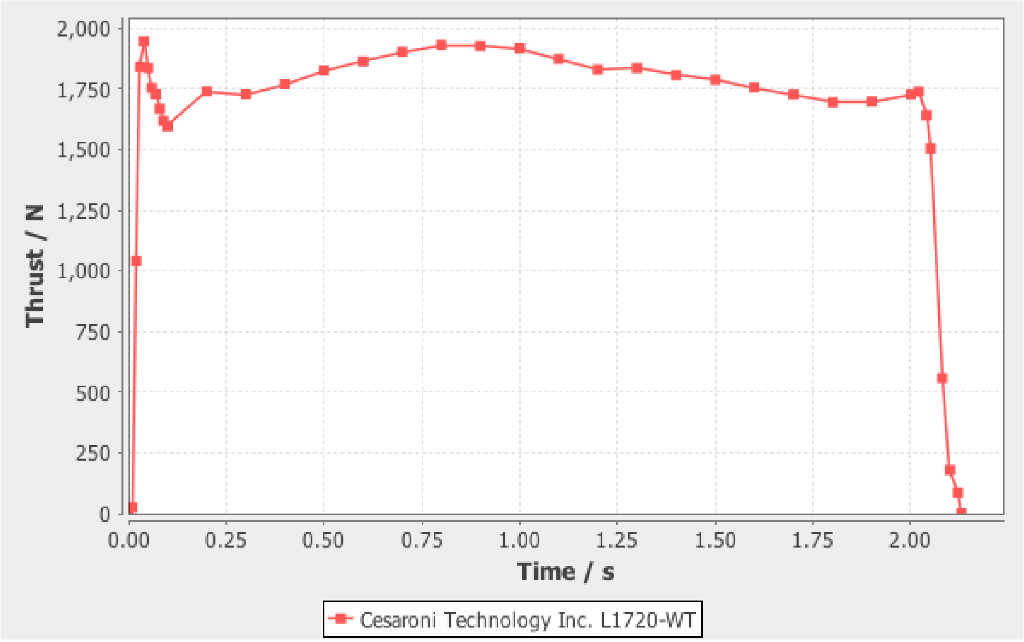


Figure 6. Cerseroni L1720 Thrust curve

Selected motor characteristics are compared between the primary, highlighted in blue, and contingency motors in Table 5.

Table 5. Motor Characteristics

	AeroTech L1150	**Cesaroni L995**	***Cesaroni L1720***
Predicted Apogee	5003 ft	5263 ft	5512 ft
Velocity off the Rail	69.3 fps	73.7 fps	84 fps
Thrust to Weight Ratio	8.22	8.03	11.61
Total Impulse	784.36 lbf*s	814.05 lbf*s	830.89 lbf*s
Average Thrust	258.08 lbf	224.21 lbf	394.31 lbf
Maximum Thrust	294.50 lbf	316.01 lbf	437.70 lbf
Burn Time	3.04 s	3.63 s	2.11 s
Liftoff Mass	130 oz	125.69 oz	118 oz
Burnout Mass	56.7 oz	55.83 oz	55.9 oz
Length	20.9 in	19.1 in	19.1 in
Propellant Grains	3	3	3

3.3 Recovery Subsystem

GPS Unit

In previous years, LTRL has used Garmin Astro trackers. While the Astro GPS unit worked well at the beginning, it consistently suffered reliability and connectivity problems. Therefore, the A&R team determined a new tracking system was necessary. After some market research, the field was narrowed to three potential options: the Garmin Astro, the BRB9000 Tx/Rx, and the SPYTEC STI GL300. To choose between these options they were evaluated based on criteria described in Table 6.

Table 6. Scale Matrix for GPS Trade Study

	Maximum Score	Score of 1	Score of 5
Reliability	5	Not reliable for more than 10 flights	Completely reliable for over 20 flights
Range	5	1 mile, requires clear line of sight	10+ miles, does not require clear line of sight
Weight	5	Weighs more than 500g	Weighs less that 100g
Durability	5	Not able to be flown more than two or three times	Able to be used for all flights for two years
Ease of Use	5	Not easy to use and very particular to set up. Difficult or unable to access data.	Easy to setup and use on launch day. Easy to access data.

Each GPS option was assigned a score for each of the above criteria to evaluate the best option. The scores for each category, as well as their weighted scores and the total scores for each option, are shown in Table 7.

Table 7. Selection Matrix for GPS Unit

		Garmin Astro 320		BRB9000 Tx/ Rx GPS Telemetry System		SPY TEC STI GL300	
Attributes	**Weight**	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Reliability	5	4	20	3	15	3	15
Range	5	5	25	2	10	5	25
Weight	3	2	6	5	15	4	12
Durability	4	2	8	3	12	3	12
Ease of Use	4	2	8	1	4	3	12
Price	3	1	3	2	6	4	12
Total Score			70		62		88

The BRB9000 Tx/Rx requires a clear line of sight to the rocket and an amateur HAM radio certification. It is impractical for LTRL to use this GPS unit because the rocket is not always within a clear line of sight and [it may be impractical to ensure a licensed club member is always in the club] no one in the club has a HAM radio certification. This year LTRL has selected to use the SPY TEC STI GL300 GPS unit.

Avionics Board Material

Historically, LTRL has used fiberglass for the avionics board. While this has been a very sturdy material, it is hazardous and difficult to precisely build the avionics bay. Last year, LTRL used 3D printed avionics boards for the subscale and full-scale rocket. The 3D printed avionics boards were precise, compact, and fully customizable. Fiberglass and 3D printed boards were again the option for the fullscale avionics board. The criteria described in Table 8 were used to choose between these options.

Table 8. Scale Matrix for Avionics Board Material Trade Study

	Maximum Score	Score of 1	Score of 5
Weight	5	Weighs more than 700g	Weighs less than 500g
Durability	5	Not able to be used for more than 10 flights	Able to be used for more than 20 flights
Ease of Construction	5	Not able to be drilled or filed easily and precisely with basic tools or manufactured	Able to be built exactly to size easily and not hazardous
Price	5	More than $20 to produce	Less than $15 to produce
Specific Strength	5	Specific strength less than 100 kNm/kg	Specific strength greater than 1000 kNm/kg

The criteria described in Table 9 were then used to choose between the options for the avionics board.

Table 9. Selection Matrix for Avionics Board Material

		3D Printed		**Fiberglass**	
Attributes	**Weight**	Score	Weighted Score	Score	Weighted Score
Weight	4	4	16	2	8
Durability	5	3	15	5	25
Ease of Construction	4	5	20	2	8
Price	2	5	10	3	6
Specific Strength	3	2	6	5	15
Total Score			67		62

This year, the avionics board will be 3D printed because, as seen in Table 8 and Table 9, the 3D printed material has the desired attributes for the avionics board.

Charges

The method used to separate the rocket and deploy the recovery system is essential for the nominal operation of the rocket and the safety of bystanders. For the purposes of this study, a CO_2 cartridge and blasting cap to open the canister is considered a "charge". After market selection for separation charges, the options were narrowed down to a CO_2 ejection system, Pyrodex charges, and Black Powder charges. The CO_2 system utilizes a CO_2 cartridge with a blasting cap that drives a pin that opens the charge. The Pyrodex and Black Powder are both explosives that have similar properties, but the Pyrodex only ignites when it is compacted, unlike the Black Powder. The metrics used to select the ejection charge are described in Table 10.

Table 10. Scale Matrix for Charges Trade Study

	Maximum Score	Score of 1	Score of 5
Adjustability	5	Only one fixed charge size.	No fixed charge size, completely variable charge size.
Ease of Use	5	Not easy to assemble or measure	Easy to assemble and use on launch day and for testing
Reliability	5	Does not deploy as expected on every flight or test	Detonates as expected every time used
Price	5	More than $200 for 15 uses	Less than $100 for 15 uses
Safety	5	Not safe to use or store in the lab, hazardous	Safe to handle and does not require special storing

Each design option was then assigned a score for each metric based on the thought process described in Table 10. These scores were then multiplied by the weights for that category and summed to evaluate the best option. This process is described in Table 11.

Table 11. Selection Matrix for Charges

		CO_2		**Pyrodex**		**Black Powder**	
Attributes	**Weight**	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Adjustability	5	2	10	5	25	5	25
Ease of Use	5	2	10	3	15	5	25
Reliability	5	3	15	4	20	5	25
Price	4	2	8	4	16	5	20
Safety	5	4	20	3	15	2	10
Total Score			68		91		105

Based on the results from Table 11, the charges used this year for the parachute deployment system will be black powder charges. This is predominantly due to the affordability, strength adjustability, and ignition reliability of black powder. The CO_2 charges have not been used often and there are only two options for the charge sizes, 12g and 8g. The lack of adjustability is a significant disadvantage. Pyrodex, while comparable to black powder, often experiences incomplete combustion due to having to be packed so tightly and is, therefore, less reliable.

Bulkhead Material

LTRL has used fiberglass and layered plywood bulkheads in past years and they have both been sturdy and successful. This year, Penn State has access to a laser cutter that can cut solid/hard woods, which makes red oak a viable option to consider. These options were evaluated based on the criteria described in Table 12.

Table 12. Scale Matrix for Bulkhead Material Trade Study

	Maximum Score	Score of 1	Score of 5
Ease of Use	5	Difficult to manufacture, drill, and adjust	Easy to manufacture, drill, and adjust
Price	5	More than $10 for two bulkheads	Less than $5 for two bulkheads
Specific strength	5	Specific strength less than 100 kNm/kg	Specific strength greater than 1000 kNm/kg
Safety	5	Hazardous to drill and file in the lab	Not hazardous to drill and file in the lab

Each option was then assigned a score for each metric based on Table 12. These scores were then used to choose the best option, as shown in the study performed in Table 13.

Table 13. Selection Matrix for Bulkhead Material

		Layered Plywood		Fiberglass		Red Oak	
Attributes	**Weight**	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Ease of Use	5	3	15	2	10	5	25
Price	2	3	6	1	2	4	8
Specific strength	5	3	15	5	25	1	5
Safety	5	3	15	1	5	5	25
Total Score			51		42		63

Table 13 shows that the red oak, with the advantage of using the laser cutter, is the best option. This newly available technology will allow LTRL to make exceptionally accurate and precise cuts, increasing the design options for a custom bulkhead. The red oak is going to be extremely easy to modify and will simplify the assembly of the avionics bay by allowing the holes for all-thread rods to align more accurately.

Avionics Bay Design

The avionics bay design has not been finalized yet. There are two leading design concepts, rendered in Figure 7 and Figure 8, that can be the basis for the final design. The avionics bay pictured in Figure 7 was the avionics bay used last year. While this design was more compact than any previous design, it took a long time to assemble and was difficult to reassemble. Reasons for the difficult assembly process include the all-thread rods only aligned with the bulkhead in one configuration, the wires were too short for the key switches, and the key switches protruding too far into the avionics bay. This year, the leading goal is to design a robust avionics bay that is easier to assemble and access on launch day. LTRL is considering making a door on the side of the rocket that will access the avionics bay. There will need to be testing to ensure that creating such a door would not be detrimental to the structural integrity of the body of the rocket. If there is a door, this will change the way the avionics bay is held in the rocket. There may not be all-thread rods going through the avionics bay, but rather some locking mechanism that is secured by closing the door. Since the avionics bay will be 3D printed, it will be easy to make and test several different designs.

Figure 7. 2016-2017 Avionics Bay

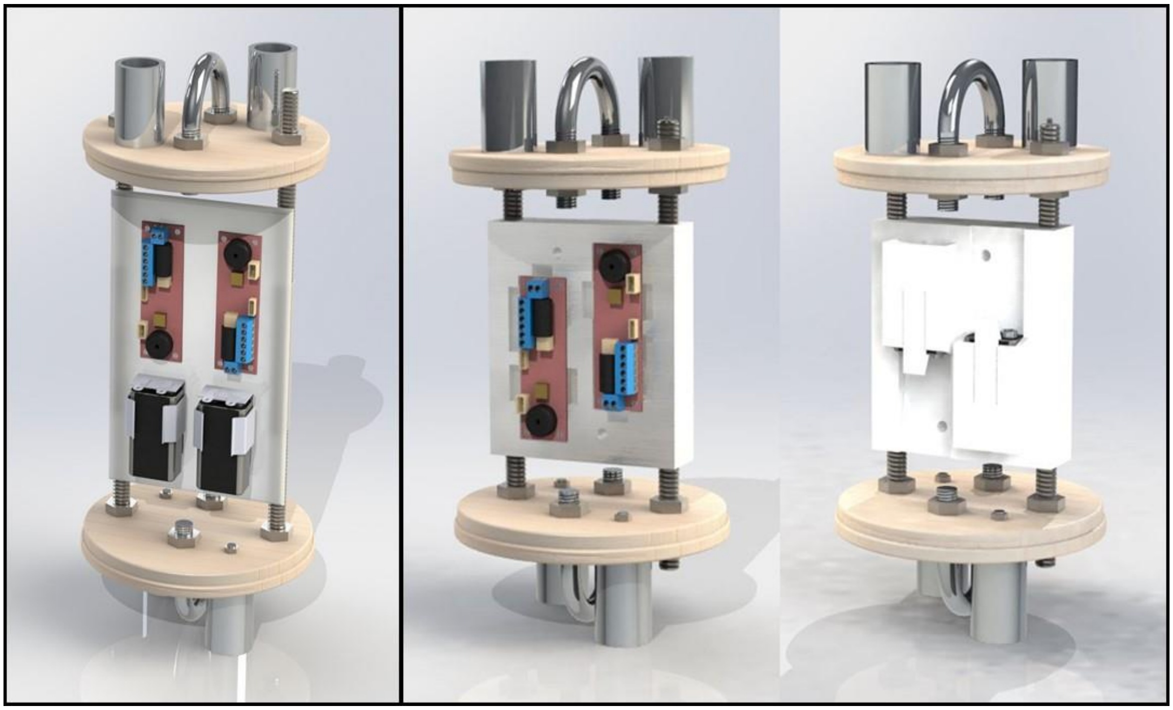


Figure 8. Vertical Avionics Bay Design Concepts

The avionics bay will have two independent sets of switches, charges, initiators, power supplies, and altimeters. This creates redundancy in the avionics bay that guarantees that the parachutes will deploy at the preset altitudes. There will be a main altimeter and a redundant altimeter. The redundant altimeter will be at a two-second delay so that two charges do not detonate in the same section at the same time. This could cause an overpressure event and damage the body of the rocket. Having redundant avionics electronics and charges also protects against there being a problem if one of the altimeters or power supplies fail.

Recovery Harness

The recovery harness will be ½” Kevlar cord. It will be secured to the rocket by using ½” quicklinks to connect the cord to 3/8” steel U-bolts on bulkheads. This has been used for many rockets for LTRL and can handle all of the forces acting on the parts of the rocket throughout the descent. Additionally, the parachutes will be protected by nomex blankets so that the black powder charges do not damage them.

Altimeters

The altimeters used in competition will be Stratologger CF altimeters. These altimeters were used in the NASA USLI competition last year and they have also been used for several other rockets. They are reliable and commercially made.

Parachutes

Preliminary analysis of descent speed and force, given predicted masses, indicate that a drogue parachute of 12” will be sufficient to steady descent at about 100 ft/s. This is accounting for the drag from the tumbling body tube, which is only factored in the team’s predictive code, not in

OpenRocket. Further analysis and simulation indicated that a main parachute of 72” would barely keep the landing force of the rocket below the 75 ft-lb limit. So, instead the team opted for a larger safety cushion and went up a size to 84”. Landing speed under main will be about 17 ft/s, which is reasonable. To compensate for the extra drift caused by the increase, the deployment altitude of the main parachute has been decreased to 600 ft.

3.4 Mission Performance Predictions

Final Flight Vehicle

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 89.9 in. aft of the tip of the nose cone, and the CG is located 59.3 in. aft of the tip of the nose cone. The final flight vehicle has a diameter of 5.5 in., with a static stability margin of 3.78 calibers. The OpenRocket model is shown in Figure 9, with a breakdown of the component weights used within the model shown in Table 14. The target apogee of exactly 1 mile will be achieved through altering the rocket's mass very slightly via incorporated ballast, along with improving 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.

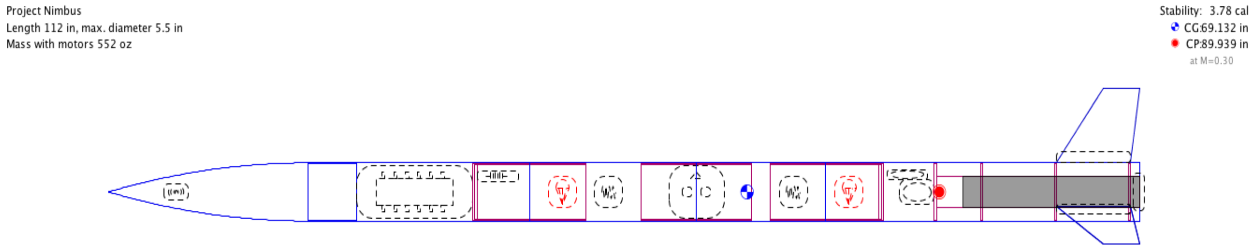


Figure 9. Fullscale OpenRocket Model

Table 14. Component weights

Component	Weight (oz)
Nose Cone	38.7
Payload Section	72.5
Payload-Main Coupler	11.4
Main Parachute Section	50
Main-Drogue Coupler	121
Drogue Parachute Section	25.1
Drogue-Booster Coupler	6.9
Booster Section	59.3
Fins (all three)	16.8
Fin Brackets (all three)	11.4

Additionally, the simulated flight profile, detailing altitude and vertical velocity versus time, are shown in Figure 10.

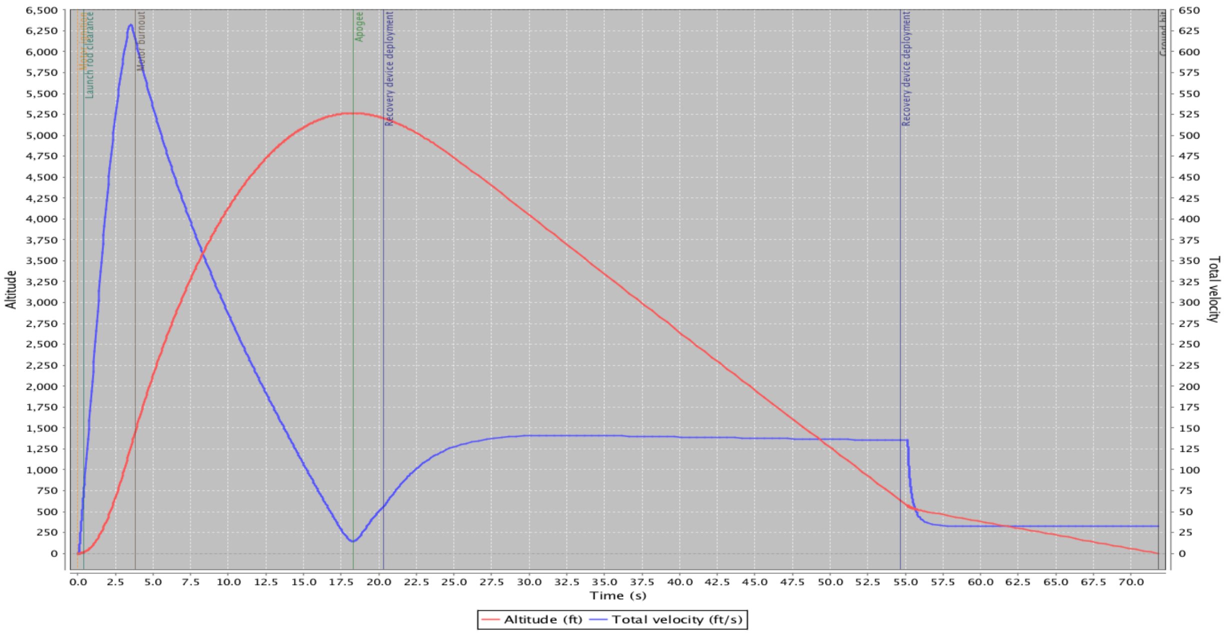


Figure 10. OpenRocket Flight Profile Simulation

Verification of OpenRocket

To verify the OpenRocket simulation results, the center of pressure, center of gravity, and flight apogee were calculated using MATLAB.

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.

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

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 5305 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 to of the OpenRocket results and the MATLAB results can be seen in Table 15.

Table 15. Simulation Results Comparison

	OpenRocket	**MATLAB**
Center of Pressure (inches from tip)	89.939	90.001
Center of Gravity (inches from tip)	68.132	68.491
Static Stability (Calibers)	3.78	3.911
Altitude at Apogee (feet)	5227	5305

The results were very similar, yet not identical. This change is likely due to the estimated drag coefficient being different. Despite this discrepancy, the two outcomes had a very low margin of error. To calculate the margin of error the following equation is used:

Margin of error = |(OpenRocket - MATLAB) / OpenRocket| * 100

The margins of errors can be seen in Table 16.

Table 16. Margin of Error

	Margin of Error
Center of Pressure	0.069%
Center of Gravity	0.53%
Static Stability	3.5%
Altitude at Apogee	1.5%

All the margins of error are less than 5%, this indicates that the simulations used in OpenRocket are highly accurate.

Kinetic Energy Calculations

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 also assumes that the parachutes do not deploy instantaneously, but rather in a linear fashion, as the 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 both the manufacturer's specifications and the experimentally derived values. The experimental results are from previous USLI competition launches and they indicate that the manufacturer provided values for main parachutes are generous. This trend has lead LTRL to make conservative choices regarding the main parachute sizing until more data has been gathered from this season's fullscale test launches. The result of a conservative main parachute selection is a parachute that is one size larger than that which is minimally sufficient to manage the kinetic energy. In this case, an 84" main parachute was chosen over a 72" parachute. Under the modest coefficient of drag, 2.0, a main of 72" results in a maximum kinetic energy at landing of 75 ft-lb, where an 84" would lead to only 53 ft-lb. The manufacturer's generous coefficient of drag, 2.2, puts the kinetic energy under the 72" at a more reasonable 65 ft-lb. Figure 11 and Figure 12 display the function of maximum kinetic energy versus parachute size for each of the coefficients of drag. A fullscale launch under the 84" parachute will provide information about where the coefficient of drag falls between these values.

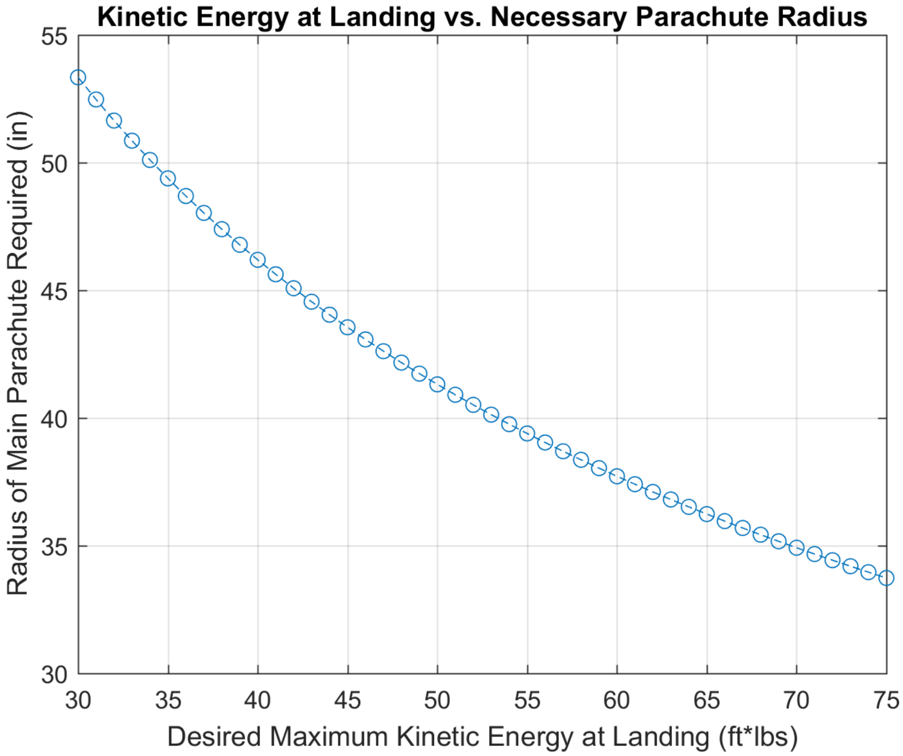


Figure 11. MATLAB Model of Kinetic Energy vs. Parachute Radius with C_D = 2.2

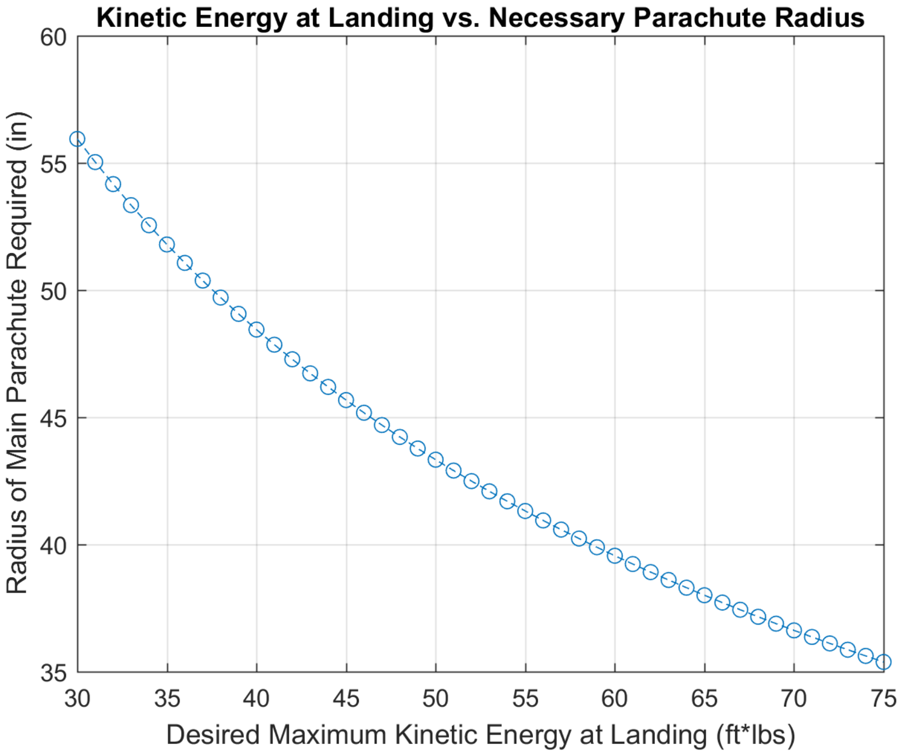


Figure 12. MATLAB Model of Kinetic Energy vs. Parachute Radius with C_D = 2.0

The MATLAB simulation's predicted landing velocity of the rocket is 16.8 ft/s with a coefficient of drag of 2.2 and 17.6 ft/s with a coefficient of drag of 2.0. Calculations of kinetic energy can then be done by simply using the kinetic energy equation, which is a function of velocity squared and mass. The rocket's descent speed is plotted in Figure 13 and Figure 14 for both coefficients of drag. The kinetic energy results for each section are shown in Table 17 for each coefficient of drag.

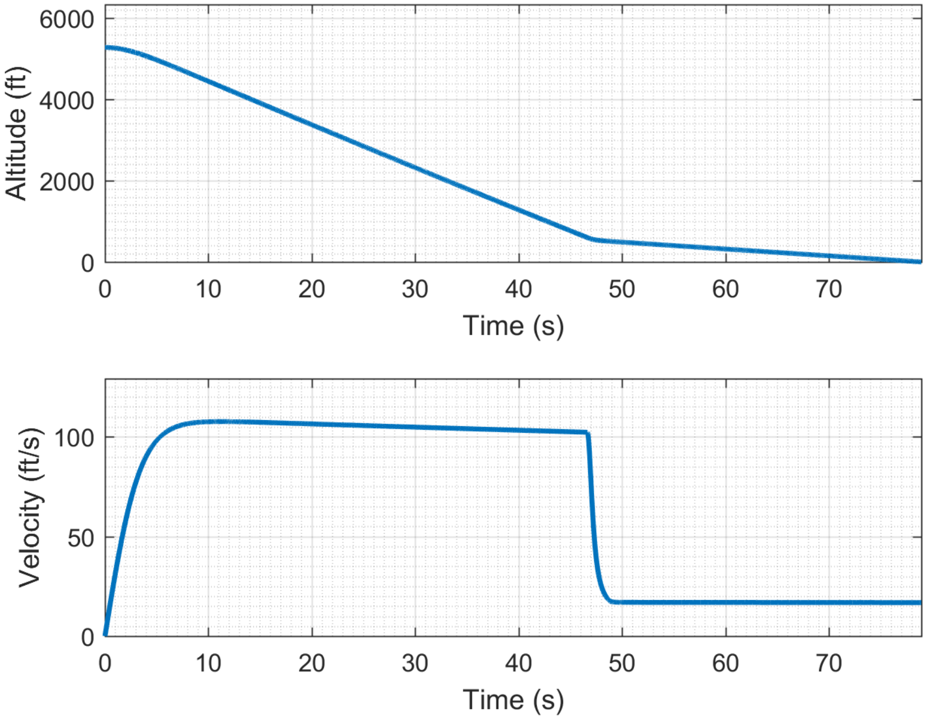


Figure 13. MATLAB Models of Descent and Altitude vs. Time with C_D = 2.2

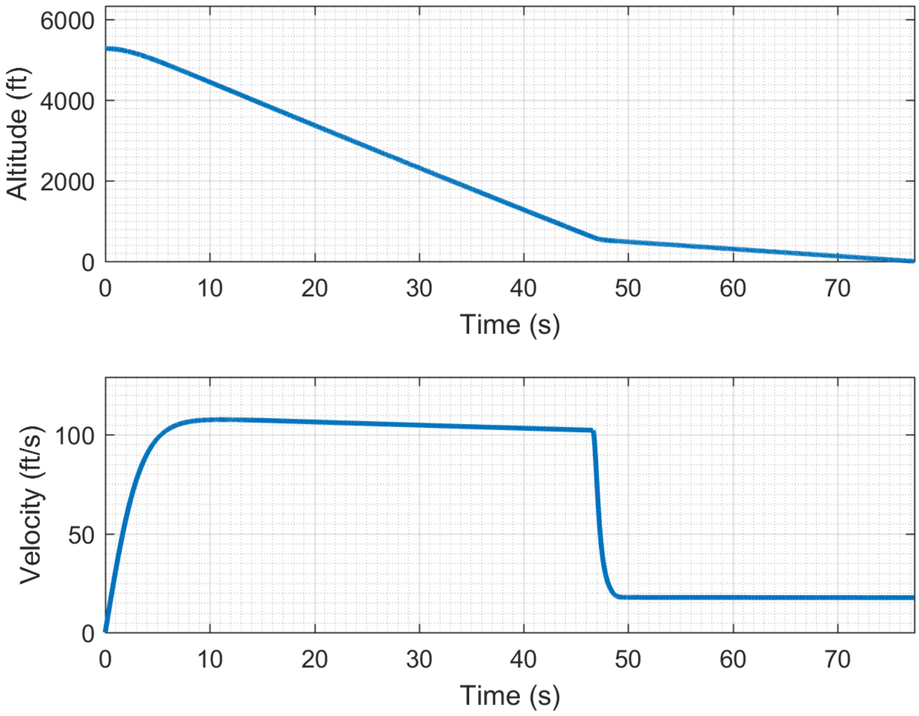


Figure 14. MATLAB Models of Descent and Altitude vs. Time with C_D = 2.0

Table 17. Kinetic Energy upon Landing of Each Component

Section	Mass (lbf)	Kinetic Energy (ft-lb) $C_D = 2.0$	Kinetic Energy (ft-lb) $C_D = 2.2$
Nose cone	8.88	42.74	38.69
Avionics bay	7.67	36.89	33.63
Booster	10.27	49.42	45.05

A secondary method of determining kinetic energy is through OpenRocket's descent velocity predictions. The results for a coefficient of drag of 2.0 is a landing velocity of 17.9 ft/s and for 2.2 is 17.1 ft/s. Calculations of kinetic energy can then be done by simply using the kinetic energy equation. The rocket's altitude, speed, and acceleration are plotted in Figure 15 for a coefficient of drag of 2.2. The kinetic energy results for each section are shown in Table 18 for each coefficient of drag.

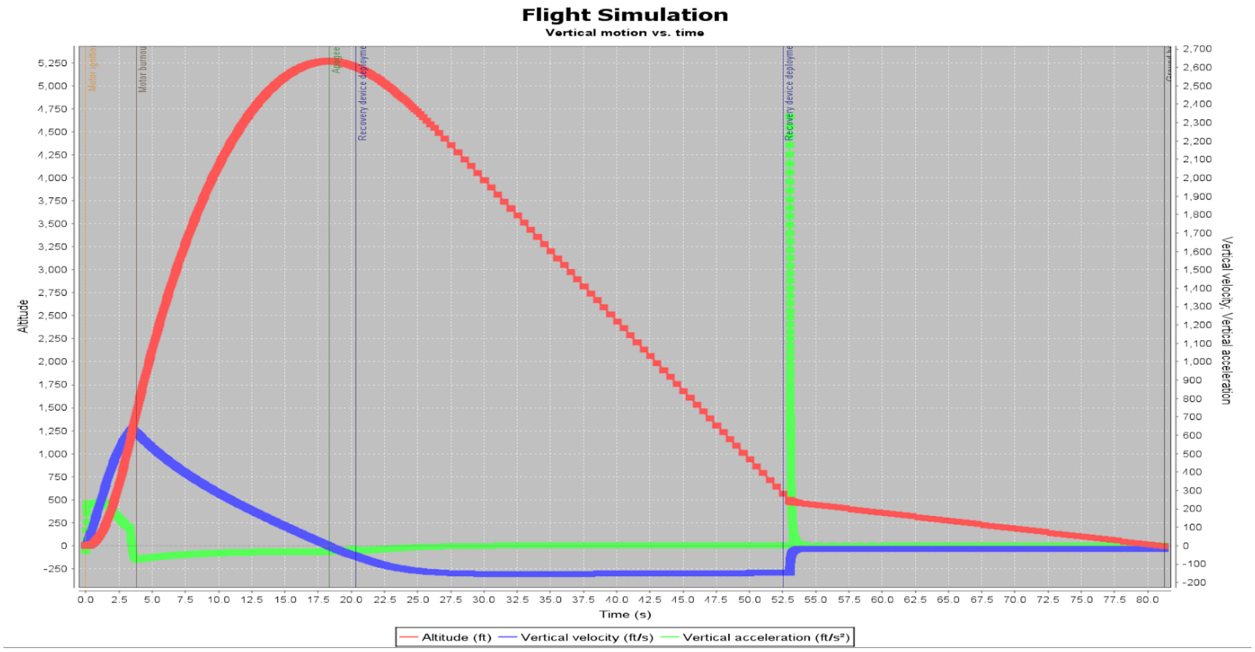


Figure 15. L995 Flight Simulation

Table 18. Kinetic Energy upon Landing of Each Component

Section	Mass (lbf)	Kinetic Energy (ft-lb) $C_D = 2.0$	Kinetic Energy (ft-lb) $C_D = 2.2$
Nose cone	8.88	59.98	54.74
Avionics bay	7.67	51.76	47.24
Booster	10.27	69.36	63.30

The conclusion has been reached that the predictions for descent speed and therefore kinetic energy differ because OpenRocket does not account for the drag of the rocket body while under drogue. It makes sense that the descent velocity and kinetic energy would then be greater than the predictions of the MATLAB program.

Drift Calculations

The calculation for the drift of the rocket is straightforward in that it is just the product of the descent time and the wind velocity. Based on the MATLAB program's predicted landing velocity a smaller drogue of 12" and a main deployment height of 600 ft are needed to compensate for the increased drift under a conservative main of 84". The drift distances at specific wind velocities are displayed in Figure 16. The coefficient of drag for this plot is 2.2, which results in the slowest descent time and therefore greater drift distances.

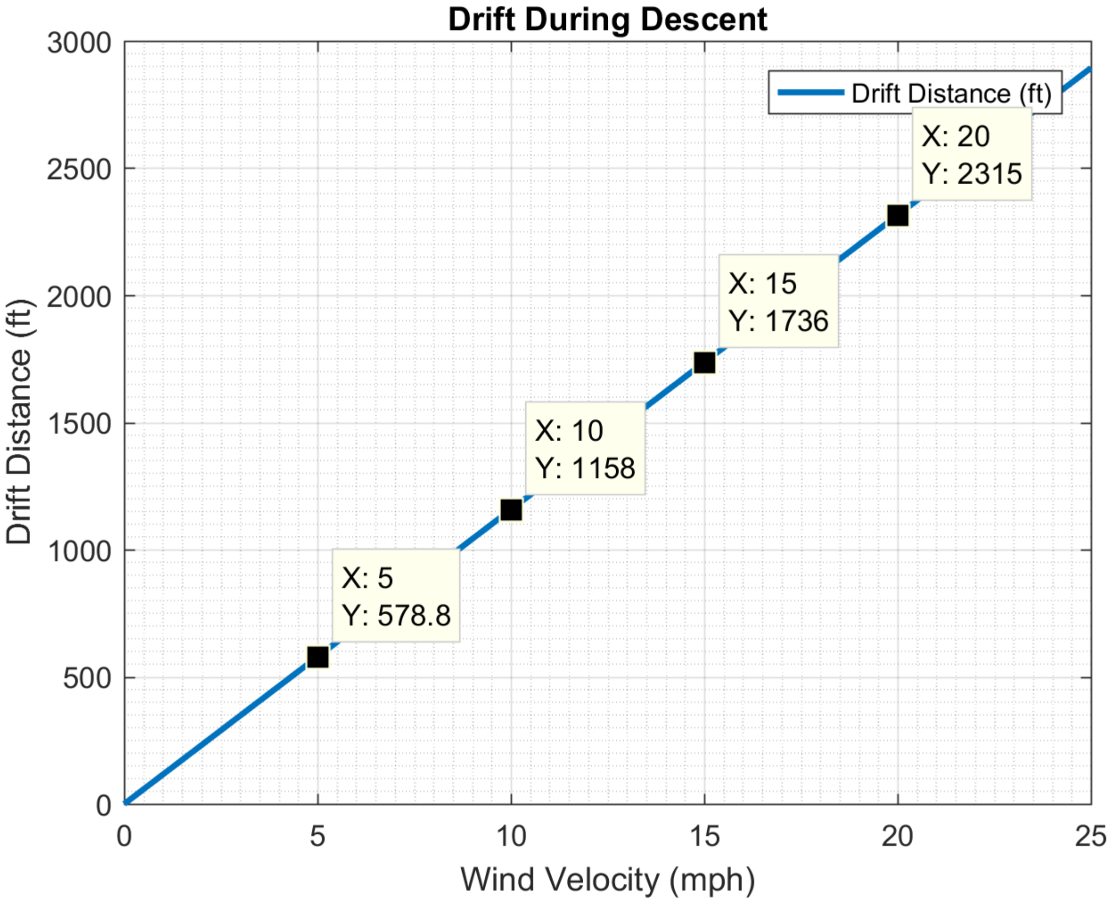


Figure 16. Drift Distance vs. Wind Speed for coefficient of drag of 2.2

OpenRocket reports descent times of 81.3 s for a simulation with a coefficient of drag for the main parachute of 2.2. Given this descent time, the longer of the two coefficients of drag, the calculations reflect the largest drift distance. Table 19 shows the drift distances at each specified wind velocity for the MATLAB Simulation and the OpenRocket model.

Table 19. Drift Speed of Rocket at Various Wind Speeds

Wind Speed (mph)	Drift Distance (ft) $C_D = 2.2$ MATLAB Simulation	Drift Distance (ft) $C_D = 2.2$ OpenRocket
0	0	0
5	578.8	596.2
10	1158	1192.4
15	1736	1788.6
20	2315	2384.8

The values differ as they do because of the difference in the prediction of descent speed under main by the two methods. Since the MATLAB program has a slower descent than OpenRocket, it shows a greater drift distance. Regardless of the varying drift values, the least ideal conditions of 16.8 ft/s descent due to a coefficient of drag of 2.2 still result in a maximum distance below 2500 ft in 20 mph winds.

4 Safety

LTRL understands that there are inherent dangers in building and flying high powered model rockets. In the safety plan below, LTRL outlines the risks identified, and the preliminary steps taken to mitigate them.

4.1 Safety Officer Responsibilities

The person responsible for drafting and maintaining the LTRL safety plan is the Safety Officer. During the 2017-2018 project cycle, the Safety Officer is Laura Reese. The safety officer's responsibilities are as follows:

- Monitor team activities to ensure safety during design, assembly and ground testing of the rocket and payload
- Monitor team activities to ensure safety during subscale and fullscale launches and recoveries
- Monitor team activities during launch day to ensure safety
- Manage and maintain current versions of the team's hazard analyses, failure modes analyses, and Safety Data Sheet (SDS) data
- Manage and maintain a database of the Penn State safety certification status of all club members
- Write and develop the team's hazard analyses
- Assist in the writing and development of the team's failure modes analyses

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 Lab Safety

Design and construction of the rocket requires use of power tools, such as a Dremel and drill, as well as use of chemicals, primarily epoxies. These create hazards, which can be mitigated by wearing proper personal protective equipment (PPE), as well as exercising caution and proper shop safety. To foster a "safety-first" attitude, and to educate members about proper chemical safety, basic laboratory safety, and proper use of PPE, all 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 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. The website then generates a certificate, which is submitted to the Safety Officer. LTRL Members who have already completed the initial course 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, and are then issued a certificate, which is submitted to the Safety Officer. The Safety Officer keeps an electronic database recording which members have completed their safety training. The Safety Officer also keeps physical copies of all members' safety certificates in a binder that is stored in the lab. Subsystem leads are 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. Fire extinguishers, both dry chemical and CO_2 types, are available in the hallway directly outside of the lab.

4.4 Launches and Motor Handling

For the LTRL subscale rocket, a J-class motor was used. The fullscale rocket will use an L-class motor. The rocket motors are purchase, handled, and transported by the club president, who has a NAR Level 2 certification. They 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.

LTRL does not currently hold its own launches. Instead, the club attends launches organized by either Maryland and Delaware Rocket Association (MDRA) and the Pittsburgh Space Command (PSC) respectively. The PSC is an NAR registered club. Both launches require the presence of a member holding either Level 1 or Level 2 NAR certification, depending on the class of motor used.

4.6 Hazardous Materials

During the project, construction and launching of the rocket will entail the handling and use of hazardous materials. Efforts to mitigate the risks posed by these hazards have been undertaken by the club.

Motor Storage

To reduce the risk of fires and explosions in the lab, all motors used by LTRL are stored in the HPCL storage magazines.

Hazardous Materials Mitigations

LTRL maintains a chemical inventory, and SDS records for all hazardous chemicals used during the project. The current list of chemicals and hazardous materials, the hazards that they pose, and the mitigations in place to lower the risk placed by those hazards is given in Table 20. This list will update throughout the course of the project, if additional hazardous materials are used by LTRL during construction or launch operations. The hazards outlined in Table 20 are based on the hazards listed in SDS for each hazardous material. These safety data sheets are attached in Appendix A: MSDS Sheets.

Table 20. List of plausible hazards and mitigations

Material	Hazards	Mitigations
JB Weld Professional	Causes skin and eye irritation	Wear protective gloves and eye protection. Wash hands thoroughly after working with epoxy.
JB Kwik	Causes skin and eye irritation	Wear protective gloves and eye protection. Wash hands thoroughly after working with epoxy.
Black powder	Explosions, fire, can also cause skin, eye, respiratory irritation	Protect black powder from flame, heat, and electrical discharge.
Fiberglass bulkheads	Skin and eye irritation, potentially severe respiratory tract irritation	Wear gloves, eye protection, and dust mask. Clear dust using a shop vacuum.
Carbon fiber wrapping	Airborne fibers can cause severe respiratory irritation. Electrically conductive airborne fibers can cause short circuits in electrical systems.	Limit airborne fiber production during machining operations. Wear a dust mask when machining carbon fiber wrapping.
Spray paint	Can explode or catch on fire. Causes serious eye irritation, skin irritation and serious respiratory tract irritation. Can be carcinogenic and is a narcotic when fumes are inhaled.	Paint only in a well-ventilated area, preferably outside. Store cans away from any potential sources of heat or flame.
No. 2 Mystik high-temp grease	No known hazards	Wear gloves while handling.
Talcum powder	May cause eye and skin irritation. Causes respiratory tract irritation which over long periods of time may lead to cancer.	Use only outside in well ventilated areas.
FibreGlast 2060 60 minute epoxy cure	Causes serious eye damage. Toxic if swallowed or inhaled. Can cause skin and respiratory tract irritation. Chronic exposure can result in harm to the liver, kidneys, eyes, skin or lungs.	Always wear gloves when applying the epoxy and epoxy cure.

FibreGlast 2000 epoxy resin	Skin and eye irritation	Wear gloves while handling.
Flexseal	Causes skin and eye irritation. Is a potential carcinogen	Wear gloves while handling.
Isopropyl alcohol	Can cause flash fire or explosion. Causes skin and respiratory irritation. Causes serious eye irritation.	Store away from potential sources of flame or heat.

4.7 Risk Assessment

To reduce the risks inherent in building and flying the rocket, the Safety Officer and Subsystem Leads have undertaken multiple risk assessments. These assessments outline personal risks to club members and environmental hazards. Failure modes of the rocket and its subsystems, their causes and effects and mitigations of these potential failures are also outlined. Lastly, risks to the overall project and club are outlined, along with mitigations of these risks.

To provide a scale of how hazardous each risk or failure is, the likelihood and severity of each risk were tabulated, and used to calculate a combined risk factor. This combined risk factor was then used to rank the risks or hazards within each table from most to least hazardous. The methodology used to assign numerical values to the likelihood and severity, and the methodology used to calculate and rate the combined risk factor is outlined below.

Explanation of Risk Assessment Quantifiers

The explanation below shows how the likelihood and severity values were assigned for risks, hazards, and failure modes.

LIKELIHOOD

1: The risk is highly unlikely. Over the historical legacy of the risk, the failure has never occurred.
2: The risk is unlikely. Over the historical legacy of the risk, the failure has never occurred, but there may have been close calls, where the risk nearly did occur.
3: The risk is moderate. Over the historical legacy of the risk, the failure has occurred at least once.
4: The risk is likely. Over the historical legacy of the risk, the failure has occurred at least once during last year’s project, or has recurred repeatedly in multiple years.
5: The risk is highly likely. Over the historical legacy of the risk, the failure has occurred more than once over the course of a past project, or has recurred each year during the project’s duration.

Historical legacy refers to the time over which current active club members have been a part of the club. Some risks have long historical legacies, whereas others may have only begun to occur during this project cycle. If the design responsible for a risk has changed substantially, the likelihood for that risk also was changed to reflect the impact of the design on the risk’s likelihood.

SEVERITY:

1: The risk is moderate. The rocket performs more poorly than expected, or does not operate within the expected parameters, the payload does not operate within the expected parameters, and/or the environment is temporarily impacted.
2: The risk is not very severe. The occurrence of the risk could result in: moderate damage to the rocket necessitating repairs on the field, portions of the payload do not operate as expected, and/or the environment is impacted.
3: The risk is severe. The occurrence of the risk could result in: severe damage to the rocket necessitating repairs of significant portions of the rocket, the payload fails completely in its mission, and/or the environment is damaged.
4: The risk is quite severe. The occurrence of the risk could result in: injuries to a club member or bystander, catastrophic damage to the rocket, and/or significant damage to other structures or facilities and the environment.
5: The risk is very severe. The occurrence of the risk could result in catastrophic damage to the rocket, severe injuries to a club member or bystander, the disbandment of LTRL by Penn State, and/or severe damage to other structures or facilities and the environment.

Severity and likelihood values were then added together to generate the combined risk factor. In Table 21 a combined risk factor matrix is given, which also ranks the combined risk factor as low, moderate, or high.

Table 21. Generation of combined risk factor

Severity		**Likelihood**				
		1	2	3	4	5
	1	Low	Low	Low	Moderate	Moderate
	2	Low	Low	Moderate	Moderate	Moderate
	3	Low	Moderate	Moderate	Moderate	High
	4	Moderate	Moderate	Moderate	High	High
	5	Moderate	Moderate	High	High	High

The likelihood, severity and combined risk factor were then used to quantify the risks, hazards, and failure modes.

Personal Hazard Analysis

Risks to LTRL members were analyzed along with their causes, and effects, and the likelihood and severity and combined risk analysis were assigned to each of the risks. This work is shown in Table 22 below.

Table 22. Personal Hazard Analysis

Hazard	Cause	Effect	Likelihood	Severity	Combined Risk Factor	Mitigation
Flying debris - during launch operations	Rockets experiencing catastrophic explosions before or during liftoff, midflight destruction of part of the airframe, rockets or portions or rockets descending with unsafe kinematic energy	Cuts or lacerations to the skin, eye damage, blunt force trauma	5	5	10, High	The design of LTRL's rocket will reduce the chance of generating flying debris. A "heads-up" stance will always be maintained when any other team or individual is launching their own rocket, until that rocket safely lands.
Burns	Touching a hot solder iron tip, touching the motor retainer or blast caps before they have cooled	Skin damage, potentially severe	3	5	8, High	Ensure that members know when the solder iron is being used, do not approach the rocket for at least sixty seconds after charges or the motor have been deployed. Exercise caution in handling the rocket after deployment of the motor or black powder charges.
Cuts and Lacerations	Improper use of power tools, accidents during machining	Cuts and lacerations, potential serious injuries	3	5	8, High	All instructions and best practices for the use of power tools will be followed. No one will work in the lab alone. Inexperienced members will always be guided by club members that are more experienced in machining protocols
Eye irritation	Eye exposure to irritating particulates	Discomfort, possible permanent eye damage	2	5	7, Moderate	Eye protection will be worn when members are machining hazardous material

Flying debris	Flying debris is generated by machining operations such as drilling or cutting.	Cuts or lacerations to the skin, eye damage	2	5	7, Moderate	A safe distance between any member cutting or drilling material and everyone is maintained. Any member cutting or drilling material wears safety glasses.
Fire in the lab	Fire begins in the lab, or spreads from another portion of the building into the lab	LTRL equipment destroyed, LTRL facility destroyed, LTRL members injured	2	5	7, Moderate	Maintain all electrical cables properly, greasy or solvent soaked rags will not be stored in the lab, e-matches will be stored away from flammable materials, only solvents needed for building the rocket will be stored in the lab, rocket motors will be stored in the HPCL
Trips and falls	LTRL member trips or falls because of obstacle in the lab or at a launch	Cuts and lacerations, broken bones	3	4	7, Moderate	Keep extension cords and electrical cables coiled and placed under desks or tables, keep backpacks in the hallway when there are more than five people in the lab, exercise caution when retrieving the rocket
Skin irritation	Skin exposure to chemicals or irritating particulates	Discomfort, potential injuries, potential long term chronic illness	2	4	6, Moderate	Gloves will be worn when members are machining hazardous material or working with chemicals
Respiratory irritation	Respiratory system exposure to volatile chemicals or irritating particulates	Discomfort, potential long term chronic illness	2	4	6, Moderate	Masks will be worn when members are machining hazardous materials. A shop vacuum will be used to limit the spread of the particulates. All operations involving volatile chemicals will either be performed outside, or in areas with sufficient ventilation
Electrical shock	Electrical shock from power tools or cords, electrical shock from extension cables	Deep skin damage from electrical burn, potential nerve damage, potential deeper tissue damage, can cause a heart attack	1	5	6, Moderate	Ensure all power tools and their cords and that all extension cords are well maintained and contain no exposed or frayed wires, or large nicks in the insulation

Black powder explosions - while handling	Black powder explodes or catches fire during measurement or transport operations	Burns and injuries from explosion	1	5	6, Moderate	No open flame, electrical spark or heat source will be used near the black powder operations
Black powder explosions - while loaded in the rocket	Black powder charges explode prematurely, or explode after the rocket has landed	Burns, blunt force injuries from explosion and potential flying rocket debris	1	5	6, Moderate	Firing circuit will not be engaged until the rocket is on the pad, exercise "muzzle awareness" around both ends of the rocket after charges have been loaded, exercise "muzzle awareness" around both ends of the rocket until it has been determined by an A&R lead that all charges have deployed. Wait sixty seconds before approaching the rocket during ground testing of charges.

Environmental Hazards

One of the main environmental concerns includes the disposal of toxic substances, due to use of such substances in rocket construction. All toxic substances will be disposed in accordance with local laws and regulations by Penn State Environmental Health and Safety (EHS). During a launch, measures will be taken to minimize changes to the local environment due to the emission of hot, toxic gases from the rocket motor during launch. A safe radius around the pad will be cleared of combustible materials. High winds during rocket flight could adversely impact the landing guidance system.

Table 23 below summarizes these risks.

Table 23. Environmental Hazards

Hazard	Cause	Effect	Likelihood	Severity	Combined Risk Factor	Mitigation
Concentrated sunlight	Heating of rocket body	Malfunctioning electronics	5	3	8, High	Use electronic components designed to withstand a range temperatures. Keep the rocket in the shade until it is moved to the launch pad.
Ground pollution	Unrecovered rockets on the ground	Residual motor components, ejection charges and electronic and structural components leach out of the submerged rocket and cause soil pollution.	4	3	7, Moderate	LTRL will always make every attempt to retrieve the rocket. A GPS transmitter will be placed in the rocket so that the team can locate the rocket.
Wind	Gusts of wind at launch site	Loose objects blow away from launch prep site	4	3	7, Moderate	Keep all tools and components stored in storage boxes when not in use. Keep trash cleaned up while working.
Flooding	The lab floods	Equipment, rocket parts, and supplies are ruined, risk of electrical shock from submerged electric cords and outlets.	3	4	7, Moderate	If a severe rainfall event is predicted, the club will move critical components, extension cords and equipment to higher places in the lab. Most components and equipment are stored in plastic boxes and are stored off the floor on shelving units.
Fire	Hot motor gases	Grass or brush fire	1	5	6, Moderate	LTRL will always use a blast deflector

Fire	Ejection charges	Grass or brush fire	1	5	6, Moderate	LTRL will not use more black powder than necessary for ejection charges. Ejection charges will be contained within the rocket.
Wind	High winds during parachute deployment	The rocket drifts out of the landing zone, and/or into hazards such as buildings, trees or power lines.	3	3	6, Moderate	The main parachute will be deployed at 700ft to limit drift.
Effect on animals	Rocket lands on animals	Animal is injured, rocket is trampled	2	4	6, Moderate	Launch in area free from livestock. Limit drift in order to land the rocket in the cleared landing area. Limit kinematic energy of rocket on landing so that potential injuries to livestock or wildlife are minimal.
Crop debris	Crop debris interferes with rover operations	Crop debris prevents the rover from exiting the rocket, or from moving forwards	3	3	6, Moderate	The rover will be designed to overcome these challenges.
Water pollution	Unrecovered rockets in bodies of water	Residual motor components, ejection charges and electronic and structural components leach out of the submerged rocket and cause water pollution.	2	4	6, Moderate	LTRL will always make every attempt to retrieve the rocket from bodies of water. The team will always launch the rocket in a manner such that its flight path will not take it over large bodies of water.
Water pollution	Improper disposal of lab chemicals	Poisonous chemicals could cause fish kills and pollution of waterways.	1	4	5, Moderate	All chemicals will be picked up by Penn State EHS and safely treated and disposed.
Ground pollution	Littering	Trash such as plastic bags, wires, and cardboard is left behind at launch prep site.	2	3	5, Moderate	LTRL will always pick up all of the trash at the launch prep site. The safety officer will check to see that all trash has been removed before the team leaves.

Ground Pollution	Improper disposal of lab chemicals	Poisonous chemicals could cause soil contamination.	2	3	5, Moderate	All chemicals will be picked up by Penn State EHS and safely treated and disposed.
Wind	Gusts of wind after rocket lands	Parachute drags rocket	3	2	5, Moderate	Use a parachute no larger than necessary to land the rocket safely.
Rain	Rain during launch window	Launch is cancelled	4	1	5, Moderate	Check weather reports before leaving for the launch.
Low level clouds or fog	Low level clouds or fog at launch site	Launch is cancelled or delayed	4	1	5, Moderate	Check weather reports before leaving for the launch.
Rain	Rain at launch site	Explosives get wet, electronics are damaged	1	3	4, Low	Protect explosives from rain until their placement in the rocket. Rocket is designed to protect explosives and electronics.
Excessive humidity	Humidity is high enough to interfere with electronics operation	Malfunctioning electronics	1	3	4, Low	Use quality electronic components less likely to be affected by humidity. If problems are experienced, use desiccants to lower the humidity near the problematic electronic components.
Cold temperatures	The temperature is below the range which the electronic components are designed to handle	Malfunctioning electronics	1	3	4, Low	Use electronic components designed to withstand a range of temperatures. Keep the payload and avionics bays in a warm environment as long as possible.

Failure Modes and Analysis

To ensure a safe and effective launch, an assessment of possible failures has been made. After analyzing the cause of the potential failure, mitigations were also proposed.

Table 24 shows the preliminary set of failure modes.

Table 24. Failure Modes and Analysis (FMEA)

PAYLOAD						
Failure	**Cause**	**Effect**	**Likelihood**	**Severity**	**Combined Risk Factor**	**Mitigation**
Premature activation of CO2 canisters	Control software triggers canisters prematurely	Nose cone of the rocket separates prematurely during flight - can cause massive instability during launch, and free-falling body sections pose a serious danger to bystanders on the ground	2	5	7, Moderate	Perform thorough rigorous testing on the control software to prevent premature triggering, build software and hardware guards for the separation trigger to prevent accidental activation
Rover tips over and is unable to right itself	Uneven terrain, failure of self -righting mechanisms	Rover will be unable to move and complete the mission	4	3	7, Moderate	Rigorously test the self-righting mechanism with various terrain
Rover containment mechanism fails during flight	Forces sustained during launch exceed the strength of the containment mechanism	Rover becomes unsecured during launch - an unsecured mass can cause instability during flight	2	4	6, Moderate	Verify structural integrity of rover housing before launch, ensure that materials used to construct rover containment mechanism can withstand launch acceleration
Shear pin failure	Forces sustained during launch exceed the strength of the shear pins	Nose cone of the rocket separates prematurely during flight - can cause massive instability during launch, and free-falling body sections pose a serious danger to bystanders on the ground	1	5	6, Moderate	Manually inspect shear pins before flight to ensure integrity

CO2 canisters fail to activate	Control software fails to trigger canisters, physical activation mechanism is damaged during flight or landing	Rover will be unable to deploy from the rocket	3	3	6, Moderate	Perform rigorous testing on the control software to ensure that canister is triggered, test physical trigger method to ensure it works consistently
Discharged battery pack	Improper charging, loose connection to battery pack	Loss of power to rover and associated electronics - payload section of the rocket will be unable to separate, leaving the rover unable to execute its mission	2	3	5, Moderate	Ensure that rover battery packs are completely charged before flight, test battery packs to ensure that they hold sufficient charge to last the duration of the mission
Structural damage to payload bay	Forces sustained during launch or landing exceed strength of the payload bay	A breach in the wall of the body tube would prevent the CO2 canister from creating enough pressure to separate the nose cone from the rocket body	2	3	5, Moderate	Check parachute deployment mechanism with A&R subsystem to ensure that the rocket does not land a high rate of speed
Physical damage to the rover	Forces sustained during launch or landing exceed strength of the rover	Rover is damaged during launch or deployment - if damage sustained is severe enough, rover may be unable to operate correctly	2	2	4, Low	Construct the rover out of materials durable enough to withstand launch forces, minimize rover weight to minimize force transferred to rover components
Structural damage to payload door	Forces sustained during launch or landing exceed strength of the payload door	If damage is severe enough, rover would be unable to deploy from the body of the rocket	1	3	4, Low	Reinforce door to be able to withstand forces of launch/landing, verify parachute deployment mechanism with A&R subsystem

STRUCTURES

Failure	**Cause**	**Effect**	**Likelihood**	**Severity**	**Combined Risk Factor**	**Mitigation**

Fin Separation from fin brackets	loosening of bolts	Sky Debris	1	5	6, Moderate	Simulation of expected stresses, material testing, pre-flight check
Eyebolts Separation from bulkheads	Extreme stress from shock cord, insufficient thread strength on bulkhead	Unwanted separation of rocket, sky debris	1	5	6, Moderate	Simulation of expected stresses, material testing, pre-flight check
Bulkhead Separation from body tube	Insufficient Epoxy strength	Unwanted separation of rocket	1	5	6, Moderate	Visual Inspection, Pre-flight check
Cascading Fracture, body tube	Extreme stress around bolt hole	Functional/Structural inadequacy	1	4	5, Moderate	Simulation of expected stresses, material testing
Crack along inner/outer seam, body tube	torsional stress, bending moment	Functional/Structural inadequacy	2	3	5, Moderate	Simulation of expected stresses, material testing
Unwanted coupler separation from body tube	Premature Shear pin fracture	Parachutes do not deploy, incorrect descent	3	2	5, Moderate	Visual Inspection, pre-flight check
Premature nose cone separation	Premature Shear pin fracture	Aerodynamic inconsistency/ Instability, sky debris	1	4	5, Moderate	Simulation of expected stresses, material testing

Fin bracket fracture	Extreme or repeated impact, bending moment	Aerodynamic instability, Structural failure	1	4	5, Moderate	Simulation of expected stresses, material testing
Coupler Fracture crack	Torsional stress, bending moment	Aerodynamic inconsistency/Structural Failure	2	2	4, Low	Simulation of expected stresses, material testing
Body tube Fracture crack	Material Defect, Repeated impact	Aerodynamic inconsistency/Structural Failure	2	2	4, Low	Visual Inspection, pre-flight check
Fin fracture crack	Extreme or repeated impact, bending moment	Aerodynamic instability, Structural failure	2	2	4, Low	Simulation of expected stresses, material testing
Bulkhead Fracture crack	Material Defect, stress on eyebolt threads, insufficient epoxy strength	Structural Failure, pressure leakage	1	2	3, Low	Visual Inspection, Pre-flight check
PROPULSION						
Failure	**Cause**	**Effect**	**Likelihood**	**Severity**	**Combined Risk Factor**	**Mitigation**
Motor CATOs	Motor casing or components rupture	Catastrophic damage to rocket	2	5	7, Moderate	Inspect motor grains prior to installation. A certified member will assemble the motor according to the assembly instructions with another observing. Develop an internal checklist.
Motor does not stay retained	Motor thrust pushes the motor into the rocket	Catastrophic damage to rocket	2	5	7, Moderate	Verify that the motor retention system can handle the motor thrust, with a safety margin

Motor does not stay retained	Ejection charges push motor out of rear of rocket	Motor does not remain in rocket	2	5	7, Moderate	Use of active motor retention, Use of lower impulse motor
Motor does not ignite	Motor does not ignite on launch day	Rocket does not lift off pad	3	1	4, Low	Use recommended igniters. Store motors properly to avoid oxidation. Verify that the initiator is inserted all the way to the top of the motor grains.
Avionics and Recovery						
Failure	**Cause**	**Effect**	**Likelihood**	**Severity**	**Combined Risk Factor**	**Mitigation**
Altimeter has complete or partial power loss in flight due to faulty wiring of battery or switch	Wiring of switch and/or battery is not secure	Parachutes may not deploy, rocket descends at terminal velocity, rocket body and/or payload components are damaged	3	5	8, High	Perform sharp, forceful 'tug' test on wires, make connections with snapping and/or pinching mechanisms, not twisting
Altimeter fails to detect outside pressure accurately	Pressure port into avionics bay is not sufficiently large to allow outside pressure to be measured	Late or no deployment of parachutes, rocket descends at terminal velocity, rocket body and/or payload components are damaged	3	5	8, High	Ensure pressure port is at least about the size of grape
Main and Drogue charges fail to separate the rocket	Use of too many shear pins, too little black powder	Parachutes do not deploy; the rocket descends at terminal velocity	3	5	8, High	Perform ground testing to determine the proper number of shear pins and proper amount of black powder.
Drift distance from launch pad is greater than required safety range	Main parachute is too large and/or deployment height is too high	Rocket falls outside of launch boundaries, may cause damage to property, vehicles, or people	3	4	7, Moderate	Select parachute sizes based on models of minimum descent speed, given various wind conditions

Altimeter loses continuity through initiators during flight	Wiring of leads from altimeter and/or connection to initiators is not secure	Altimeter cannot ignite initiator, parachute is not deployed, rocket descends too quickly	3	4	7, Moderate	Perform sharp, forceful 'tug' test on wires, make connections with snapping and/or pinching mechanisms, not twisting
Main side charges fail to separate rocket	Ejection charge strength is not matched to shear pin strength	Rocket descends and lands too quickly, damage may be inflicted onto rocket body	3	4	7, Moderate	Ground testing to determine ratio of shear pins to balck powder
Drogue parachute undergoes fire damage due to ejection charge denotation	Parachute is damaged and may fail upon deployment	Rocket descends too quickly, main parachute may be damaged or cause damage to body tube upon deployment	3	3	6, Moderate	Standard operating procedure for parachute packing, included wrapping with fire retardant blanket
Main parachute undergoes fire damage due to ejection charge denotation	Parachute is damaged and may fail upon deployment	Rocket descends and lands too quickly, damage may be inflicted onto rocket body	3	3	6, Moderate	Standard operating procedure for parachute packing, included wrapping with fire retardant blanket
Fire retardant blanket slides up shroud lines of parachute and prevents it from opening fully	Fire retardant blanket is attached by running shroud lines through the hole in blanket as opposed to directly to the quicklink	Parachute's effectiveness is diminished, rocket descends and/or lands too quickly, damage may be inflicted onto rocket body	3	3	6, Moderate	Secure fire retardant blanket to quicklink
Drogue side charges fail to separate rocket	Ejection charge strength is not matched to exceed shear pin strength	Rocket descends too quickly, main parachute may be damaged or cause damage to body tube upon deployment	3	3	6, Moderate	Ground testing to determine ratio of shear pins to balck powder
Electromagnetic field triggers altimeter to detonate early	Faraday cage is not constructed to effectively shield altimeter	Rocket experiences explosive separation while on the ground and/or while being handled	2	4	6, Moderate	Construct faraday cage so that it is sufficiently thick and has complete coverage, testing

Main parachute either does not leave body tube or does not unfurl	Parachute, fire retardant blanket, and/or shock cord are not packed correctly	Rocket descends too quickly, damage may be inflicted onto rocket body	1	4	5, Moderate	Standard operating procedure for parachute packing
Main parachute deploys at apogee with drogue parachute	Main side shear pin strength is not matched to exceed drogue side ejection charge strength; main and drogue parachutes are mistakenly swapped	Rocket descends too slowly, drift distance exceeds maximum	3	2	5, Moderate	Ground testing to determine ratio of shear pins to black powder; standard operating procedures for assembling recovery harnesses and parachutes
Jostling of rocket vertically triggers altimeter to detonate early	Altimeter detects changes in pressure that resemble apogee and detonates drogue charges	Rocket experiences explosive separation while on the ground and/or while being handled	1	4	5, Moderate	Setting minimum detonation height of altimeter to at least 100 ft above ground level, only enabling altimeters with charges on the launch pad
Body tube of the rocket is zippered by shock cord during parachute deployment	Rocket is falling too quickly when parachute is deployed	Permanent damage to body tube, which may need to be replaced	3	2	5, Moderate	Select parachute sizes based on models of maximum descent speed, use cushioned ball around shock cord to prevent damage
Kinetic energy at landing is above required safety threshold	Main parachute is not sufficiently large to slow descent	Rocket lands with too much force, rocket body and/or payload components are damaged	2	3	5, Moderate	Select parachute sizes based on models of maximum descent speed, ensure masses of rocket sections are accurate and up to date
Drogue parachute either does not leave body tube or does not unfurl	Parachute, fire retardant blanket, and/or shock cord are not packed correctly	Rocket descends too quickly, main parachute may be damaged or cause damage to body tube upon deployment	1	3	4, Low	Standard operating procedure for parachute packing
Main parachute deploys below drogue parachute and tangles	Shock cord lengths are incorrectly proportioned	Rocket descends and lands too quickly, damage may be sustained by rocket body	1	3	4, Low	Designating specific lengths based on rocket section lengths, weights, and parachute locations

Explanation of Project Risk Assessment

The risks to the overall project were assessed, not with numerical values, but with descriptors such as “low”, “moderate”, and “high” for Likelihood and Impact. These were assigned based on list given below.

LIKELIHOOD:
Low: The risk is unlikely. Over the historical legacy of the risk, it has never occurred.
Moderate: The risk is likely. Over the historical legacy of the risk, it has occurred at least once.
High: The risk is very likely. Over the historical legacy of the risk, is has occurred several times.

IMPACT:
Low: The risk will cause disruption within the club, and could delay the progress of the project.
Moderate: The risk could cause the project to be severely delayed and/or reduce the quality of the finished product.
High: The risk could cause the project to fail, cause the team to be unable to make it to Alabama, or cause the club to be disbanded by Penn State.

Project Risk Assessment

There are several concerns with the overall project, mostly related to budget and personnel management. These are presented in Table 25 below.

Table 25. Project Risk Analysis

Risk	Cause	Effect	Likelihood	Impact	Mitigation
Club loses funding	One or more sources can no longer provide funding	There is not enough money to pay for transportation or necessary parts and equipment	Moderate	High	Dedicated member to track expenses and make funding contracts possible.
Project over budget	Testing/fabrication/travel costs exceed expectations	Project cost exceeds amount of money projected	Moderate	High	Compare prices from different vendors, avoid excess shipping costs
Parts are unavailable	Parts needed for the rocket are not available commercially	Rocket cannot be completed using the planned parts	Moderate	High	Use non-exotic materials and check for availability. Order parts far in advance
Damage during testing	Accident/malfunction during testing	Catastrophic damage to the rocket	High	Moderate	Ground testing, maintain a stock of spare parts
Project falls behind schedule	Team fails to build critical components in a timely manner	Major milestones are not met in time	Moderate	Moderate	Weekly status meetings, follow project plan
Failure to acquire transportation	Transportation to Alabama not acquired	Team is unable to travel to the competition	Low	High	Carpool to Alabama if necessary

Injury of team personnel	Hazards outlined in Table 22	Team member is injured	Low	High	Inform and enforce team safety
Club loses facilities	University revokes club access to the lab	Club loses access to 46 Hammond	Low	High	Maintain clean and safe environment in the lab and store hazardous materials safely
Labor leaves/graduates	Seniors graduate, or students stop attending meetings	There are no longer enough students available to perform the necessary work	Low	Moderate	Recruitment at the beginning of each semester. Team building activities.
Theft of equipment	Parts or testing equipment get stolen	Rocket construction becomes more difficult, excess cost to the club	Low	Moderate	Only subsystem leaders and officers will have card access to the LTRL lab

5. Payload Criteria

The objective of the payload is to remotely deploy an autonomous rover after the landing of the rocket has been verified. After being remotely deployed from the rocket, the rover will travel 5 feet away from any point of the rocket and deploy a set of foldable solar panels.

Within the payload bay the rover will be contained within two parallel shelves mounted to the interior of the rocket. These shelves are three inches apart, and will likely be 3D printed as one piece so that they can easily be secured into the rocket perfectly aligned. Wood has also been considered but difficulty securing two separate shelves accurately into the rocket body is a concern.

To accomplish the objectives of the rover as stated above, the payload subsystem has been divided into 6 subsystems. The subsystems are Object Avoidance, Rocket Integration, Software, Chassis and Electronics, Drivetrain, and Solar Panel Deployment.

5.1 Object Avoidance Subsystem

The Object Avoidance subsystem will be responsible for ensuring that the rover does not get stuck and predicts and avoids obstacles. Table 26 below outlines the design options for the Object Avoidance subsystem. The table includes descriptions of each design and the tests that will be done to ensure that the most effective option is chosen. Pros and cons are also listed for each design option.

Table 26.Obstacle Avoidance Design Concepts

	Description	Test/ Verification	Pros	Cons
Parallelogram Shape	The vertical cross section of the rover would be a parallelogram. This shape would allow the rover to climb obstacles more easily due to the decreased amount of torque necessary to climb.	Ground tests will be performed to determine if the rover can climb obstacles more easily with the parallelogram shaped body.	A parallelogram design makes it much easier to climb due to the decreased amount of torque required to climb objects.	This design decreases the mobility because it is only effective in one direction.
Plow	Use a plow to divert objects out of the rover's path by guiding them out of the way or divert the rover's path away from the obstacles.	Ground tests will be performed to determine how effective a plow would be at enabling the rover to avoid obstacles.	A plow is simple and doesn't require electronics.	A plow could be heavy and add unnecessary weight to the rover.

Sensors	Use infrared sensors to scan the rover’s path for obstacles that may be in the way and change course to avoid them.	Program rover to drive along a path containing various types of expected debris and verify that it effectively adjusts path around objects.	Sensors would be the most accurate way to make sure that something is not in the way of the rover.	The sensors could have difficulty distinguishing between obstacles and troughs.

For the rover to be successful, it will need to avoid obstacles. Making the vertical cross section of the rover be a parallelogram shape may make obstacles easier for the rover to climb over, however, this shape is only beneficial if the rover moves in the direction of the upward slant. Having a plow in front of the rover will allow the rover to push objects to the side that are in its path, or divert the rover away from immobile obstacles; however, the plow may get stuck in the ground if the rover drives over a patch of very loose soil. If the rover has sensors on it, then it will be able to detect if there is an object in its way, allowing the rover to go around the object and continue its original path, or change its path all together. These sensors, however, may not be to tell the difference between a trough and a rock, so it may constantly change its path.

The functionality of each concept is based on how it fits the following six traits:

- Range – The avoidance system avoids all obstacles within path, but does not interact with objects that are not a concern.
- Light Weight – The components needed for the avoidance system are light in weight. This criterion relates to integration with the rocket as well as battery efficiency.
- Effective – The avoidance system avoids all objects of concern.
- Agility – The avoidance system will not catch obstacles in or under the rover that would cause the rover to become immobile.
- Low Power – The avoidance system consumes low amounts of electric power. This criterion affects required electric input of components and weight due to required battery size.
- Small - Components of the avoidance system will fit into the payload bay in the launch vehicle.

Table 27 is used to determine relative weights of each obstacle avoidance system trait. Each component is scored relative to the other components on a range of 1-10.

Table 27. Criteria for Obstacle Avoidance System

	Range	Light Weight	Effective	Agility	Low Power	Small	Total	Weighted Total
Range	1.000	4.000	0.143	0.200	3.000	4.000	12.343	0.168
Light	0.250	1.000	0.200	0.250	2.000	0.250	3.950	0.054
Effective	7.000	5.000	1.000	1.000	7.000	3.000	24.000	0.326
Agility	5.000	4.000	1.000	1.000	6.000	0.333	17.333	0.236
Low Power	0.333	0.500	0.143	0.167	1.000	0.200	2.343	0.032
Small	0.250	4.000	0.333	3.000	5.000	1.000	13.583	0.185
							73.552	

According to Table 27, effectiveness, the ability to be agility, range, and size are the most important criteria for obstacle avoidance. Low power and lightweight are the least important criteria for this part of the rover.

Table 28 scores each Obstacle Avoidance concept against each weighted need on a range of 1-5.

Table 28. Selection Matrix for Obstacle Avoidance System

	Weight	Sensors	Parallelogram Shape	Plow
Range	0.168	4	1	3
Light	0.054	5	4	3
Effective	0.326	3	2	4
Agility	0.236	3	1	3
Low Power	0.032	2	5	4
Small	0.185	5	4	3
		3.613	2.169	3.358

Although sensors scored the highest, a combination of sensors and a plow could be more effective for obstacle avoidance. Testing the rover in terrain like that of the launch site will determine which individual or combination would create the most effective way to avoid obstacles.

A model of the front-end plow that was scored as the best physical method of obstacle avoidance is shown in Figure 17.

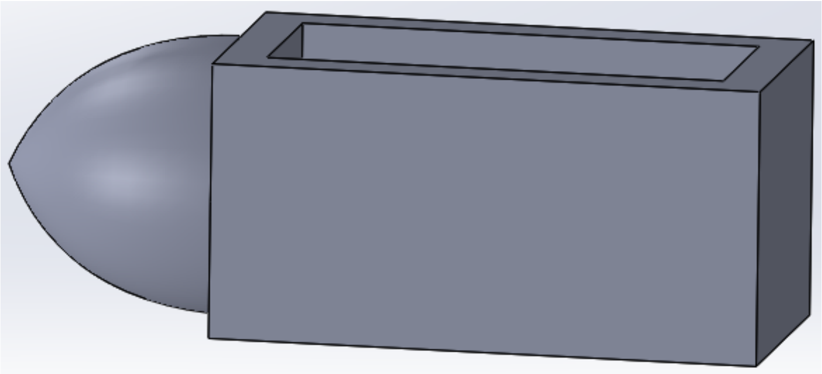


Figure 17. Front-end Plow

The rectangular prism represents the body of the rover, and the dome on the front is the plow. The wheels, not shown in the figure, would go on the faces of the rover that are perpendicular to that of the plow.

Another aspect of obstacle avoidance is orientation correction, as this ability is crucial so that the rover can continue its mission after meeting all types of obstacles. Table 29 outlines self-righting mechanism design ideas.

Table 29. Self-righting Mechanisms

	Description	Test/ Verification	Pros	Cons
Rounded Hubcaps	Elliptic paraboloid hubcaps will be mounted on all four of the wheels. This design will prevent the rover from tipping and remaining on its side.	Try balancing rover on side in various conditions. If rover is capable of balancing on side, the design fails. Otherwise, the design passes.	Hubcaps would allow only one point of contact in which the rover could get stuck.	Hubcaps could be a heavy component.
Rotating Arms	Install servo-operated load-bearing arms that rotate/extend to flip rover over back to correct orientation	Place rover in different positions in various terrain conditions and test whether arms can flip rover to the correct orientation	Rotating arms would allow the rover to precisely adjust orientation.	Rotating arms could be unnecessarily complicated.

These two design options ensure that the rover stays in the correct driving orientation and will not get stuck on its side. Having hubcaps on the driving mechanism of the rover will keep it upright if the rover ever tips sideways. These hubcaps will provide a larger surface area to keep the rover in the correct driving orientation, but it could potentially be heavy, causing the rover to move more slowly or need more power. The rotating arms will allow the rover to adjust its orientation more precisely, however, will be more complicated.

A brief description of each criteria is listed:

- Effective – The self-righting system can flip the rover back into its correct orientation.
- Small – The orientation correction system will not consume too much space in payload bay of rocket.
- Low Power- The orientation correction system does not require significant amounts of power to operate electronics or propel weight.

Table 30 below compares the needs for self-righting mechanisms. This table is used to determine relative weights of each obstacle avoidance system trait. Each component is scored relative to the other components on a range of 1-10.

Table 30. Criteria for Self-Righting Mechanism

	Effective	Small	Low Power	Total	Weighted Total
Effective	1.000	6.000	4.000	11.000	0.660
Small	0.167	1.000	0.333	1.500	0.090
Low Power	0.167	3.000	1.000	4.167	0.250
				16.667	

The table shows that effectiveness is the most important trait, as an ineffective orientation correction system would not be worth the complexity and weight it adds to the rover. Table 31 scores each Self-Righting Mechanism concept against each weighted need on a range of 1-5. Based on the final scoring, hubcaps have been determined to be the best option for self-righting.

Table 31. Selection Matrix for Self-Righting Mechanism

	Weight	Hub Caps	Rotating Arms
Effective	0.660	4	2
Small	0.090	2	2
Low Power	0.250	5	1
Total		4.070	1.750

Hubcaps received the highest rating of the two design choices because they can be lightweight, and do not need power. They will also likely be effective at preventing the rover from tipping over. Figure 18 shows a SolidWorks model of the hubcaps.

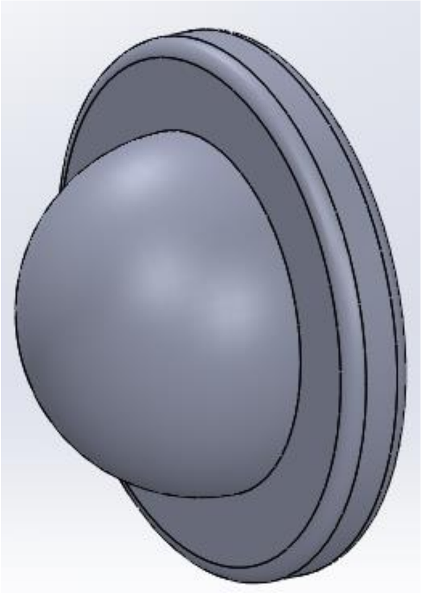


Figure 18. Wheel-mounted Hubcaps

The hubcap would be secured onto the exterior of the wheel, increasing the surface area of the wheel so that the rover is less likely to tip over and has more contact with the ground. The hubcaps will likely be 3D printed so that a mounting mechanism can easily be built into them. While 3D printing can be fragile, the hubcaps will not be supporting the weight of the rover nor are they mission critical.

5.2 Rocket Integration Subsystem

The Rocket Integration subsystem will be responsible for ensuring that the payload easily integrates into the rocket and is structurally sound. The subsystem will also ensure the rover's protection from separation of the rocket. Table 32 below outlines the rocket integration designs which will ensure that the rover remains secure inside the rocket. Pros and Cons are listed for each option.

Table 32. Rocket Integration Design Concepts

	Description	Test/ Verification	Pros	Cons
Door	To keep the rover in place at separation and to protect from any separation charges, a servo operated door will be implemented to hold and protect the rover from damage. The door will lock itself by rotating a rod, via servo mounted onto the door, into slits in the shelves holding the rover.	The door will be tested during subscale. Strength of materials tests simulating rocket flight will be conducted to determine if 3D printed material or wood will be used to make the door.	A door would increase the protection of the rover during separation. The door also secures the rover during flight so that it moves minimally.	A door is a heavy element and can be complicated.
Locking mechanism built into the rover	In the case that a door is not necessary to protect the rover, a similar design to the door would be implemented. To keep the rover in place, the rover would lock into the mounted shelves with a rod and servo attached to the front of the chassis.	A fullscale test launch would be used to verify that the rover can lock itself into place on the mounted shelves and be safe from the separation charges. To protect the actual rover during testing, a test model of the rover will be used.	This mechanism could decrease the complexity of the containment system and decrease the weight of the payload section.	Building the locking mechanism into the rover would add weight to and increase the complexity of the rover.

The rover will be secured during all stages of the rocket flight to avoid damaging to the rover and ensuring that a free weight inside the launch vehicle does not affect rocket stability. This securing mechanism is also very important for rover protection during the detonation of the CO_2 charge that will open the payload bay to release the rover.

The door will separate the rover bay from the CO_2 charge in the nosecone. The door will have a servo arm mounted in the center on one side. The arm will start in a locked position where the servo arm is through holes in the two shelves containing the payload. The locked door will keep rover in place inside the rocket. Once the rocket lands, the arm on the servo will rotate and the door will become unlocked. The rover will drive to push open the door and drive out of the payload bay to complete its task. The door will be either 3D printed or made out of wood. If the door is 3D printed, it will be easier to place a servo on it as the door could be manufactured to have a slot for the servo. However, 3D printing the door may make it heavier as it will need to be structurally sound to withstand the blast from the separation charges. A wooden door may be lighter, however, securing the servo to a wooden door would be more difficult. 3D printing is the favored option due to construction simplicity. However, the structural integrity of 3D printed materials has been a concern in the past, therefore, the strength of the 3D printed locking mechanism and door will be tested via rocket flights.

These concepts have not been scored against each other as that is not the proper method of concept selection for this category. The preference for one design over the over will be determined by experiments and testing that will occur at a later date. These tests will entail detonating a CO2 charge in a sealed chamber and measuring the change in temperature and pressure experienced. This experiment is needed to determine whether a CO2 detonation would risk damaging the rover and its electronics. If test results prove that the rover will not be damaged by the blast, then the blast door will not be necessary. If a protection system is required, the same test will be done to determine which concept will work. If both concepts work, the lighter of the two options will be chosen.

5.3 Software Subsystem

The Software subsystem will be responsible for working with the Object Avoidance, Rocket Integration, Drivetrain, and Solar Panel Deployment subsystems to develop the code required to execute their respective tasks.

Table 33 outlines the necessary software tasks required by the payload subsystem. The payload subsystem will be utilizing Git as a version control tool this year to organize code and increase the effectiveness of collaborative coding. This decision was made because of confusion caused with software organization in the past.

Table 33. Software Tasks

Software Tasks	Description	Testing/ Verification
Remotely deploy the rover from the launch vehicle.	Using a communications system with XBee radios, program the rover to release the locking mechanism and drive out of the rocket when a “go” command is received from the ground station.	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 5 feet from the rocket.	Determine if the rover has moved the minimum distance from the rocket using one of the methods discussed in Table 34. The distance attempted will be greater than 5 feet to account for error.	Verify via test program that the rover stops after moving the correct distance on a terrain akin the launch field.
Maintain orientation.	Using an accelerometer to measure the relative direction of gravity, determine which way the wheels need to turn to move away from the rocket. Constantly check orientation in case of flipping.	This system will be tested by placing the rover in different orientations to the rocket and having it attempt to drive at least 5 feet away from the rocket.

Avoid obstacles.	Using infrared sensors, ensure that the rover avoids running into potential obstacles.	Put various obstacles in front of the rover and test to see if it will avoid them.
Deploy solar panels.	Once the rover has stopped moving, use a servo to unfold the solar panels.	Write and run a test program that causes the rover to stop multiple times and deploy the solar panels to ensure that they unfold correctly.

The rover's processor will be an Arduino Nano microcontroller. An Arduino was chosen over other micro-controllers 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 ports 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 below.

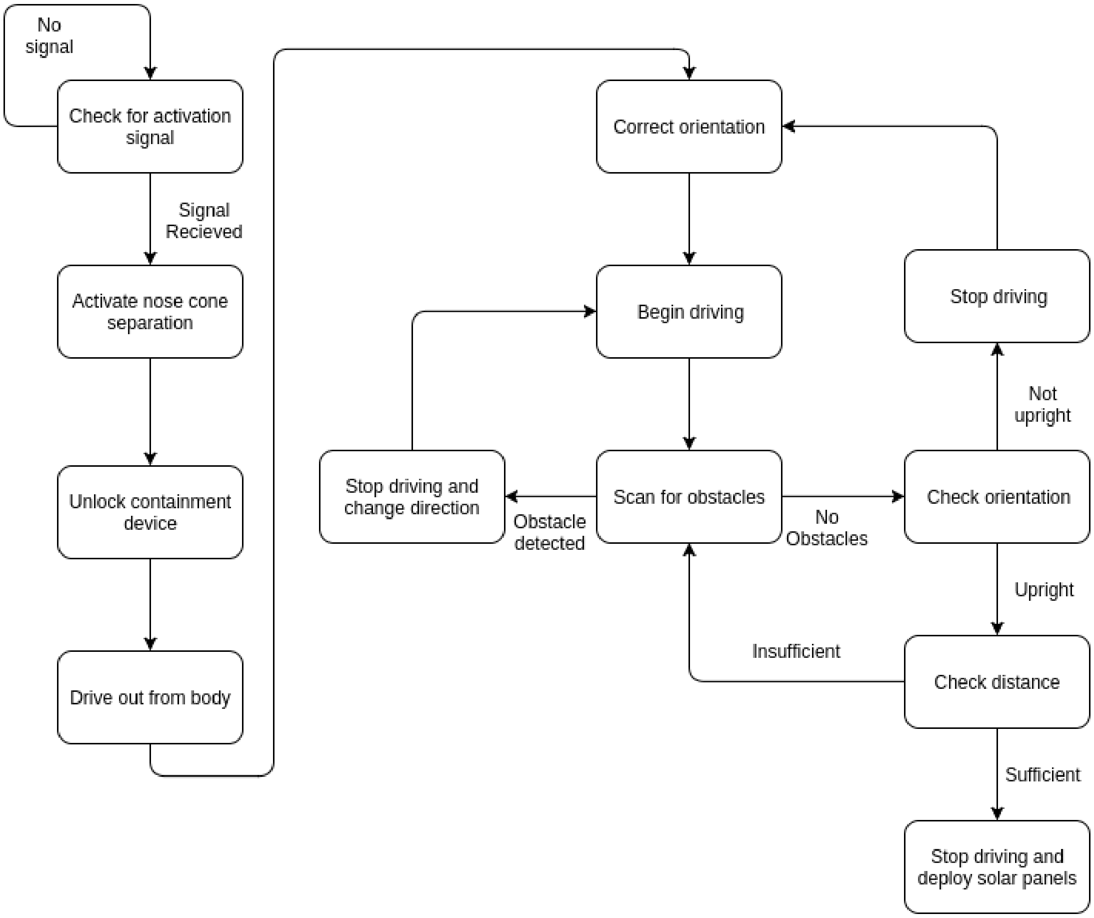


Figure 19. Software Flowchart

Upon receiving the activation signal from the ground station via XBee radio, the control software will trigger the nose cone separation mechanism, a compressed CO_2 canister. The program will unlock the rover containment device, and drive the rover out of the rocket. Upon exiting the rocket, the rover will correct its orientation. Because the likelihood that the rover will deploy in the correct orientation is low, the rover will always right itself upon deployment instead of checking its orientation to reduce the length of the control code.

After the rover has successfully deployed from the rocket, the software will enter a continuous feedback loop. The rover will begin driving after it corrects its orientation. While driving, the software will continuously check for obstacles in the rover’s path, check the orientation of the rover to determine if it is still upright, and check to see if the rover has travelled a sufficient distance from the rocket. As described in Figure 19, each of these checks will trigger a corrective action within the software if they detect any issues. If the software determines that the rover has driven far enough from the rocket, it will stop the rover and deploy the attached solar panels. Table 34 below describes the design options being considered to determine if the rover has travelled the minimum distance.

Table 34. Distance Measurement Techniques

	Description	**Test/ Verification**
Accelerometer	Program Arduino board to convert XYZ accelerations read from accelerometer into displacement.	Program rover to drive in various paths in varied conditions and compare calculated displacement to actual displacement.
GPS	Program Arduino board to use GPS to determine initial and active coordinates to derive displacement vector and its magnitude.	Run trials to test accuracy/precision of GPS in areas where satellite signal is limited.
Wheel Encoder	Program Arduino board to use input from wheel encoder to convert wheel rotations into a displacement.	Test at various angles of incline to check for wheel slip.
String on pin	Fix a spool of string with string length greater than five feet inside rocket with other end attached to a removable pin in the back end of the rover. When sting is fully extended, pin will be pulled from back end of rover, which will disengage drivetrain.	Test in various landing orientations to ensure that rover will not get tangled in string. Test minimum force required to pull pin from slot without risking the pin falling out when no force is applied.

The design options presented in the above table will be judged on how they meet three criteria. A brief description of each criteria is listed below.

- Accurate – Distance calculated is close to actual displacement. Measurement error is low.
- Low Risk – The measurement system does not introduce potential for overall rover or rocket failure.

- Adaptable – Distance measurement system preforms function regardless of environment.

Table 35 is a weighting matrix for the criteria of this system. Each component is scored relative to the other components on a range of 1-10.

Table 35. Criteria Weighting Matrix for Distance Measurement System

	Accurate	Low Risk	Adaptable	Total	Weighted Total
Accurate	1.000	3.000	7.000	11.000	0.555
Low Risk	0.333	1.000	6.000	7.333	0.370
Adaptable	0.333	0.167	1.000	1.500	0.076
				19.833	

Below, Table 36 scores each distance measurement concept against each weighted need on a range of 1-5.

Table 36. Selection Matrix for Distance Measurement System

	Weight	Accelerometer	GPS	Wheel Encoder	String on Pin
Accurate	0.555	4	2	3	4
Low Risk	0.370	4	2	3	1
Adaptable	0.076	5	3	4	2
Total		4.076	2.076	3.076	2.739

Based on the final scoring, an accelerometer is the best option for distance measurement. A combination of the top two design concepts, an accelerometer and a wheel encoder, as two separate measurement systems, is also being considered for redundancy.

5.4 Chassis/Electronics Subsystem

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. Table 37 outlines the possible materials for the chassis design as well as the pros and cons of each material.

Table 37. Chassis Material

	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 test the strength.	It is 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.

3D printed PLA is the favored of the two options because of 3D printing allows the team to build complex shapes and mounts easily. Since fragility and weight are concerns with the PLA, the team will run SolidWorks FEA on the chassis models with multiple infill percentages, to determine if the material can be reliable.

5.5 Drivetrain Subsystem

The Drivetrain subsystem will be responsible for determining the type of drivetrain that will be necessary for the rover. They will also work closely with the Chassis/ Electronics subsystem in order to integrate the drivetrain into the chassis of the rover and the power source.

Table 38. Driving Mechanism Design Concepts below outlines the drivetrain options. Included in the table are descriptions of each design for the drivetrain and the tests that will be done to determine the most effective option. The pros and cons of the different driving mechanisms are also listed.

Table 38. Driving Mechanism Design Concepts

Drivetrain Options	Description	Test/ Verification	Pros	Cons
Spurred Wheels	Use wheels powered by servos and/ or differentials.	Ground tests will be performed to determine the effectiveness of wheels on terrain similar to that of the launch site.	Less power is required for wheels than the other two options. There are also less wheels required.	Harder to move on ground that is loose and objects may get stuck in between the wheels.
Tracks	Use tracks powered by two motors.	Ground tests will be performed to determine the effectiveness of the tracks on terrain that is	Easier to move on loose ground and over mounds.	Heavier and harder to turn, causing them to require more power.

		similar to that at the launch site.		
Augers	Use two augers on either side of the rover to drive the vehicle forward.	Ground tests will be performed to determine the effectiveness of the augers on terrain similar to that of the launch site.	If ground is solid, the rover will move more easily because it can turn up the soil.	If soil is loose, rover will not move forward.

The driving mechanism for the rover will require further testing to determine which method will be best suitable on the terrain predicted to be at the launch site. SolidWorks models of the three drivetrain concepts are contained in Figure 20 in the order they appear in Table 38.

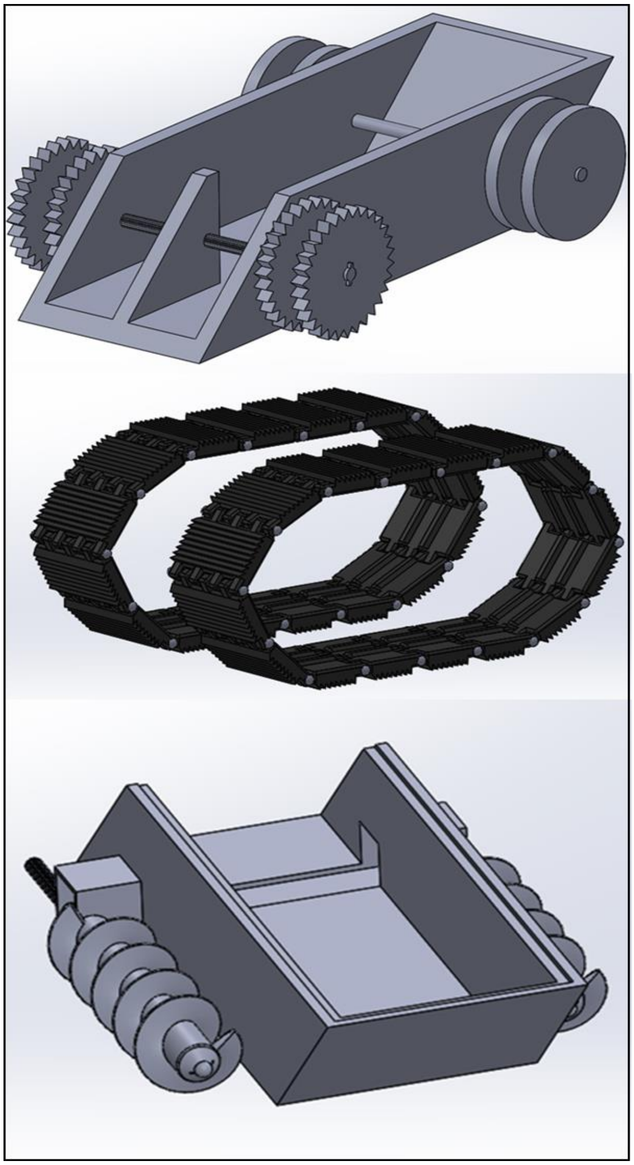


Figure 20. Drivetrain SolidWorks Models

If the drivetrain is wheels, there would only be four required. The front two wheels would be spurred to increase traction. The rover will require less power to move forward, however, wheels are not optimal on loose soil. Tracks, which are shown in the middle model of Figure 20, will allow easier movement on loose ground because they will reduce slippage; however, treads will be heavier than wheels since they will require more and heavier components. The augers are a heavy design choice, and are only being considered because of their effectiveness when dealing with the terrain of the landing area.

A brief description of each criteria is listed below.

- Maneuverable – Drivetrain has wide range of motion.
- Low risk – Operation of drivetrain does not jeopardize overall operation of rover or rocket.
- Traction – Drivetrain traverses soil without slipping.
- Torque output – Drivetrain generates enough torque to climb over terrain from provided voltage source.
- Durable – Drivetrain will not get damaged upon landing or by terrain.
- Weight – Weight of rover does not affect rocket flight or require significant battery power.

Table 39 compares needs for the Drivetrain subsystem. Each component is scored against each other component on a range of 1-10. This method is used to determine relative weights of desired Drivetrain traits.

Table 39. Criteria Weighting Matrix Drivetrain System

	Maneuverable	Low Risk	Traction	Torque Output	Durable	Weight	Total	Weighted Total
Maneuverable	1.000	5.000	2.000	0.333	4.000	6.000	18.333	0.259
Low Risk	0.200	1.000	0.167	0.200	1.000	2.000	4.567	0.064
Traction	0.500	6.000	1.000	0.500	5.000	6.000	19.000	0.268
Torque Output	3.000	5.000	2.000	1.000	5.000	5.000	21.000	0.296
Durable	0.250	1.000	0.200	0.200	1.000	3.000	5.650	0.080
Weight	0.167	0.500	0.167	0.200	0.333	1.000	2.367	0.033
							70.917	

Maneuverability, traction, and torque output are the highest rated criteria for this area of the rover. Table 40 scores each Drivetrain concept against each weighted need on a range of 1-5.

Table 40. Selection Matrix for Drivetrain Concepts

	Weight	Wheels	Treads	Auger
Maneuverable	0.259	2	4	3
Low Risk	0.064	3	3	2
Traction	0.268	2	4	4
Torque Output	0.296	2	3	2
Durable	0.080	2	4	3
Weight	0.033	4	2	1
Total		2.131	3.573	2.841

Based on the final scoring, treads have been determined to be the best option for Drivetrain. Testing will be done to confirm that this option the most effective.

5.6 Solar Panel Deployment Subsystem

The Solar Panel Deployment subsystem will be responsible for ensuring that the foldable solar panels are deployed from the rover once it has moved at least 5 feet from any point on the rocket. Table 41 below outlines the proposed ideas for deploying the solar panels.

Table 41. Solar Panel Deployment Methods

	Description	Test/ Verification	Pros	Cons
Servo	Use a servo to rotate the solar panels outside of the rover.	Program the servo to rotate the solar panels and test to make sure that it deploys completely.	A servo is a simple design that would be easy to implement into the chassis design.	A servo has a restricted plane of motion and could need a lot of space to deploy the solar panels.
Spring loaded	Use a spring mechanism to pop the solar panels out the front and back of the rover. The spring can be released by a servo and pin mechanism that is triggered when the rover is finished moving.	Program the servo to release a pin from the spring that causes the solar panels to be deployed.	Easier to deploy solar panels as it has a larger range of motion.	Would take up a larger amount of room and would be heavier than just servo alone.

The servo will release the solar panels by either using an arm or a spring-loaded mechanism. Further testing is required to determine which method will be more effective. Using a servo alone would be simpler, however, there will be a restricted plane of motion since a servo operates by using an arm. A spring-loaded mechanism will have a larger range of motion, thus allowing the solar panels to be deployed easier. This method, however, will take up more room and be heavier than the servo alone.

6. Project Plan

6.1 Requirements Verification

The following five tables explain how LTRL will meet all the requirements set forth by NASA.

Table 42. General Requirements

Requirement	Method of Verification	Verification
1.1	Inspection	The club is 100% student run, and only turns to mentors for advice and motor assembly, handling all ejection charges, and preparation and installation of electric matches.
1.2	N/A	The team has established Gantt Charts to maintain a project plan that includes but is not limited to project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations.
1.3	N/A	Foreign National members will be identified to NASA by PDR via email.
1.4	N/A	The team will identify all members attending launch week activities by CDR via email.
1.4.1	Inspection	LTRL leadership will keep track of the students who are actively engaged in the project, and only send them to launch week activities.
1.4.2	N/A	The team will bring their mentor.
1.4.3	N/A	The team will bring no more than two adult educators.
1.5	Inspection	The team will engage at least 200 participants in hands-on, educational STEM activities by participating in STEM events at middle and high schools in Centre County and going to visit team members' former middle and high schools to give STEM talks.
1.6	Inspection	The team has created a website on Penn State's sites server which it will continually update during the project year.
1.7	Inspection	The team will post the required deliverables to the LTRL website before the due dates specified in the NASA USLI Handbook.
1.8	Inspection	The files will be posted to the website in PDF format.
1.9	Inspection	LTRL will include a table of contents in all reports that includes major sections and subsections.
1.10	Inspection	The team will always include page numbers at the bottom of each page of each report.
1.11	Inspection	The team will ensure they have all equipment necessary for a video teleconference at the time of each review conference. LTRL will make sure they have a speakerphone that is not a cellular phone.

1.12	Inspection	The team will make sure their rocket does not require a custom launch rail, and that their rocket can be launched on the launch pads provided by the USLI launch service provider.
1.13	Inspection	LTRL will implement the Architectural and Transportation Barriers Compliance Board EIT Accessibility Standards (36 CFR Part 1194)
1.14	Demonstration	Alex Balcher is LTRL's mentor for this academic year. He maintains a level 2 certification and is in good standing through NAR. He is the designated owner of the rocket and will travel with the team during launch week.

Table 43. Vehicle Requirements

Requirement	Method of Verification	Verification
2.1	Analysis	Data from the altimeters used during flight will verify that the rocket reached a 5,280 ft. altitude with the payload in it.
2.2	Demonstration	An altimeter will be purchased and used to record the official apogee of the launch vehicle.
2.3	Demonstration	The launch vehicle will be designed so that the avionics bay's switch can easily be turned on from the exterior of the vehicle while it is on the launch pad.
2.4	Demonstration	The avionics bay will be designed so that a 9 volt battery can be safely secured into the rocket and provide power to the altimeter.
2.5	Demonstration	The avionics switch will be secured so that it will remain in the ON position during flight without possibility of the switch disarming.
2.6	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.
2.7	Demonstration	The rocket will be designed and built with knowledge that it can only contain four independent sections. On launch day, there will be no more than four independent sections.
2.8	Analysis	Analysis of the launch vehicle profile via OpenRocket and MATLAB simulations will be done to ensure that the vehicle reaches the target altitude with a single stage design.
2.9	Demonstration	The team will keep a timer during all fullscale test launches to ensure that the build time does not take longer than 3 hours. The rocket will be designed with assembly timing in mind.
2.10	Demonstration / Testing	The launch vehicle will be designed so that all components 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.
2.11	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.
2.12	Demonstration	All electronics will be contained within the launch vehicle with the exception of the initiator required to light the motor upon launch.
2.13	Demonstration	The motor used for competition launch will be from a trusted manufacturer (Ceseroni or Aerotech), using NAR approved APCP propellant.
2.13.1	Analysis	In-depth mass analysis of the rocket using OpenRocket and SolidWorks will be performed to ensure mass estimates are accurate by CDR therefore, ensuring a proper motor selection.
2.13.2	N/A	The final flight vehicle motor will not be changed after CDR.
2.14.1 - 3	N/A	The final flight vehicle will not contain any custom pressure devices with the exception of possible CO_2 cartridges which will be commercially bought.
2.15	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.
2.16	Test	Stability will be calculated with various programs to ensure that the vehicle's stability is over 2.0 off the rail.
2.17	Test	Launch velocity will be calculated with various programs to ensure that the vehicle's velocity off the rail is at least 52 fps.
2.18	Demonstration	A launch vehicle approximately 60% the size of the fullscale rocket will be designed and launched to accurately imitate the fullscale rocket's main design features.
2.18.1	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.
2.18.2	Demonstration	The avionics bay will be designed to include an altimeter that will record the altitude the launch rocket reaches.
2.19	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.
2.19.1	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.
2.19.2	Demonstration	If the payload is not ready for a fullscale test launch, it will not be flown, but it should be thoroughly tested regardless.
2.19.2.1	Demonstration	Appropriate ballast will be added to each section to simulate missing payload mass.
2.19.2.2	Demonstration	The simulated payload mass will be placed in a calculated area to best simulate the missing payload mass.
2.19.3	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 full scale test launches.
2.19.4	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.
2.19.5	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 full scale test launches to ensure that the ballast is an accurate representation for launch day's rocket.
2.19.6	Inspection	Between the full scale test flight and SLI competition, the final flight vehicle will not be modified in any way.
2.19.7	Demonstration	LTRL will strictly follow it's Gantt charts and own deadlines to ensure that the fullscale rocket can be launched prior to March 6th.
2.20	Demonstration	The rocket will be designed so that all possible protuberances such as the camera cover will be located aft of the center of gravity.
2.21.1	Demonstration	The rocket will be designed so that no forward canards are necessary to the vehicle's flight or payload.
2.21.2	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.
2.21.3	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.
2.21.4	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.
2.21.5	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.
2.21.6	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.
2.21.7	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.
2.21.8	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.

Table 44. Recovery Requirements

Requirement	Method of Verification	Verification
3.1	Demonstration	Altimeter will be programmed so that drogue will deploy at apogee, main will deploy at 700ft.
3.2	Test	LTRL will ground test ejection charges before any subscale or fullscale launch.
3.3	Analysis	The parachutes sizes will be determined by modelling so that each component of the rocket lands within the kinetic energy constraint of 75 ft-lbs.
3.4	Inspection	The recovery system wiring will be completely independent of any payload components.
3.5	Inspection	Each altimeter will have an independent, commercially available battery.
3.6	Inspection	There will be two independent, commercially available altimeters per avionics bay. Each altimeter will have independent power, ejection charges, and switches for redundancy.
3.7	Inspection	Motor ejection will not be used to separate the rocket at any point.
3.8	Inspection	Removable shear pins will be used to secure all parachute compartments until altimeters initiate separation.

3.9	Analysis	The parachutes sizes will be determined by modelling so that recovery area will not exceed a 2500 ft. radius from the launch pads in various wind conditions.
3.10	Inspection	An electronic tracking device will be installed in the launch vehicle and will transmit the position of any independent section to a ground receiver.
3.10.1	Inspection	Any rocket section, or payload component, which lands untethered to the launch vehicle, will also carry an active electronic tracking device.
3.10.2	Test	The electronic tracking device performance will be tested in a variety of scenarios, including test flights.
3.11	Demonstration	The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight.
3.11.1	Inspection	The recovery system altimeters will be a separate compartment within the vehicle without any other payloads or electronic components.
3.11.2	Test	A faraday cage will be tested for ability to shield the recovery system electronics from all onboard transmitting devices.
3.11.3	Test	A faraday cage will be tested for ability to shield the recovery system electronics from all onboard devices which may generate magnetic waves.
3.11.4	Test	A faraday cage will be tested for ability to shield the recovery system electronics from any other onboard devices which may adversely affect them.

Table 45. Experimental Requirements

Requirement	Method of Verification	Verification
4.1	N/A	Option 2 (Deployable Rover)
4.2	N/A	No additional experiments
4.3	N/A	No additional experiments
4.4	N/A	N/A
4.5	N/A	Deployable Rover
4.5.1	Inspection	No part of the rover will protrude from the payload bay.
4.5.2	Test	Using XBee radios, 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.
4.5.3	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 at least five feet from all parts of the rocket.

4.5.4	Test	The rover will deploy its foldable solar panels after it has confirmed it has moved at least five feet from all parts of the launch vehicle.
4.6	N/A	N/A

Table 46. Safety Requirements

Requirement	Method of Verification	Verification
5.1	Demonstration	The team will use launch and safety checklists during all fullscale launches.
5.2	Demonstration	Laura Reese is identified as the club safety officer in each report.
5.3.1	Demonstration	Laura Reese will perform all of the duties of the safety officer.
5.3.2	Demonstration	The safety officer will implement the safety procedures developed by the team for construction, assembly, launch and recovery activities.
5.3.3	Demonstration	The safety officer will manage and maintain current revisions of the team's hazard analyses, failure modes analyses, and SDS data.
5.3.4	Demonstration	The safety officer will assist in the writing and development of the team's hazard analyses and failure modes analyses
5.4	Demonstration	LTRL will abide by the rules and guidance of the RSOs of the Pittsburgh Space Command, Maryland Delaware Rocketry Association, and any other launch which the club chooses to attend.
5.5	Demonstration	LTRL will only launch at locations which have been given FAA clearance for the altitude to which the rocket is projected to attain.

Team-Derived Requirements

Table 47 list the teams derived goal for this year’s competition. These goals are divided by section of the rocket to create individual milestones that the team can work towards accomplishing throughout the project.

Table 47. Team Derived Requirements

Requirement	Method of Verification	Verification
Flight Vehicle		
Launch vehicle fins will be removable	Demonstration	Fins on the launch vehicle will be able to be removed without disassembly of the launch vehicle.
Launch fin brackets will be removable	Demonstration	Fins brackets on the launch vehicle will be able to be removed without disassembly of the launch vehicle.
Camera will be housed in the launch vehicle with aerodynamics in mind	Demonstrations / Testing	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 wrapping the body tube in carbon fiber	Demonstration / Testing	The team will test different methods of wrapping the body tube with carbon fiber to ensure that the body tube will not warp after wrapping and compressing.
Flush cuts between separation points to ensure structural integrity	Demonstration / Testing	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	Demonstration	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 twice the diameter of the rocket to ensure structural integrity	Demonstration	The team will purchase couplers that are twice the length of the diameter and measure couplers to verify length.
Rocket is designed so that assembly is optimized on launch day	Analysis / Demonstration	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.
Camera can start recording after it is fastened into the rocket.	Demonstration	The 3D-printed camera cover design 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.
A fullscale primary motor will be test fired prior to the fullscale test launch.	Demonstration	Develop and carry out procedures to test firing at Penn State's HPCL.
Reduce motor assembly time on launch day to 15 minutes.	Demonstration	Create and follow a very detailed checklist for motor assembly on launch day.

Choose a ballast level and motor combination that results in a predicted apogee within 1% of the target of a mile.	Analysis / Test	An OpenRocket and a MATLAB simulation will be created to predict the apogee.
Have a static stability margin of greater than 2.5 at the point of rail exit.	Analysis / Demonstration	An OpenRocket and a MATLAB simulation will be created to calculate the static stability margin at the point of rail exit, and this margin will be demonstrated by physically finding the CG of the completed rocket.
Avionics and Recovery		
The avionics bay will be able to be assembled into a transportable state within 2 hours.	Demonstration	The avionics bay will be able to be partially assembled within two hours and be able to be transported.
Avionics bay will be able to be transformed from a transportable state to a launch ready state in 30 minutes.	Demonstration	The avionics bay will be able to be assembled within 30 minutes on launch day.
The detonation of charges shall not cause the pressure within the avionics bay to exceed the rated pressure for the body tube	Analysis	The charges will not overwhelm the body tube and the redundant charges will be at a two-second delay.
The pressure produced during detonation shall exceed the rating of the shear pins by a factor of at least 2.5	Test	The black powder will be tested against the amount of force it would take to release the parachute but not cause an overpressure event.
The avionics bay shall contain fully redundant parachute deployment systems	Inspection	The avionics bay will have two independent altimeters with corresponding independent charges, power supplies, and switches.
Each altimeter arming switch shall be no more than five feet up the rocket	Inspection	The avionics bay will not be more that five feet up the rocket.
The avionics bay shall utilize a simple design that allows for clear and unambiguous instructions and assembly	Demonstration	The avionics bay will be designed to be easily assembled and bulkheads will be laser cut to ensure perfect symmetry.
The faraday cage shall protect the avionics bay	Test	The avionics bay will be enclosed in a faraday cage that will protect it from interference from other electronic components.

from both internal and external interference		
Any load-bearing hardware in the recovery system shall have a factor of safety of at least 3	Analysis	All load-bearing hardware will be ensured to have at least a safety factor of at least 3.
Avionics bay shall have a system to easily incorporate ballast securely	Demonstration	The avionics bay and avionics bay coupler will allow a ballast to be incorporated in the coupler.
Payload		
Provide constant communication with base after rover deployment	Test	Test the range of the communication system to ensure that is it greater than the maximum drift distance of the rocket.
Correct rover orientation if the rover is overturned	Demonstration	The rover will be equipped with self-righting hubcaps which will correct the orientation of the rover back over if it tips onto its side.
Avoid obstacles on the ground during navigation	Demonstration	Show that the rover can successfully navigate obstacles.
Solar panels are deployed so that they are pointing at the sun	Inspection	The solar panels are facing the sun.
Safely detonate CO2 charge to eject nosecone	Demonstration	Show that nosecone ejection does not harm the rover or the launch vehicle.

6.2 Budget Plan

Table 48 displays the expected costs of the 2017-2018 year with the current design plan. This table includes all anticipated costs for the club for the USLI competition.

Table 48. Expected Outflow 2017-2018

Fullscale			
Payload			
Arduino	5	$15.99	$79.95
Servo Motor	3	$16.99	$50.97
Wheel and Treads Kit	1	$14.95	$14.95
Solar Panels	2	$5.69	$11.38
Containment Mechanism for Inside the Rocket	1	$25.00	$25.00
Miscellaneous	1	$100.00	$100.00
Structures			
5.5” Fiberglass Ogive Nosecone	1	$84.95	$84.95
5.5” Blue Tube (48” Length)	3	$56.95	$170.85
5.5” Blue Tube Couplers	5	$18.95	$94.75
Carbon Fiber Wrapping	3	$64.95	$195.85
Epoxy Resin for Carbon Fiber	1	$44.95	$44.95
Epoxy Hardener for Carbon Fiber	1	$21.95	$21.95
1.25” Shrink Tape	2	$39.95	$79.90
Fiberglass Sheet ⅛” x 1 square feet	4	$27.00	$108.00
Large Rail Buttons for 1515 Rail	1	$4.65	$4.65
Center Rings 75mm to 5.36”	2	$13.55	$27.10
5.36” Tube Bulkheads	6	$7.61	$45.66
5.26” Coupler Bulkheads	5	$7.61	$38.05
Avionics and Recovery			

Blast Caps	4	$15.00	$60.00
GPS	1	$50.00	$50.00
GPS Monthly Fee	7	$25.00	$175.00
Initiators	2	$27.20	$54.40
Shear Pins	1	$20.00	$20.00
3D Printing Filament	1	$20.00	$20.00
Switches	1	$20.00	$20.00
Wire Connector	1	$10.00	$10.00
Propulsion			
Cesaroni 75mm 3-Grain Hardware Kit	1	$319.00	$319.00
Cesaroni L995 Motor Reload	3	$209.00	$627.00
Fullscale Total			$2,554.31
Subscale			
Structures			
75 mm Blue Tube	2	$29.95	$59.90
75 mm Blue Tube Coupler	3	$9.95	$29.85
Fiberglass Sheet ⅛" x 1 square feet	2	$27.00	$54.00
Centering Rings 54mm to 75mm	2	$7.30	$14.60
Tube Bulkhead Disk 75mm	5	$3.83	$19.15
Large Rail Button for 1515 Rail	1	$4.65	$4.65
1.25" Shrink Tape	2	$39.95	$79.90
Satin Weave Carbon Fiber Fabric	1	$79.95	$79.95
Epoxy Hardener for Carbon Fiber	1	$21.95	$21.95
Epoxy Resin for Carbon Fiber	1	$104.95	$104.95
Shipping Expenses	1	$56.27	$56.27

Propulsion			
JS80SS 54-2 Grain Motor	1	$79.20	$79.20
Subscale Total			$604.37
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

The fullscale and subscale budget 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 past years. The cost of the subscale rocket is final as the club already finished this rocket. Travel costs come from mostly the trip to Alabama as well as fuel costs for getting to and from test launches. Outreach costs also contribute to the club’s expenditures due to needing miscellaneous supplies to host STEM outreach events throughout the academic year. Table 49 gives the breakdown for the budget by each overall component of the competition.

Table 49. Overall Outflow

Budget	Total Cost
Fullscale	$2,554.31
Subscale	$604.37
Travel	$8,000.00
Outreach	$300.00
Miscellaneous	$500.00
Total	**$11,458.68**

Table 49 shows the total costs from each header of Table 48 to clarify the overall alignment of the budget. As expected, travel and fullscale are LTRL's most expensive sectors. An additional $500 was added into the budget in case unexpected costs arise. The team currently pursues funding to cover the expected budget from many Penn State Departments and Committees. Table 50 displays the funding sources and their expected donation amount for the 2017-2018 school year.

Table 50. Expected Inflow 2017-2018

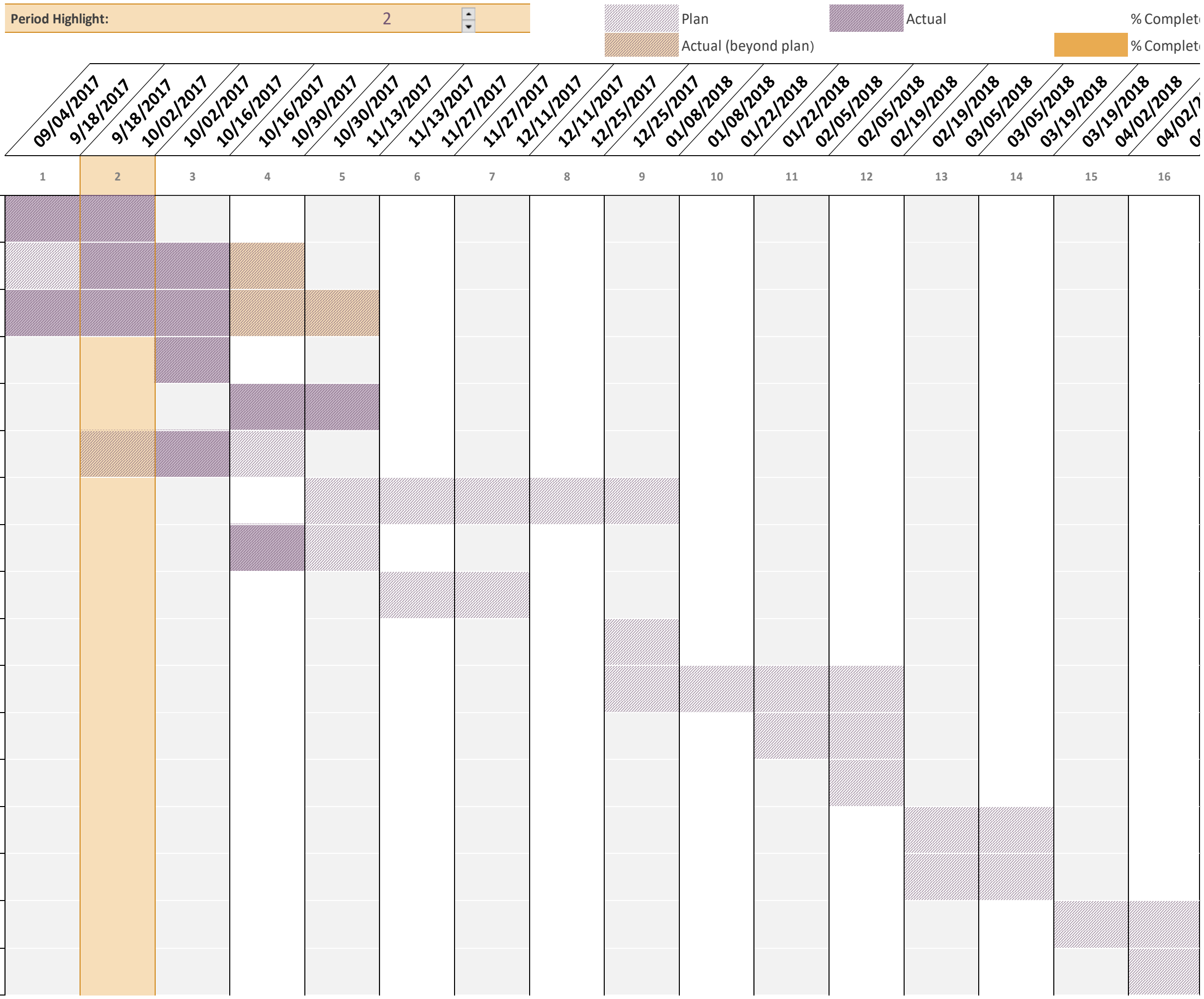
Donor	Requested Amount
Penn State Department of Aerospace Engineering	$5,000.00
Penn State Department of Mechanical and Nuclear Engineering	$1,000.00
Club Fundraising	$1,100.00
University Park Allocations Committee	$5,000.00
Engineering Undergraduate Council	$3,000.00
Total	**$15,100.00**

The table shows the club sponsors and how much funding they provide. Penn State's Department of Aerospace Engineering has donated to the club in the past, and LTRL anticipates their support again this year. The PSU Aerospace Engineering Department also offers the club lab space. Penn State's Department of Mechanical and Nuclear Engineering has donated $1,000.00 for the 2017-2018 academic year. Club fundraising entails income from annual dues and other fundraising opportunities. To date, the club has $975.00 from yearly dues. University Park Allocations Committee (UPAC) is a university organization that sponsors Penn State clubs. They have donated to LTRL in the past, and the club hopes for the same in this year. They often sponsor the club for travel purposes, and LTRL is working on completing applications for their funding now. Engineering Undergraduate Council (EUC) is another club that helps support other university organizations. As travel is the club's biggest expense, EUC would help fund the club's travel costs as well. LTRL is also pursuing a new sponsorship form the Penn State Electrical Engineering and Computer Science Department. The club will continue to seek funds from more companies and Penn State resources to provide extra money for unforeseen circumstances, to increase club capital, and to have extra money for the start of next competition year.

6.3 Timeline

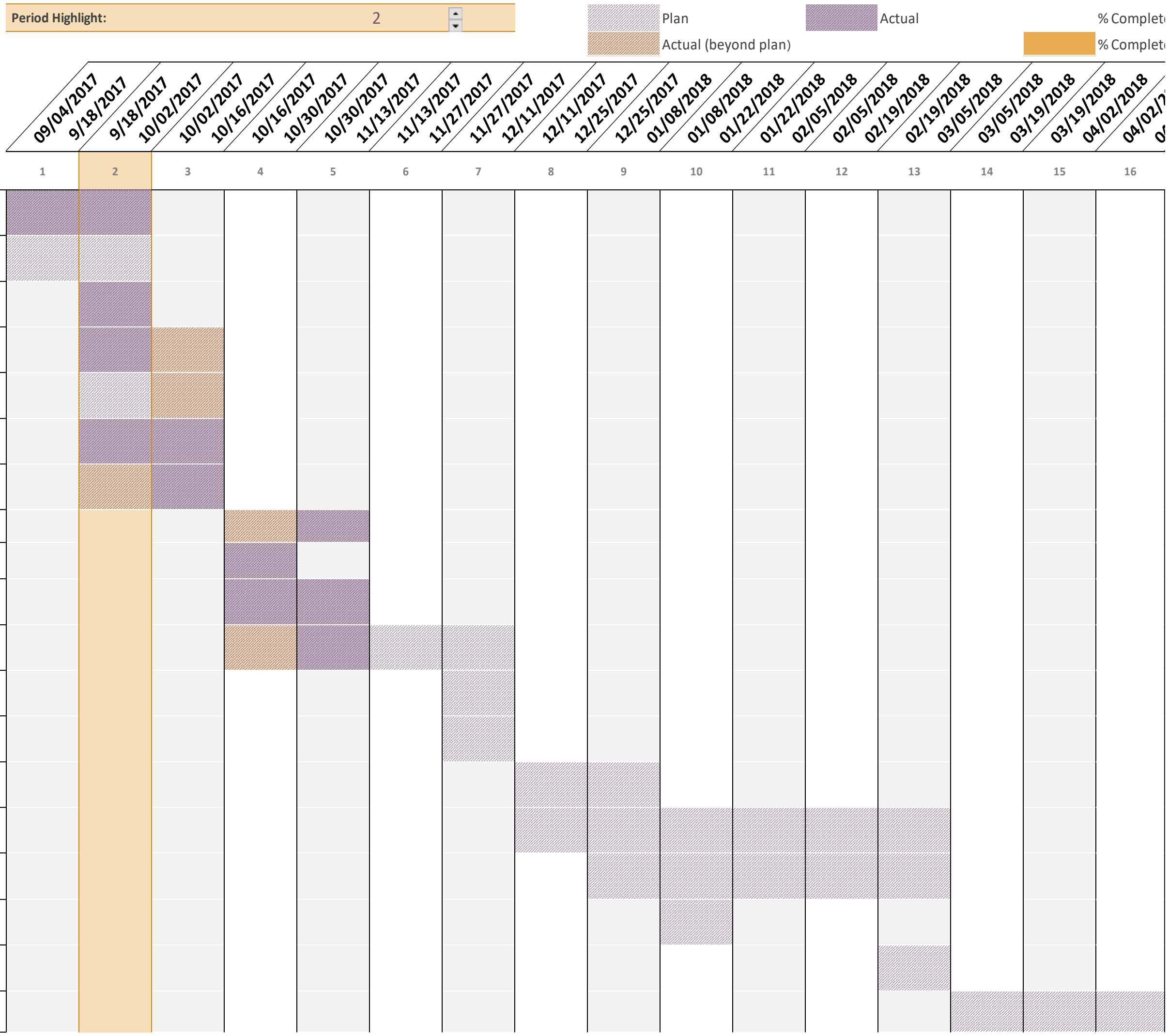
LionTech Rocket Labs 2017-2018 USLI Gantt Chart

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Proposal Report	1	2	1	2	0%
Fullscale Design	1	3	2	3	0%
Payload Design	1	3	1	5	0%
Subscale Design	3	1	3	1	0%
PDR	4	2	4	2	0%
Subscale Fabrication	3	2	2	2	0%
Payload Construction	5	5	0	0	0%
Subscale Test Launch	4	2	4	1	0%
Redesign	6	2	0	0	0%
CDR	9	1	0	0	0%
Fullscale Fabrication	9	4	0	0	0%
Payload Integration	11	2	0	0	0%
Fullscale Test Launch	12	1	0	0	0%
FRR	13	2	0	0	0%
Pre Launch Modifications	13	2	0	0	0%
LRR	15	2	0	0	0%
USLI Competition	16	1	0	0	0%



2017-2018 Structures USLI Gantt Chart

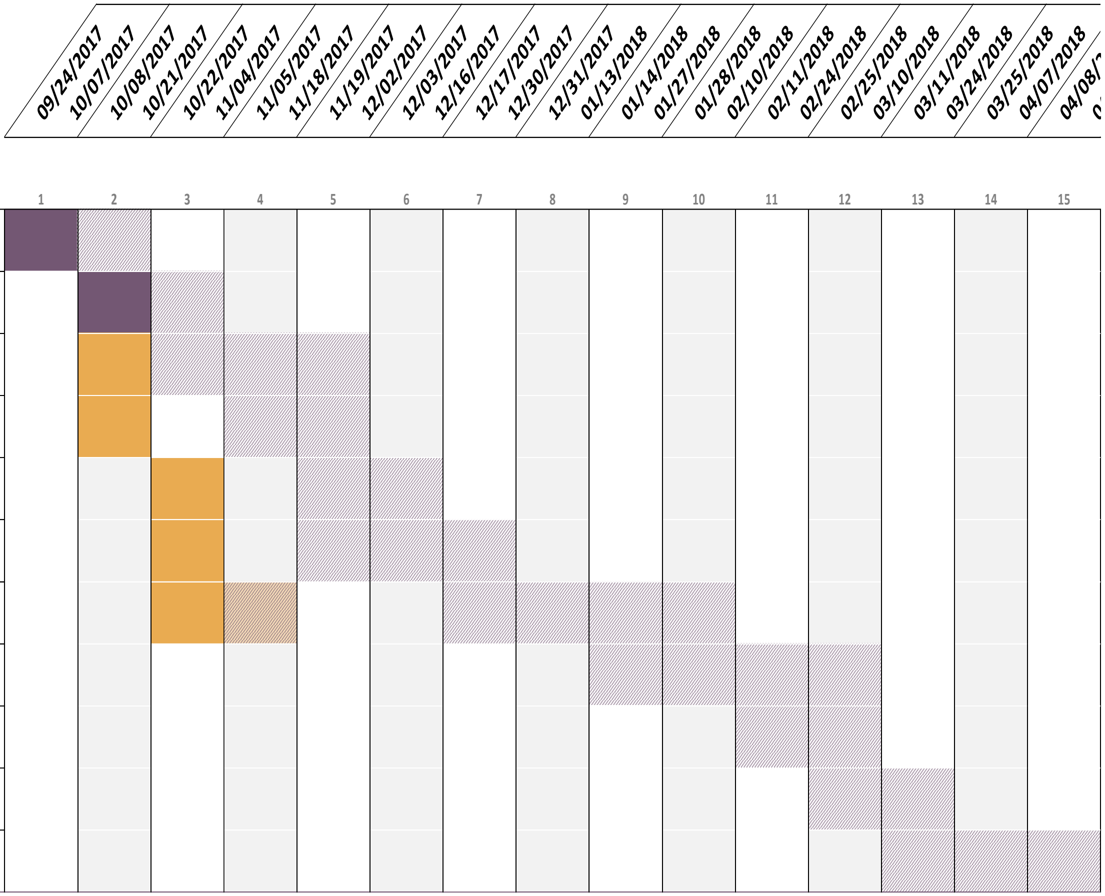
Period Highlight: 2



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Preliminary Design	1	2	1	2	0%
Material Testing	1	2	0	0	0%
Proposal Report	2	1	2	1	0%
Subscale Design	2	1	2	2	0%
Subscale Motor Testing	2	1	3	1	0%
Subscale Modeling & Simulations	2	2	2	2	0%
Subscale Construction	3	1	2	2	0%
Subscale Evaluation	5	1	4	2	0%
Subscale Launch	4	1	4	1	0%
Preliminary Design Rev	4	2	4	2	0%
Finalize Fullscale Design	5	3	4	2	0%
Modeling & Simulations	7	1	0	0	0%
Fullscale Motor Testing	7	1	0	0	0%
Fullscale Construction	8	2	0	0	0%
Fullscale Evaluation	8	6	0	0	0%
Fullscale Test Launch	9	5	0	0	0%
Critical Design Review	10	1	0	0	0%
Flight Readiness Reviev	13	1	0	0	0%
USLI Prep and Launch	14	3	0	0	0%

Avionics and Recovery 2017-2018
USLI Gantt Chart

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Preliminary Recovery System Concept	1	2	1	1	100%
Subscale Recovery System Design	2	2	2	1	100%
Subscale Recovery System Construction	3	3	2	1	100%
Subscale Recovery System Testing	4	2	2	1	100%
Final Subscale Recovery System Verification	5	2	3	1	100%
Fullscale Recovery System Modeling	5	3	3	1	100%
Fullscale Recovery System Design	7	4	3	2	50%
Fullscale Recovery System Construction	9	4	0	0	0%
Fullscale Recovery System Testing	11	2	0	0	0%
Fullscale Recovery System Verification	12	2	0	0	0%
USLI Preparation and Launch	13	3	0	0	0%

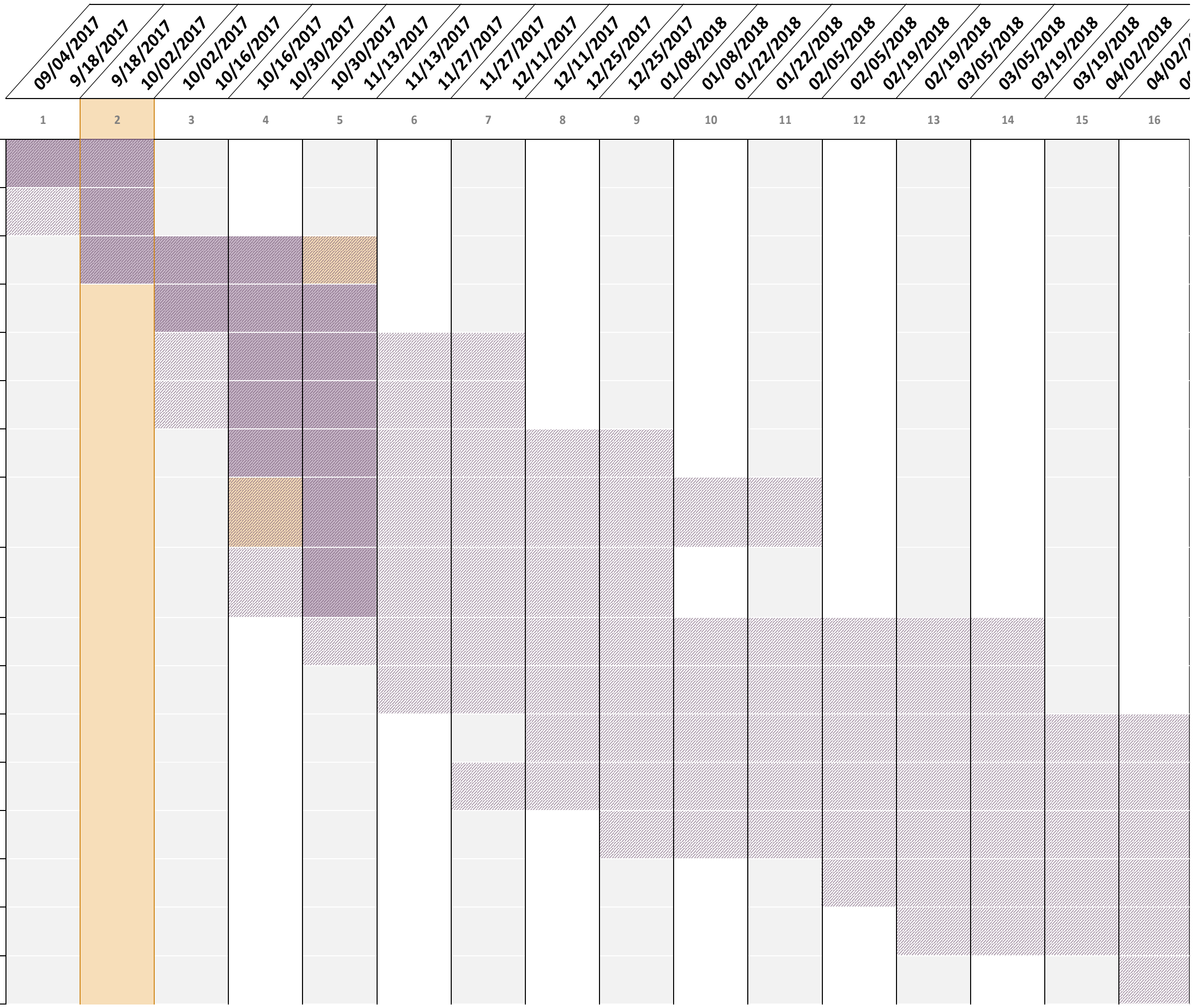


2017-2018 Payload USLI Gantt Chart

Period Highlight: 2

▨ Plan
▨ Actual
% Complet
▨ Actual (beyond plan)
% Complet

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Preliminary Conceptualization	1	2	1	2	0%
Material Selection	1	2	2	1	0%
Electronics Container Design	2	3	2	4	0%
Motor Selection	3	3	3	3	0%
Drive Train Design	3	5	4	2	0%
Frame/Suspension Design	3	5	4	2	0%
Tread Design	4	6	4	2	0%
Solar Panel Deployment Mechanism Design	5	7	4	2	0%
Create Software Flowchart/Identify Modules	4	6	5	1	0%
Assembly of Rover	5	10	0	0	0%
Complete Software Modules	6	9	0	0	0%
Test/Review Modules Independently	8	10	0	0	0%
Design/Build Containment Chamber	7	11	0	0	0%
Consolodate Modules	9	12	0	0	0%
Test Subsystems of Rover	12	13	0	0	0%
Test Full Assembly of Rover	13	14	0	0	0%
USLI Competition	16	1	0	0	0%



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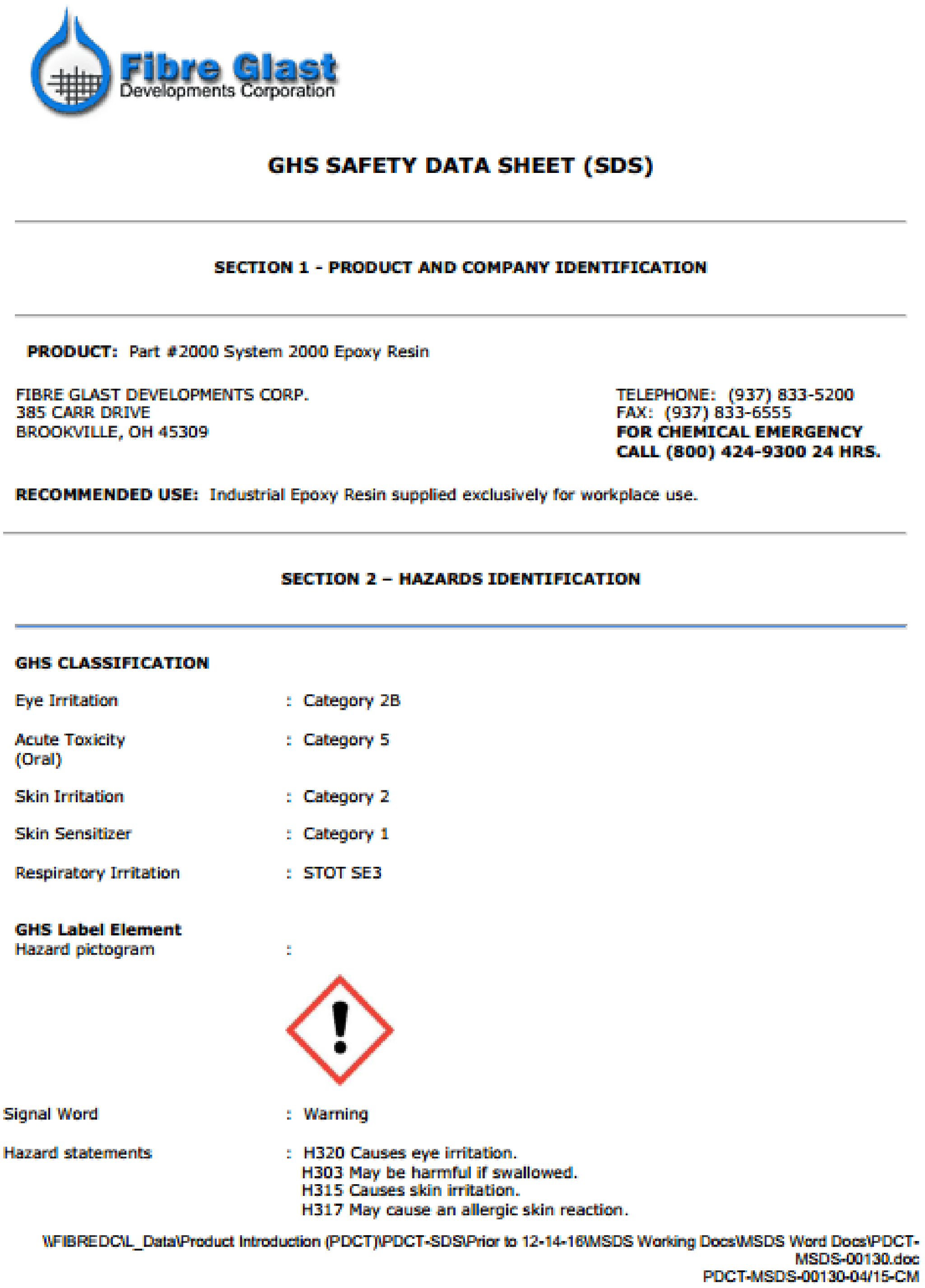
Appendix A: MSDS Sheets

Epoxy Resin SDS



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 (800) 424-9300 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

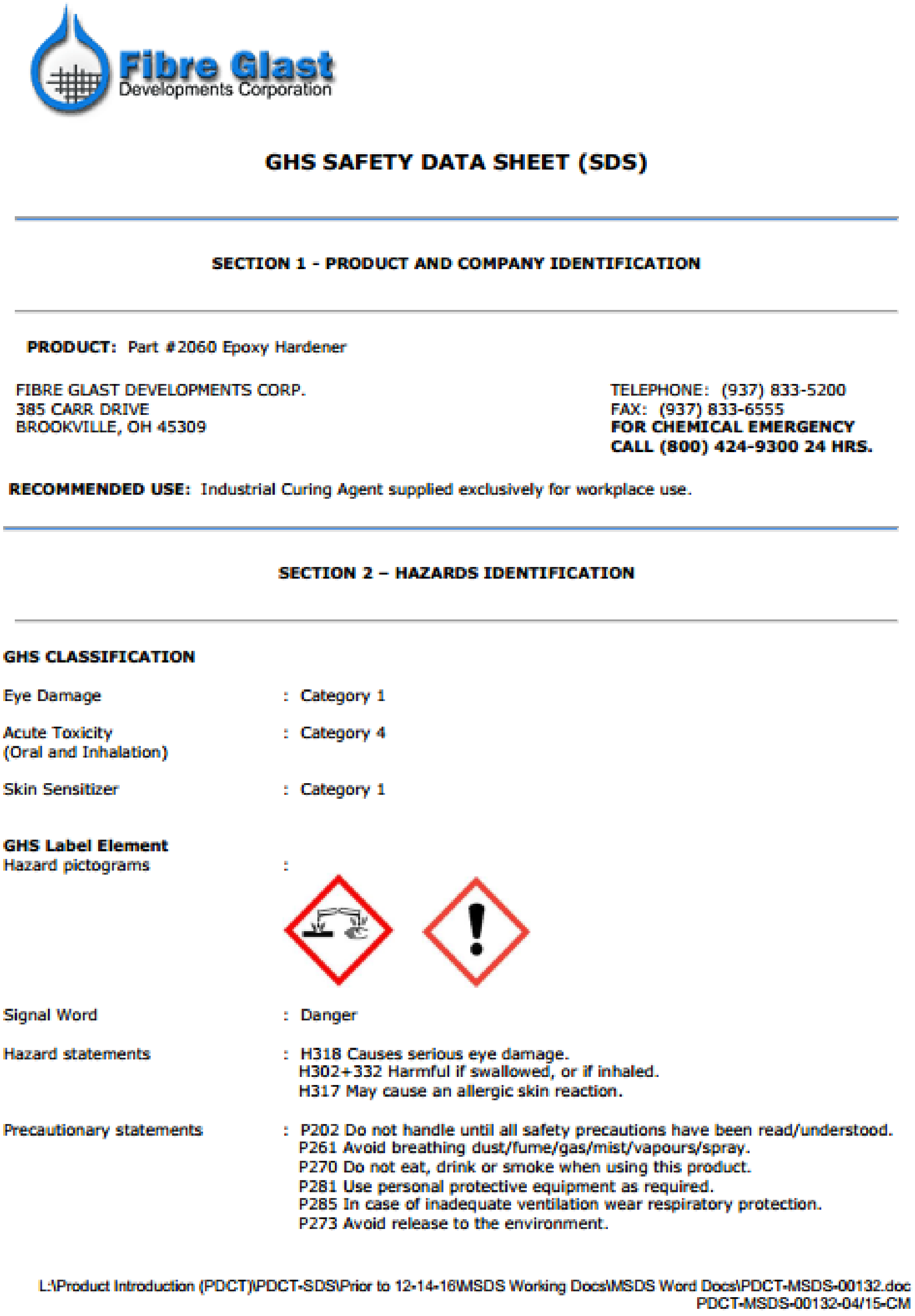
GHS Label Element
Hazard pictogram :

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.

\\FIBREDC\L_Data\Product Introduction (PDCT)\PDCT-SDS\Prior to 12-14-16\MSDS Working Docs\MSDS Word Docs\PDCT-MSDS-00130.doc
PDCT-MSDS-00130-04/15-CM

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 (800) 424-9300 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

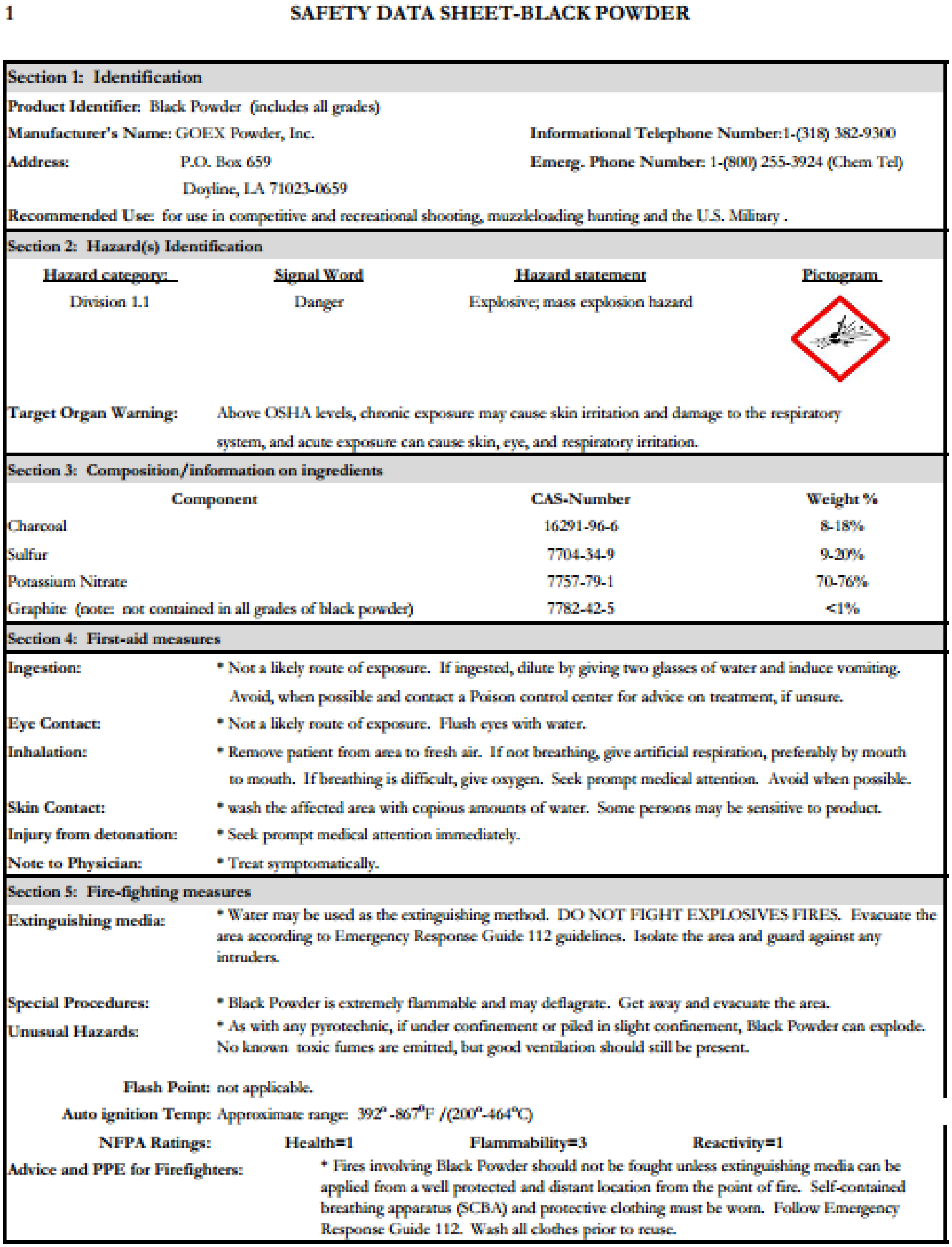
GHS Label Element
Hazard pictograms :

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.

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.

Address: P.O. Box 659
Doyline, LA 71023-0659

Informational Telephone Number: 1-(318) 382-9300

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.

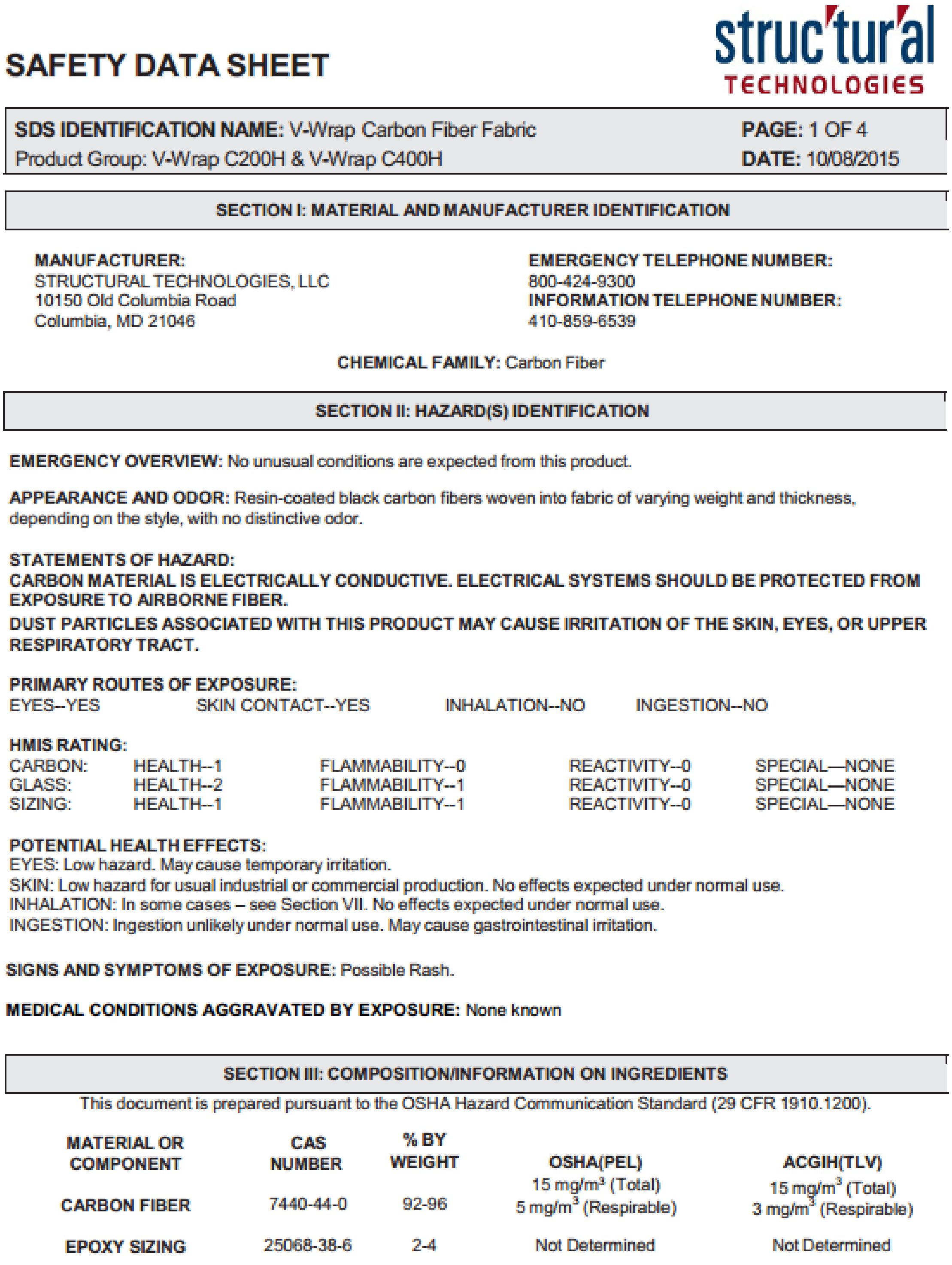
Flash Point: not applicable.

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.

Carbon Fiber Fabric Wrap SDS



struc'tur'al
TECHNOLOGIES

SAFETY DATA SHEET

SDS IDENTIFICATION NAME: V-Wrap Carbon Fiber Fabric
Product Group: V-Wrap C200H & V-Wrap C400H

PAGE: 1 OF 4
DATE: 10/08/2015

SECTION I: MATERIAL AND MANUFACTURER IDENTIFICATION

MANUFACTURER:
STRUCTURAL TECHNOLOGIES, LLC
10150 Old Columbia Road
Columbia, MD 21046

EMERGENCY TELEPHONE NUMBER:
800-424-9300
INFORMATION TELEPHONE NUMBER:
410-859-6539

CHEMICAL FAMILY: Carbon Fiber

SECTION II: HAZARD(S) IDENTIFICATION

EMERGENCY OVERVIEW: No unusual conditions are expected from this product.

APPEARANCE AND ODOR: Resin-coated black carbon fibers woven into fabric of varying weight and thickness, depending on the style, with no distinctive odor.

STATEMENTS OF HAZARD:
CARBON MATERIAL IS ELECTRICALLY CONDUCTIVE. ELECTRICAL SYSTEMS SHOULD BE PROTECTED FROM EXPOSURE TO AIRBORNE FIBER.
DUST PARTICLES ASSOCIATED WITH THIS PRODUCT MAY CAUSE IRRITATION OF THE SKIN, EYES, OR UPPER RESPIRATORY TRACT.

PRIMARY ROUTES OF EXPOSURE:
EYES--YES SKIN CONTACT--YES INHALATION--NO INGESTION--NO

HMIS RATING:

CARBON:	HEALTH--1	FLAMMABILITY--0	REACTIVITY--0	SPECIAL—NONE
GLASS:	HEALTH--2	FLAMMABILITY--1	REACTIVITY--0	SPECIAL—NONE
SIZING:	HEALTH--1	FLAMMABILITY--1	REACTIVITY--0	SPECIAL—NONE

POTENTIAL HEALTH EFFECTS:
EYES: Low hazard. May cause temporary irritation.
SKIN: Low hazard for usual industrial or commercial production. No effects expected under normal use.
INHALATION: In some cases – see Section VII. No effects expected under normal use.
INGESTION: Ingestion unlikely under normal use. May cause gastrointestinal irritation.

SIGNS AND SYMPTOMS OF EXPOSURE: Possible Rash.

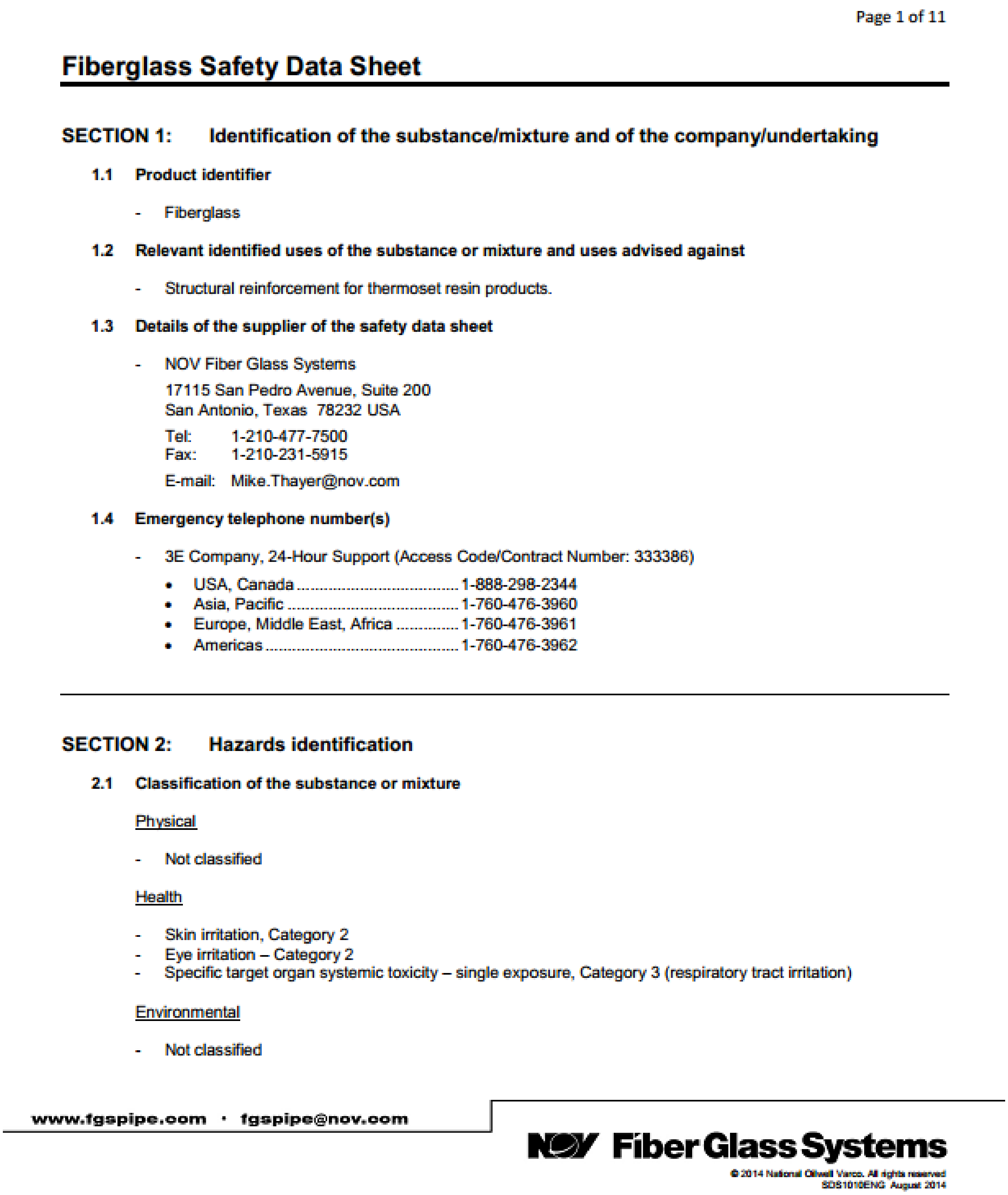
MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: None known

SECTION III: COMPOSITION/INFORMATION ON INGREDIENTS

This document is prepared pursuant to the OSHA Hazard Communication Standard (29 CFR 1910.1200).

MATERIAL OR COMPONENT	CAS NUMBER	% BY WEIGHT	OSHA(PEL)	ACGIH(TLV)
CARBON FIBER	7440-44-0	92-96	15 mg/m^3 (Total) 5 mg/m^3 (Respirable)	15 mg/m^3 (Total) 3 mg/m^3 (Respirable)
EPOXY SIZING	25068-38-6	2-4	Not Determined	Not Determined

Fiberglass SDS



Fiberglass Safety Data Sheet

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

1.1 Product identifier

- Fiberglass

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

- Structural reinforcement for thermoset resin products.

1.3 Details of the supplier of the safety data sheet

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

1.4 Emergency telephone number(s)

- 3E Company, 24-Hour Support (Access Code/Contract Number: 333386)

USA, Canada	1-888-298-2344
Asia, Pacific	1-760-476-3960
Europe, Middle East, Africa	1-760-476-3961
Americas	1-760-476-3962

SECTION 2: Hazards identification

2.1 Classification of the substance or mixture

Physical

- Not classified

Health

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

Environmental

- Not classified

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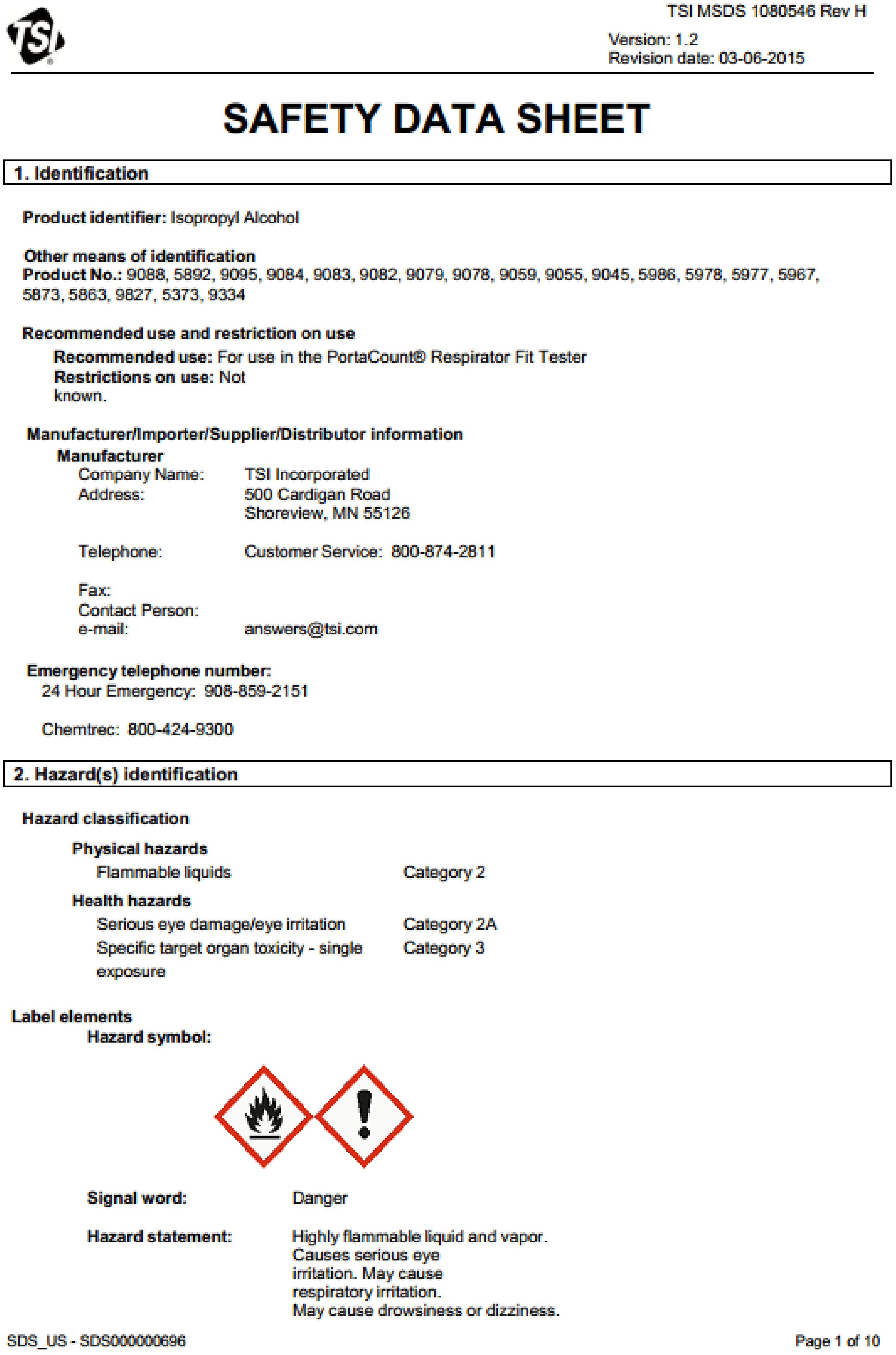
Isopropyl Alcohol SDS



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

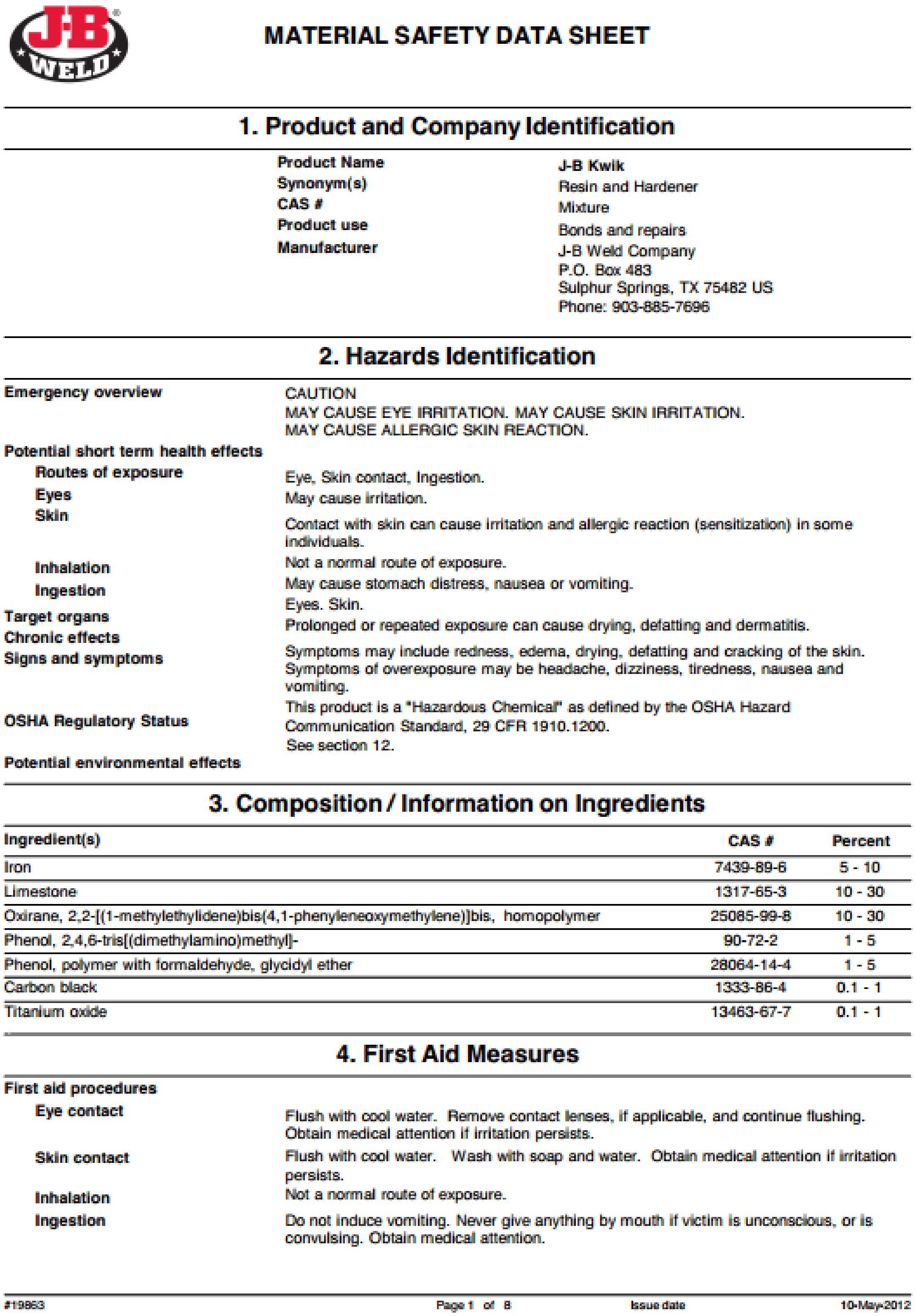
Physical hazards	
Flammable liquids	Category 2
Health hazards	
Serious eye damage/eye irritation	Category 2A
Specific target organ toxicity - single exposure	Category 3

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.

JB 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.

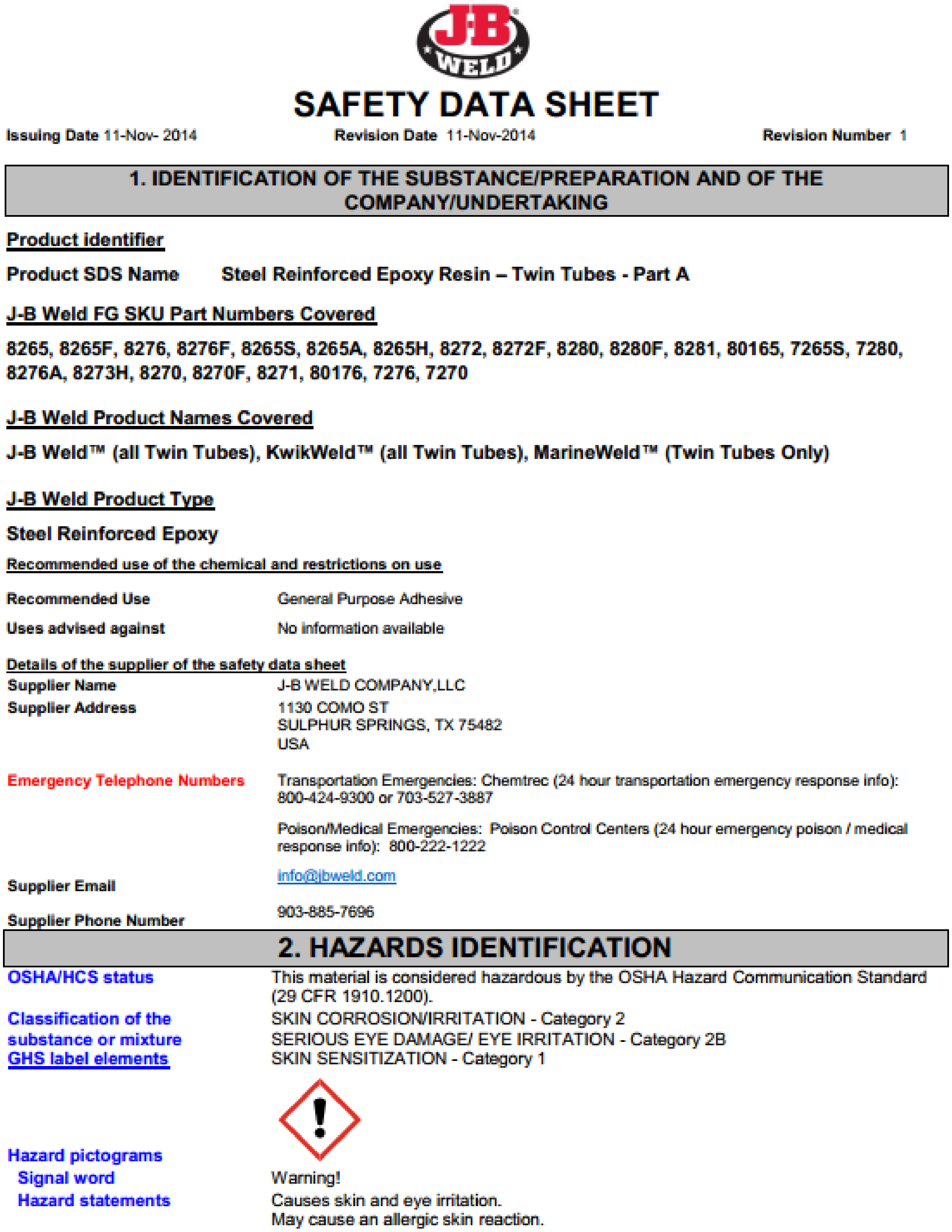
3. Composition / Information on Ingredients

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.

JB Weld 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

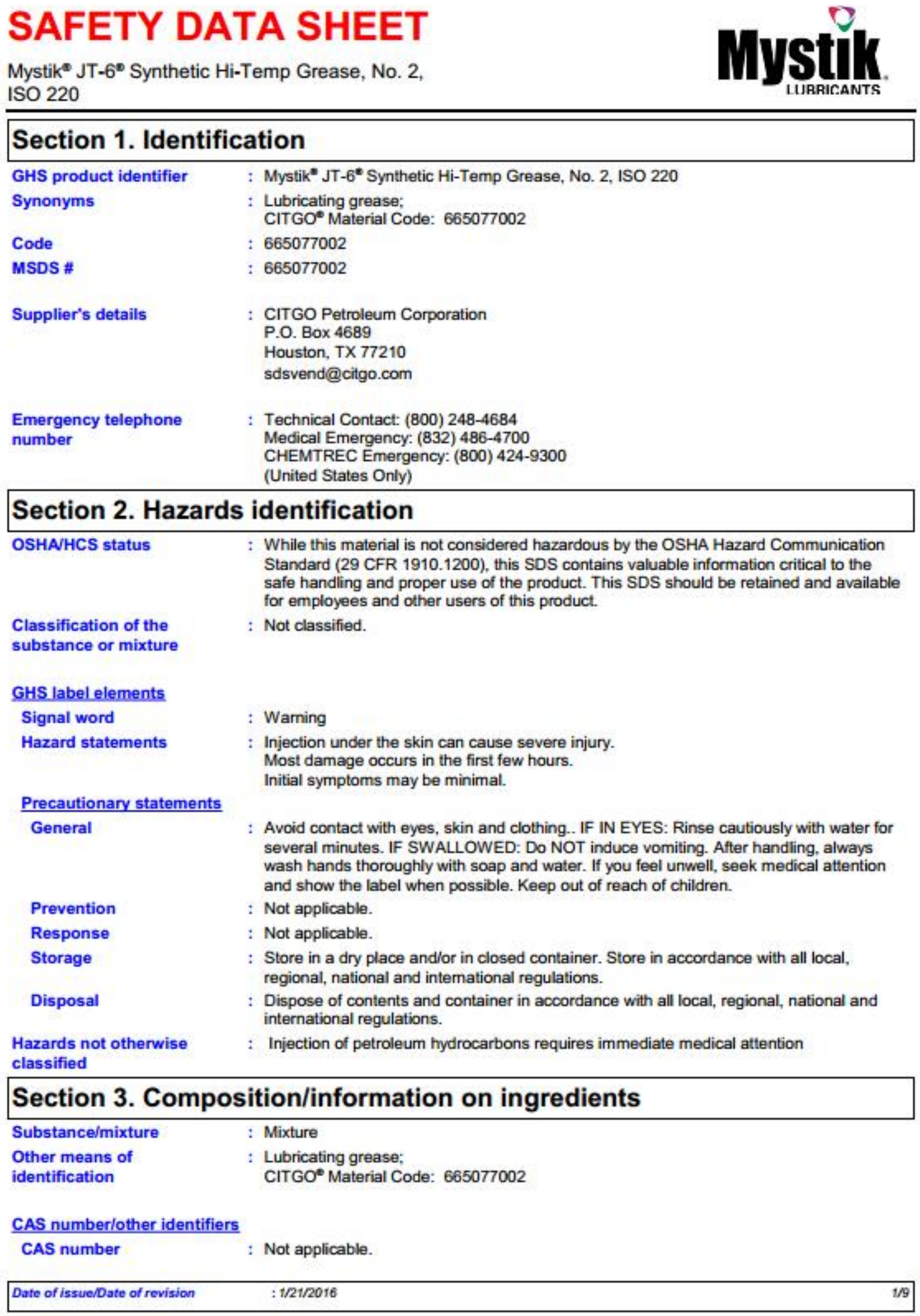
Details of the supplier of the safety data sheet

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.

Mystik Hi-Temp Grease SDS



SAFETY DATA SHEET

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

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

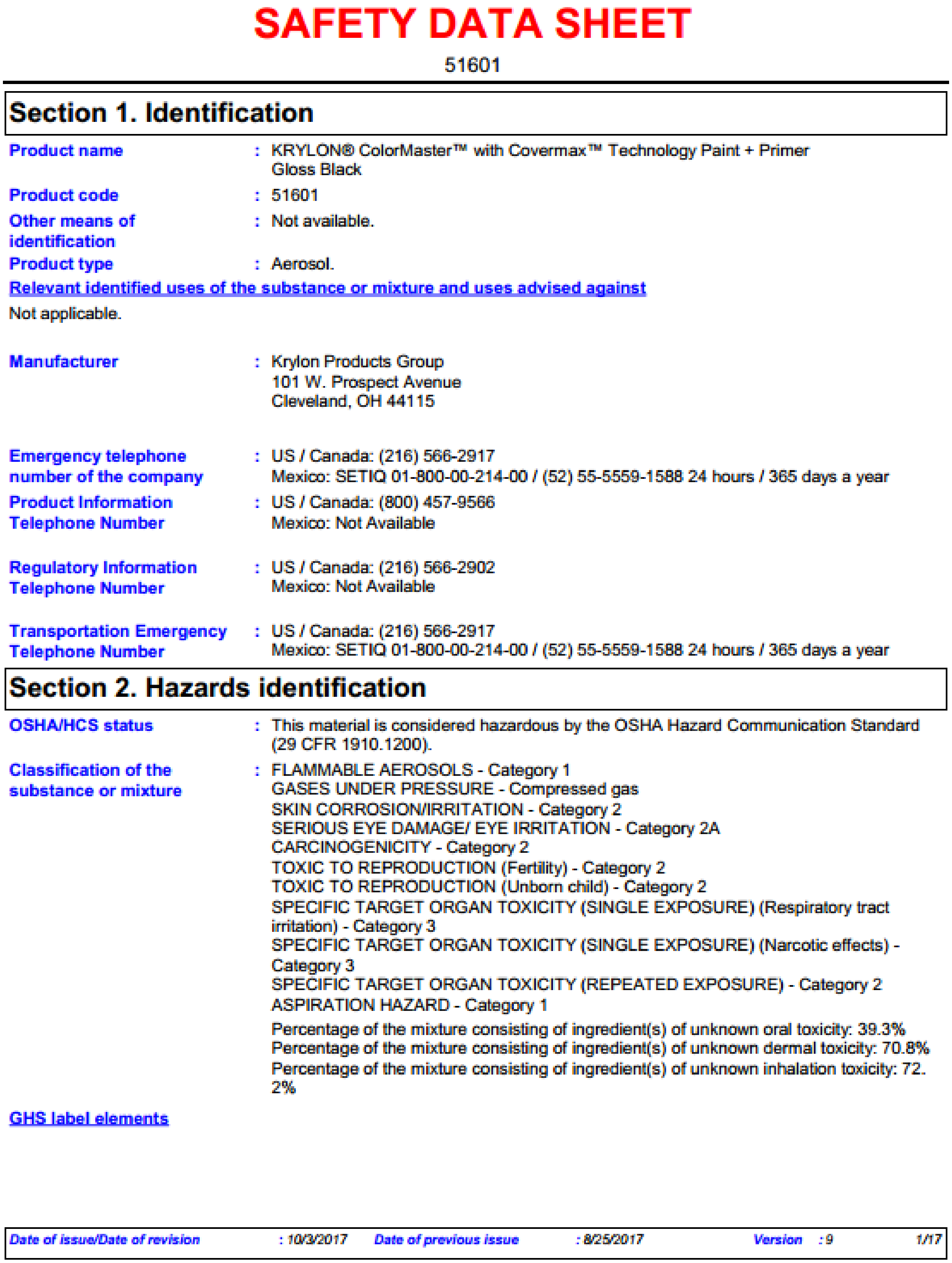
Other means of identification : Lubricating grease;
CITGO® Material Code: 665077002

CAS number/other identifiers

CAS number : Not applicable.

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

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

Not applicable.

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).

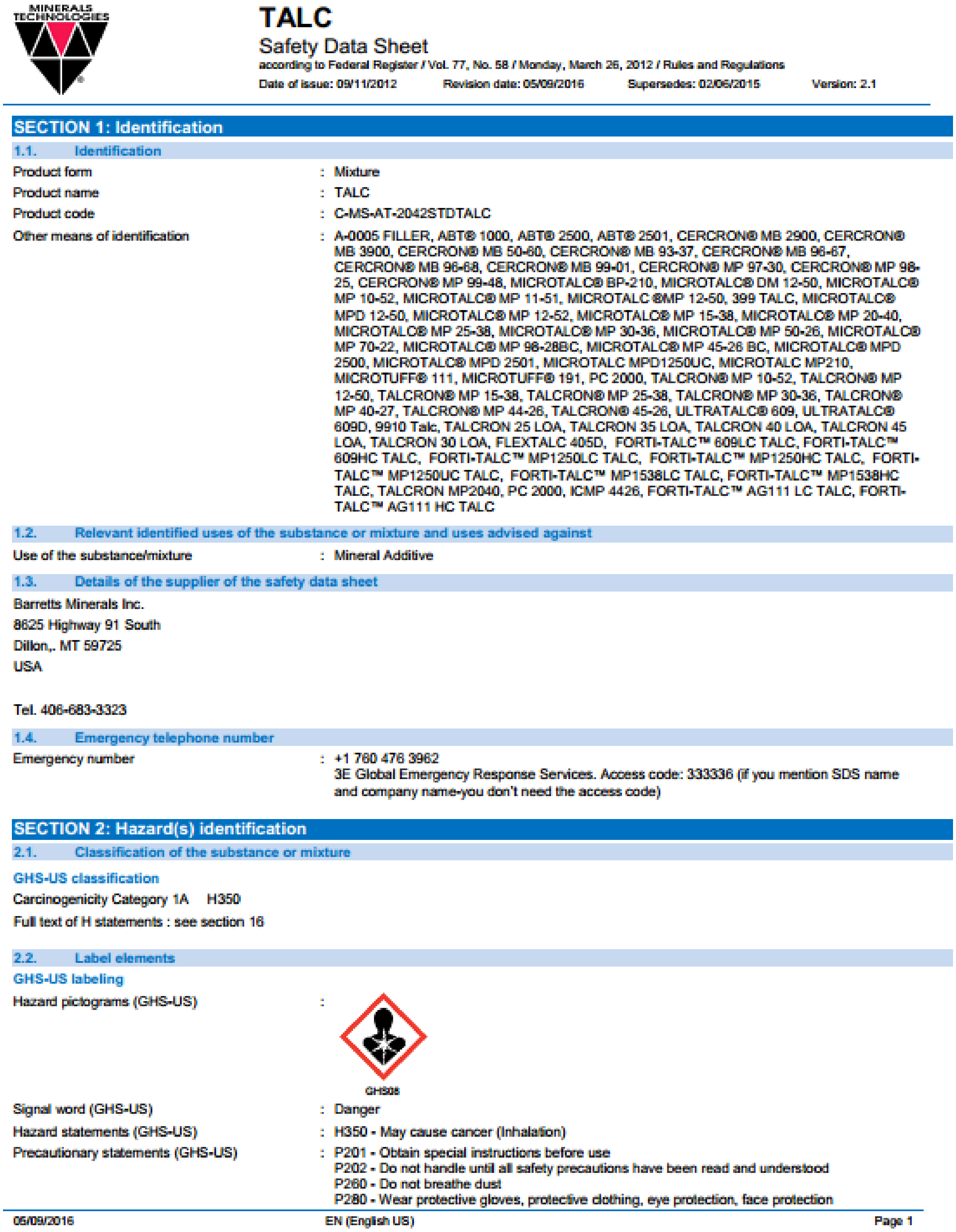
Classification of the substance or mixture : FLAMMABLE AEROSOLS - Category 1
GASES UNDER PRESSURE - Compressed gas
SKIN CORROSION/IRRITATION - Category 2
SERIOUS EYE DAMAGE/ EYE IRRITATION - Category 2A
CARCINOGENICITY - Category 2
TOXIC TO REPRODUCTION (Fertility) - Category 2
TOXIC TO REPRODUCTION (Unborn child) - 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

Date of issue/Date of revision : 10/3/2017 *Date of previous issue* : 8/25/2017 *Version* : 9 1/17

Talcum Powder 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

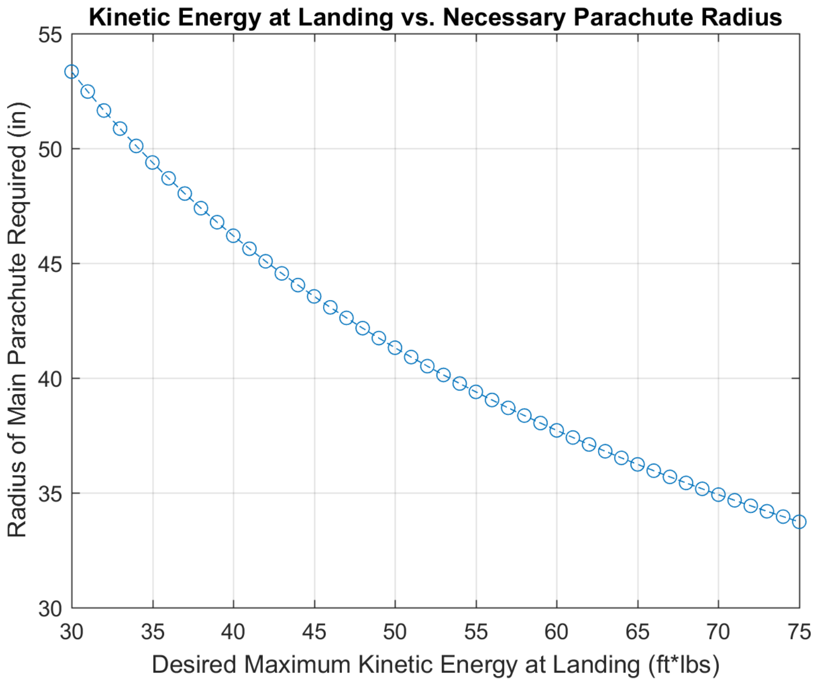
Appendix B: Recovery Decent Profile Calculator

```
% 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;
```



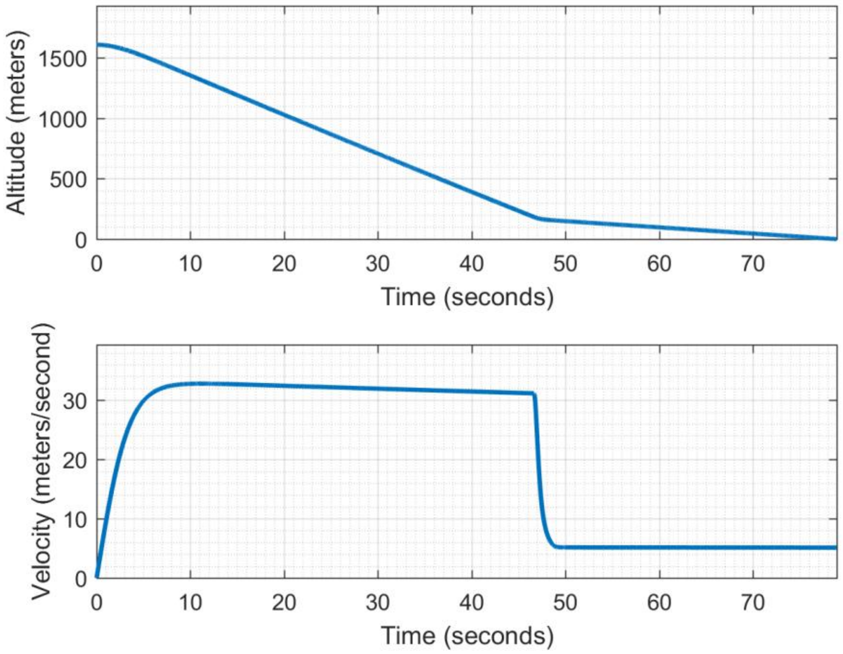
Calculating Force based results

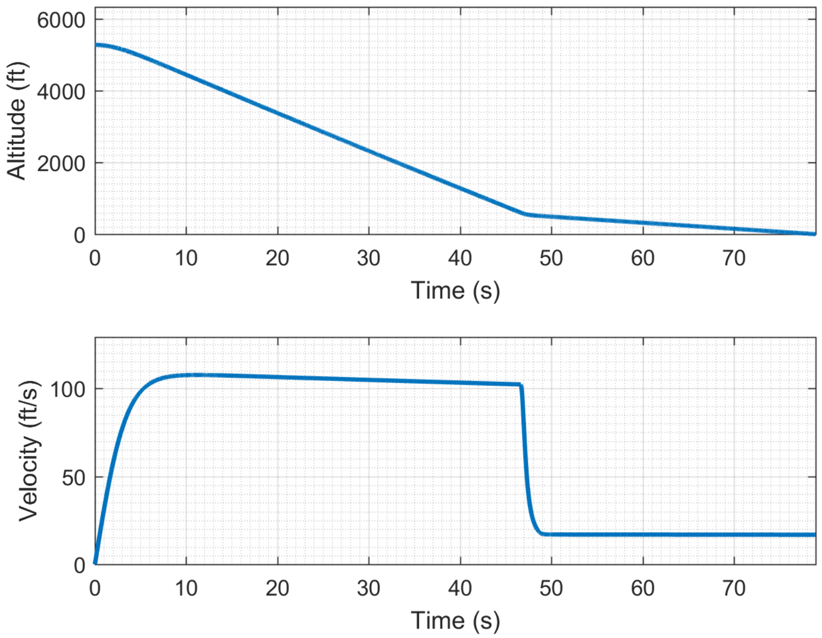
```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Input Begin %%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Rd_in = 6; %radius of drogue[in]
Rm_in = 42; %radius of main[in]
Rr_in = 7.5; %simulated radius of "tumbling" rocket parachute[in]

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;
```

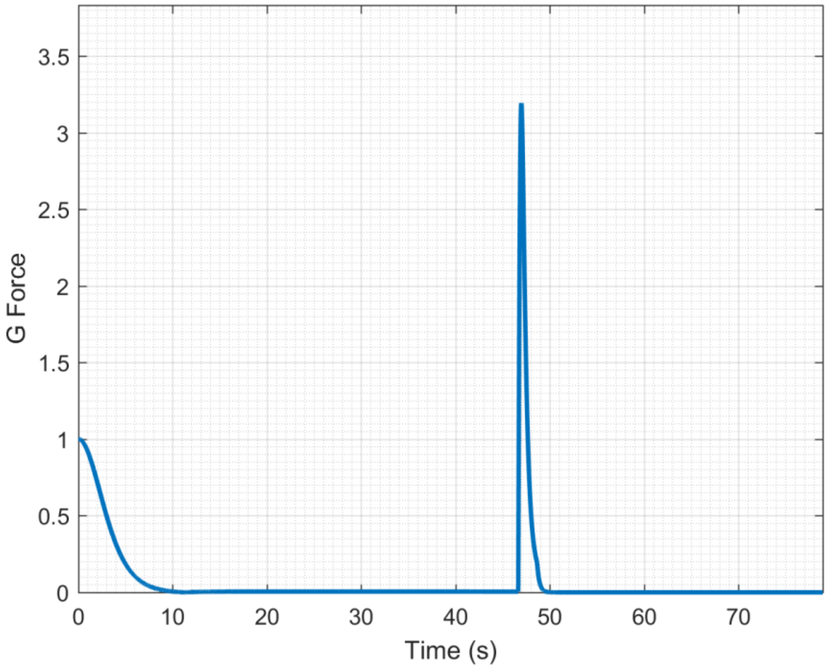
```
altDrogue = 0.3048*altDrogueft;
altMain = 0.3048*altMainft;

% 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]);
```





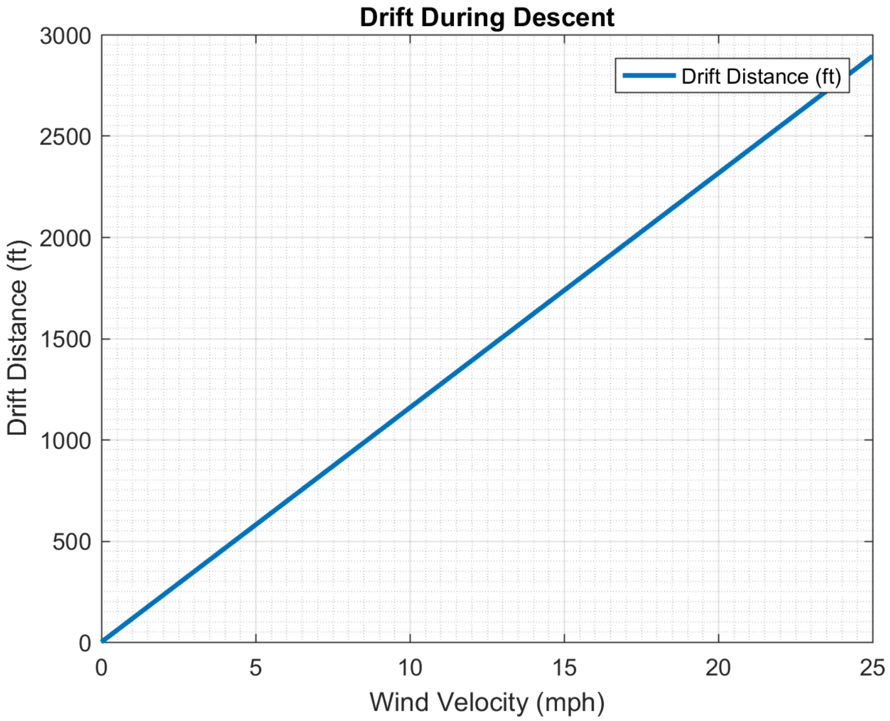


Calculate Drift Distance

```
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
```



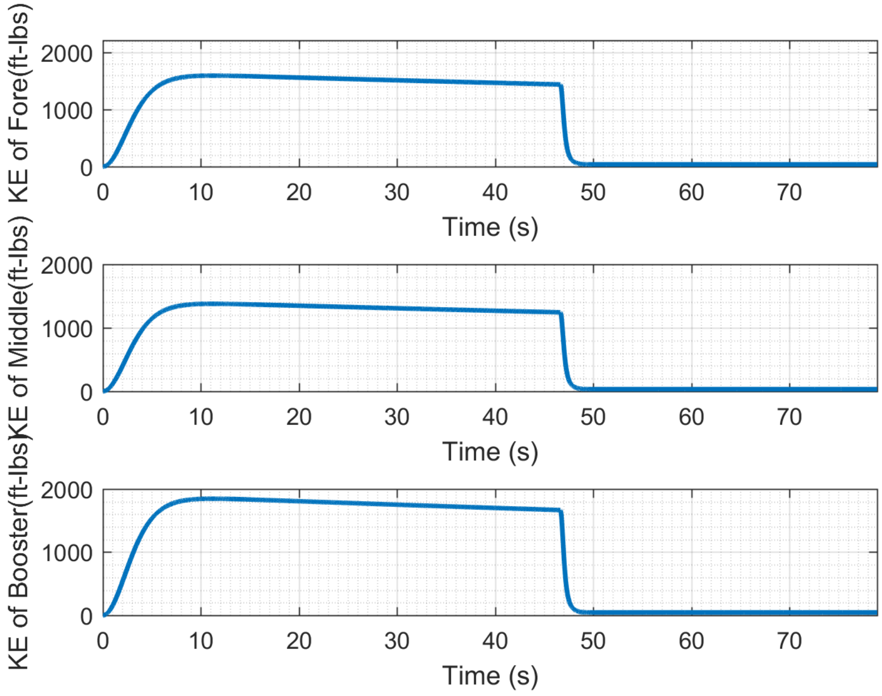
Calculate KE History of each component

```
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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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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