Student Launch Critical Design Review (CDR)

Carbon Dioxide Analysis in Troposphere with Autonomous Air Brakes

Mailing Address:
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AIAA OC Section
1/13/17

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1 Summary of CDR

1.1 Team Summary

The official team name is AIAA OC section. The mailing address is:

15 Wyoming
Irvine, CA 92606

1.1.1 Team name and mailing address

1.1.2.1 Robert Koepke (Electrical Engineer, Programmer, Level 2 NAR)

Robert has been co-leading TARC teams for eight years and a part of the STEM outreach for AIAA for seven years. He has a BS degree in Electrical Engineering from USC and has worked as an electronics designer, programmer, and now the manager of the software department for Honeywell. Robert worked on the F-20 Tigershark while at Northrop. Robert launched his first rockets shortly after Sputnik in 1957 and has continued in rocketry with his own children and grandchildren and Indian Princesses and Indian Guides.

1.1.2.2 Jann Koepke (Artist, Mom, Level 1 NAR)

Jann has been co-leading TARC teams for eight years. She has a bachelor's degree in Fine Arts from Cal State University Los Angeles in 1979. She has worked in electronic business as an assembler and in the accounting office. Now she is retired. She has been doing Rocketry for 25 years with her husband children and grandchildren. Jann is the AIAA OC Section Council member in charge of education. She has also led 4H projects in livestock, including lambs, goats, and beef.

1.2 Launch Vehicle Summary

- Length - 101.5 in
- Diameter - 4 in
- Semi Span of Fins - 4.5 in
- Total Mass - 9798.167 g
- Motor Choice - Cesaroni K555
- Launch Stability Margin - 3.47 calibers
- Recovery System -The recovery electronics will be in the avionics bay, a 12.2.5" tube coupler with a 3" collar made of 4" G10 fiberglass body tube to separate the upper and

middle body tubes. It is a redundant dual deploy system with an 84” main parachute and 18” drogue parachute.

- The Milestone Review Flysheet provides further specifics and is available under the tab **SL 2016-2017 > Documents** at verticalprojectile.org.

1.3 Payload Summary

Our payload, the K30 CO_2 sensor, has the sole purpose of collecting carbon dioxide samples from different altitudes. Our scientific experiment is to test the effect of altitude on carbon dioxide levels, hoping to find a strong correlation and regression (exponential, linear, or parabolic) within the explanatory and response variables. Our goal is to establish some sort of trend between the two variables, so it therefore follows that a successful experiment constitutes of a well defined correlation between altitude and carbon dioxide levels.

2 Changes made since PDR

2.1 Changes made to vehicle criteria

- Removed aft fins to move center of pressure upward, avoid excessive overstability
- Stability margin increased to be over minimum stability margin of 2.0 calibers at rail exit
- Added of 3 number 10 screws at non-separation points of modules to withstand shock of ejection
- Changes to push, not pull, out parachutes
    - Addition of 8” extension module with eyebolt and bulkheads to allow ejection charge to push out parachute
    - Payload bay attached to nose cone as a module to allow ejection charge to push out parachute
- Drogue delay is 3 seconds instead of one
- Main Parachute deploys at 700 ft for main and 500 ft for backup instead of 900 ft and 700 ft
- Switched placement of drogue chute and main chute to increase static stability margin
- More realistic stability margin and mass
- Changed from 72” toroidal parachute to 84” toroidal parachute to meet kinetic energy requirement
- 1 battery for RRC3 instead of 2 to avoid additional risks
- Changed from 9V batteries to Lipo batteries to power air brake controls in order to supply sufficient current to air brakes

2.2 Changes made to Payload criteria

We switched the Arduino Uno for the Teensy 2.0 Because the Arduino is not able to control multiple devices at the same time. Therefore, it can not perform tasks for the altimeter and the CO2 Sensor simultaneously. The Teensy does not have this problem, however.

2.3 Changes made to Project Plan

2.3.1 Budget

We edited the following on our budget sheet:

- Removed extended costs because it was unclear
- Added a comments section for any notes
- Added quantity column to avoid writing numbers in descriptions

- Renamed “extended costs” to “subtotal” to make things more clear

2.3.2 Timeline

We added dates for purchasing parts, educational engagement events, test days, and milestones for the timeline and readjusted other dates if they were unrealistic or inaccurate.

3 Vehicle Criteria

3.1 Design and Verification of Launch Vehicle

3.1.1 Flight Reliability and Confidence

Following our subscale flight on January 7, 2017, the Student Launch team can say with absolute confidence that the design is functional and safe for the project. There was a successful dual deploy, and the air brakes were able to bring the subscale close to our target altitude of 1900 ft.

There was a small error in the algorithm, so the air brakes did not open for the entire duration from motor burnout to apogee, but we were close to our target altitude nonetheless thanks to their performance.

We have also noted the fluctuations in the rocket's air brake altimeter, which the algorithm takes into account during the rocket's ascent. We have concluded that we need to seal the air brake electronics more properly to prevent these fluctuations.

3.1.1.1.1 Mission Statement

The AIAA OC Section team will construct a rocket that controls its ascent with air brakes to collect data on carbon dioxide levels one mile into the troposphere down to the lithosphere.

3.1.1.1.2 Mission Success Criteria

A successful mission is determined by the vehicle's success in the following areas: data collected, ascent, altitude reached, descent.

- If the payload establishes some sort of trend between altitude and carbon dioxide levels and reads a three digit number, preferably near 350 ppm, which is the safe level of carbon dioxide in the atmosphere, the mission is a success in this aspect.
- If the rocket achieves a minimum velocity of 52 feet/s, achieves a static stability margin of 2.0 at rail exit, does not utilize a motor that exceeds 2560 Newton-seconds, and safely ascends to one mile, then the mission is a success in this aspect.
- If the rocket utilizes its air brakes to increase drag and achieve its target altitude of one mile, the mission is a success in this aspect..
- If the rocket safely descends with a maximum kinetic energy of 75 ft-lbf, returns data from the payload, and can be reused again, then the mission is a success in this aspect.

3.1.1.2.1 Recovery Subsystem

The recovery subsystem will be discussed in detail in Section 3.1.3 Recovery Subsystem.

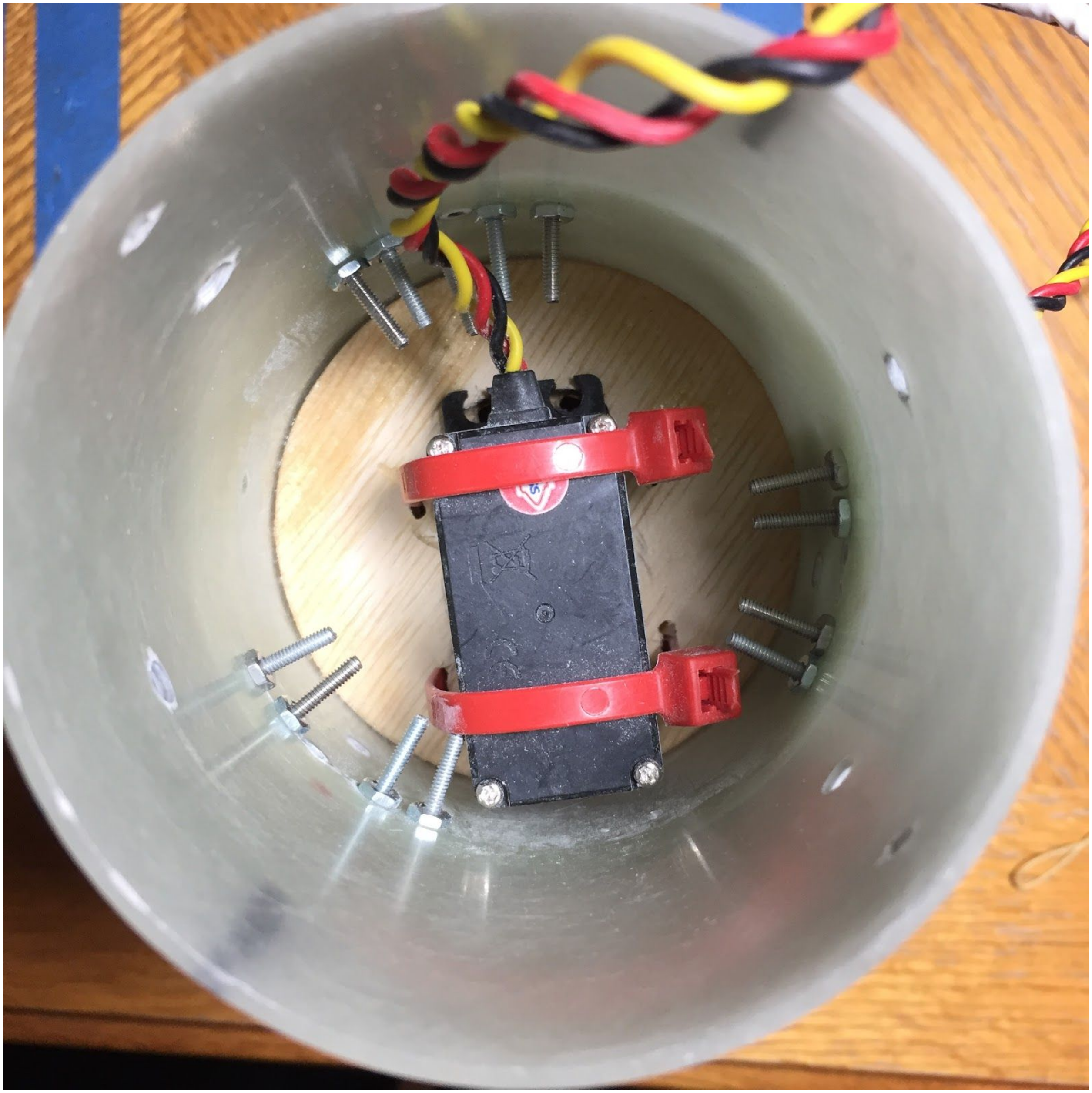
3.1.1.2.2 Air Brakes Subsystem

In the full-scale rocket, the air brake module will have an 8.25” long G10 fiberglass body tube, with a 6.5” long G10 fiberglass tube coupler, and. It will have a 4” diameter. It will be independently powered by a Lithium Polymer battery, meaning it will not have any connection with the recovery subsystem or the K30 CO_2 payload.

In our subscale rocket,
The body tube of the air brake module will be 3.375 in, and the air brakes will be made of a 6 in long fiberglass tube coupler with a 3.9” diameter. It will be independently powered by a Lithium Polymer battery, meaning it will not have any connection with the recovery subsystem or the K30 CO_2 payload.

Both are constructed to be modular and have an opening for repairing electronics. The wooden bulkhead will not undergo any stress from the explosion of the ejection charge or sustain the rocket via attachment of an eyebolt.

After constructing the air brakes module, we found that the joints that connected the servo to the air brakes required more flexibility. Originally, we used shortened servo horns and snap-on connectors to create the braking mechanism. We purchased ball-bearing swivels at a hobby store to add more flexibility to the rotational points. This swivel provides an additional hinge for the arm to turn on, so the air brake wing will come out.



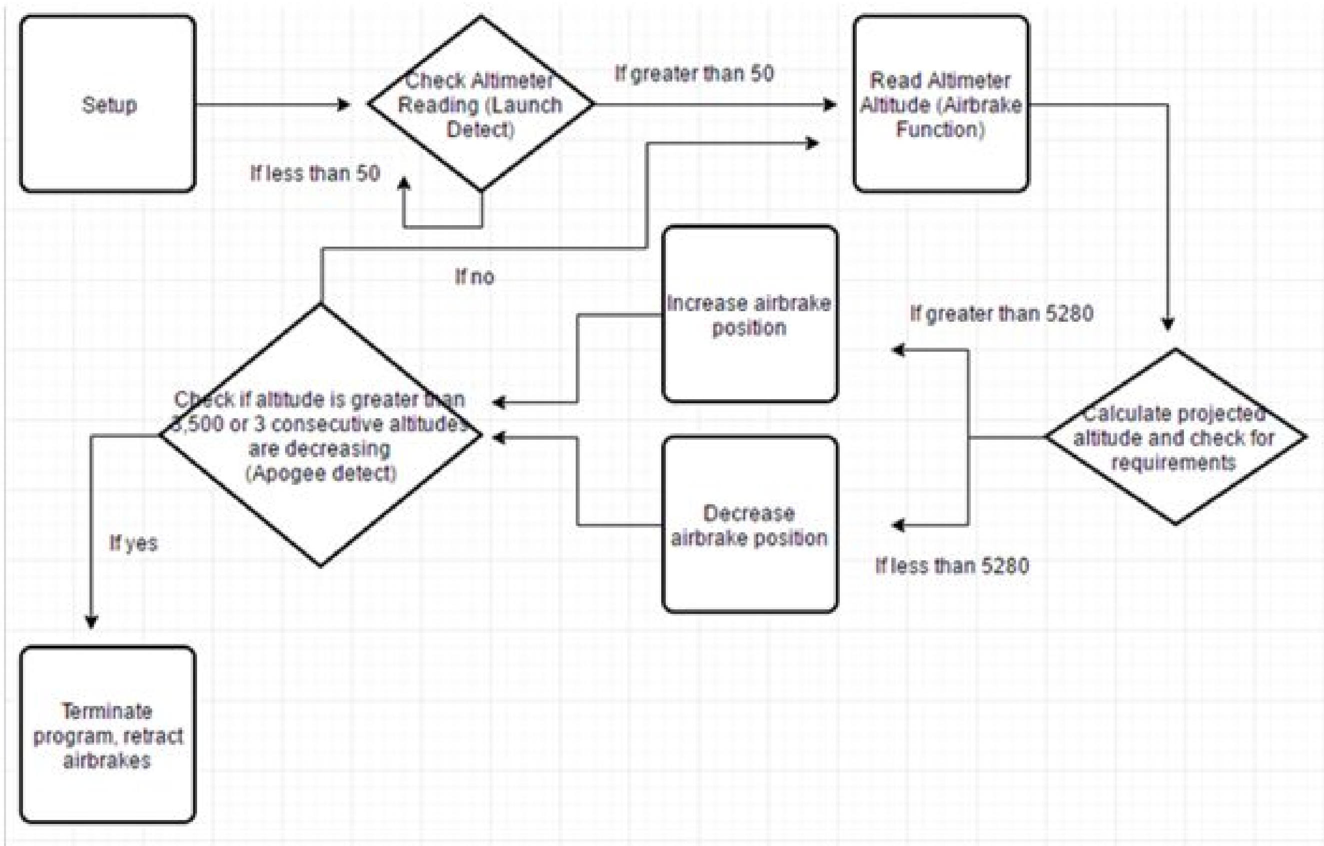
The above pictures are of the rocket's subscale air brake module.

We tested the air brakes to run continuously for one minute to account for any problems. We did not find any. The rocket's ascent lasts for less than 20 seconds, depending on weather conditions. If the air brakes can function without fail for longer than that time, then they are safe to fly. The battery is strong enough to last the designated standstill time on the launchpad prior to launch. We also tested the airbrakes with varied servo speeds to see if they would open and close systematically, regardless of torque, and function was normal.

3.1.1.2.2.1 Algorithm Development

The overall algorithm we will use to automate our airbrakes has four major facets: the initial setup, the launch detect function, the actual airbrake function, and the apogee detect function. The initial setup, or void setup, initializes the Teensy's serial monitor to a baud rate of 9600 Bd, along with blinking a built in LED light to indicate to the user that the system was functional. Next, the launch detect function is perhaps the most vital piece of the code. It is a boolean function which analyzes the readings from the altimeter, and when it sees a value which is greater than 50 feet, it starts the main airbrake program. The airbrake function then checks the altimeter values and uses basic physics formulas (factoring in air resistance, pressure, etc) to determine velocity and projected altitude. If this projected altitude is greater than the actual altitude, the airbrake will expand to a certain angle (where 120 degrees was the maximum) using a fairly linear formula. The airbrake function works simultaneously with the apogee detect formula, which analyzes the altitudes from the Pnut and checks to see whether the rocket reaches apogee. Since this is a boolean function, it has to satisfy 2 conditions in order to be true. First, three consecutive altitudes has to be descending, as this will indicate a descending rocket and thus the arrival of apogee. However, we have to account for errors in the Pnut readings, so the second condition is that the altitude has to be at least 3,500 feet. If the detect apogee function satisfies these two conditions, it will terminate the airbrake function and stop the overall program, retracting the airbrakes to zero position. There is no use of the airbrakes after apogee.

3.1.1.2.2.2 Algorithm Flowchart



The algorithm also uses this equation, which we derived from our understanding of the Law of Conservation of Energy. *U* and *K* denote potential and kinetic energy, respectively.

$$U_0 + K_0 = U_f + K_f$$

$$mgh_0 + \tfrac{1}{2}mv_0{}^2 = mgh_f + \tfrac{1}{2}mv_f{}^2;\ v_f = 0\ mph\ at\ apogee;\ v_0,\ h_0 > 0$$

$$mgh_0 + \tfrac{1}{2}mv_0{}^2 = mgh_f$$

$$h_f = h_0 + \frac{v_0{}^2}{2g}$$

If the difference between the predicted altitude and the target altitude is greater than or equal to 20 ft, then the air brakes will use coarse tuning. Coarse tuning involves opening the air brakes at a greater angle for a longer period of time.

If the difference between the predicted altitude and the target altitude is less than 20 ft, then the air brakes will use fine tuning. Fine tuning opens the air brakes at a reduced angle for a shorter period of time.

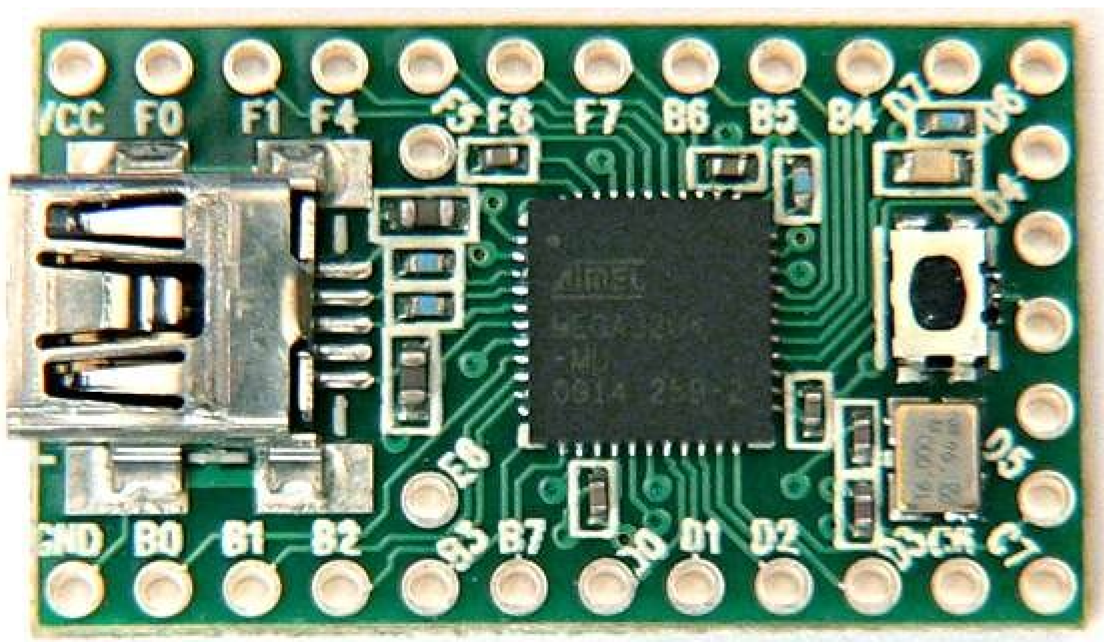
The above calculations do not account for air friction because air density decreases as the rocket ascends and becomes negligible as the rocket ascends.

3.1.1.2.2.3 Components of Air Brakes

For the 2017 Team America Rocketry Challenge (TARC), we developed an air brake system. The current model pushes the air brakes through holes that we carved into the body tube. After testing the design ten times, recording the air brakes in flight with an on-board flight camera, and examining post-flight data, we determined that the air brake system was reliable and applicable for our purposes in Student Launch. The air brakes will use similar but stronger materials that we have used in our TARC rocket for the 2017 season.

Due to space, we will use a Teensy 2.0, which is Arduino compatible but smaller than an Arduino Uno. The dimensions of the Teensy are 1.2”x 0.7”x 0.125”. We have experience with the Teensy because we used it for air brake control in our TARC rockets.

The Teensy can also carry an SD card, so we will use this to determine how the Teensy predicted the velocity of its ascent, how many times the air brakes opened, and how much our rocket decelerated.

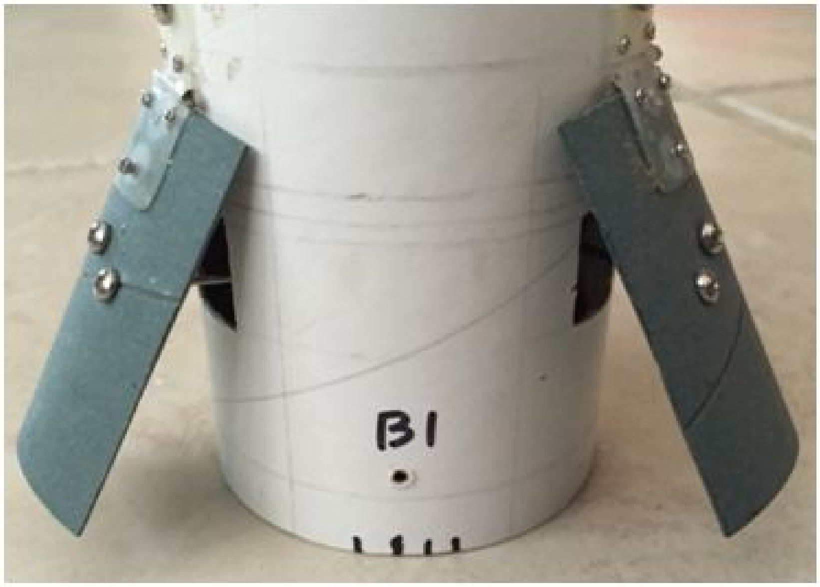


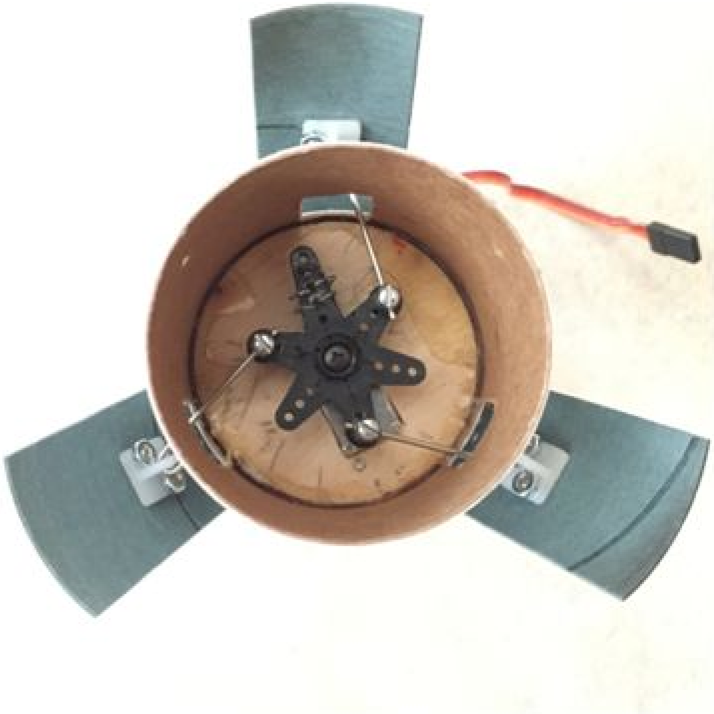
To make the legs on our airbrake system to push and pull the air brakes, we used strong dental wire and dental tools from Albert’s father, who is a dentist. Our system required flexibility around the rotational points, like a ball and socket joint on the human shoulder. We cut and bent the wires into hooks and attached them to loops we made ourselves to accomplish this design. We first made a proof of concept of the mechanism on June 27, 2016, which can be found here. Our current design can be found here.

We have not yet decided upon a horn, so the length of the wire used has not yet been finalized. We will use stronger wire or rods to accommodate this new design.

A Teensy will be used to control the mechanism and run the algorithm. Its small size and processing power is capable of controlling the rocket.

To make the air brakes we will evenly cut the tube coupler into sixths and place three of the pieces equally apart in a specified area. The air brakes will extend beyond the air brake module. The air brakes will be used for controlling the altitude of the rocket through drag rather than relying on the variable thrust of the motor as a result of manufacturing.



The above three pictures are of the TARC rocket's air brake module.

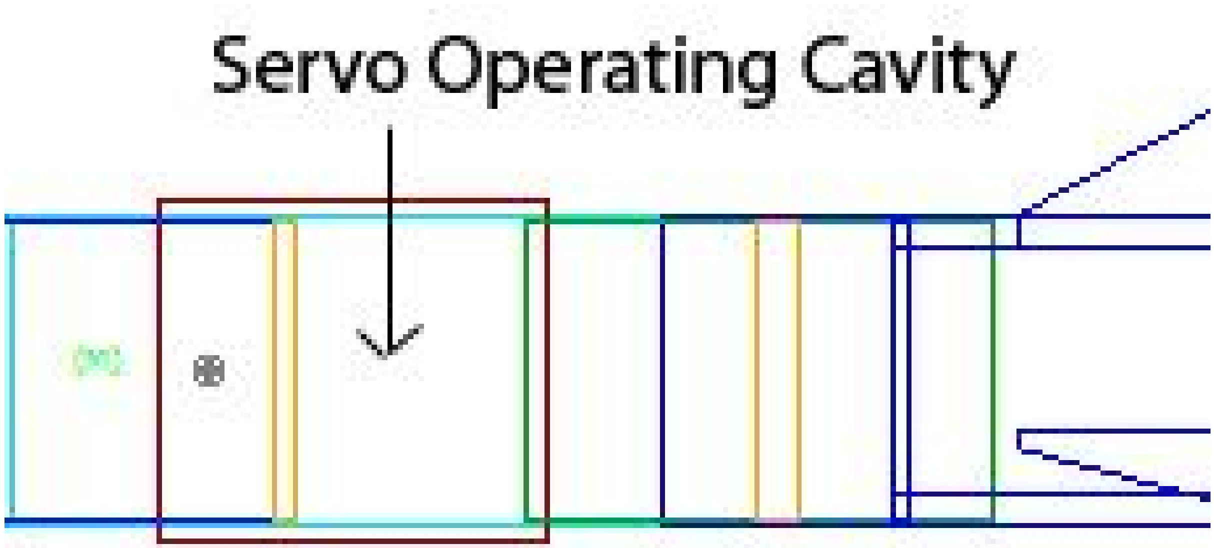
The air brakes will use a Hitec HS-7890T circular servo, which have the following statistics:

Dimensions	1.72" x 0.88" x 1.57" (43.8 x 22.4 x40 mm)
Product Weight	2.76 oz (78.2g)
No-Load Speed (6.0V)	0.21 sec/60°
No-Load Speed (7.4 V)	0.17 sec/60°
Stall Torque (6.0V)	500oz/in (26 kg.cm)
Stall Torque (7.4V)	611oz/in (44kg.cm)
Travel per µs (out of box)	.080°/µsec
Travel per µs (reprogrammed high res)	.132°/µsec

We received our inspiration from a YouTube video of a mechanical flower. A student from the University of Twente used this flower for a bachelor thesis.

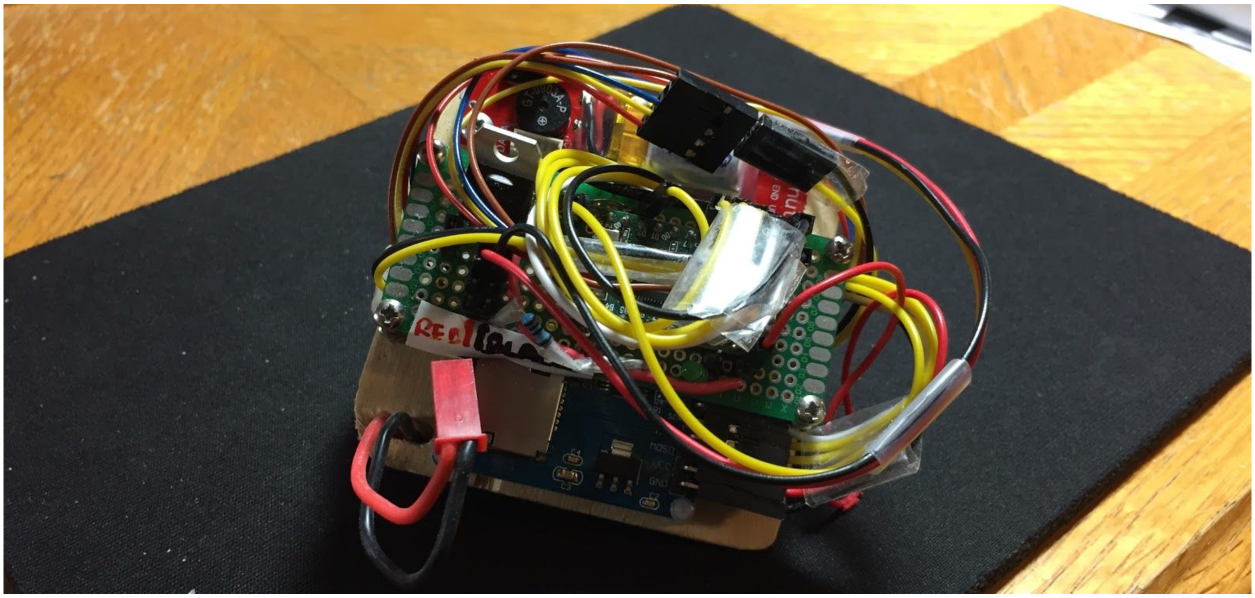
We also have video of us testing the air brakes.

The area for the servo to operate will be in this area:

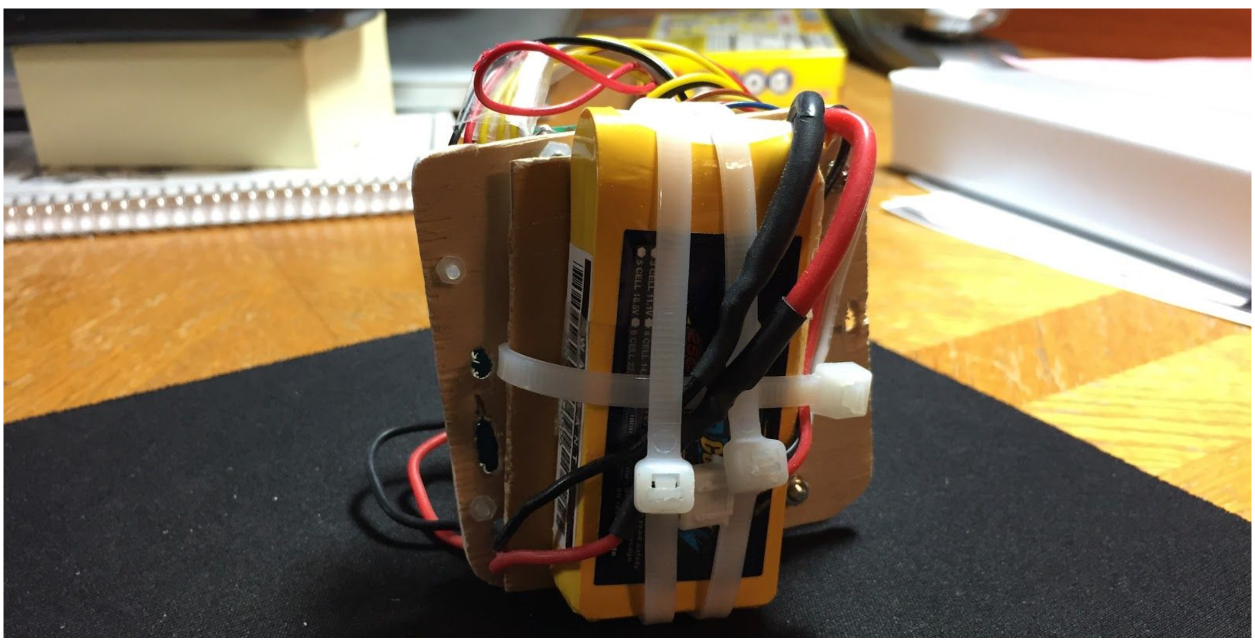


The Lithium Polymer battery will run a 5 Volt current to power the servo. Its dimensions are 2.17”x1.22”x0.79”.
The length of body tube where the servo can rotate is 1.25 in, which allows for the air brakes to rotate. The green mass object closest to the center of gravity represents the servo that will operate the air brakes. The volume where the servo and its electronics, including the battery will be placed is a 3.9”d x 2”h, inside a 4” long tube coupler. The diameter is large enough to fit the Teensy and servo in one place. We will cut a 0.115” thick bulkhead to fit the rectangular shape of the servo and position the servo so that it can operate the air brakes, as seen in the TARC air brake module pictures above. The bulkhead will fit snugly in the specified tube coupler.
The estimated mass of this subsystem is 815 g.

This is a picture of the air brake electronics from the subscale rocket. In the full scale, we anticipate being able to fit all of our electronics on a larger board.



Top View (total 140 g)



Bottom View (With battery)

3.1.1.2.2.1 Air Brakes Subsystem Alternatives

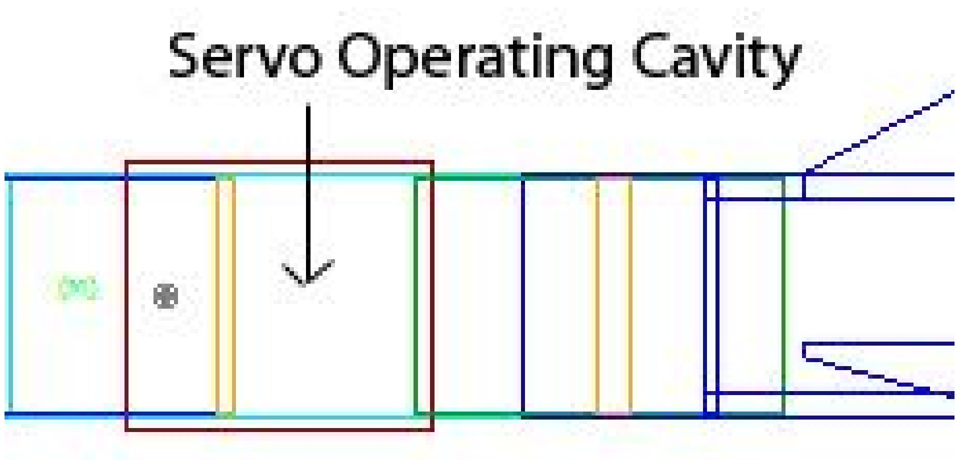
Alternatives	Reasons for not choosing them
Linear actuators	• Not effective in terms of space or

	speed compared to circular servo. ● Required additional body tube length to fit

3.1.1.2.2.2 Conclusions Drawn from Air Brakes Subsystem

We have tested the air brakes on our Team America Rocketry Challenge rockets, and we can ascertain that they work in-flight. We attached a video camera on the rocket to film the module's performance.

The area for the servo to operate will be in this area:



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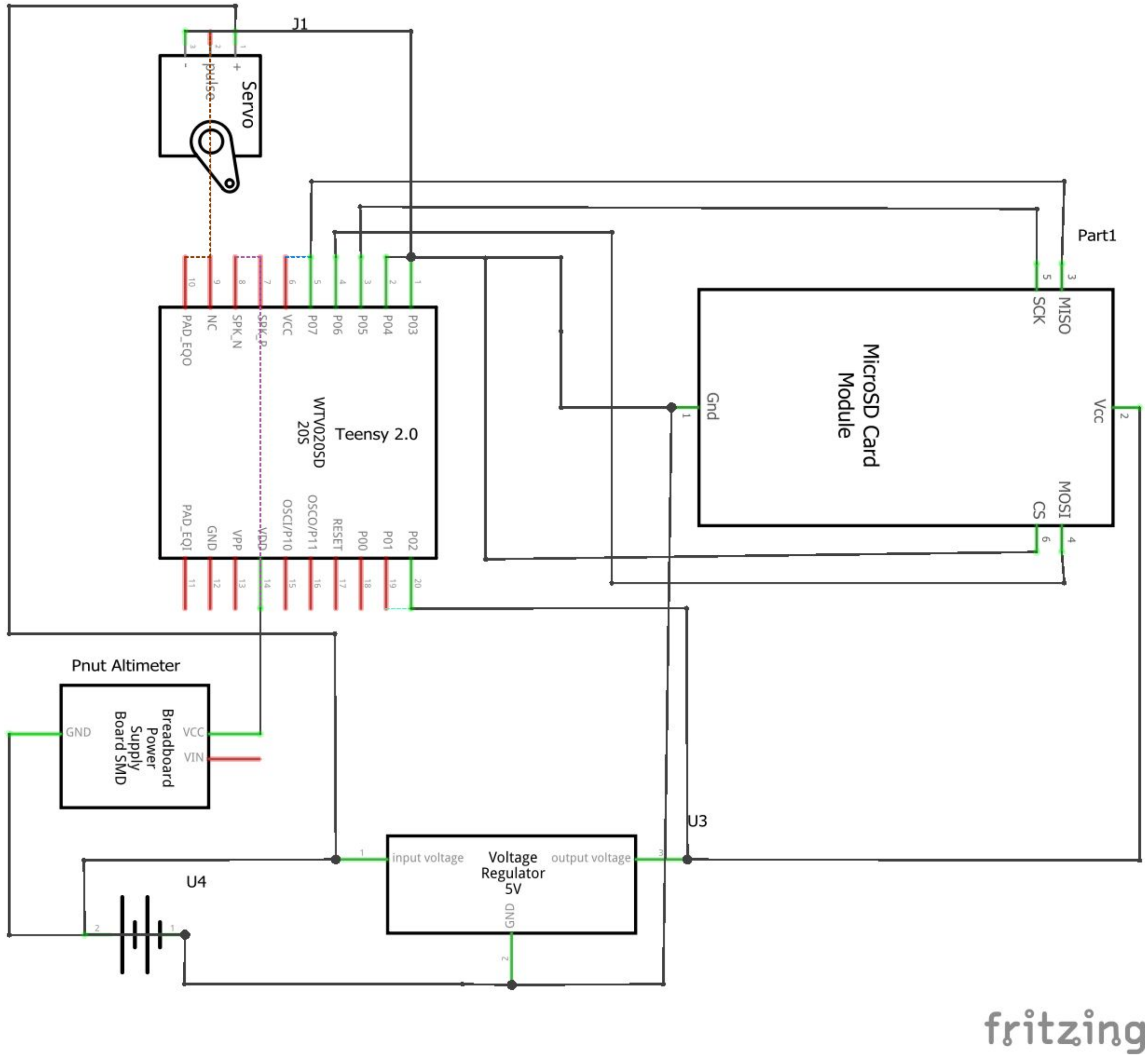
The total mass of this subsystem, including the electronics is 815 g.

3.1.1.2.2.3 Air Brakes Schematic



3.1.1.2.3 GPS Subsystem

The GPS that we will be using is the Whistle GPS dog tracker, as seen below.

3.1.1.2.3.1 GPS Subsystem Alternatives

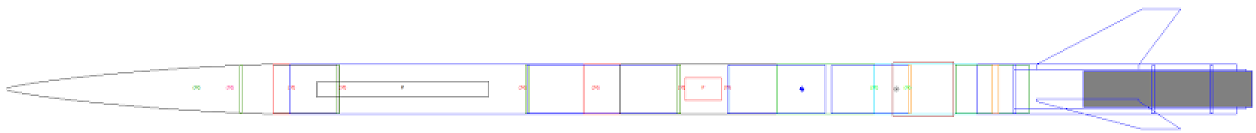
GPS system	Pros	Cons
Whistle GPS dog tracker	Easy to use because it requires knowledge of using a smartphone app. It can be recharged easily using the base station and is not dependent on any other external electronics. No additional telemetry required.	Only works where there is cellular coverage. Bigger than the other GPS options. More expensive because of money needed for cellular service.
EM-506 GPS Receiver	Really small, really accurate in rough geographical conditions like canyons, relatively cheap.	Relatively difficult to use compared to dog tracker. Also not as durable. Additional telemetry may be required.
Arduino GPS tracker	Small and easy to set up. It will be easy for us to use because of our experience with Arduino in TARC.	Additional space required for battery, really expensive, will require use to use a new and unfamiliar version of Arduino. Additional

		telemetry may be required, making it relatively harder to use.

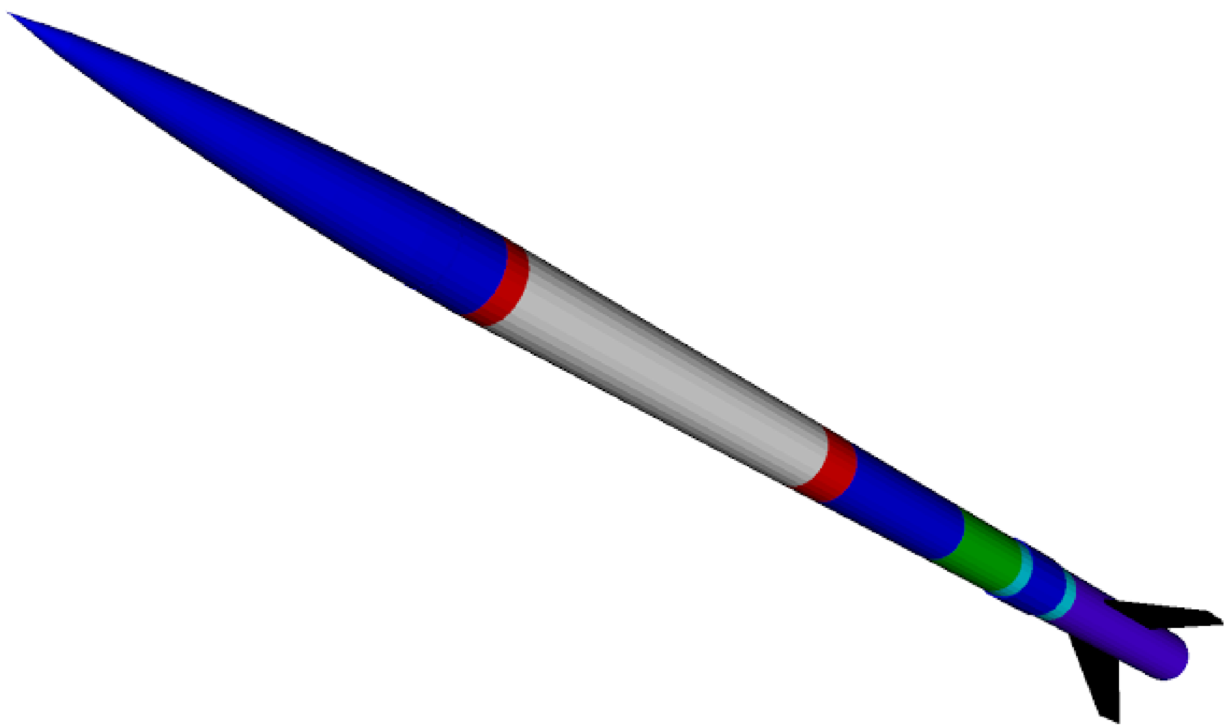
3.1.1.2.3.2 Conclusions Drawn from GPS Subsystem

The Whistle GPS is the most affordable and reliable of the GPS alternatives.

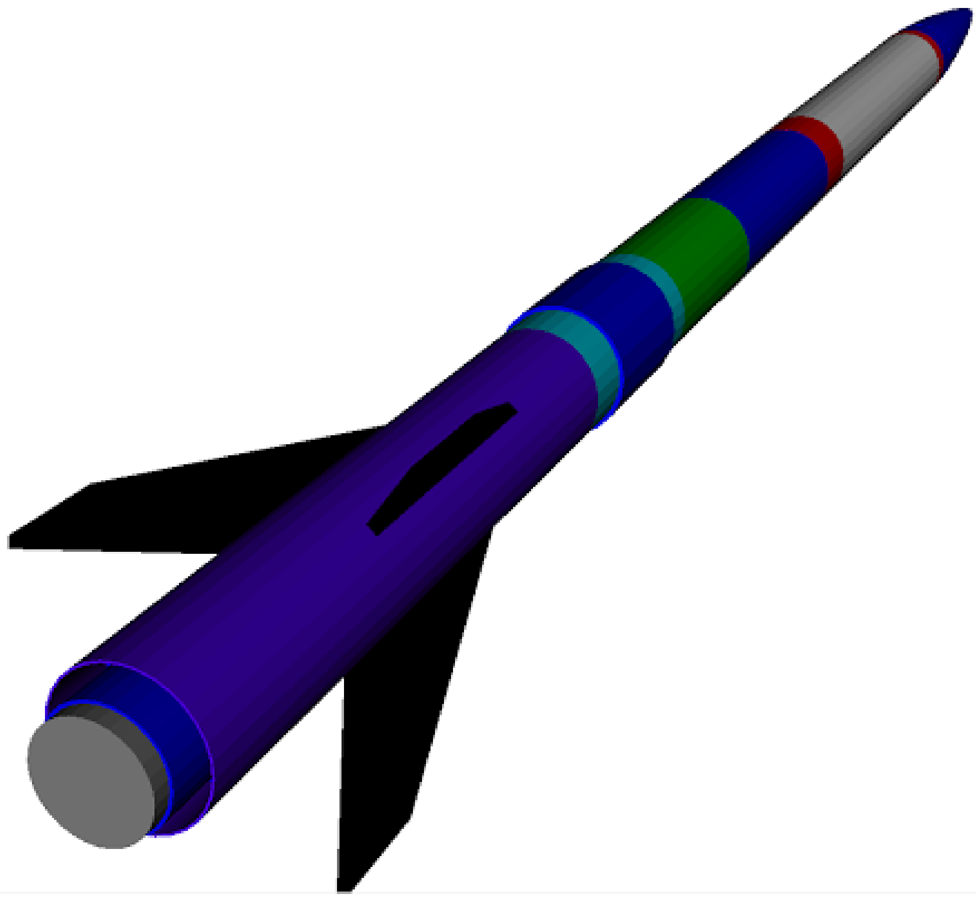
3.1.1.3 Illustrated Final Design



2D View



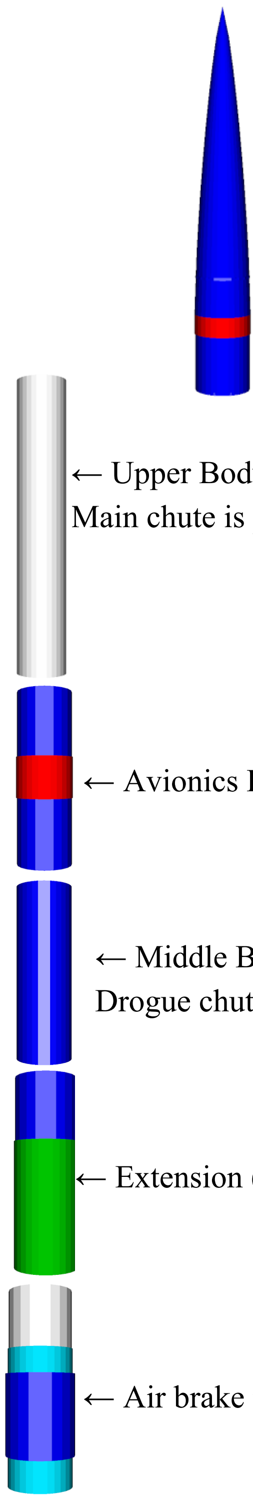
Front View



Rear View

The different colored body tubes of the above 3D rocket diagrams delineate a module.

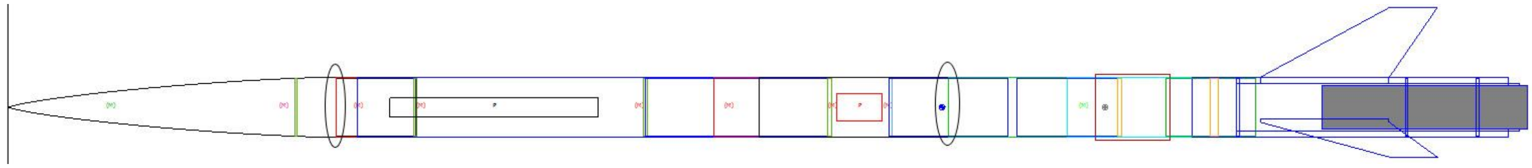
Exploded Diagram (CAD)



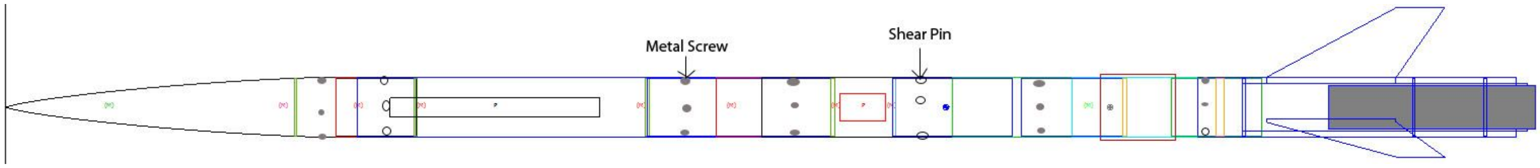
<u>The nose cone and payload module comprise one independent section.</u>

<u>The upper body tube, avionics bay, and middle body tube comprise one independent section.</u>

<u>The remaining modules comprise one independent section.</u>

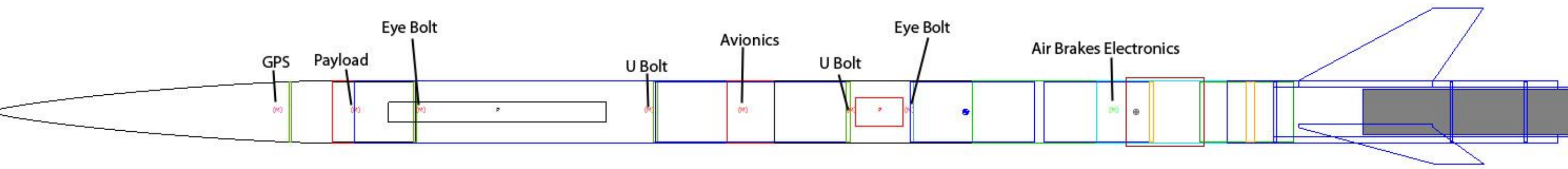


Separation Points Denoted by Black Ovals



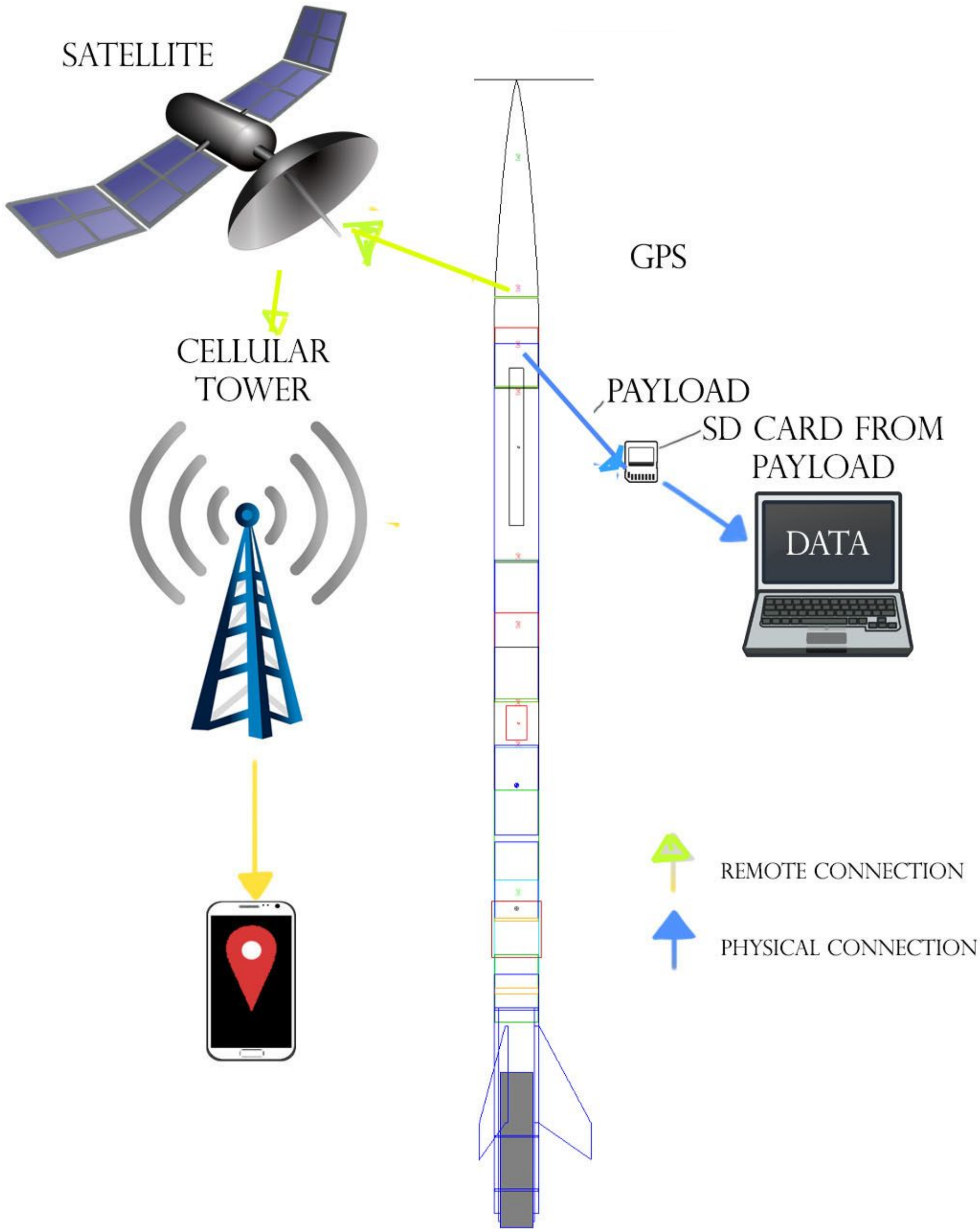
Metal Screws, Shear Pins Marked

We are using #10 screws, with three at each intersection, and #2 shear pins, with three at each separation point.



Mass objects Denoted

3.1.1.4 Meeting System Level Functional Requirements



Systems Diagram

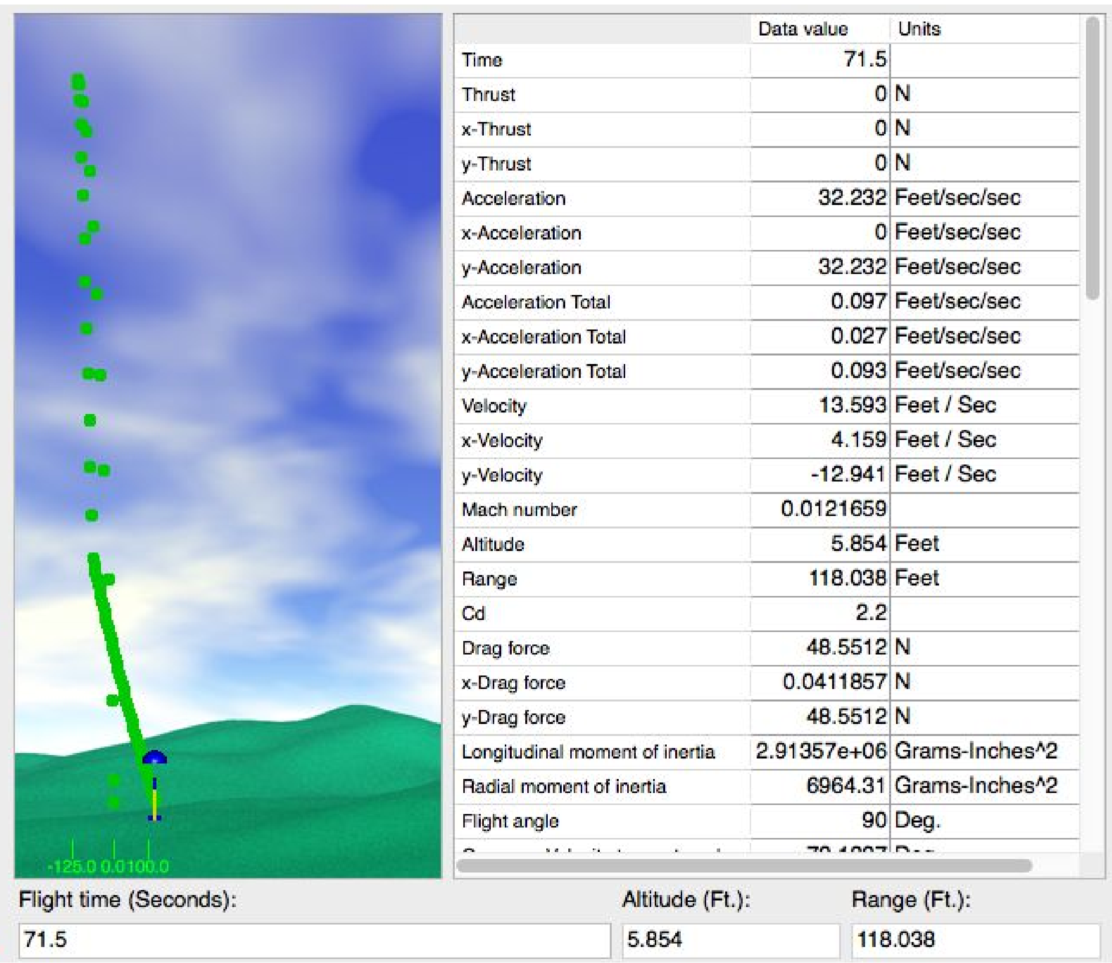
The team will meet the system level functional requirements by carrying a payload 4500 ft AGL. The payload can collect data, and we will use a micro SD card to collect the data and analyze what we collected post-flight.

The rocket will also utilize a dual deployment recovery system, which is redundant.

A GPS is on board to track the rocket

3.1.1.5 Design Integrity

Using RockSim, we were able to test the rocket's stability, it's estimated flight pattern, and the estimated flight details, as shown in the picture below:



	Data value	Units
Time	71.5	
Thrust	0	N
x-Thrust	0	N
y-Thrust	0	N
Acceleration	32.232	Feet/sec/sec
x-Acceleration	0	Feet/sec/sec
y-Acceleration	32.232	Feet/sec/sec
Acceleration Total	0.097	Feet/sec/sec
x-Acceleration Total	0.027	Feet/sec/sec
y-Acceleration Total	0.093	Feet/sec/sec
Velocity	13.593	Feet / Sec
x-Velocity	4.159	Feet / Sec
y-Velocity	-12.941	Feet / Sec
Mach number	0.0121659	
Altitude	5.854	Feet
Range	118.038	Feet
Cd	2.2	
Drag force	48.5512	N
x-Drag force	0.0411857	N
y-Drag force	48.5512	N
Longitudinal moment of inertia	2.91357e+06	Grams-Inches^2
Radial moment of inertia	6964.31	Grams-Inches^2
Flight angle	90	Deg.

The above picture shows the 2D simulation flight profile at the end of the flight with the details tab pulled out. The graph below shows the simulation summaries of the rocket.

	Simulation	Results	Engines loaded	Max. altitude Feet	Max. velocity Feet / Sec	Max. acceleration Feet/sec/sec	Time to apogee	Velocity at deployment Feet / Sec	Altitude at deployment Feet
19	18		[J293BS-None]	2781.13	420.10	[illegible]	13.95	0.03	2781.13
20	19		[J293BS-None]	2781.13	420.10	1513.08	13.95	0.03	2781.13
21	20		[J293BS-None]	2781.13	420.10	3172.12	13.95	0.03	2781.13
22	21		[J293BS-None]	2781.13	420.10	3172.12	13.95	0.03	2781.13
23	22		[J280SS-*]	2052.25	358.27	3157.48	12.17	16.62	2052.26
24	23		[J280SS-*]	2057.10	358.35	3157.76	12.18	8.54	2057.10
25	24		[J280SS-*]	2055.65	358.33	3157.67	12.18	11.56	2055.65
26	25		[J280SS-*]	2053.51	358.29	3157.55	12.17	14.95	2053.51
27	26		[J280SS-*]	2053.60	358.29	3157.55	12.17	14.83	2053.60
28	27		[J280SS-*]	2056.81	358.35	3157.74	12.18	9.23	2056.81
29	28		[J280SS-*]	2055.39	358.32	3157.66	12.18	12.03	2055.39
30	29		[J280SS-*]	2053.79	358.30	3157.56	12.17	14.56	2053.79
31	30		[J280SS-*]	2055.63	358.33	3157.67	12.18	11.59	2055.63

We used West Systems Epoxy to ensure that the rocket was constructed well, and would hold together during the flight. The avionics bay was colour coordinated, to allow for less confusion and easier usage of the avionics system. Arming the avionics was done by two keys that were located on the outside of the avionics bay, that allowed for full control of when the avionics were powered on and off. In the event of a system failure from one avionics board, we have a redundant system, where a second board will control the flight events and the parachute ejection.

The proof of a redundant avionics system is in section 3.1.3.3.1.

The rocket was constructed using West Systems epoxy resin and J.B. Weld glue, both of which are highly resilient and non flammable adhesives.

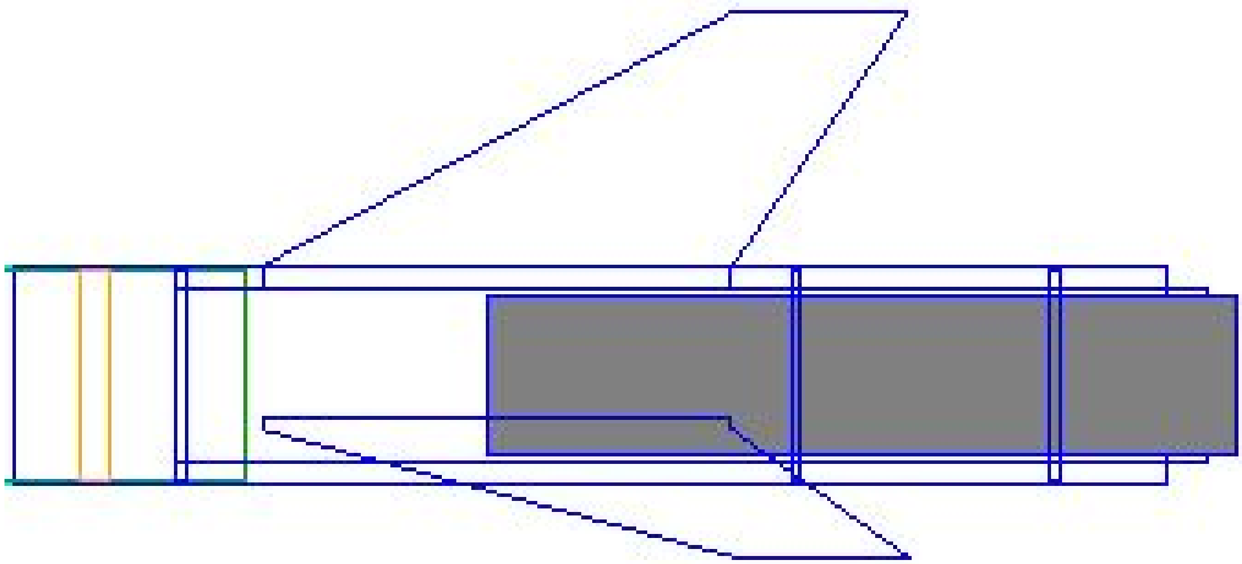
Fiberglass is a hard material and will not shatter easily.

The air brakes use J.B. Weld glue to secure the hinges and are made of fiberglass body tubes.

3.1.1.5.1 Suitability of Shape and Fin Style for Mission

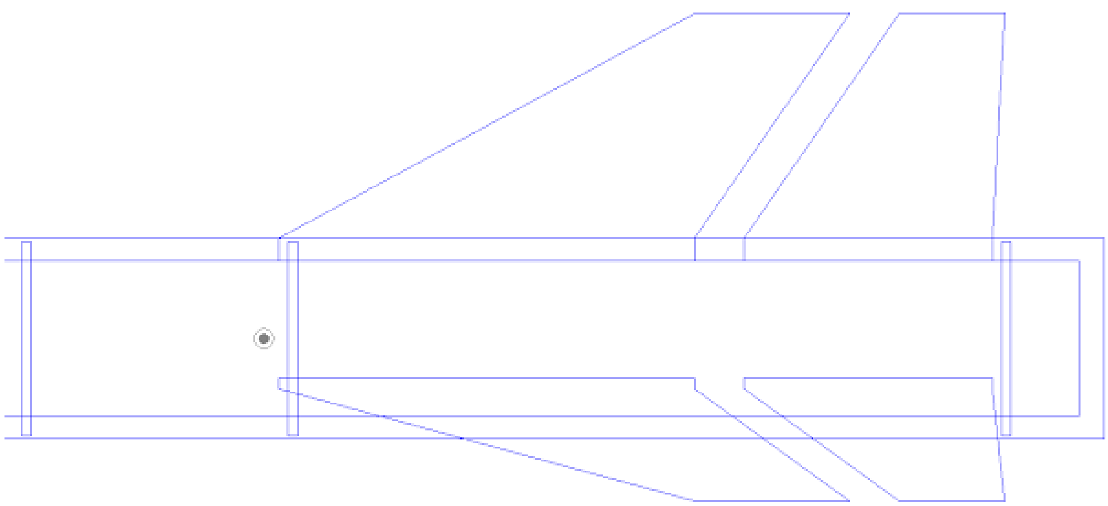
Mike Stoop designed the Frenzy XL kit. The Student Launch team asked him if it was acceptable to remove the aft fins, and after he reviewed the RockSim file and noted the static stability margin, he said the rocket would perform without malfunctioning on quiet days with little to no wind.

He did note that a rocket with a higher stability margin would perform better on windy days.



Booster Section of Full Scale

The original kit included another set of fins.



Both fin sets exhibited in 4” Frenzy XL

3.1.1.5.2 Proper Use of Materials in Fins, Bulkheads, and Structural Elements

Bulkheads are either aluminum or fiberglass. Those that are aluminum are 0.25” thick.

The aluminum bulkheads were purchased from Mad Cow Rocketry. A total of four of these bulkheads are used to house the avionics electronics and the payload.

The two holes that are not in the center of the bulkhead are used to hold the rails to the electronics boards. These rails run through 0.25” launch lugs that are glued to the back of the electronics board for easy access when the rocket is not on the launch pad and security during the rocket’s flight

Those that are fiberglass tend to be made of two individual fiberglass bulkheads that are stuck together with West Systems epoxy, providing additional reinforcement to withstand the shock of ejection and ejection charge force. Together, the two fiberglass bulkheads are 0.25” thick. These were purchased from Mad Cow Rocketry.

There are four fiberglass bulkheads used in total on this rocket. Two of them are combined, as mentioned in the previous paragraph. One of them has a machine closed eyebolt and tethers the bottom-most independent section to the middle independent section. The other is in front of the motor, where the ejection charge would face if it were not removed. Both provide sufficient protection against small black powder discharges.

G10 fiberglass can withstand the force the rocket will experience in-flight. Body tubes are 0.118” thick and tube couplers are 0.2” thick.

3.1.1.5.3 Sufficient Motor Mounting and Retention

The motor mount was sanded down so we could dry-fit the retainer. Once we confirmed that the motor retainer fit the mount, we used JB Weld glue to attach the retainer to the rocket. We used AeroPack Fiberglass 54mm and 75mm Motor Tube Retainers, purchased from Madcow Rocketry.

Aero Pack 75mm Retainer (Fiberglass Motor Tubes) (RA75P)

Aero Pack 54mm Retainer (Fiberglass Motor Tubes) (RA54P)

3.1.1.5.4 Estimated Final Mass of Launch Vehicle and Subsystems

Subsystem Name	Estimated Mass (g)
Launch Vehicle/Total Mass	9798.167
Air Brakes Module	857
Avionics	930
Payload	611

3.1.2 Subscale Flight Results

The flight was performed on January 7, 2017. It successfully deployed both of its parachutes at their respective times during the flight. The drogue deployed at apogee, and the main deployed at 700 ft.

The rocket's ascent was controlled and straight, with no aberrations.

3.1.2.1 Data Recorded on Subscale Flight

Apogee reached: 1934 ft
Motor used: Cesaroni J280SS

3.1.2.2 Scale Factor

Because the subscale as a 3" diameter, and the full scale as a 4" diameter, the scale factor is 3 to 4, subscale to full scale.

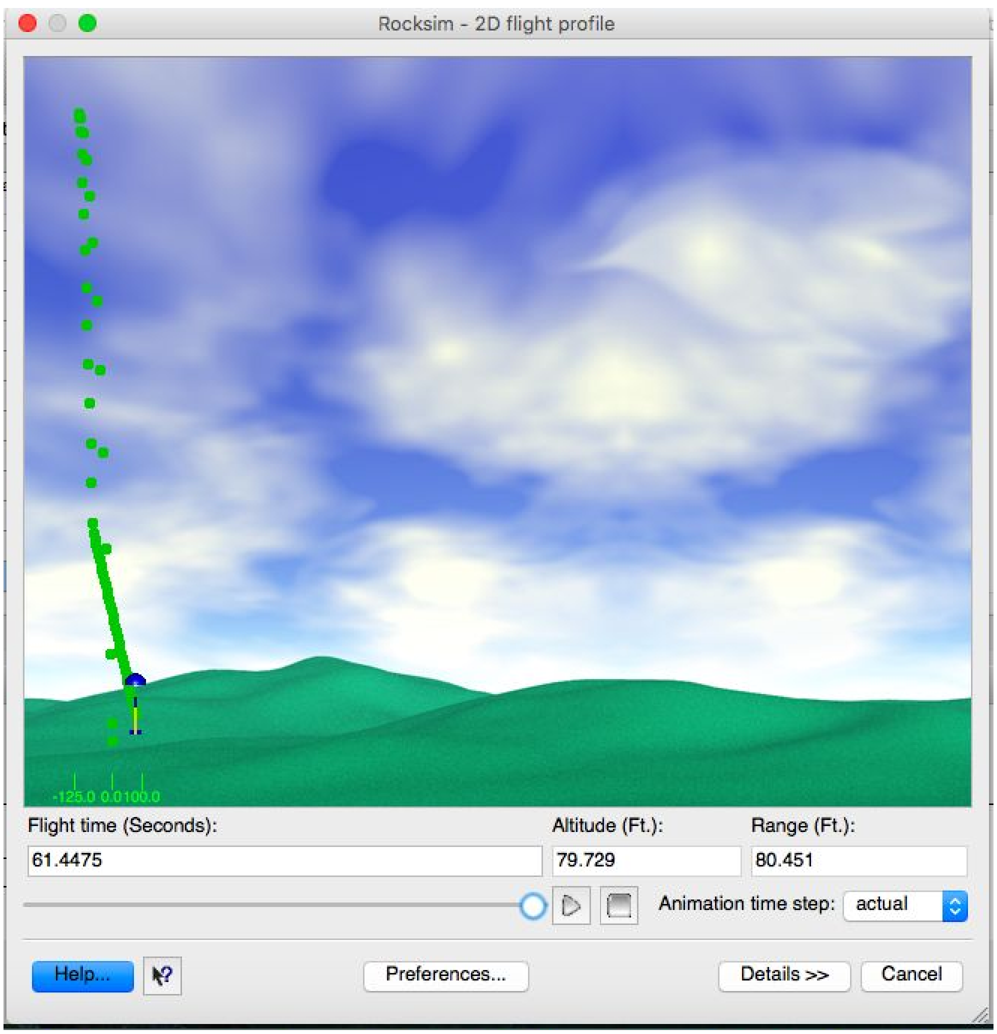
The subscale's body tube that housed the main chute had to be made larger to accommodate the 60" parachute, which is quite difficult to fit inside a 3" diameter. The ratio of length (subscale to full scale) is 0.77.

We tried to keep the rest of the masses consistent, but we should expect some error in the scale factor before and after building.

3.1.2.3 Launch Day Conditions

Temperature	61° F
Wind conditions	2-3 mph
Cloud coverage	20%
Barometric pressure	30.3 in Hg
Humidity	28%
Elevation	54 ft
Latitude	32.91° N
Longitude	115.4° W

3.1.2.3.1 Simulation with Launch Day Conditions



Temperature	61° F
Wind conditions	2-3 mph
Cloud coverage	20%
Barometric pressure	30.3 in Hg
Humidity	28%
Elevation	54 ft
Latitude	32.91° N
Longitude	115.4° W

3.1.2.4 Subscale Flight Analysis

3.1.2.4.1 Predicted Flight Model, Actual Flight Data Comparison

The following tables only relate to the subscale flight.

Predicted Flight Model

Vehicle Properties	
Total Length (in)	78.7500
Diameter (in)	3.0188
Gross Lift Off Weight (lb)	13.6
Airframe Material	Fiberglass
Fin Material	Fiberglass
Coupler Length	Payload Bay: 6.375” 1.74” in Nose Cone 3.5” in Upper Body Tube Avionics Bay: 9” 3.5” in Upper Body Tube 3.5” in Middle Body Tube TC for Air Brakes Module: 3.75” 1.875” in Middle Body Tube 1.875” in Air Brake Module TC for Booster Module: 4.5” 3” in Air Brake Module 1.5” in Booster

Stability Analysis	
Center of Pressure (in from nose)	57.5678
Center of Gravity (in from nose)	48.5282
Static Stability Margin	3.05
Static Stability Margin (off launch rail)	4.29
Thrust-to-Weight Ratio	6:1
Rail Size and Length (in)	Quarter; 8 inches
Rail Exit Velocity	55.5 ft/s

Ascent Analysis	
Maximum Velocity (ft/s)	358.27
Maximum Mach Number	0.308
Maximum Acceleration (ft/s^2)	3157.48
Target Apogee (From Simulations)	2000
Stable Velocity (ft/s)	346
Distance to Stable Velocity (ft)	426

Recovery System Properties				
Drogue Parachute				
Manufacturer/Model	Fruity Chutes			
Size	18”			
Altitude at Deployment (ft)	Apogee: 2052			
Velocity at Deployment (ft/s)	16.59			
Terminal Velocity (ft/s)	76			
Recovery Harness Material	Tubular Nylon			
Harness Size/Thickness (in)	.75			
Recovery Harness Length (ft)	1.167			
Harness/Airframe Interfaces	Eyebolt			
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	$Kinetic\ energy = \frac{1}{2}mv^2 = \frac{1}{2}(2.75\ lbs)(76\ ft/s)^2(\frac{1\ lbf\ s^2}{32.2\ lbm\ ft}) = 246.65\ lbf$	$Kinetic\ energy = \frac{1}{2}mv^2 = \frac{1}{2}(3.42\ lbs)(76\ ft/s)^2(\frac{1\ lbf\ s^2}{32.2\ lbm\ ft}) = 306.74\ lbf$	$Kinetic\ energy = \frac{1}{2}mv^2 = \frac{1}{2}(6.24\ lbs)(76\ ft/s)^2(\frac{1\ lbf\ s^2}{32.2\ lbm\ ft}) = 559.66\ lbf$	

Recovery System Properties

Main Parachute				
Manufacturer/Model		Fruity Chutes		
Size		60”		
Altitude at Deployment (ft)			700	
Velocity at Deployment (ft/s)			56	
Terminal Velocity (ft/s)			56	
Recovery Harness Material			Tubular Nylon	
Harness Size/Thickness (in)			.75	
Recovery Harness Length (ft)			5.167	
Harness/Airframe Interfaces		Eyebolt		
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	$Kinetic\ energy = \frac{1}{2}mv^2$ $= \frac{1}{2}(2.75\ lbs)(6\ ft/s)^2(\frac{1\ lbf\ s^2}{32.2\ lbm\ ft})$ $= 3.07\ lbf$	$Kinetic\ energy = \frac{1}{2}mv^2$ $= \frac{1}{2}(3.42\ lbs)(6\ ft/s)^2(\frac{1\ lbf\ s^2}{32.2\ lbm\ ft})$ $= 1.91\ lbf$	$Kinetic\ energy = \frac{1}{2}mv^2$ $= \frac{1}{2}(6.24\ lbs)(6\ ft/s)^2(\frac{1\ lbf\ s^2}{32.2\ lbm\ ft})$ $= 3.49\ lbf$	

Actual Flight Data Comparison

Vehicle Properties	
Total Length (in)	78.75
Diameter (in)	3
Gross Lift Off Weight (lb)	12.3
Airframe Material	Fiberglass
Fin Material	Fiberglass
Coupler Length	Payload Bay: 6.375” 1.74” in Nose Cone 3.5” in Upper Body Tube Avionics Bay: 9” 3.5” in Upper Body Tube 3.5” in Middle Body Tube TC for Air Brakes Module: 3.75” 1.875” in Middle Body Tube 1.875” in Air Brake Module TC for Booster Module: 4.5” 3” in Air Brake Module 1.5” in Booster *We realized during the construction that to ensure the TC does not move, it must be at least 2” inside the BT. Unfortunately, some of these flaws were noticed well after the glue had set, and therefore we were unable to change it. We will take action to ensure that we do not make the same mistakes on the Full Scale, which we plan to place the TC at least 3” inside the BT.

Stability Analysis	
Center of Pressure (in from nose)	57”
Center of Gravity (in from nose)	43”
Static Stability Margin	3.05
Static Stability Margin (off launch rail)	4.29
Thrust-to-Weight Ratio	6:1
Rail Size and Length (in)	Quarter; 8 inches
Rail Exit Velocity	55.5 ft/s

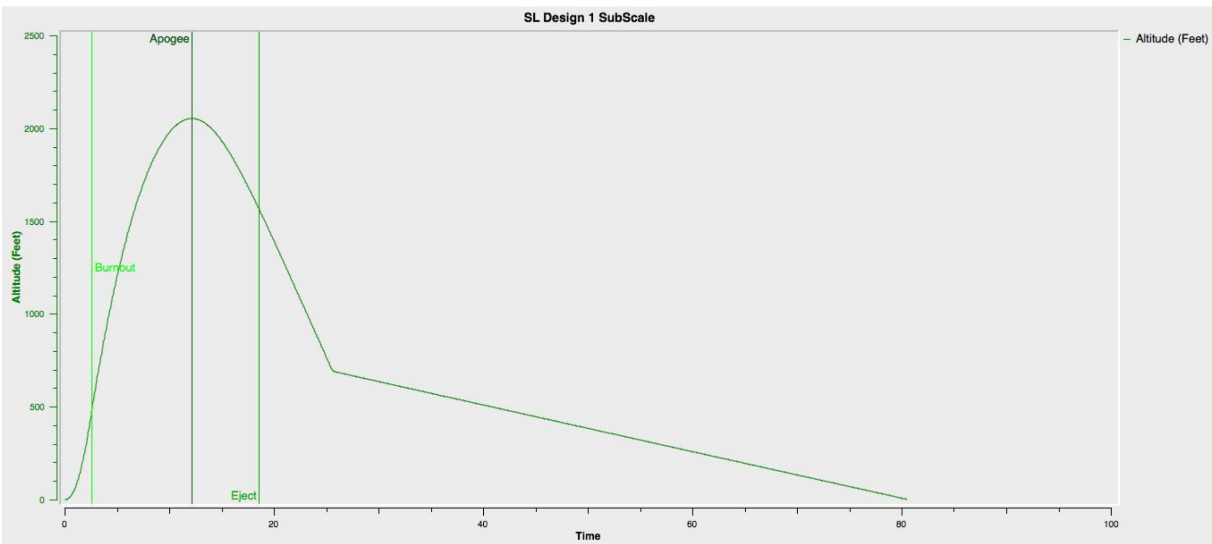
Ascent Analysis	
Maximum Velocity (ft/s)	349
Maximum Mach Number	0.308
Maximum Acceleration (ft/s^2)	3157.48
Target Apogee (From Simulations)	1900
Stable Velocity (ft/s)	346
Distance to Stable Velocity (ft)	551

Recovery System Properties				
Drogue Parachute				
Manufacturer/Model	Fruity Chutes			
Size	18”			
Altitude at Deployment (ft)			1934	
Velocity at Deployment (ft/s)			95	
Terminal Velocity (ft/s)			76	
Recovery Harness Material			Tubular Nylon	
Harness Size/Thickness (in)			.75	
Recovery Harness Length (ft)			1.167	
Harness/Airframe Interfaces	Eyebolt			
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	$Kinetic\ energy = \frac{1}{2}mv^2$ $= \frac{1}{2}(2.75\ lbs)(76\ ft/s)^2(\frac{1\ lbf}{32.2\ lb}$ $= 246.65\ lbf$	$Kinetic\ energy = \frac{1}{2}mv^2$ $= \frac{1}{2}(3.42\ lbs)(76\ ft/s)^2(\frac{1\ lbf\ s^2}{32.2\ lbm\ ft})$ $= 306.74\ lbf$	$Kinetic\ energy = \frac{1}{2}mv^2$ $= \frac{1}{2}(6.24\ lbs)(76\ ft/s)^2(\frac{1\ lbf\ s^2}{32.2\ lbm\ ft})$ $= 559.66\ lbf$	

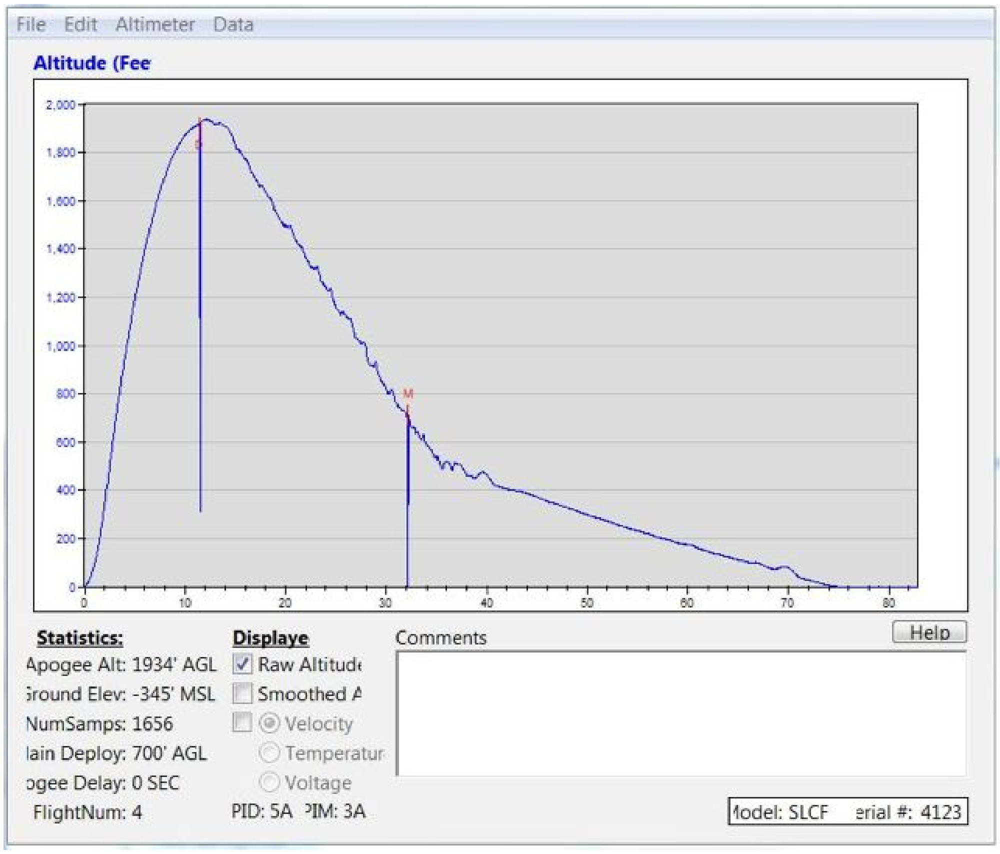
Recovery System Properties	
Main Parachute	
Manufacturer/Model	Fruity Chutes

Size	60”			
Altitude at Deployment (ft)			700	
Velocity at Deployment (ft/s)			56	
Terminal Velocity (ft/s)			56	
Recovery Harness Material			Tubular Nylon	
Harness Size/Thickness (in)			.75	
Recovery Harness Length (ft)			5.167	
Harness/Airframe Interfaces	Eyebolt			
Kinetic Energy of Each Section (Ft-lbs)	Section 1	Section 2	Section 3	Section 4
	$Kinetic\ energy\ =\ \frac{1}{2}mv^2$ $=\frac{1}{2}(2.75\ lbs)(6\ ft/s)^2(\frac{1\ lbf\ s}{32.2\ lbm}$ $=3.07\ lbf$	$Kinetic\ energy\ =\ \frac{1}{2}mv^2$ $=\frac{1}{2}(3.42\ lbs)(6\ ft/s)^2(\frac{1\ lbf\ s^2}{32.2\ lbm\ ft})$ $=1.91\ \ lbf$	$Kinetic\ energy\ =\ \frac{1}{2}mv^2$ $=\frac{1}{2}(6.24\ lbs)(6\ ft/s)^2(\frac{1\ lbf\ s^2}{32.2\ lbm\ ft})$ $=3.49\ lbf$	

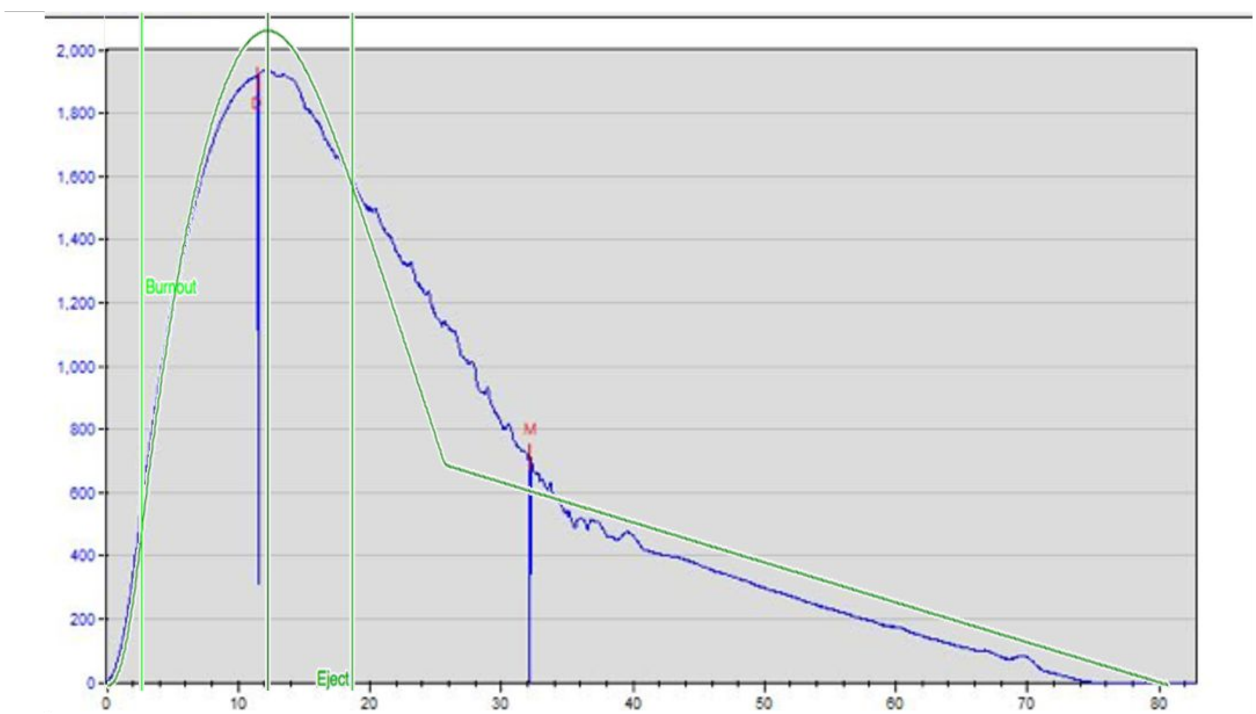
3.1.2.4.2 Error Between Actual and Predicted Flight Data



The above graph is a graph of the simulated flight in RockSim using launch day conditions



The above graph is the graph of the actual flight performed on January 7th, 2017.



The above graph is a graph of the two graphs overlaid, the green being the simulation graph, and the blue being the actual flight graph.

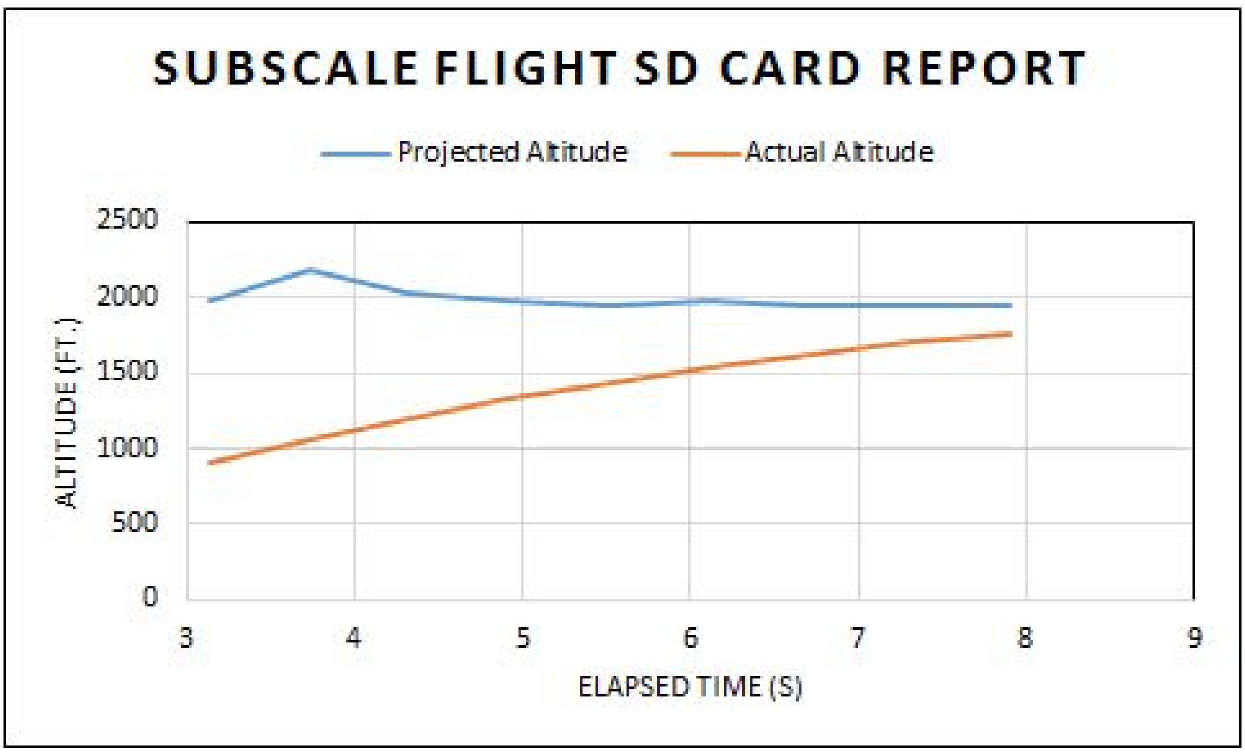
The predicted apogee was higher, due to the fact that we weren't able to simulate the airbrakes in RockSim. The real flight, shown in blue, implemented the use of air brakes. Also, the simulated flight was estimated to be about 81 seconds, when in reality, the flight was only about 74-75 seconds.

3.1.2.4.3 Estimated Drag Coefficient of Full Scale Rocket with Subscale Data

Based on the data from the subscale flight, the estimated coefficient of drag is 0.658.

Our SD Card Analysis indicates that our rocket would have achieved an altitude of 2024 ft before it first opened the air brakes. Our simulated data indicates the rocket achieved an altitude of 2024 with a coefficient of drag of 0.658. We overrode the calculated coefficient of drag in RockSim. Based on this, we estimate that the full scale rocket will have a coefficient of drag of 0.658.

3.1.2.4.4 SD Card Data Analysis for Subscale Flight



3.1.2.5 Impact of Subscale Data on Full Scale Launch Vehicle

The success of the subscale indicates that the omission of the aft fins will work well for the rocket on quiet days, with little to no wind.

The success of the air brakes also indicates that their use is viable in the full-scale. We will use these air brakes in our full-scale launch.

3.1.3 Recovery Subsystem

3.1.3.1 Recovery Subsystem Design Alternatives

Flight Computer	Pros	Cons
G-Wiz HCX	Easily programmable, dual deployment can be set in 100 foot increments. Comes with an SD card to record flights. Can also be used with 2 batteries to optimize safety.	Not available for sale anymore.
Stratologger CF	Easy to program, reliable manufacturer (PerfectFlite). It can record altitudes up to 100,000 feet, and stores 20 flights a second. Main deployment can be set in 1 foot increments for more precision.	Can only launch drogue at certain altitudes. Doesn't allow two batteries for increased safety.
RRC3 Sport	Easy to program and is pre set up at drogue deployment at apogee and main deployment at 500 feet. Reliable manufacturer (Mad Cow Rocketry) which we used in TARC. Allows two batteries.	Bigger than the stratologger and heavier (17g).
TeleMega Altimeter	Has an on board integrated GPS receiver (eliminating need for dog collar). Has accelerometer. Pyro events	Really expensive (costs $500). Relatively heavy (25g).

	like dual deploy can be configured to specific heights and times to increase accuracy.	
Raven Flight Computer	Really small (saves space). High quality data (accelerometer, barometric pressure, etc). Main deployment at 700 feet (fits with our deployment plan).	Hard to program. No flexibility with main deployment (can't change the altitude). Really expensive ($155).

3.1.3.1.1 Conclusions Drawn from Recovery Subsystem Design Alternatives

We decided to use the Stratologger CF flight computer as our primary flight computer and the RRC3 as our secondary one, keeping in mind cost and ease of accessibility. These two were our cheapest options, since both sold for less than $100. Even though they only provided altitude data, they were also the easiest to program compared to the other options. Finally, we picked them because they had reliable manufacturers. Our team had experience working with Mad Cow Rocketry for TARC, as we received parts from them, and we saw the reliability of Perfect Flite on multiple forums and product reviews.

The estimated mass of the subsystem is 930 g.

We will use an 18" diameter drogue chute and 84" diameter main chute. Both of them are from Fruity Chutes. Rationale for selecting this main chute can be found with the kinetic energy calculations in section 3.1.4.3.1.2.

3.1.3.2 Components of Recovery Subsystem

There are four primary components of recovery: the parachutes, the harnesses, the bulkheads, and attachment hardware.

3.1.3.2.1 Parachute

In the full scale, we will use a Fruity Chutes 84" Iris Ultra Standard Parachute as our main parachute

84" Iris Ultra Standard Information	
Parachute Material	Rip-stop nylon
Shroud Line Material	400lb Flat tubular Nylon

Mass	539 g
OD	84"
ID	36"
Shroud line length	84"
Shape	Toroidal
Coefficient of drag	2.2
Colors	Red, White

Picture above is of the Fruity Chutes Iris Ultra Standard Parachute from the Fruity Chutes website.

The full scale rocket will also use a Fruity Chutes 18" Classical Elliptical Parachute for its drogue chute

18" Classical Elliptical Information

Parachute Material	1.1 oz rip-stop nylon
Shroud Line Material	220 lb tubular nylon
Mass	49 g
OD	18”
ID	6”
Shroud line length	24”
Shape	Elliptical
Coefficient of drag	1.5-1.6
Colors	Red, White

The subscale rocket will use a Fruity Chutes 60” Iris Ultra Standard Parachute for its main chute.

60” Iris Ultra Standard Information	
Parachute Material	Rip-stop nylon
Shroud Line Material	220 lb tubular nylon
Mass	49 g
OD	60”
ID	28”
Shroud line length	62”
Shape	Toroidal
Coefficient of drag	2.2
Colors	Red, White

The subscale rocket will use a hexagonal parachute used in low-powered rockets for its drogue chute.

Hexagonal Parachute Information

Parachute Material	Rip-stop nylon
Shroud Line Material	Nylon
Mass	32 g
OD	18”
ID	6”
Shroud line length	24”
Shape	Hexagon
Coefficient of drag	Not provided by manufacturer; estimated to be 1.5
Colors	Brown

3.1.3.2.2 Harnesses

Name	Basic Information	Size on Full Scale	Size on Subscale
Tubular nylon for Fruity Chutes shroud lines	From Mad Cow Rocketry;must be replaced after several black powder tests and/or launches	400 lb tubular nylon	220 lb tubular nylon
Nylon Shock Cord	From Mad Cow Rocketry	1” Wide; Breaks at over 4000 lbs	9/16” Wide; Breaks at over 1500 lbs
Shock Cord Protector	From Mad Cow Rocketry; 30” long; accommodates 1” Wide Nylon Shock Cords and below; uses 7 oz orange fabric; flame resistant, but must be replaced after several black powder tests and/or launches	Identical protectors	Identical protectors
Swivels	From Mad Cow Rocketry;	1000 lb	1000 lb

	ball-bearing swivels, attach parachutes to shock cord		

3.1.3.2.3 Bulkheads

On the full scale, we will use 4” aluminum bulkheads from Mad Cow Rocketry to protect the avionics and payload electronics. These are 0.25” thick and have holes to hold the electronics sleds for both subsystems.

We have glued two 4” G10 fiberglass bulkheads from Mad Cow Rocketry, both 0.25” thick, to add more protection. This does absorb shock from the black powder charge for the drogue chute and the shock cord. It lies directly above the electronics powering the air brakes.

On the subscale, we will use 3” aluminum bulkheads from Mad Cow Rocketry to protect the avionics and payload electronics. These are 0.25” thick and have holes to hold the electronics sleds for both subsystems.

We have glued two 3” G10 fiberglass bulkheads from Mad Cow Rocketry, both 0.25” thick, to add more protection. This does absorb shock from the black powder charge for the drogue chute and the shock cord. It lies directly above the electronics powering the air brakes.

We have used a 4” wooden bulkhead to support the circular servo that opens and closes our air brakes. This does not absorb any shock from the rocket’s separation or from the ejection charge.

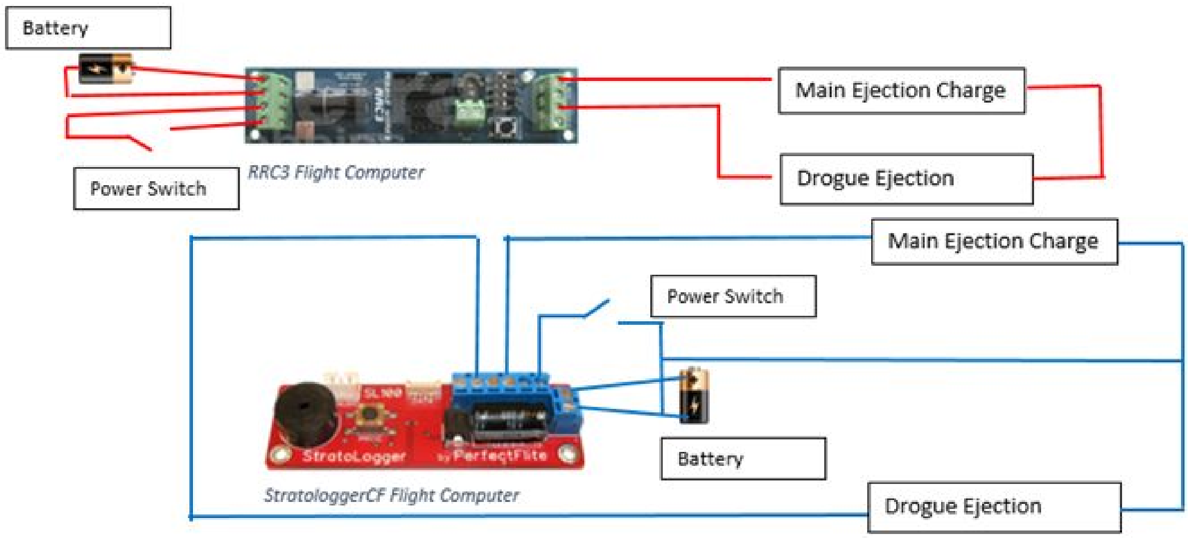
We have done the same thing with a 3” wooden bulkhead.

3.1.3.2.4 Attachment Hardware

Name	Basic Information	Size on Full Scale	Size on Subscale
Sea Dogs Machine Closed Eyebolts	Secured tightly with a nut to aluminum or fiberglass bulkheads Strength: 1000 lbs		1” wide
U-Bolt	Secured tightly with four nuts and a rectangular washer Strength: 1500 lbs	2” wide	

3.1.3.3 Electrical Components

3.1.3.3.1 Proof of Redundancy



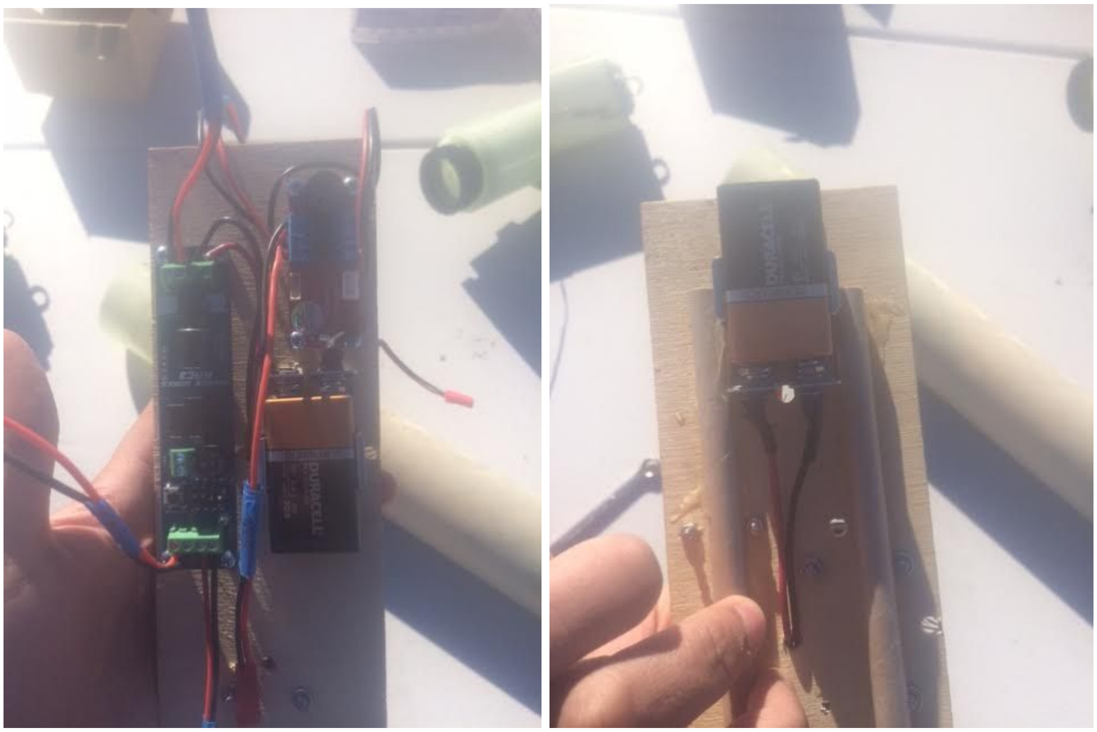
The fact that the wires of the stratologger and RRC3 do not get mixed together proves the redundancy of the dual-deploy system

3.1.3.4 Diagrams

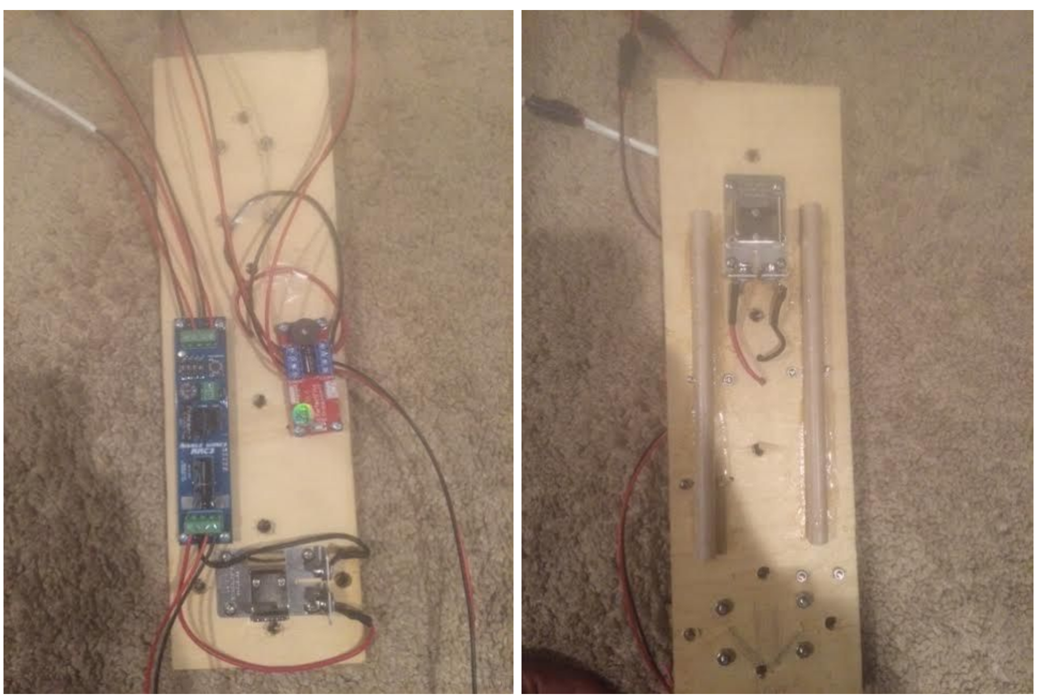
The following are the diagrams associated with recovery electronics.

3.1.3.4.1 Drawings and Sketches

Subscale:

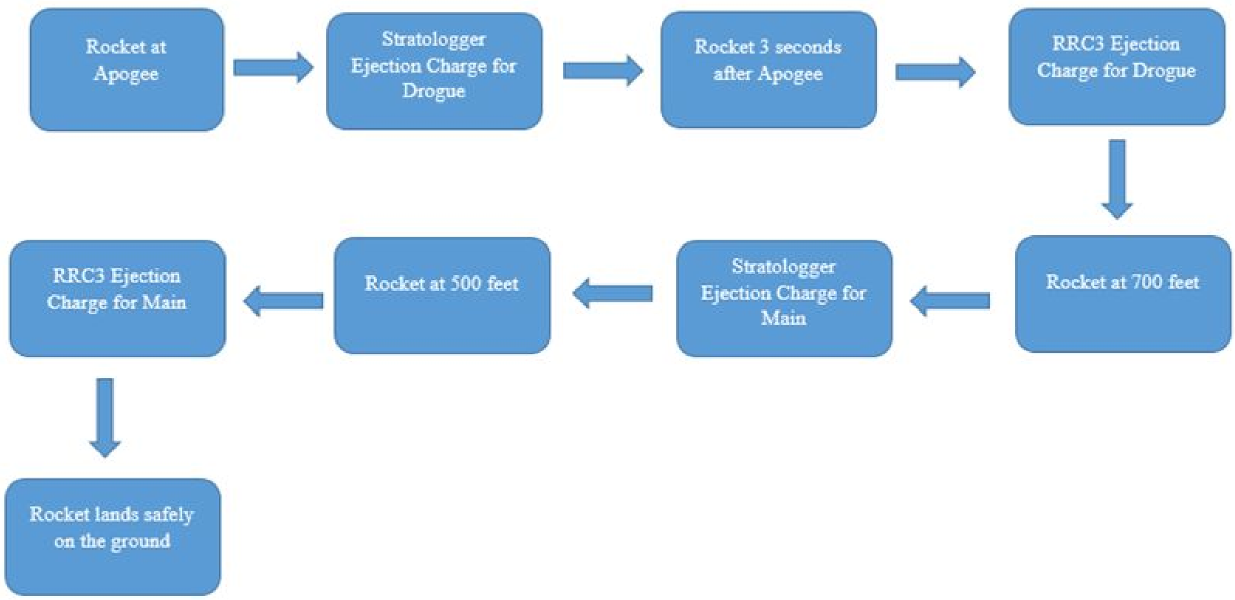


Full Scale:



3.1.3.4.2 Block Diagrams

This is the block diagram for recovery.



3.1.3.4.3 Electrical Schematics

As of now there are no electric schematics for the avionics bay.

3.1.3.5 Operating Frequency of Locating Tracker

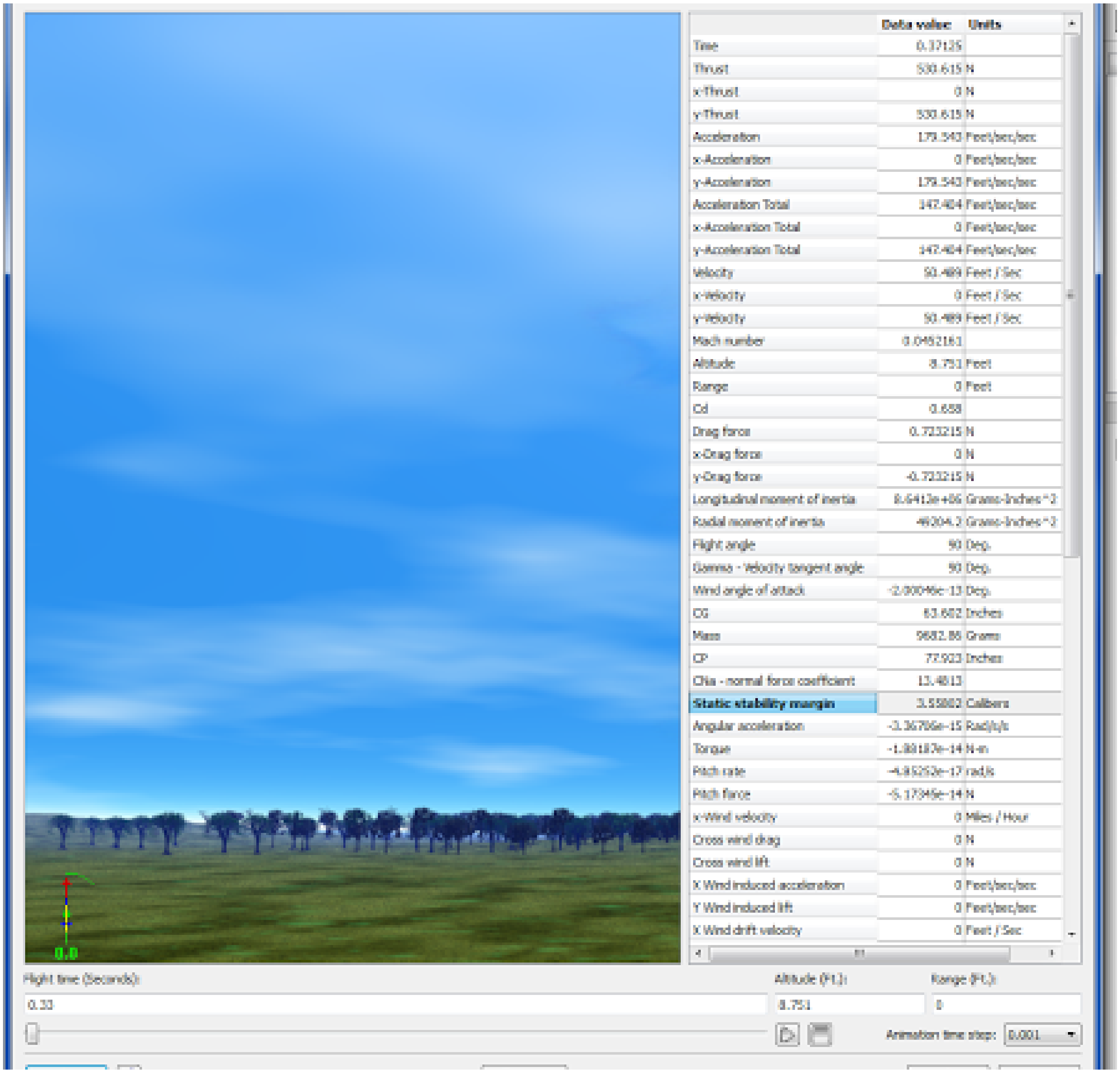
There is no separate GPS for recovery. The GPS can be located using the official Whistle GPS smartphone app. It can relay the battery percentage and rocket's location to a smartphone that is paired with the GPS.

3.1.4 Mission Performance Predictions

3.1.4.1 RockSim 9 Simulations

3.1.4.1.1 Flight Profile Simulations

These are flight profiles of our full-scale flight, in no wind:

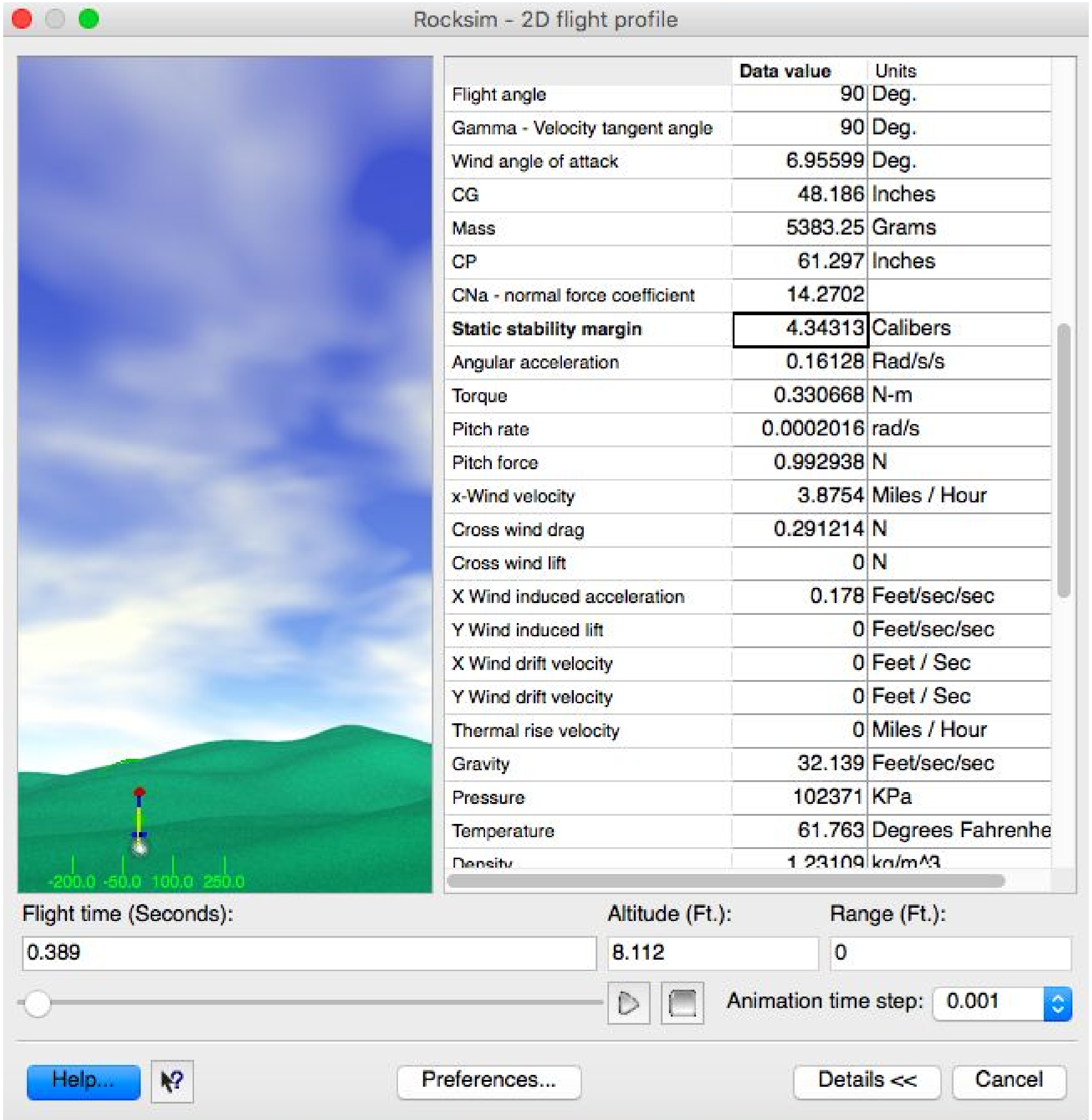


The rocket has a stability margin greater than 2.0 calibers at rail exit. It has a velocity of 48.28 ft/s at rail exit. The rail is 8 ft long.

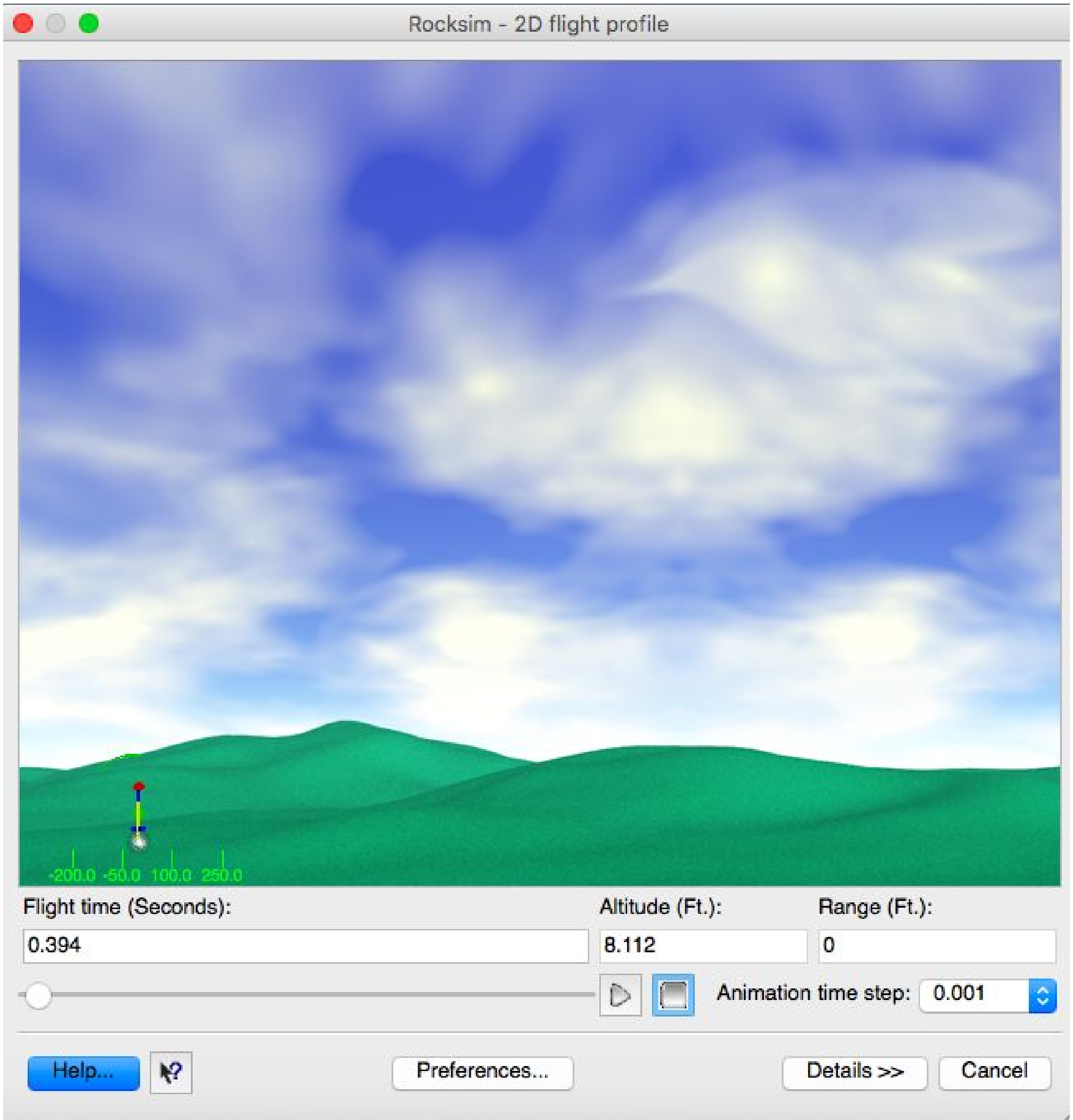
However, with the subscale's recreated flight, we found that RockSim predicted a rail exit velocity of 45.62 ft/s. The rail exit velocity during the rocket's actual flight was 55.5 ft/s. We suspect RockSim has an error in determining the actual rail exit velocity of the rocket.

The maximum altitude achieved by the rocket, without the assistance of air brakes, is 5724 ft.

These are flight profiles of our subscale flight:



Because RockSim's software is not completely user-friendly, we have managed to record the stability margin of the rocket near rail exit. We cannot find a way on RockSim to pinpoint at what moment the rocket leaves its 96" rail. The stability margin of the rocket must be at least 2.0 at rail exit; ours is 4.34.



In section 1.15 of the Statement of Work, the minimum velocity of the rocket is required to be 52 ft/s at rail exit. Our rocket achieved 55.5 ft/s at rail exit, according to the Stratologger.

3.1.4.1.2 Altitude Predictions with Vehicle Data

The predicted altitude of the rocket, without the aid of air brakes, is generally higher than the target altitude. We anticipate that the air brakes will be effective in bringing the altitude closer to the target altitude, but we must empirically test if the air brakes can lower the rocket by approximately 150 feet. If this altitude is determined to be too high, then we will select a

different motor that will bring the rocket closer to the target altitude without air brakes and still overshoot. Or, we will change the air brakes' length to increase drag.
The full scale rocket's maximum altitude, without the aid of air brakes and in no wind, is 5724 ft.

	Simulation	Results	Engines loaded	Max. altitude Feet	Max. velocity Feet / Sec	Max. acceleration Feet/sec/sec	Time to apogee	Velocity at dep Feet / Sec
2	1		[2406-K555-WH-P-N	5217.75	624.20	615.97	18.65	
3	2		[2406-K555-WH-P-N	5217.75	624.20	615.97	18.65	
4	3		[2406-K555-WH-P-N	5217.75	624.20	615.97	18.65	
5	4		[2406-K555-WH-P-N	5217.75	624.20	615.97	18.65	
6	5		[2406-K555-WH-P-N	5217.75	624.20	615.97	18.65	
7	6		[2406-K555-WH-P-N	5780.64	652.38	615.92	19.67	
8	7		[2406-K555-WH-P-N	5599.80	647.06	615.92	19.30	
9	8		[2406-K555-WH-P-N	5724.77	661.14	615.88	19.42	
10	9		[2406-K555-WH-P-N	5724.77	661.14	615.88	19.42	
11	10		[2406-K555-WH-P-N	5724.77	661.14	615.88	19.42	
12	11		[2406-K555-WH-P-N	5724.77	661.14	615.88	19.42	

We anticipate utilizing the air brakes will be a bit difficult in lowering the rocket's altitude, so we will experiment with longer air brake exposure on smaller rockets that use softer materials. We have used air brakes on Team America Rocketry Challenge launch vehicles and have continued testing them for the duration of this project. We can experiment there, with a much lower risk to people and the team's full-scale rocket.

The subscale's flight was recreated within RockSim. It helped us predict the coefficient of drag on the full scale.

3.1.4.1.3 Component Weights

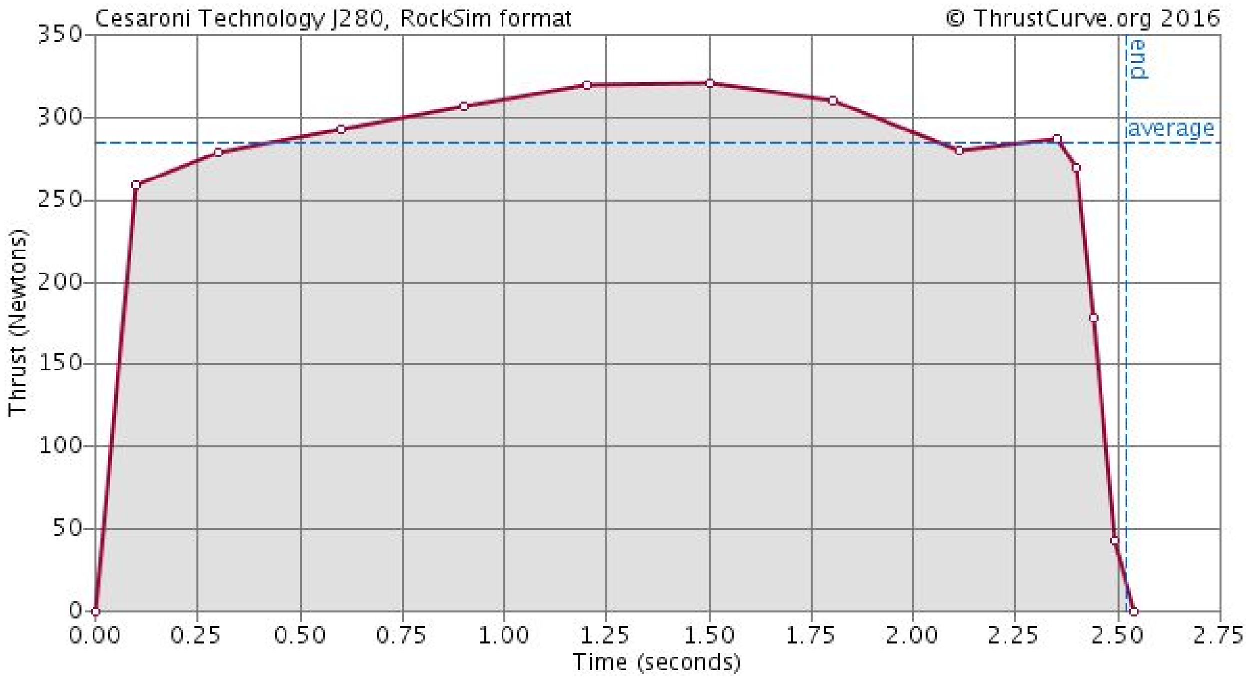
Component Name	Mass (g)	Length (in)	Thickness, if applicable (in)
Nose Cone	538.4	22	0.2
Whistle GPS	240		
Payload Collar	40	1.375	
Payload Enclosure (TC)	239	8	
Aluminum Bulkhead	80	0.25	0.25

Payload	142		
Aluminum Bulkhead	80	0.25	0.25
Eye Bolt	30		
Upper Body Tube	725	26	
84” Main Chute, swivel	540		
Blast Cloth	125		
Shock Cord	150		
Avionics Collar	60	1.5	
U Bolt	25		
Aluminum Bulkhead	80	0.25	0.25
Recovery Electronics (Avionics)	240		
2 Key Slots	60		
Electronics Bay (TC)	360	12.25	
Aluminum Bulkhead	80	0.25	0.25
U Bolt	25		
Middle Body Tube	315	12.75	
Shock Cord	150		
Drogue Chute	60		
Extension	210	8	
Eye Bolt	30		
2 Fiberglass	50	0.25	0.25

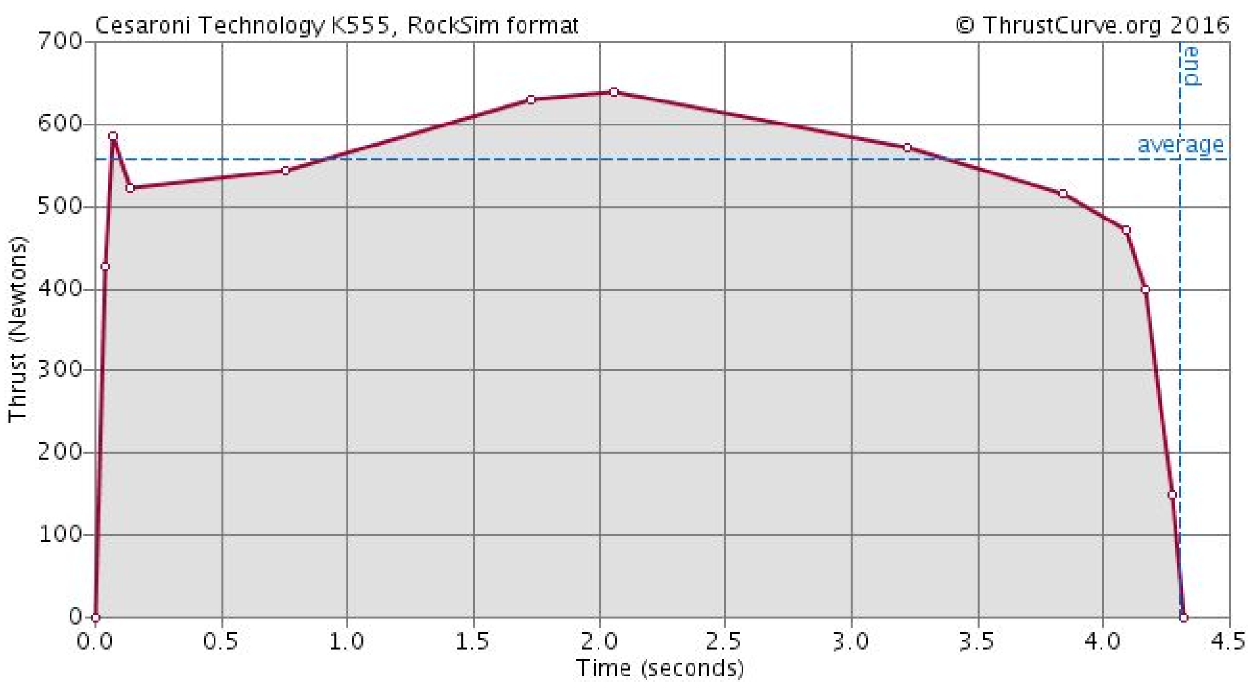
Bulkheads			
Tube Coupler	210	8	
Air Brake Module	235	8.375	
Tube Coupler	200	6.75	
Birch Bulkhead	37	0.25	0.25
Air Brakes	60	5	
Air Brakes Electronics	140		
Servo	185		
Booster	240	21.25	
Tube Coupler	200	7	
2 Fiberglass Bulkheads	50	0.25	0.25
Centering Ring	52.289	0.188	0.188
75 mm Motor Mount	400	19	
Fin Set	276	Semi-span: 4.5	0.3785
Centering Ring	52.289	0.188	0.188
Centering Ring	52.289	0.188	0.188
Total	9798.167	101.5*	

*Some of the lengths were not included because they are inside. For example, a tube coupler does not contribute to the overall length of the rocket.

3.1.4.1.4 Simulated Motor Thrust Curve



This is the simulated thrust curve of the Cesaroni J280, which has been used in our RockSim simulations of the subscale rocket.



This is the simulated thrust curve of the Cesaroni K555, which has been used in our RockSim simulations of the full-scale rocket.

Name	Total impulse (Ns)	Total Mass (g)	Max Altitude (ft), no air brake function	Max velocity (ft/s)	Max acceleration (ft/s^2)
K555	2400.688	2759.0	5724.77	661.14	615.88

3.1.4.1.5 Testing and Verification of Vehicle Robustness

The vehicle suffered no damage during its flight.

Its recovery harnesses can withstand enough force upon ejection. Please consult section 3.1.3 to see the details regarding the recovery.

The recovery subsystem was unharmed, albeit covered in the waste generated by discharging the black powder.

3.1.4.2 Stability Margin

On the full-scale:

CG = 63.9729” from nose cone

CP = 72.8491” from nose cone

$$Static\ stability\ margin = \frac{CP - CG}{Body\ Tube\ Diameter}$$

$$= \frac{72.8491" - 63.9729"}{3"}$$

$$= 2.22\ calibers$$

On the subscale:

CG = 47.9684” from nose cone

CP = 57.5678” from nose cone

$$Static\ stability\ margin = \frac{CP - CG}{Body\ Tube\ Diameter}$$

$$= \frac{57.5678" - 47.9674"}{3"}$$

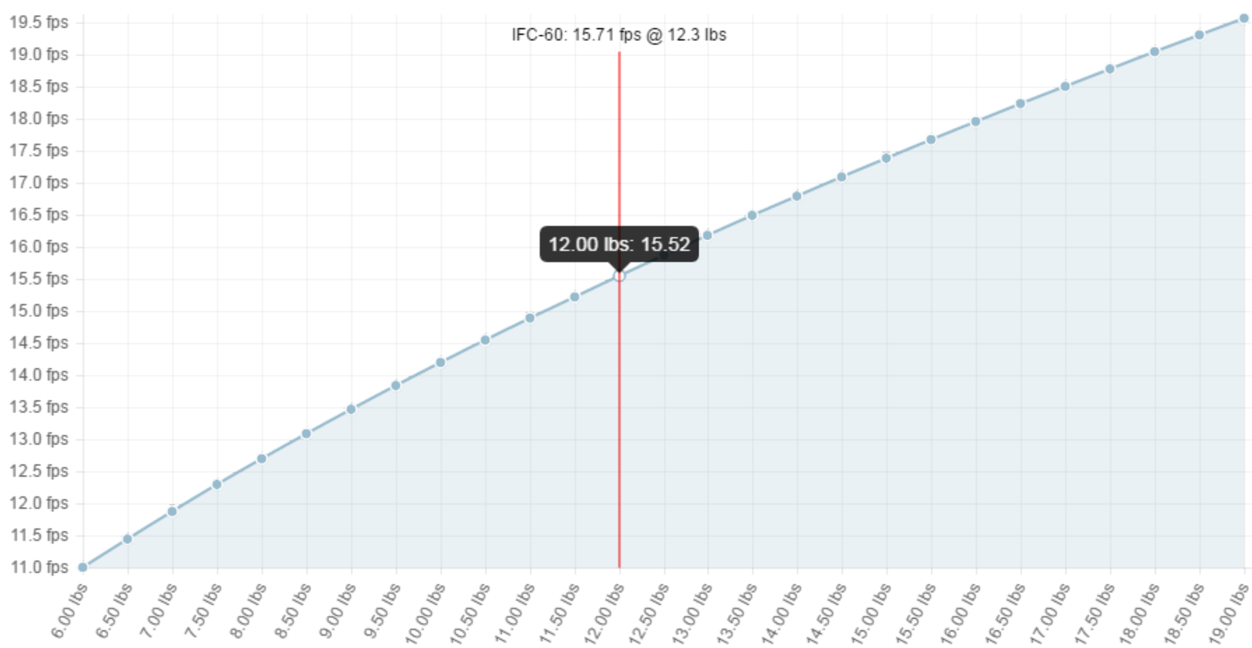
$$= 3.2\ calibers$$

3.1.4.3 Calculations

3.1.4.3.1 Kinetic Energy

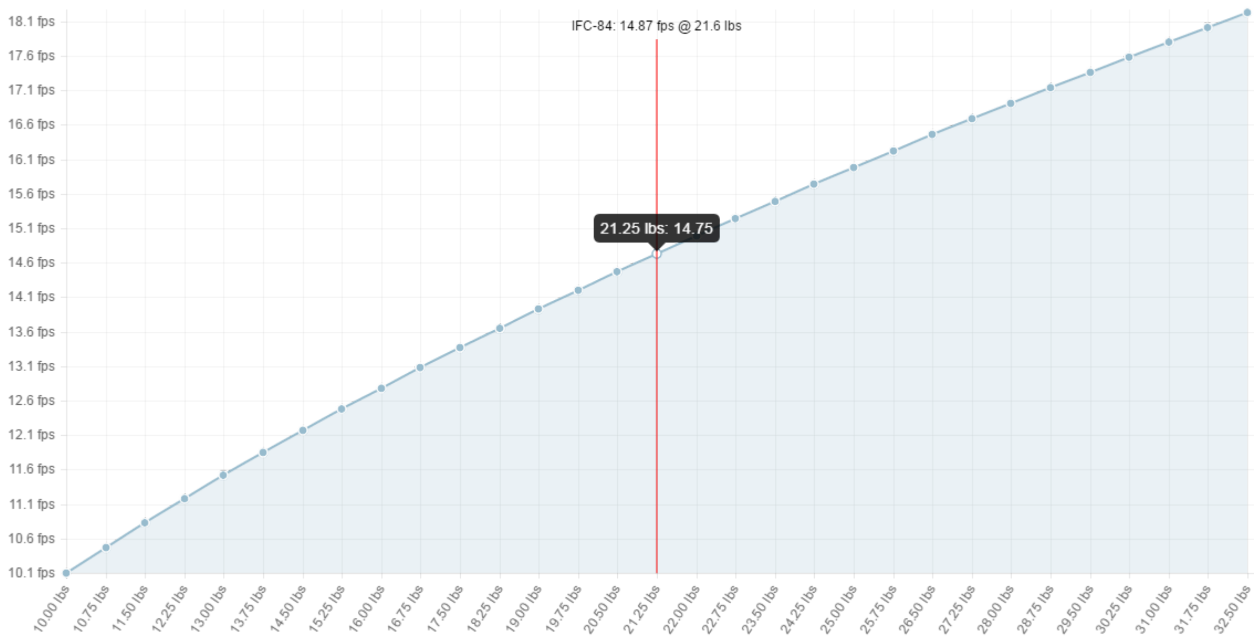
The following graphs relate to the subscale rocket's descent rate:

Subscale Descent Rate vs Weight, Main

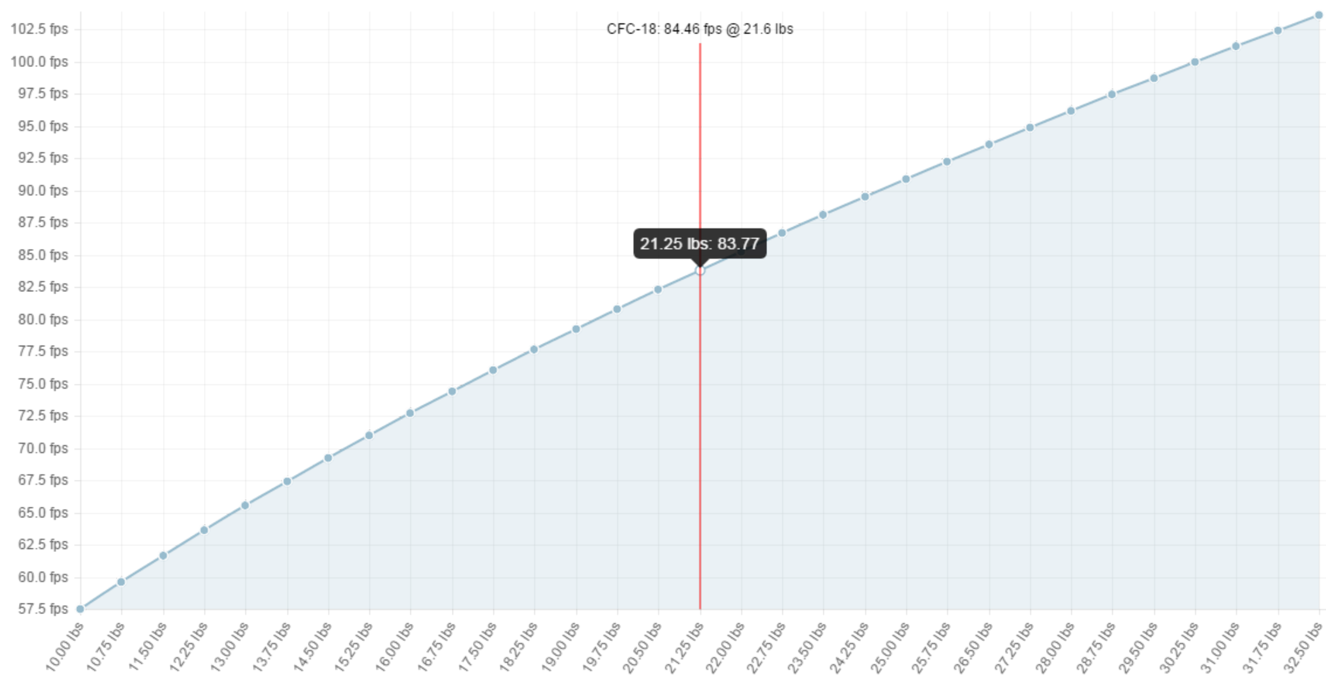


The following relates to the full scale rocket's descent rate.

Full Scale Descent Rate vs Weight, Main



Full Scale Descent Rate vs Weight, Drogue



Graphs from the parachute manufacturer: Fruity Chutes. This is their descent rate calculator.

On the full scale:

M = 9798.167 g = 21.6 lbs
V after drogue chute ejection = 84.46 ft/s
V after main chute ejection = 14.87 ft/s

On the subscale:
M= 5579.186 g = 12.3 lbs
V after drogue chute ejection = 135.6 ft/s*
V after main chute ejection, at landing = 6 ft/s*

⌂Our subscale rocket's drogue chute does not come from Fruity Chutes, so we are unable to give a graph.
*For the sake of real world accuracy, we will include the descent rates we obtained from our altimeter data.

3.1.4.3.1.1 Kinetic Energy With Drogue Chute Out

Full-scale calculations:
Kinetic energy with drogue chute out:

$$Kinetic\ energy = \frac{1}{2}mv^2$$
$$= \frac{1}{2}(21.6\ lbs)(84.46\ ft/s)^2\left(\frac{1\ lbf\ s^2}{32.2\ lbm\ ft}\right)$$
$$= 2392.600\ lbf$$

Subscale Calculations:
KE with drogue, on subscale:

KE with actual mass

$$Kinetic\ energy = \frac{1}{2}mv^2$$
$$= \frac{1}{2}(12.3\ lbs)(135.6\ ft/s)^2\left(\frac{1\ lbf\ s^2}{32.2\ lbm\ ft}\right)$$
$$= 3511.871\ lbf$$

3.1.4.3.1.2 Kinetic Energy With Main and Drogue Parachute Out

Full-scale calculations:
Kinetic energy with main and drogue chute out:

$$Kinetic\ energy = \frac{1}{2}mv^2$$
$$= \frac{1}{2}(21.6\ lbs)(14.87\ ft/s)^2\left(\frac{1\ lbf\ s^2}{32.2\ lbm\ ft}\right)$$
$$= 74.163\ lbf$$

Subscale calculations:

KE with main and drogue, on subscale:

KE with actual mass

$$Kinetic\ energy\ =\ \frac{1}{2}mv^2$$
$$= \frac{1}{2}(12.3\ lbs)(6\ ft/s)^2(\frac{1\ lbf\ s^2}{32.2\ lbm\ ft})$$
$$= 6.88\ lbf$$

3.1.4.3.2 Drift

The following drift calculations shall be performed under the assumption that the rocket will be launched straight up, or at a zero degree launch angle.

The subscale and full scale deploy their drogue chutes at apogee, and their main chutes at 700 ft AGL.

$$Drift\ =\ descent\ time\ \times\ descent\ velocity\ of\ wind$$

3.1.4.3.2.1 Drift in No Wind

Fullscale:

$$Drift = 122.1\ s\ \times\ 0\ mph$$
$$= 0\ miles$$

Subscale:

$$Drift = 70.12\ s\ \times\ 0\ mph$$
$$= 0\ miles$$

3.1.4.3.2.2 Drift in 5-mph Wind

Fullscale:

$$Drift = 122.2\ s \times (\frac{5\ miles}{1\ hour} \times \frac{1\ hour}{3600\ seconds})$$
$$= .170\ miles$$

Subscale:

$$Drift = 70.12\ s \times (\frac{5\ miles}{1\ hour} \times \frac{1\ hour}{3600\ seconds})$$
$$= 0.0974\ miles$$

3.1.4.3.2.3 Drift in 10-mph Wind

Fullscale:

$$Drift = 122.2\ s \times (\frac{10\ miles}{1\ hour} \times \frac{1\ hour}{3600\ seconds})$$
$$=\ 0.339\ miles$$

Subscale:

$$Drift = 70.12\ s \times \left(\frac{10\ miles}{1\ hour} \times \frac{1\ hour}{3600\ seconds}\right)$$
$$= 0.1948\ miles$$

3.1.4.3.2.4 Drift in 15-mph Wind

Fullscale:

$$Drift = 122.2\ s \times \left(\frac{15\ miles}{1\ hour} \times \frac{1\ hour}{3600\ seconds}\right)$$
$$= .509\ miles$$

Subscale:

$$Drift = 70.12\ s\ \left(\frac{15\ miles}{1\ hour} \times \frac{1\ hour}{3600\ seconds}\right)$$
$$= 0.2922\ miles$$

3.1.4.3.2.5 Drift in 20-mph Wind

Fullscale:

$$Drift = 122.2\ s \times \left(\frac{20\ miles}{1\ hour} \times \frac{1\ hour}{3600\ seconds}\right)$$
$$= .679\ miles$$

Subscale:

$$Drift = 70.12\ s \times \left(\frac{20\ miles}{1\ hour} \times \frac{1\ hour}{3600\ seconds}\right)$$
$$= 0.3896\ miles$$

3.1.4.3.3 Energetics Calculation

We will calculate how much 4F black powder we need in the rocket's two cavities. The black powder is a necessary component of our recovery subsystem.

3.1.4.3.3.1 Energetics with Subscale Model

In the body tube, where the main chute is stored, the cavity is 17.5 in long.

$$N = 0.00052\ F \times L$$
$$F = A \times P + force\ needed\ to\ shear\ a\ shear\ pin \times number\ of\ shear\ pins$$
$$= \left(\frac{Diameter}{2}\right)^2 \times P + force\ needed\ to\ shear\ a\ shear\ pin \times number\ of\ shear\ pins$$

$$N = 0.00052\ (A \times P + \sum shear\ pin\ force) \times L$$

$$= 0.00052\ \left(\left(\frac{3\ in}{2}\right)^2 \pi \times 24\ psi + (3\ pins)(35 lbs/pin)\right) \times 17.5\ in$$
$$\approx 2.50\ g$$

In the body tube, where the drogue chute is stored, the cavity is 6.25in long.

$$N = 0.00052\,F \times L$$

$$F = A \times P + \textit{force needed to shear a shear pin} \times \textit{number of shear pins}$$

$$= (\tfrac{Diameter}{2})^2 \times P + \textit{force needed to shear a shear pin} \times \textit{number of shear pins}$$

$$N = 0.00052\,(A \times P + \textstyle\sum \textit{shear pin force}) \times L$$

$$= 0.00052\,((\tfrac{3\,in}{2})^2\pi \times 22\,psi + (3\,pins)(35 lbs/pin)) \times 6.25\,in$$

$$\approx 0.85\,g$$

3.1.4.3.3.2 Energetics with Full Scale Model

In the body tube, where the main chute is stored, the cavity is 18.5 in long.

$$N = 0.00052\,F \times L$$

$$F = A \times P + \textit{force needed to shear a shear pin} \times \textit{number of shear pins}$$

$$= (\tfrac{Diameter}{2})^2 \times P + \textit{force needed to shear a shear pin} \times \textit{number of shear pins}$$

$$N = 0.00052\,(A \times P + \textstyle\sum \textit{shear pin force}) \times L$$

$$= 0.00052\,((\tfrac{4\,in}{2})^2\pi \times 24\,psi + (3\,pins)(35 lbs/pin)) \times 188 in$$

$$\approx 3.81\,g$$

In the body tube, where the drogue chute is stored, the cavity is 4 in long.

$$N = 0.00052\,F \times L$$

$$F = A \times P + \textit{force needed to shear a shear pin} \times \textit{number of shear pins}$$

$$= (\tfrac{Diameter}{2})^2 \times P + \textit{force needed to shear a shear pin} \times \textit{number of shear pins}$$

$$N = 0.00052\,(A \times P + \textstyle\sum \textit{shear pin force}) \times L$$

$$= 0.00052\,((\tfrac{4\,in}{2})^2\pi \times 24\,psi + (3\,pins)(35 lbs/pin)) \times 5\,in$$

$$\approx 1.06\,g$$

4 Safety

4.1 Launch Concerns and Operation Procedures

When entering the launch process, numerous issues and concerns are present in regard to the safety of the process. These concerns will be identified later on through mitigation charts and FMEA charts. Step by step processes of the final preparation of the rocket prior to launch, ensuring the consideration of safety during every part of our preparation and launching process.

4.1.1 Draft of Final Assembly and Launch Procedures

The vehicle itself is in three separate sections – a top section, the avionics bay, and the bottom section. Within the top section is the payload bay, GPS, and main parachute.. The bottom section has the drogue chute, airbrake module, and finally followed by the booster with the motor. To assemble the rocket:

1. Upper Section Initial Assembly
    a. Turn on the GPS and place it in the nose cone of the rocket. Once turned on, check connection to the app on the phone.
    b. Secure the payload bay to the nose cone with designated screws. (For the subscale flight, we will not be launching our payload, so a substitute mass must be placed in the bay)
    c. Fold the main parachute and make certain it is attached to the blast cloth and an ample amount of shock cord. Wrap the parachute in the blast cloth and slide into the main parachute body tube.
    d. Tie the ends of the main parachute shock cord to the bulkheads of the payload bay and avionics bay. Check the knots for security.
2. Upper Section Final Assembly
    a. Make sure that the ends of the shock cords are attached to both the payload bay and the avionics bay.
    b. Check for GPS function.

c. Prepare two ejection charges for the main parachute and attach to the terminal blocks on the avionics bay.
d. Secure the payload bay to the nose cone with two designated screws.
e. Secure the main parachute body tube to the payload bay with three shear pins.

3. Avionics Bay Assembly
    a. Make certain that fresh batteries are installed in the avionics bay, and ziptie them.
    b. Attach the 4 wires from the terminal blocks on the upper end of the avionics bay to the terminal blocks on the sled for the drogue and main.
    c. Attach the 2 wires from the key switches to the terminal blocks on the sled.
    d. Slide the sled in.
    e. The avionics bay can now be secure with the two nuts.
    f. Turn the switches ON and short each pyro charge on the terminal blocks checking that the beeping reflects an ematch connected.
    g. Make certain that all switches are off, and attach the ejection charges.
4. Lower Section Initial Assembly
    a. Fold the drogue parachute and make certain it is attached to the blast cloth and an ample amount of shock cord. Wrap the parachute in the blast cloth and slide into the drogue parachute body tube.
    b. Tie the ends of the drogue parachute shock cord to the bulkheads on the avionics bay and in the drogue parachute body tube.
    c. Place airbrake electronics inside slot above the airbrakes in the airbrake module.
5. Lower Section Final Assembly
    a. Prepare two ejection charges for the drogue and attach to the terminal blocks on the avionics bay.
    b. Place the two ejection charges into the lower section of the body tube.
    c. Plug in the battery on the designated pins in the airbrake electronics.
    d. Secure the drogue parachute body tube to the to the airbrake electronic section with two designated screws.
    e. Secure this portion of the rocket with the booster section with two designated screws.
    f. Secure the front end of the drogue chute body tube to the avionics bay with 3 shear pins.

4.1.1.1 Recovery Preparation

Iris Ultra Standard Parachute Folding Manual

Steps:

1. Spread the parachute out completely on the flat surface.
2. Fold left side of the rocket over to the right side of the rocket (or vice versa).

3. Make sure the shroud lengths are not tangled.
4. Fold once more from either side to side.
5. Repeat step 4 with step 3 immediately following it until parachute is a reasonable size.
6. Section the remaining parachute top to bottom into thirds but don't fold.
7. Fold the top third onto the middle third while folding the shroud lengths up into the bottom half but not exceeding the limit of the bottom third section.
8. Finish folding the thirds into one piece.
9. Roll tightly on the long side.
10. Have another person pull tightly on the shroud lengths while you wrap the parachute up in the shroud lengths.
11. Roll the shroud lengths to one side of the parachute and then roll back towards the other side.
12. Place in blast cloth and cover side of parachute facing towards blast sufficiently.
13. The rolled up parachute should be thinner on one edge than the other so place the yellow connector on the thinner half while the split half should be at the top of the parachute.
14. After covering the top and bottom of the parachute with the blast cloth, pull one side of blast cloth to cover parachute and begin rolling towards the other side of the blast cloth.
15. Fit the parachute and blast cloth into rocket cavity and measure the psi needed to pull out the blast cloth. Do this by hooking the ring onto the split half or by pulling with bare hands.
16. If psi exceeds 3 or is tough to pull out of body tube, repeat steps 10 - 15.

Patience is highly necessary for parachute folding

4.1.1.2 Motor Preparation

The ejection charge for the motor must be removed. So, we will scrape out all ejection charge gunpowder.

After removing the ejection charge, we will insert the motor into its Cesaroni motor casing, secure the motor inside of the casing and screw the motor retainer tightly over the motor casing. The motor should not slide further into the rocket's motor mount.

The full checklist for motor preparation is in section 6.2.

4.1.1.3 Setup on Launcher

When placing the rocket on the launch rail, we will make sure the igniter is out of the rocket. The avionics must be turned off during the preparation stage. If the battery voltage is around 9.2 V-9.3 V, we will proceed with the launch. If otherwise, we will terminate the launch immediately. The SL team will make sure the igniter is placed in last so that in case of a unexpected launch, the recovery systems are armed and ready to deploy in flight. The following sections will also describe our troubleshooting for each section of the rocket, and our inspection plan after the flight as well.

4.1.1.4 Igniter Installation

Remove the igniter from its antistatic package and twist the leads. Run it all the way up the nozzle until it reaches the end. Mark on the igniter's wires where the match head stops. This mark should indicate how far the igniter should be inside the motor.

Before the igniter is installed, check for continuity. This can be easily checked by tapping the two alligator clips to produce a red light at the main electronics center. To install the igniter correctly so the launch can proceed without a delay or any other mishap, the igniter must be straightened out and stuck up the motor as far as possible. This is done by lowering the launch rail horizontally to the ground and then pushing in the wire, hence the easier access. Once the tip of the igniter cannot be shoved in any further, untwist the leads and wrap them separately around the alligator clips. Once this is completed, set the alligator clips at the side of the launch rail but without touching any metal which could create a short circuit and not launch the rocket.

4.1.1.5 Troubleshooting

4.1.1.5.1 GPS Troubleshooting

Our Whistle GPS uses an iPhone app. To see if the GPS is ready for launch, we will check the Whistle GPS app.

Problem	Mitigation
The battery percentage is not displayed.	The Whistle GPS will be turned on, and we will check the Whistle GPS app to see that its battery is turned on. We should now see a percentage and the location of the GPS.
The GPS is not inside of its "Whistle Zone," the designated 1-mile radius area where the rocket will be launching.	We will reset the Whistle Zone to the current location of the launch or to a different location of our choosing via the Whistle GPS app. Now we will be able to monitor the GPS's movement during the rocket's ascent and descent.
The GPS is out of battery.	We will return the GPS to its base station and have it sufficiently charged. The base station will alert us through the app if the GPS is

	charging. Charging must be done before the launch to prevent this scenario from being realized.
The GPS is not mounted on its board.	We will use zipties and loop them through the holes we drilled on the board. We will secure the GPS by tightening the zipties until the GPS is unable to move. We will cut the zipties when we need to remove the GPS.

4.1.1.5.2 Payload Troubleshooting

Problem	Mitigation
Battery is not plugged in	We will make sure the light on the Teensy and CO2 Sensor are on to confirm that the battery is plugged in.
Battery is low	Always check the battery voltage using a voltmeter to see if it is at least 7 volts before every flight. Otherwise, replace the battery.
Wires are loose	We will be sure that the wires connecting the electronics are securely tightened around the pins before every launch. If some become loose, we will either tape the wires or replace them.
Any electronic device isn't securely mounted on the sled	Tighten the zipties around the Teensy, battery, and CO2 Sensor to keep it attached on the board during the flights.

4.1.1.5.3 Main Chute Troubleshooting

Problem	Mitigation
Parachute is too bulky	Refold the parachute, and wrap the shroud lengths tighter around the parachute to shrink the space needed in the body tube for the parachute.

Blast cloth wrapped insufficiently	Before placing the folded parachute and blast cloth into the body tube, have another person check that the blast cloth is facing towards the blast with the cleaner side on the inside (holding the parachute) and the darker side facing the blast.
Tangled shroud lengths	Refold the parachute by starting completely from the beginning and have another person pull on all of the shroud lengths while you turn the parachute in your hands right or left to untangle.

4.1.1.5.4 Avionics Troubleshooting

Problem	Mitigation
Flight computers are not turning on.	Check to see if the power switch wires and battery wires on the sled are connected. 99% of the time, this will be the problem. Otherwise, don't launch.
Flight computers beep different from what is expected.	Reprogram the flight computer according to the manual. If it is still showing different than what you would expect, then the flight computer is probably broken.
Battery Voltage is not over 9.	Replace the batteries.
The board is not fitting inside the coupler.	Check to see if the wires are all in the right sides. The power switch wires should be on the other side of the board, as well as one of the main wires and one of the drogue wires.

4.1.1.5.5 Drogue Chute Troubleshooting

Problem	Mitigation
Parachute is too bulky	Refold the parachute, and wrap the shroud lengths tighter around the parachute to shrink the space needed in the body tube for the

	parachute.
Blast cloth wrapped insufficiently	Before placing the folded parachute and blast cloth into the body tube, have another person check that the blast cloth is facing towards the blast with the cleaner side on the inside (holding the parachute) and the darker side facing the blast.
Tangled shroud lengths	Refold the parachute by starting completely from the beginning and have another person pull on all of the shroud lengths while you turn the parachute in your hands right or left to untangle.

4.1.1.5.6 Air Brakes Troubleshooting

Problem	Mitigation
A team member putting together the airbrake electronics does not know which wires connect to which pins.	The pins and wires are color coded, and the pins are labeled. For the battery input, red and black pins are clearly labeled.
The battery is not connected correctly, with reverse polarity.	The battery wire will be attached last and the work done by one person will be closely checked by the other. Labels should also prevent this from occurring,
When the battery is connected, the Teensy does not flash red.	The battery will be disconnected and all the connections will be checked.
Airbrakes might not function during the flight of the rocket.	Prior to launch, a vacuum test will be performed. By putting the altimeter in the vacuum, a height will be simulated, and airbrakes will be checked to see if they open.
The airbrake breaks, whether it is the arm, the wing, the hinge, or horn.	The airbrake wings will need to be taken off to reattach the broken part. Construction is required.

4.1.1.5.7 Motor Troubleshooting

Problem	Mitigation
The motor still has its ejection charge.	We will scrape out all of the ejection charge and add a plug to prevent an internal explosion. This is so the rocket does not damage itself after the motor finishes burning.
The motor retainer is very loose.	We will tighten the retainer until it is secure. If the retainer falls during flight, it could pose a lethal hazard to bystanders and could also impede the rocket's flight should the motor fall out.

4.1.1.6 Post-flight Inspection

After the flight is completed and the rocket is safely on the ground, (do not jump and catch any part of the rocket) carefully pick up the rocket and bring it back to the setup area. Unscrew the (middle part) and the nosecone to check the results of the altimeter and the egg, respectively. Once altimeter has been taken note of and the egg is not damaged in any way, examine the rocket for any tears or scrapes that need fixing.

4.2 Safety and Environment (Vehicle and Payload)

To complete this SL project, each member of the team needs to deliver the tasks asked from them. Overall, the rocket design, payload specifications, educational engagement, budget specifications, and safety plans are the basic measures necessary for the success of the project. Safety is a key consideration in every aspect of this project, as team members must be aware of certain risks and dangers while designing the rocket, physically constructing the rocket, launching the rocket, and recovering the rocket. Risks can be consequential for all components of the project, as it can create setbacks if the risks fail to meet requirements. To avoid this, project planning has been established, along with making sure that safety is not looked over when focusing on efficiency.

4.2.1 Safety Analyses

Our team has created checklists for launch preparation, which should take less than 3 hours. The checklists guide the team through safe and complete preparations for launch. The checklists for the rocket as a whole and its designated sections are located in Section 4.1 Launch Concerns and

Operations Procedures and Section 6 Launch Operation Procedures. Below is the summary for the checklists we have.

- Preparation for launch and assurance that all safety interlock switches are off and batteries uninstalled.
  - The safety interlock switches will be verified as “OFF” and batteries for the recovery electronics will be installed.
- The battery for the GPSs and payload will be installed but will remain off.
  - The Whistle GPS will be placed in a foam cutout and secured to the shock cord. The drogue parachute will be packed in the second main body tube. and the main parachute packed in the main body tube. The payload will be turned on throughout the entire flight, and since there is no telemetry but rather an SD card to store the payload data, the SD card will start recording the moment the Arduino’s battery is turned on in the ground.
- Four ejection charges will be prepared and installed (1 for the drogue and 1 for the main for each of the redundant and backup electronics).
  - The two ejection charges for the main will be placed behind the parachutes from Fruity Chutes, and will be in series. The shear pins can be put into place holding the vehicle sections above and below the avionics bay. The rocket can then be placed on the pad (standard launch rail), electronics armed, igniter installed and connected to the electronics launch system. It is necessary only to apply power to the igniter for the launch. The total time for setting up on the pad should take less than 1 hours.
- Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.
  - There will be shear pins (2mm nylon screws) at all separation points. The shear pins will keep all points of separation attached while the rocket is moving upwards, and this is mainly to make sure that the rocket does not separate before necessary. The primary and backup ejection charges will have enough force to break through the shear pins, ensuring that the main and drogue parachutes deploy.
- Folding and protecting the parachutes
  - The drogue and main parachutes must be placed inside blast protectors so that they are not damaged by the black powder charges and remain functional for a safe descent.
- Listening to the beeps of the avionics electronics
- Checking electronic programming and functionality
- Checking for continuity
- Igniter installed correctly
- Check if range and sky are clear

Launch procedures and waivers will be taken care of by the Rocketry Organization of California in Lucerne Dry Lake, where we plan to have our full-scale model and scale model flights.

4.2.1.1 Personal Hazard Analysis

The SL team has developed a series of risk mitigation plans to reduce the risk of this project.

4.2.1.1.1 Hazardous Materials Safety

While completing the launch vehicle, team members will frequently come into contact with hazardous materials. These substances will not be dangerous to the team members as long as these rules are followed when handling. Concerning materials include adhesives, paints, and the actual materials used to build the vehicle. The manufacturer of those materials knows best about the posed hazards. Each manufacturer and safety organizations publish MSDS for each product. Handling these materials will require the use of Personal Protective Equipment (PPE).
An MSDS (Material Safety Data Sheet) is available to provide an overview explaining how to work safely with and handle specific chemicals or materials. It is compiled by the manufacturer of the particular chemical. Although MSDS do not have a particular format, they are required to have certain information per OSHA (Occupational Safety and Health Administration) 29 CFR 1910.1200. A list of the required information can be found here on this website.
Listed are some threats to team members' safety that must be accounted for (see details below the table):

Risk	Mitigation
Impact to the body	Gloves, apron, goggles
Cut or puncture	Gloves and Apron
Chemicals – fumes and/or direct contact	Gloves, respirator, goggles
Heat/cold	Gloves
Harmful Dust and small particles	Mask and Goggles
Loud noises	Earplugs

The team will keep a copy of the MSDS for all materials used in the making of the vehicle when an MSDS exists for a certain material. The following items will be present and available for team member use whenever they are working, constructing the vehicle or payload, or launching.

- Safety goggles
- Rubber gloves
- Protective aprons
- Ear Plugs

- Leather gloves
- Respirators / Dust Masks

Eye protection must be worn whenever there is a danger of:

- Dust, dirt, metal, or wood chips entering the eye. This can happen when sawing, grinding, hammering, or using power tools.
- Strong winds during a launch (common at Lucerne Dry Lake)
- Chemical splashes when using paints, solvents, or adhesives
- Objects thrown (intentionally or inadvertently) or swinging into a team member

These types of gloves must be worn to protect the team member's hands whenever there is danger of contact with a hazardous material:

- Latex or rubber gloves for possible contact with hazardous chemicals such as adhesive, paint, or thinners, or dangerous solid materials.
- Leather gloves to protect against impact, cuts, or abrasions (e.g. in the use of some power tools such as grinders)

Team members will always work in a clean, well-ventilated area. Protection for a team member's lungs (dust mask or respirator) must be used when:

- Working with chemicals emitting fumes (e.g. paints and solvents). In this case, the team member must wear a respirator.
- Working in an environment where there is dust (e.g. sanding and working with power tools). The team member must wear a dust mask.

Body protection, such as an apron must be worn whenever there is danger of:

- Splashes or spills from chemicals
- Possible impact from tools

Ear protection (plugs or ear muffs) must be worn whenever there are loud noises present, which include:

- Using loud power tools or hammers
- Launching larger rocket motors at launches

When creating documents that require work with potentially hazardous materials including chemicals, that section will be marked with the following:

"HAZARDOUS MATERIAL - SEE MSDS"

A sample MSDS is included in Appendix to show what is included. As materials are identified during the research and design phases of this project, suitable MSDS for those materials used will be gathered and made available to all team members in hard copy form at the work area as well as on the web site.

4.2.1.1.2 Range Safety Officer (RSO) Duties

Based on the requirements set by the Statement of Work, Sahil, the RSO, must:

- Monitor team activities with an emphasis on Safety during:

- Design of vehicle and launcher
- Construction of vehicle and launcher
- Assembly of vehicle and launcher
- Ground testing of vehicle and launcher
- Sub-scale launch test(s)
- Full-scale launch test(s)
- Launch day
- Recovery activities
- Educational Engagement Activities
- Implement procedures developed by the team for construction, assembly, launch, and recovery activities
- Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data
- Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.

4.2.1.1.3 Vehicle Risk Mitigation

1. Risk - The engine does not ignite while conducting the launch of the rocket. Mitigation - Prior to launch, multiple team members will check to make sure the igniter is properly inserted in the engine to its full length, ensuring ignition of the motor.	4. Risk - The rocket body caves in, or collapses on itself. Mitigation - The team will use fiberglass for the body tube, a material capable of withstanding outside forces. Inside, flight boards, bulkheads, and centering rings will help to maintain the circular frame of the body tube.	7. Risk - The electronic matches fall out of their designated place. Mitigation - Before placing the shear pins, the matches will be checked to ensure that they have been tightened down to remain in place. This task will be placed on a checklist that members will go through while preparing the rocket for launch.
2. Risk - The engine does not fit (too loose or tight) in the motor casing. Mitigation - The team will make sure the engine is inserted in the proper motor casing, and cannot be shaken or pulled out with ease. The team will also check when the motor casing is inserted	5. Risk - The quick links are not attached properly. Mitigation - The team will double check all connections to ensure that the rocket is assembled completely before preparing the rocket for launch. These tasks will be written on a checklist, which members who checked the	8. Risk: Motor explodes Mitigation: Detailed instructions will be followed step by step when building the motor. Team members will be required to maintain focus and detail while putting together the motor.

into the motor mount.	task will sign off to take responsibility.	
3. Risk: Airbrakes do not function while in flight. Mitigation: When electronics, are activated at ground level, a test for airbrake function will be performed. The airbrake motors will checked prior to assembling the whole rocket.	6. Risk - The shear pins do not shear due the ejection charge. Mitigation - When purchasing the pins, the team will note the force required to shear them. The team will perform black powder ground tests to make sure the ejection charges exert more force than the pins can withstand. To ensure shearing, the backup charge will have a greater amount of black powder.	9. Parachute was not packed correctly and does not deploy Mitigation: The team will check to make sure the parachuted is fitted correctly into the body of the rocket prior to launch. However, if the primary ejection charge does not separate the rocket, backup ejection charges with greater amounts of black powder will allow the parachute to deploy.

4.2.1.1.4 Payload Risks and Mitigations

1. Risk: SD card is defective Mitigation: Test run before the actual flight.	4. Risk: SD card is not plugged in Mitigation: Double check that the SD card is properly placed in its socket.	7. Risk: Arduino fails to start. Mitigation: Program an LED light to blink when the Arduino is connected to the power supply.
2. Risk: Batteries are not fully charged Mitigation: Charge the batteries to max before the flight.	5. Risk: Wires detach from the Teensy Mitigation: Securely strap the wires to the circuit board using Velcro or other adhesives.	8. Risk: Defective CO2 Sensor Mitigation: Test run before the actual flight.
3. Risk: The VCC is not connected to the sensor, so the sensor does not work	6. Risk: Batteries fail Mitigation: Use Voltmeter to check if the battery is	9. Risk: The supply and ground wires are switched.

Mitigation: Check if the supply wire is securely attached from the 5 volt pin of the teensy to the Sensor.	fully charged before the flight.	Mitigation: Have two other people keep an eye on the wire connections.

4.2.1.1.5 Recovery Risks and Mitigations

1. Risk: Backup ejection charges do not ignite. Mitigation: Check to make sure the RRC3 is beeping in the specific sequence as denoted in the manual.	4. Risk: Drogue chute flies at wrong altitude Mitigation: Double check that the Stratologger and RRC3 both are beeping in their specific sequences.	7. Risk: Main chute doesn't deploy Mitigation: Backup Flight Computer and ejection charges should take care of this.
2. Risk: The Batteries of Backup Electronics Fall out Mitigation: Use battery holders and zip ties to ensure that the batteries do not fall out, and double check the sturdiness of these before every launch.	5. Risk: Airbrakes fail to close, interfering with recovery Mitigation: Double check that the LED light is blinking on the Arduino. Also, make sure the most recent code is uploaded in the Arduino.	8. Risk: Stratologger CF Flight Computer is not turned on Mitigation: The team will have three members check the Stratologger to see if it is beeping in its specific sequence, and they will affirm its status by signing their name in the checklist.
3. Risk: The Backup RRC3 Flight Computer is not turned on Mitigation: The team will have three members check the Flight Computer to see if it's beeping and affirm its status by signing their name in the checklist.	6. Risk: Drogue doesn't deploy Mitigation: Double check that the electronics are turned on and beeping, and have three people sign the checklist to affirm. Also, back up ejection charges will take care of this.	9. Risk: Main batteries fail Mitigation: Use fresh batteries and make sure the electronics will power up first in a test second before flight.

4.2.1.2 Failure Modes and Effects Analysis

The FMEA table below highlights some of the issues the team might encounter during the design, construction, and launch of the rocket. Other issues are displayed in the previous mitigation charts, and checklists in Section 6 Launch Operation Procedures as well.

Potential Issues/ Failure Mode	Potential Failure Effects	Severity (1-10)	Potential Causes	Occurrence (1-10)	Mitigation
Battery for the CO2 Sensor (payload) explodes or fail.	The rocket can be damaged, forcing a complete redesign and new construction process.	9	Incorrect wiring or the battery cannot withstand certain malfunctions in the coding.	1	The team decided to switch to a 9 volt battery to better suit the payload. A checklist will be followed when constructing the rocket so no incorrect actions will occur.
The CO2 Sensor fails to work during the launch.	Experiment cannot be conducted. Sparking could occur within the rocket.	5	Wiring is incorrect. Battery was not activated, or no connection in the circuit.	1	A checklist will be followed during construction and when preparing the rocket to launch.
The rocket does not fly in a stable manner.	Altitude might not be met. Damage to the rocket can occur. The rocket will fly uncontrollably, possible hurting someone.	6	While constructing the rocket, mass change might have occurred. During the design process, stability margin might not have been considered. Weather conditions also influence instability.	3	Stability margin is always looked at when designing the rocket and when making any changes to that design. Weather conditions will be monitored, and the rocket will not be launched in unsafe conditions.
Rocket components and pieces are not	When launched, inconsistent flights could take	7	Team members are not paying attention and	2	Checklists will be made and each team member working on a certain part of the

constructed properly (Right length is not cut, epoxy is not well applied, screws are not screwed in properly, electronics are not wired correctly, etc.).	place, rocket electronics will not function properly, and rocket could combust.		giving close detail during the construction process. Team members are unclear of proper process of construction or the putting together of the rocket.		rocket will be checked by another member to ensure safety and proper execution.

Key	
L	Low
M	Medium
H	High

Risk	Likelihood	Impact	Mitigation Technique
Time	M	H	If we do not have enough time, then there is nothing to do other than to work harder and reduce quality. To prevent this, we will create a coherent work schedule, divide the work evenly, and clearly delineate the formatting of the deliverables for uniformity in advance. Failing to meet deadlines in time may result in the termination of the SL team's participation.
Budget	M	M	If we run out of funds, we can either fundraise or gather money from within the team. The first method would guarantee a minimum $100 profit. The second would guarantee a minimum $700.
Functionality	L	H	If functionality within the project decreases, then we can mitigate this risk by providing clear work schedules and creating team activities to relax.
Resources	L	M	If we run out of resources, we can buy more and use our funds.

4.2.1.3 Environmental Hazard Analysis

Below we have compiled potential environmental hazards that could hinder our progress in launching the rocket. The FMEA chart displays which events are most severe, and how we plan to mitigate their possible occurrence.

Potential Issues/ Failure Mode	Potential Failure Effects	Severity (1-10)	Potential Causes	Occurrence (1-10)	Mitigation
Wind speeds are unsuitable for launching the rocket.	If rocket is launched, rocket will fly in an unstable manner, making it difficult for performing proper tasks.	6	Environmental conditions are not suitable and worsen as the day proceeds at Lucerne Dry Lake.	6	Launch rail can be tilted at an angle that is with the wind in correlation with the speed of the wind. If wind speeds are too strong, the team will wait for conditions to improve.
Rain falls when the rocket is on the launch pad or in preparation.	Drag increases, resulting a possible lower altitude for the rocket. Stability also decreases.	5	Weather conditions are not suitable.	4	Rocket will be launched if rain is light; if rain is too strong, the team will wait for conditions to improve.
A fire can spread to the surrounding environment.	The launch site can catch on fire, resulting in damage to the nature.	9	Rocket can malfunction and once it lands, a fire can begin. Malfunction of the motor, sparks or ignition can set the rocket on fire.	0	If the rocket does catch on fire in any way, no parts of the environment will catch on fire. There is only dirt at Lucerne Dry Lake for miles. No grass is near the launch site.
The rocket will affect trees, power lines, buildings, or people not involved in the launch.	The rocket could hurt people near the launch site who are not aware. It may cause additional damage to the	9	If the rocket is not stable, if may go off in the wrong path. Instability can be caused by the weather or rocket design.	1	There are no power lines, trees, or buildings within miles of the launch site. People nearby will be warned prior to the launching of the rocket. Stability margin of rocket will be made sure to be within safe limits during the design process.

	surrounding environment.				
Rocket components are harmful to the environment in terms of air and land pollution.	The team will be contributing to pollution and its harmful effects on the surrounding nature and the earth's population.	1	During the construction of the rocket, the team may come across disposable material such as electronics, batteries, and other rocket parts. After launching the rocket, the motor cannot be used again and must be disposed.	1	The team will dispose batteries and motors at Higgins Environmental in Huntington Beach to promote environmental awareness.
Ammonium perchlorate composite motors that are not disposed of safely pose a threat to human and environmental safety.	The team will contribute to the pollution of the ground and affect surrounding ecosystems by leaving used up motors in the environment. This can release hydrogen chloride, which, mixed in water, can create hydrochloric acid. The acid is corrosive and can acidify soil and water.*	1	After a motor has been used, the team could leave a motor behind without noticing.	3	The team will promptly remove the motor and place it in a designated bag to take to a nearby disposal center that will properly dispose of the motor. The team will also scout the area they occupied for any trash and dispose of the trash as well.

More epoxy resin than necessary is left out in the environment or disposed of improperly.	The epoxy could result in dermatitis, chemical burns, respiratory irritation, and environmental pollution. [#]	1	The team overestimated how much epoxy they could use.	1	The team must consistently underestimate the total volume of epoxy resin they will use during the construction of the rocket. To prevent pollution, the team will take excess epoxy resin and the supplies that were used in mixing the resin to a nearby waste disposal center.

*Source: wikipedia.org
[#]Source: westsystem.com

5 Payload Criteria

5.1 Payload Alternatives

The pros and cons of the alternatives for the electronics platform, Sensor, SD card, altimeter, and battery are organized below.

Possible Components for Payload

Alternative	Pros	Cons
Arduino Uno	Easily programmable and comes with wires, breadboard, resistors, and other accessories.	Slow software processing speed. Can not multi-task
Teensy 2.0	Easily programmable. Able to multi-task and control multiple electronic devices at the same time. Smaller size. Experience from TARC	Does not have a built-in regulator and pins on its surface. Requires soldering.
K30 CO2 Sensor SE-0018	High measurement range: 0-10,000 ppm. Very accurate and simple to program.	Soldering required. Requires holes in the rocket around the sensor to ensure air flow. More expensive too
TMP36 Temperature Sensor	Very small and light. Easily assembled and simple to program.	Outputs voltage proportional to the temperature so doesn't give exact temperature.
Micro SD Storage Board	Easy to program and very cheap. Perfect small size for the electric control board. Experience from TARC	Has a 2-200mA current range which is high.
Breakout Board for MicroSD RB-Spa-197	Simple to control and very small too.	More costly.
Pnut Altimeter	Very precise: yields a 0.1% accuracy. Reports battery voltage and immune to false triggering. Experience from TARC	More expensive.

Firefly Altimeter	Cheap and has a large battery life	Too simple. Not as many features as Pnut.
9v Battery	Easily used through the Arduino’s built in regulator when the battery is placed in its battery casing that attaches to the Arduino.	Not rechargeable
Two cell Lipo Battery	500mAH and rechargeable. Lasts longer and smaller. Current density is optimal compared to 9v battery. Experience from TARC	Requires regulator to make energy usable for the Teensy. Needs to be at recommended storage voltage, 7.56 V, when not in use. Needs more care.

5.1.1 Conclusions Drawn from Payload System

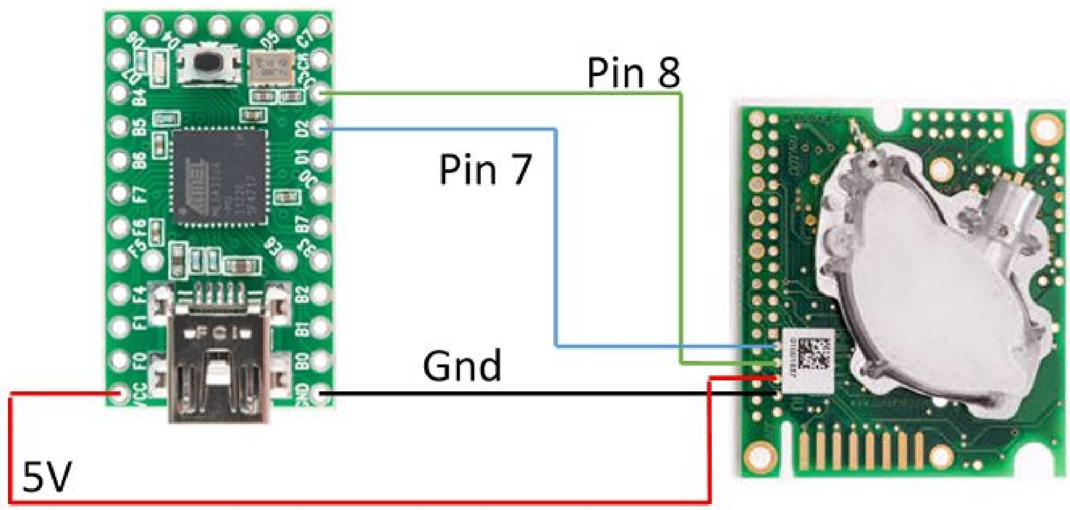
The final components are the Teensy 2.0, the K30 CO2 Sensor, the Pnut Altimeter, the Micro SD Card Module, and the 9v battery. We decided to choose the Teensy 2.0, Micro SD Card Module, Pnut, and lipo battery because we use them for our TARC rocket and are more familiar with them. Also, the Arduino Uno is a very old model and cannot perform multi-task functions simultaneously.

We also decided to test the levels of carbon dioxide instead of measure temperature change for different altitudes for our payload because we wanted to test whether the calculated level of carbon dioxide in the atmosphere is near the safe level. The CO2 Sensor also has a 9600 baud rate and runs on 5 volts.

Although the lipo battery has a safety hazard if it was used after it was left at under 5 volts for an extended period of time, and must always be handled with extreme care when charging or storing, it is still the better choice because we are more familiar with its connection with the Teensy through our TARC experience.

5.2 System-Level Design Review

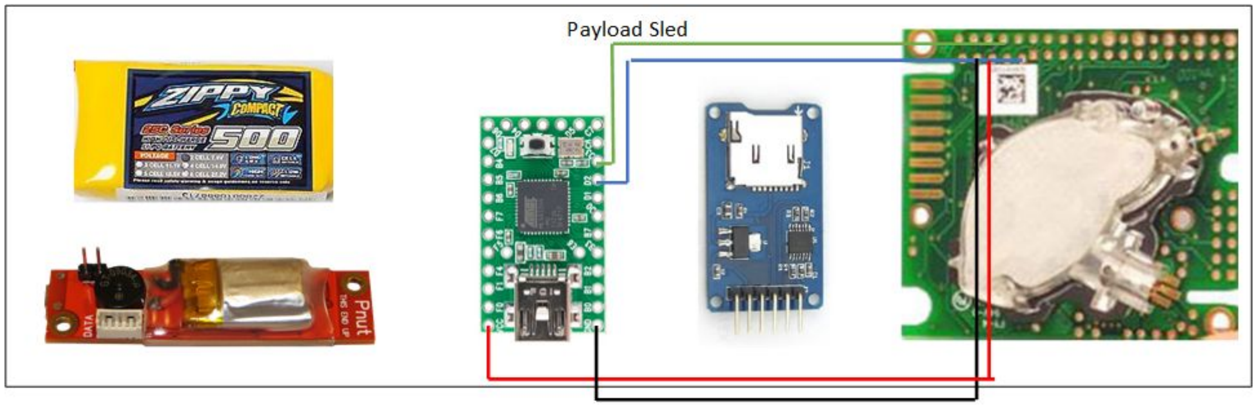
5.2.1.1 Drawing and Specifications of Payload Components



The connections between the Teensy and the sensor are illustrated above. The CO2 Sensor reads the carbon dioxide levels in the atmosphere and sends data to the Teensy. At the same time, the Pnut will send its altitude readings to the Teensy so that it can be determined what carbon dioxide level is read at each altitude.

5.2.1.2 Drawings and Specifications of Entire Payload

The entire payload sled design is shown below. After the flight, where the altitudes and the carbon dioxide level readings are loaded into the Teensy, the SD card will inform us the level of carbon dioxide at every 100 feet. The analysis of this data will be done at ground level using our PCs.



5.3 Meeting Team-Derived Functional Requirements

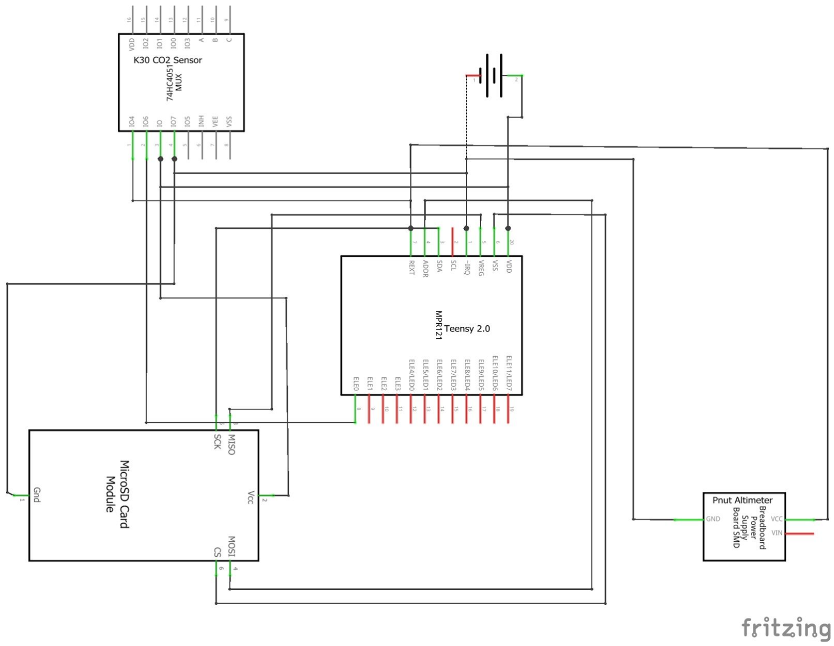
Risk	Mitigation
The Teensy isn't loaded with the appropriate code.	Sometimes we would load the Teensy with the test codes of individual electronic devices to see if they work. It is important that we switch back to the main code before launch.
The Teensy and CO_2 sensor are not powered up because the battery wasn't connected.	A few team members must confirm that they saw the Teensy and sensor blink their lights, which shows that the battery was connected.
We are not able to receive any data of our flight because the SD card wasn't in its socket.	A few team members must confirm that they see the SD card lock in place so that we are sure that all data sent to the Teensy can be viewed after the flight.

In short,

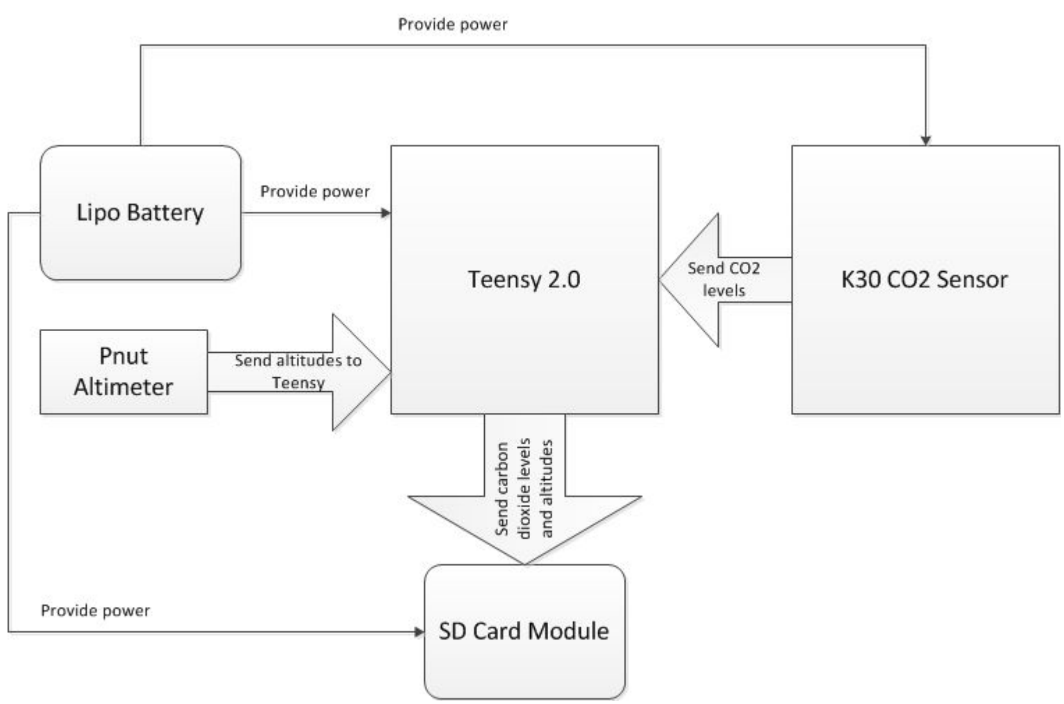
- Using a CO_2 sensor will help test our hypothesis, which is
  - If the rocket ascends and descends, the CO_2 concentration will decrease and increase as a result of decreased air density.
- The Pnut altimeter will allow us to match each CO_2 level according to altitude

5.4 Payload Electronics, Safety Switches and Indicators

5.4.1 Drawings and Schematics



5.4.2 Block Diagrams



5.4.3 Batteries/Power

We will have one lipo battery controlling the entire payload system. Although the 9v battery does not have the risk of exploding or catching fire when remained at low power and does not need too much care when storing and handling, it is harder to make connections to the Teensy and requires a battery holder.

5.4.4 Switch and Indicator Wattage and Location

There will be no need for switches because it is easy to access the top of the rocket to connect or disconnect the battery. Unlike the recovery subsystem, the payload does not contain explosives and is not a safety hazard when handling the battery and other electronics.

6 Launch Operations Procedures

To make sure the flight goes smoothly, we have included our checklists on the CDR.

6.1 Recovery Preparation Checklist

Recovery Preparation Checklist	
	Replace the battery, then ziptie them • **Risk**: Battery falls out
	Attach the wires according to color (green to green, white to white, etc) • **Risk**: Drogue or main is ejected at the wrong time • **Note**: Attach orange and green wires first, and have orange, green, blue, and yellow in the same side. • **Note**: The bulkhead with blue and yellow is at the bottom, and the bulkhead with white and purple is at the top.
	Attach ejection charges • **Risk**: Parachutes don't go eject • **PPE**: goggles
	Unlock the keys for stratologger and check the beeps according to key card • **Risk**: What if something is wrong with the stratologger?
	Unlock the keys for RRC3 and check the beeps according to key card • **Risk**: What if something is wrong with the RRC3?

6.2 Motor Preparation Checklist

Motor Preparation Checklist	
	Remove the motor from its package. • **Risk**: There will be no motor to fly the rocket!
	Remove the ejection charge from the motor. • **Risk**: The explosion may cause internal and irreparable damage to rocket.
	Scrape out all ejection charge powder.

	• **Risk**: may cause internal and irreparable damage to rocket. • **PPE**: work gloves, safety goggles
	Replace the ejection charge (now with no powder) back onto the motor. • **Risk**: The motor will not fit properly in its casing and will not have enough pressure to propel the rocket. • **Note**: It is helpful to have sanded down the charge so more of it fits inside the motor. This will help with extracting the motor after its launch. Insufficient sanding will cause the ejection charge to catch in the casing and lead to spilling out waste inside of the casing.
	Apply a thin layer of grease all around the motor. • **Risk**: It will be difficult to extract the motor after the launch if no grease is applied. • **PPE**: a disposable glove to spread grease, soap, water
	Push the motor into the engine casing and screw tightly. • **Risk:** A loose motor will not retain pressure inside the rocket and lead to flight inconsistency and lower altitudes. • **Note**: Have other people tighten the casing to make sure it is tight.
	Screw in the motor retainer as tightly as possible • **Risk**: A loose motor may pose safety hazard to bystanders, will not retain pressure inside of rocket and lead to flight inconsistency and lower altitude. • **Note**: Have other people tighten the retainer to make sure it is tight.

6.3 Payload Checklist

Payload Checklist	
	Make sure battery is fully charged • **Risk**: The payload system may stop working mid-flight if the battery runs out.
	Securely connect the Sensor, Pnut, battery, and micro SD card module to the Teensy • **Risk**: If the wires are not securely plugged in, it is possible that the data of the flight will not be received
	Put SD card into the micro SD card module • **Risk**: Without the SD card in the payload, there is no way of knowing the carbon dioxide levels during the flight.
	Make sure battery is plugged into the Teensy • **Risk**: Without the battery connected, almost all of the electronics would not function during the flight.

	Check if Teensy and Sensor blink after the battery is plugged in. • **Risk**: If the Teensy does not blink, it could be because the battery is dead. If the sensor does not blink, then it could mean that the wires were switched.
	Replace the tape around the groups of wires if necessary • **Risk:** The tape keeps any wire from unplugging itself during the flight. • **Note**: As an extra precaution, have other people make sure the wires don't come out when the payload sled goes in the rocket.

6.4 Air Brakes Checklist

Air Brakes Checklist	
	Charge the battery to full • **Risk**: All the electronics and the air brakes will fail if the battery runs out in the middle of the flight.
	Connect the Pnut to the Teensy. • **Risk**: The Teensy will not read the altitude from the altimeter if they are not connected to each other.
	Make sure the jumper is connected on the Teensy circuit board. • **Risk**: Without the jumper, the battery wouldn't be connected to the servo that controls the air brakes.
	Connect the servo to the Teensy. • **Risk**: The teensy would not be able to control the servo if they are not connected to each other, and the air brakes would not work.
	Put SD card into the micro SD card module. • **Risk**: We would not be able to see the data sent by the Teensy without the SD card.
	Plug in the battery to the Teensy. • **Risk**: None of the electronics would work without power.
	Check that the Teensy blinks after the battery is plugged in. • **Risk:** If the Teensy does not blink, either the battery is dead or the polarities were reversed. Reversing the battery's polarities poses a safety hazard and the battery and Teensy could be severely damaged. • **Note**: Have other people check that the supply and ground wires are aligned before plugging in the battery.

6.5 Setup on Launcher Checklist

Setup on Launcher Checklist	
	Tilt the rail back ● **Risk**: Beware of not catching it before it falls too fast! Lower it slowly so the launchpad and people aren't damaged. ● **Note:** If necessary, use hard hats.
	Mount the rocket and slide it all the way down. ● **Note:** Make sure the rail buttons align and are in the right place. Also check to make sure no screws conflict with the rail.
	Tilt the rail back up.
	Level the launch pad accordingly. ● **Note:** The rocket must not point toward people in the proximity of the launchpad.

6.6 Igniter Installation Checklist

Igniter Installation Checklist	
	Twist the igniter leads. ● **Risk**: Accidental ignition can damage rocket during launch if the rocket is not fully set up and poses a risk to Student Launch members. Twist the leads! ● **Note:** Wear clothing that does not generate static electricity. An accidental discharge of static electricity may cause the igniter to ignite. This is much more dangerous around the black powder charges.
	Mark how far up the igniter should be prior to installation ● **Risk**: The rocket will not launch even if the igniter goes off. ● **Note**: The igniter must be as far up the motor as possible in order to have contact with the solid fuel.
	Install the rocket on the launch pad before placing the igniter. ● **Risk**: accidental ignition when transporting the rocket, which can lead to injuries and rocket damage
	Coil the igniter after it is pushed in all the way. ● **Risk**: The igniter must be as far up the motor as possible in order to have contact with the solid fuel.

	• **Note**: The coil will help maintain how far the igniter is inside the motor.
	Replace the plug • **Risk**: The igniter will fall out and the rocket won't launch
	Untwist igniter leads and attach the alligator clips. • **Risk**: If skipped, the rocket will not launch.
	Check for continuity. • **Risk**: If skipped, the rocket may not launch.

6.7 Launch Procedure Checklist

Launch Procedure Checklist	
	Arm the pad.
	Check to make sure there are no people or pets in the range. Call loudly and clearly, "Range is clear!" if there are no people pets in the range.
	Check to make sure there is no aircraft over the launchpad or headed toward the launchpad. Call loudly and clearly, "Sky is clear!" if there are no aircraft in immediate danger. • **Note:** Birds flying overhead do not warrant a delayed launch.

6.8 Troubleshooting Checklist

Troubleshooting Checklist	
	GPS Troubleshooting: Run down the GPS troubleshooting mitigation table in section 4.1.1.5.1
	Payload Troubleshooting: Run down the payload troubleshooting mitigation table in section 4.1.1.5.2
	Parachute Troubleshooting: Run down the parachute troubleshooting mitigation tables of either section 4.1.1.5.3 or section 4.1.1.5.5. Both tables are identical.
	Avionics Troubleshooting: Run down the avionics troubleshooting mitigation table in section 4.1.1.5.4
	Air Brakes Troubleshooting: Run down the air brakes troubleshooting mitigation table

	in section 4.1.1.5.6
	Motor Troubleshooting: Run down the motor troubleshooting mitigation table in section 4.1.1.5.7

6.9 Post-flight inspection Checklist

Post-Flight Inspection Checklist	
	Once the rocket has landed, approach carefully and inspect any major issues, dangers, or damages done to the rocket.
	Each team member should grab a section of the rocket or the parachute and bring back to the team table where the rocket was constructed.
	Hear the altitude of the rocket with the beeps from the avionics bay.
	Open avionics bay, payload bay, and airbrake module and check for any visible issues.
	Cut the power source and take out the SD cards to read the data collected from the CO2 sensor and air brake module.
	Wrap the parachutes and place them back into the their respective body tubes to avoid damage.

7 Project Plan

7.1 Testing

7.1.1 Vehicle Test Plan

To verify that the vehicle is ready, it is necessary to design a subscale model of it. We used a 3" subscale rocket and verified that the design and its subsystems are safe for the flight of the fullscale.

Test Objective:
To verify the functionality and safety of the rocket

Success Criteria: The rocket has a suitable stability margin (greater than or equal to 2 calibers), was flown and recovered successfully, met the minimum rail exit velocity (52 ft/s), and flew the avionics and air brakes subsystems.

Test Plan:

1. Design a full-scale and subscale rocket. Simulate. If the rockets do not meet the Student Launch handbook's criteria, then revise and simulate again.
2. Pick suitable motors for each rocket.
3. Build the subscale rocket. Measure for:
    a. Center of Gravity, relative to nose cone
    b. Total Mass

   These details should be inputted in RockSim to receive a better prediction of the subscale's flight.
   This should also include the rocket's air brakes and avionics.
4. Test the recovery system and air brakes.
5. Fly the subscale, with the air brakes and avionics on board and active.
6. The following depends on the flight's results
    a. If the rocket has crashed, diagnose what went wrong, redesign if necessary, rebuild, and fly again.
    b. If a subsystem did not function at all, diagnose what went wrong, redesign if necessary, and fly again.
    c. If the rocket is successful, then record the results in the Critical Design Review.

Test Plan Results:

The rocket successfully flew and was recovered. In general, it was a straight flight. The rocket did not sustain any damage. Both subsystems on the rocket performed well. There was ballast to simulate the payload on the rocket.

The rocket after its flight

The results of the subscale's flight will help us predict the coefficient of drag on the rocket, which is useful for predicting the full-scale rocket's apogee. It also indicates that the rocket's design is functional, so we will continue with this design in the full scale.

7.1.2 Recovery Test Plan

Testing for the avionics bay is fairly straightforward, as it requires the team to listen to a specific series of beeps from the flight computers to ensure their functionalities. For the stratologger, there should be seven sets of beeps, in the following manner:

Present number - 1 through 9
Main Deploy Altitude
Long beep if Apogee delay set
Altitude of last flight (Warble = Power lost)
Battery Voltage (needs to be about 9V)
Continuity beeps (repeats every 0.8 seconds)

Zero beeps = no continuity
One beep = Drogue OK
Two beeps = Main OK
Three beeps = Drogue + Main OK (ideal scenario)

For the RRC3, the continuity check is the following:

5 second long beep (init mode)
10 second baro history init time (silence)
Settings beep (when enabled) or POST fault code beep (if a fault, see POST fault codes)
10 second launch commit test time (silence)
Launch Detect mode (continuity beeps)
A long beep indicates no continuity on any event terminal.
One short beep indicates continuity on only the drogue terminal.
Two short beeps indicate continuity on only the main terminal.
Three short beeps indicate continuity on the main and drogue terminals.

7.1.3 Energetics Test Plan

We will perform ground tests to verify our calculations of how much black powder is safe to use on a rocket. In an isolated area, we will test different masses of black powder changes and remotely detonate these charges with a 9 Volt current.
If the rocket deploys its respective parachutes without exploding the body tubes, then we will have found the correct mass of the black powder that is safe to use on the flight. If the rocket is unable to deploy a parachute, then we will increase the mass of the black powder used and check to see if there is continuity with the recovery electronics and the electric match that detonates the black powder.
We will find the minimum amount of black powder that is safe for use.
This ground test will be used on the full-scale and scale model of the rocket.
If we have calculated the correct mass, then it doesn't popu out, we need to find out why.
Account for nylon screws and the force of the black powder and the friction that results from the avionics bay rubbing against the body tube.

7.1.4 Air Brakes Test Plan

Testing of the airbrakes is fairly easy to understand.

First, check the module to see any possible structural damages. Tighten all screws, from the hinges of the airbrakes to the arms of the servo. If not already uploaded, the airbrake test code should be uploaded to the Teensy via laptop. We then perform two tests with two codes.

Connect the servo cable to the respective wire on the airbrake electronics. Once the battery is connected, the simple code should just open and close the airbrakes continuously. During this preliminary test, team members in charge of the airbrakes will look for any improper functionality in the rocket. If no issues have come up after one minute of running the code, remove the battery connection from the Teensy and upload the flight code.

Connect the servo cable to the respective wires on the airbrake electronics. Connect the other respective cable to the Pnut altimeter, and then place the Pnut in the vacuum chamber. Finally, connect the Lipo battery source to the designated location on the Teensy board. Turn on the vacuum chamber. As pressure changes in the chamber, the airbrakes should open and close irregularly to adjust the simulated altitude. If the airbrakes and servo do respond, the airbrake module is ready for flight.

7.1.5 GPS Test Plan

To test the GPS, one must turn on the Whistle GPS app and set up the Whistle Zone, a circle with a one mile radius. After the Whistle Zone is set up and the base station is in place, a team member can drive up to a mile with the GPS, and the phone should be able to track the pathway of the car.

Refreshing location is useful in checking to see if the GPS has changed its position. The GPS will only update the phone if the GPS has left the designated Whistle Zone. The update provides the location of the GPS before it left the Whistle Zone.

7.1.6 Payload Test Plan

To test the payload, one must plug in the battery and plug in the jumper of the Pnut to activate the Teensy, CO_2 Sensor, and altimeter. Then the Pnut must be placed into a closed plastic container, which contains small holes along the circumference and has the nozzle of a vacuum cleaner stuck inside of it. Turn on the vacuum cleaner and slowly cover up holes using tape to simulate the flight. Then check the SD card to see if the CO_2 levels and altitudes are displayed.

7.2 Requirements Compliance

7.2.1 CDR Cross Reference

Handbook Number	Section Description	CDR Report Section
I)	**Summary of CDR Report**	1
	Team Summary ● Team name and mailing address ● Name of mentor	1.1
	Launch vehicle Summary ● Size and mass ● Final motor choice ● Recovery System ● Rail size ● Milestone Review Flysheet	1.2
	Payload Summary ● Payload Title ● Summarize Experiment	1.3
II)	**Changes made since PDR**	2
	Highlight all changes made since PDR and the reason for those changes	
	● Changes made to vehicle criteria	2.1
	● Changes made to payload criteria	2.2
	● Changes made to project plan	2.3
III)	**Vehicle Criteria**	3
	Design and Verification of Launch Vehicle	3.1
	Flight Reliability and Confidence	3.1.1
	● Include unique mission statement and mission success criteria	3.1.1.1.1 3.1.1.1.2

	● Identify which of the design alternatives from PDR is chosen as the final components for the launch vehicle. Describe why that alternative is the best choice.	
	● Using the final designs, create dimensional and computer aided design (CAD) drawing to illustrate the final launch vehicle, its subsystems, and its components	3.1.1.3
	● Demonstrate that the design can meet all system level functional requirements with an acceptable level of risk.	3.1.1.4
	● Discuss the integrity of the design.	3.1.1.5
	❏ Suitability of shape and fin style for mission	3.1.1.5.1
	❏ Proper use of materials in fins, bulkheads, and structural elements	3.1.1.5.2
	❏ Sufficient motor mounting and retention	3.1.1.5.3
	❏ Estimate the final mass of launch vehicle, as well as its subsystems	3.1.1.5.4
	Subscale Flight Results	3.1.2
	● At least one data gathering device must be on board the launch vehicle during the test. At a minimum, this device must record the apogee of the rocket. If the device can record more than apogee, please include the actual flight data.	3.1.2.1
	● Describe the scaling factors used when scaling the rocket. What variables are kept constant and why?	3.1.2.2
	● Describe the launch day conditions, and perform a simulation using those	3.1.2.3

	conditions	
	● Perform an analysis of the subscale flight	3.1.2.4
	❏ Compare the predicted flight model to the actual flight data. Discuss the results	3.1.2.4.1
	❏ Discuss any error between the actual and predicted flight data	3.1.2.4.2
	❏ Estimate the drag of coefficient of full scale rocket with subscale data	3.1.2.4.3
	● Discuss how the subscale flight data has impacted the design of the full-scale launch vehicle	3.1.2.5
	Recovery Subsystem	3.1.3
	● Identify which of the design alternatives from PDR is chosen are chosen as the final components for the recovery subsystem. Describe why the alternative is the best choice	3.1.3.1
	● Describe the parachute, harnesses, bulkheads, and attachment hardware	3.1.3.2
	● Discuss the electrical components, and prove that redundancy exists within the system	3.1.3.3
	● Include drawings/sketches, block diagrams, and prove that redundancy exists within the system	3.1.3.4
	● Provide operating frequency(s) of the locating tracker(s).	3.1.3.5
	Mission Performance Predictions	3.1.4
	● Show flight profile simulations, altitude predictions with simulated vehicle data, component weights, and simulated	3.1.4.1

	motor thrust curve, and verify that they are robust enough to withstand the expected loads	
	Show stability margin, simulated Center of Pressure (CP)/Center of Gravity (CG) relationship and locations	3.1.4.2
	Calculate the kinetic energy at landing for each independent and tethered section of the launch vehicle	3.1.4.3.1
	Calculate the drift for each independent and tethered section of the launch vehicle. Different Cases: no win, 5-mph wind, 10-mph wind, 15-mph wind, and 20-mph wind. The drift calculations should be performed with the assumption that the rocket will be launched straight up (zero degree launch angle)	3.1.4.3.2
IV)	**Safety**	4
	Launch concerns and operation procedures	4.1
	● Submit a draft of final assembly and launch procedures including:	4.1.1
	❏ Recovery preparation	4.1.1.1
	❏ Motor preparation	4.1.1.2
	❏ Setup on launcher	4.1.1.3
	❏ Igniter installation	4.1.1.4
	❏ troubleshooting	4.1.1.5
	❏ Post-flight inspection	4.1.1.6
	Safety and Environment	4.2
	● Update the Personnel Hazard Analysis, the Failure Mode and Effects Analysis, and the Environmental Hazard Analysis to include:	
	❏ Finalized hazard descriptions,	

	causes and effects	
	❏ A near-complete list of mitigations, addressing the hazards and/or their causes	
	❏ A preliminary list of verifications for the identified mitigations	
V)	**Payload Criteria**	5
	Design of Payload Equipment	
	● Identify which of the design alternatives from PDR is chosen as the final components for the payload. Describe why that alternative is the best choice.	5.1
	● Review the design at a system level	5.2
	❏ Include drawings and specifications for each component of the payload, as well as the entire payload assembly	5.2.1.1 5.2.1.2
	❏ Describe how the payload components interact with each other	
	❏ Describe how the payload integrates within the launch vehicle	
	● Demonstrate that the design can meet all team derived functional requirements within acceptable levels of risk	5.3
	● Discuss the payload electronics with special attention to given safety switches and indicators	5.4
	❏ Drawings and schematics	5.4.1
	❏ Block diagrams	

	❑ batteries/power	5.4.3
	❑ Switch and indicator wattage and location	5.4.4
VI)	**Launch Operations and Procedures**	6
	Provide preliminary procedures for the following (as a minimum)	
	● Recovery Preparation	6.1
	● Motor Preparation	6.2
	● Setup on launcher	6.5
	● Igniter installation	6.6
	● Launch Procedure	6.7
	● Troubleshooting	6.8
	● Post-flight inspection	6.9
	These procedures should include specially demarcated steps related to safety. Examples include:	
	● Warnings of hazards that result from missing a step	
	● PPE required for a step in the procedure (identified BEFORE the step)	
	● Required personnel to complete a step or to witness and sign off verification of a step	
VII)	**Project Plan**	7
	Testing	7.1
	● Identify all tests required to prove the integrity of the design	
	● For each test, present the test objective	

	and success criteria, as well as testing variable and methodology	
	● Present results of any completed tests	
	● Describe the tests plan, and whether or not the test was a success	
	● How do the results drive the design of the launch vehicle and/or payload	
	Requirements Compliance	7.2
	● Create a verification plan for every requirement from sections 1-5 of this handbook. Identify if test, analysis, demonstration, or inspection are required to verify the requirement. After identification, describe the association plan needed for verification. Provide a status update for each requirement, and mention the part of the document that includes the testing or analysis used to verify	
	● Create a set of team derived requirements. These are a set of minimal requirements for mission success that are ideally beyond the minimum success requirements presented in this handbook. Like before, create a verification plan identifying whether test, analysis, demonstration or inspection is required with an associated plan and status	7.2.2
	Budgeting and timeline	7.3
	● Line item budget with accurate market values for individual components	7.3.1
	● Funding plan describing sources of funding, and allocation of funds	7.3.2
	● Timeline including all team activities, and activity duration. Gantt charts are	7.3.3

	encouraged	

7.2.2 Team Derived Requirements

Teamwork Dynamics

Risk	Mitigation
Consecutive long work days	Update the Gantt chart frequently, schedule hourly breaks
Uneven distribution of work	Update the Gantt chart frequently
Avionics bay not assembled in time	Give the person in charge of avionics (Kush) more time to practice

Rocket Construction

Risk	Mitigation
Finding the right parachutes	Simulate, calculate drift and kinetic energy, and fit the parachutes and their respective shock cords
Finding the right way to mount masses	Use zipties and duct tape, cut boards
Couplers that are too short or do not have enough body tube length	All tube couplers should be halfway inside. For the full scale, tube couplers must be a minimum of 3” inside a body tube. For the subscale, tube couplers must be a minimum of 2.5” inside a subscale rocket body tube and 3” inside a full-scale rocket body tube
Metal screws tearing	Screw in more delicately, designate a few people to use screws

Vehicle

A successful mission is determined by the vehicle’s success in the following areas : data collected, ascent, altitude reached, descent.

If the payload establishes some sort of trend between altitude and carbon dioxide levels and reads a three digit number, preferably near 350 ppm, which is the safe level of carbon dioxide in the atmosphere, the mission is a success in this aspect. If the rocket achieves a minimum velocity of 52 feet/s, achieves a static stability margin of 2.0 at rail exit, does not utilize a motor that exceeds 2560 Newton-seconds, and safely ascends to one mile, then the mission is a success in this aspect. If the rocket safely descends with a maximum kinetic energy of 75 ft-lbf, returns data from the payload, and can be reused again, then the mission is a success in this aspect.
To go outside of the handbook's requirements, the rocket must land within a 1 mile radius of the launchpad and must utilize its air brakes to increase drag and achieve or almost achieve its target altitude of one mile.

Payload

Risk	**Mitigation**
The Teensy isn't loaded with the appropriate code.	Sometimes we would load the Teensy with the test codes of individual electronic devices to see if they work. It is important that we switch back to the main code before launch.
The Teensy and CO2 sensor are not powered up because the battery wasn't connected.	A few team members must confirm that they saw the Teensy and sensor blink their lights, which shows that the battery was connected.
We are not able to receive any data of our flight because the SD card wasn't in its socket.	A few team members must confirm that they see the SD card lock in place so that we are sure that all data sent to the Teensy can be viewed after the flight.

Our scientific experiment is to test the effect of altitude on carbon dioxide levels, hoping to find a strong correlation and regression (exponential, linear, or parabolic) within the explanatory and response variables. Our goal is to establish some sort of trend between the two variables, so it therefore follows that a successful experiment constitutes of a well defined correlation between altitude and carbon dioxide levels.

Other team dynamics goals:

- Develop clear goals for each day we meet
- Present individual roles and progress to the team
    - I.e. inform them on how to make the avionics work
- Revise the current air brakes design to adjust for fiberglass

- Bring plenty of shock cord to launches
- Figure out how to pack shock cord better
- Fill old holes with epoxy and then drill new ones
- Develop checklists in the event the person in charge of a specific aspect is unable to come to an event
- Stay focused while building. Don't get distracted by animals
    - DO NOT engage Parbo the Macaw. Except for spraying.
- Schedule hourly break times
- Create more organized Gantt Charts

7.3 Budgeting and Timeline

7.3.1 Line Item Budget

Description	Unit Cost	Quantity	Subtotal		Comments
Scale Vehicles and Engines					
3" Fiberglass Frenzy XL	$200	1	$200		
3" G12 Thin-Wall Airframe (12" length)	$20	1	$20		
3" G12 Coupler (6" length)	$14	2	$28		
3" G12 Coupler (9" length)	$21	1	$21		
HS-7980TH Servo	$190	1	$190		
2-56 wire	$10	1	$10		
Heavy unit easy connector	$5	1	$5		
Iris Ultra 84" Compact parachute	$225	1	$345		
18" Elliptical Parachute	$53	1	$53		
Aerotech K661	$135	3	$405		The range for a motor is $120-$150, depending on where it is purchased.
Total Scale Vehicle Cost				$872	
Vehicle					
4" G12 Coupler (12" length)	$31	3	$93		
4" G12 Coupler (8" length)	$21	2	$42		

4" Fiberglass Frenzy XL	$300	1	$300		
4" G12 Airframe (12" length)	$23	1	$23		
75mm Aerotech K560	$70	3	$210		
HS-7980TH	$190	1	$190		
2-56 wire	$10	1	$10		
Heavy unit easy connector	$5	1	$5		
Cesaroni K661	$52	5	$260		
Total Vehicle Cost				$1,133	
Recovery					
Iris Ultra 120" Compact Parachute	$504	1	$504		
24" Elliptical Parachute	$60	1	$60		
4F Black Powder	Kept by mentor				
Batteries (9v, 2 pack)	$7	3	$21		
Battery Holder	$1	5	$5		
Stratologger CF Flight Computer	$55	1	$55		
RRC3 Flight Computer	$70	1	$70		
PerfectFlite Pnut (2 units)	$55	2	$110		
Total Recovery Cost				$825	
Payload					
K30 CO2 Sensor	$85	1	$85		
Teensy 2.0	$28	1	$28		
SD card + Adapter	$10	1	$10		
PerfectFlite Pnut Altimeter	$50	2	$100		
Lithium Ion Battery (rechargable)	$100	1	$100		
Total Payload Cost				$323	
GPS System					
Whistle GPS Dog Tracker Kit	$75	1	$75		

Cellular Service Fee (3 months free, 5 months to pay)	$40	1	$40		
Total Payload Cost				$115	
Educational Outreach					
Color fliers (250 copies)	$170				
Total Educational Outreach Cost				$170	
Travel (7 Members)					
Trips to Lucerne ($2.80/gal, 112mi; $21.00 per trip per car)					
Huntsville, Alabama (roundtrip plane ticket)	$332	7	$2,324		
Hotel (4 rooms, 6 days)	$130	24	$3,120		
Hotel (2 people per room, 6 days)	$25	6	$1,050		
Total Travel Cost (Estimated)				$6,494	
Total Estimated Project Expenses				$9,819	

7.3.2 Funding Plan

Our rocket team will procure funds from various sources. Action plans include the following: sell See's candies and Mary Kay cosmetics to fundraise, go around the community to collect items for a garage sale and also ask for donations, explain to them what the team's goal is, send letters to local businesses and aerospace companies requesting financial aid, and speak to vendors involved in rocketry and other supplies for discounts and donations. We have already obtained funds from selling artwork to art patrons and will continue doing so. The sponsors we have currently are Apex Desks, Pegasus Management, Yogurtland, IvyMax, and Velur Enterprises, Inc.

7.3.3 Timeline

Appendix A: Statement of Work Cross Reference

No.	Requirement in SOW	CDR Section	Method of Validation
Vehicle Requirements			
1.1	The vehicle shall deliver the science or engineering payload to an apogee altitude of 5,280 feet above ground level (AGL).	**3.1.1.1**	
1.2	The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner. Teams will receive the maximum number of altitude points (5,280) if the official scoring altimeter reads a value of exactly 5280 feet AGL. The team will lose one point for every foot above or below the required altitude.	**3.1.1.1**	
1.3	All recovery electronics shall be powered by commercially available batteries.	**3.1.4.1**	
1.4	The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	**7.2.2**	
1.5	The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.	**4.1.1**	
1.6	The launch vehicle shall be limited to a single stage.		
1.7	The launch vehicle shall be capable of being prepared for flight at the launch site within 4 hours, from the time the Federal		

	Aviation Administration flight waiver opens.		
1.8	The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.		
1.9	The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system. The firing system will be provided by the NASA-designated Range Services Provider.		
1.10	The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).		
1.11	The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).		
1.12	Pressure vessels on the vehicle shall be approved by the RSO and shall meet the following criteria		
1.12.1	The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) shall be 4:1 with supporting design documentation included in all milestone reviews		
1.12.2	The low-cycle fatigue life shall be a minimum of 4:1.		
1.12.3	Each pressure vessel shall include a solenoid pressure relief valve that sees the full pressure of the tank.		

1.12.4	Full pedigree of the tank shall be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.		
1.13	The total impulse provided by a Middle and/or High School launch vehicle shall not exceed 2,560 Newton-seconds (K-class).		
1.14	Any team who wishes to apply for a larger motor impulse limit may include a section within the proposal detailing why the larger motor is necessary. Educator and mentor experience in high power rocketry should also be included in this section. Motor impulses may increase to a maximum of 6,120 Newton-seconds (L-class). If, during the design review process, the rocket design does not safely allow for use of an L motor, the Student Launch office reserves the right to revoke the increased impulse limit.		
1.15	The launch vehicle shall have a minimum static stability margin of 2.0 at the point of rail exit.		
1.16	The launch vehicle shall accelerate to a minimum velocity of 52 fps at rail exit		
1.17	All teams shall successfully launch and recover a subscale model of their rocket prior to CDR		
1.17.1	The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale shall not be used as the subscale model.		
1.17.2	The subscale model shall carry an altimeter capable of reporting the model's apogee altitude		
1.18	All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket		

	flown at FRR must be the same rocket to be flown on launch day. The purpose of the full-scale demonstration flight is to demonstrate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at a lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full scale demonstration flight:		
1.18.1	The vehicle and recovery system shall have functioned as designed.		
1.18.2	The payload does not have to be flown during the full-scale test flight. The following requirements still apply:		
1.18.2.1	If the payload is not flown, mass simulators shall be used to simulate the payload mass.		
1.18.2.2	The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass.		
1.18.3	If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems shall be active during the full-scale demonstration flight.		
1.18.4	The full-scale motor does not have to be flown during the full-scale test flight. However, it is recommended that the full-scale motor be used to demonstrate full flight readiness and altitude verification. If the full-scale motor is not flown during the full-scale flight, it is desired that the motor simulate, as closely as possible, the predicted maximum velocity and maximum acceleration of the launch day flight.		

1.18.5	The vehicle shall be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the launch day flight.		
1.18.6	After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA Range Safety Officer (RSO)		
1.18.7	Full scale flights must be completed by the start of FRRs (March 6th, 2016). If the Student Launch office determines that a re-flight is necessary, than an extension to March 24th, 2016 will be granted. This extension is only valid for re-flights; not first time flights.		
1.19	Any structural protuberance on the rocket shall be located aft of the burnout center of gravity		
1.20	Vehicle Prohibitions		
1.20.1	The launch vehicle shall not utilize forward canards.		
1.20.2	The launch vehicle shall not utilize forward firing motors.		
1.20.3	The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)		
1.20.4	The launch vehicle shall not utilize hybrid motors.		
1.20.5	The launch vehicle shall not utilize a cluster of motors.		
1.20.6	The launch vehicle shall not utilize friction fitting for motors.		
1.20.7	. The launch vehicle shall not exceed Mach		

	1 at any point during flight.		
1.20.8	Vehicle ballast shall not exceed 10% of the total weight of the rocket.		
2.1	The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude. Tumble recovery or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the Range Safety Officer.		
2.2	Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full scale launches.		
2.3	At landing, each independent sections of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.		
2.4	The recovery system electrical circuits shall be completely independent of any payload electrical circuits.		
2.5	The recovery system shall contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.		
2.6	Motor ejection is not a permissible form of primary or secondary deployment.		
2.7	Each altimeter shall be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.		

2.8	Each altimeter shall have a dedicated power supply.		
2.9	Each arming switch shall be capable of being locked in the ON position for launch		
2.10	Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.		
2.11	An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.		
2.11.1	Any rocket section, or payload component, which lands untethered to the launch vehicle, shall also carry an active electronic tracking device.		
2.11.2	. The electronic tracking device shall be fully functional during the official flight on launch day.		
2.12	The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing).		
2.12.1	The recovery system altimeters shall be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.		
2.12.2	The recovery system electronics shall be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics		
2.12.4	The recovery system electronics shall be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.		

3.1	The launch vehicle shall carry a science or engineering payload. The payload may be of the team's discretion, but shall be approved by NASA. NASA reserves the authority to require a team to modify or change a payload, as deemed necessary by the Review Panel, even after a proposal has been awarded.		
3.2	`Data from the science or engineering payload shall be collected, analyzed, and reported by the team following the scientific method.		
3.3	Unmanned aerial vehicle (UAV) payloads of any type shall be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given the authority to release the UAV.		
3.4	Any payload element that is jettisoned during the recovery phase, or after the launch vehicle lands, shall receive real-time RSO permission prior to initiating the jettison event.		
3.5	The payload shall be designed to be recoverable and reusable. Reusable is defined as being able to be launched again on the same day without repairs or modifications.		
4.1	Each team shall use a launch and safety checklist. The final checklists shall be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.		
4.2	Each team must identify a student safety officer who shall be responsible for all items in section 4.3		

4.3	The role and responsibilities of each safety officer shall include, but not limited to:		
4.3.1	Monitor team activities with an emphasis on Safety during:		
4.3.1.1	Design of vehicle and launcher		
4.3.1.2	Construction of vehicle and launcher		
4.3.1.3`	Assembly of vehicle and launcher		
4.3.1.4	Ground testing of vehicle and launcher		
4.3.1.5	Sub-scale launch test(s)		
4.3.1.6	Full-scale launch test(s)		
4.3.1.7	Launch day		
4.3.1.8	Recovery activities		
4.3.1.9	Educational Engagement Activities		
4.3.2	Implement procedures developed by the team for construction, assembly, launch, and recovery activities		
4.3.3	Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data		
4.3.4	Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.		
4.4	Each team shall identify a "mentor." A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor shall maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli		

	Rocketry Association (TRA) for the motor impulse of the launch vehicle, and the rocketeer shall have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to launch week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attends launch week in April.		
4.5	During test flights, teams shall abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch Initiative does not give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at other club launches. Teams should communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.		
4.6	Teams shall abide by all rules set forth by the FAA.		
5.1	Students on the team shall do 100% of the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor).		
5.2	The team shall provide and maintain a project plan to include, but not limited to		

	the following items: project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations.		
5.3	Foreign National (FN) team members shall be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN's may be separated from their team during these activities.		
5.4	The team shall identify all team members attending launch week activities by the Critical Design Review (CDR). Team members shall include:		
5.4.1	Students actively engaged in the project throughout the entire year.		
5.4.2	One mentor (see requirement 4.4).		
5.4.3	No more than two adult educators.		
5.5	The team shall engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the Educational Engagement Activity Report, by FRR. An educational engagement activity report shall be completed and submitted within two weeks after completion of an event. A sample of the educational engagement activity report can be found on page 28 of the handbook.		
5.6	The team shall develop and host a Web site for project documentation		
5.7	Teams shall post, and make available for download, the required deliverables to the team Web site by the due dates specified in the project timeline.		

5.8	All deliverables must be in PDF format		
5.9	In every report, teams shall provide a table of contents including major sections and their respective sub-sections.		
5.10	In every report, the team shall include the page number at the bottom of the page.		
5.11	The team shall provide any computer equipment necessary to perform a video teleconference with the review board. This includes, but not limited to, a computer system, video camera, speaker telephone, and a broadband Internet connection. If possible, the team shall refrain from use of cellular phones as a means of speakerphone capability		
5.12	All teams will be required to use the launch pads provided by Student Launch's launch service provider. No custom pads will be permitted on the launch field. Launch services will have 8 ft. 1010 rails, and 8 and 12 ft. 1515 rails available for use.		
5.13	Teams must implement the Architectural and Transportation Barriers Compliance Board Electronic and Information Technology (EIT) Accessibility Standards (36 CFR Part 1194) Subpart B-Technical Standards (http://www.section508.gov): § 1194.21 Software applications and operating systems. § 1194.22 Web-based intranet and Internet information and applications.		

Appendix B: Partners in Industry

Dr. James Martin
Dr. Martin holds degrees from West Virginia University, Massachusetts Institute of Technology, and George Washington University. He has worked at the NASA Langley Research Center, The University of Alabama, and Boeing. His work has mostly involved the design and evaluation of reusable launch vehicles. Some recent work has been on crew escape for the Shuttle, the Space Launch Initiative, and a robotic lander on the moon. Dr. Martin retired from Boeing when the Launch vehicle business was sold. He continues to be active in aerospace doing consulting, as an Associate Editor for AIAA J. Spacecraft and Rockets, and as Chair of the local AIAA Orange County Section.

Jonathan Mack (Electrical Engineer and Programmer)
Jonathan graduated with a Bachelor of Science from Long Beach State. Currently he is an electronics design engineer involved in hardware and software development including diverse fields such as toys, audio, and currently printing. He has led a 4H project in mechanical, electrical and software design areas in robotics. At home his hobbies mainly focus on improving DIY (Do It Yourself) knowledge, including everything from mad science projects to more mundane things like welding and cooking (usually not at the same time.)

Guy Heaton (Mechanical Engineer)
Guy graduated with a Bachelor of Science from Pepperdine University. Currently he is a Senior Mechanical Engineer and has been working on printing solutions for 12 years. Responsibilities include designing for injection and blow molding and extrusions. He also does mechanical systems, drive trains, cabling, durability testing, and sheet metal design. When not designing new printers he does manufacturing time analysis, line balancing, and documentation.

Mike Stoop (Fiberglassing, Programming, Design)
Mike Stoop is currently the CTO of PriceDoc, Inc, a healthcare related web services company. Mike has been in the software industry for 30 years and an avid rocketeer for 40 years. Mike achieved his level 3 certification in 2002 and has participated in many individual and team 'M" class and above rocket projects. He has launched K and larger engines with electronic dual deploy many more than 15 times. Mike is also the owner of Madcow Rocketry, a mid/high power rocket kit manufacturer.

Drew , SpaceX (Fiberglassing, Programming, Design)
Mr. Drew Beckett holds BS and MS degrees in aerospace engineering from the Dwight Look College of Engineering at Texas A&M University at College Station. Mr. Beckett developed and

operated unmanned aircraft technology demonstrators for the Texas A&M Flight Mechanics Laboratory (later Unmanned Flight Laboratory) while employed by the Texas Engineering Experiment Station. More recently, Mr. Beckett has been in the employ of Space Exploration Technologies where he is responsible for the inertial guidance, navigation, and control sensors for the Falcon 9 launch vehicle and Dragon spacecraft as well as navigating Dragon on-orbit as a mission operator.

Appendix C: Written Statement from Team Members Regarding Safety

We, the team members of the Student Launch team of the AIAA OC Section will understand and abide by the following safety regulations:

- Range safety inspections of each rocket before it is flown. Each team shall comply with the determination of the safety inspection or be removed from the program.
- The Range Safety Officer has the final say on all rocket safety issues. Therefore, the Range Safety Officer has the right to deny the launch of any rocket for safety reasons.
- Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

No.	Date	Name	Signature
1	8/20/16	Albert Wen	AlbertW
2	8/20/16	Norman Chu	Norman Chu
3	8/20/16	David Chang	David Chang
4	8/20/16	Kushagra Pandey	Kushagra P.
5	8/20/16	Claire Chang	Claire Chang
6	8/20/16	Sahil Patne	SPatne
7	8/20/16	Allison Chen	Allison Chen

Appendix D: Shop Safety

<u>AIAA OC Section Shop Safety Rules</u>
<u>For all rocketry activities (Youth – TARC – modified for SL)</u>

In an emergency, dial 911
California Poison Control Center: 1-800-222-1222

There is always a risk when someone is handling shop tools or is near another who is handling shop tools. Great precaution measures should always be taken. The following are the AIAA Orange County Section shop rules:

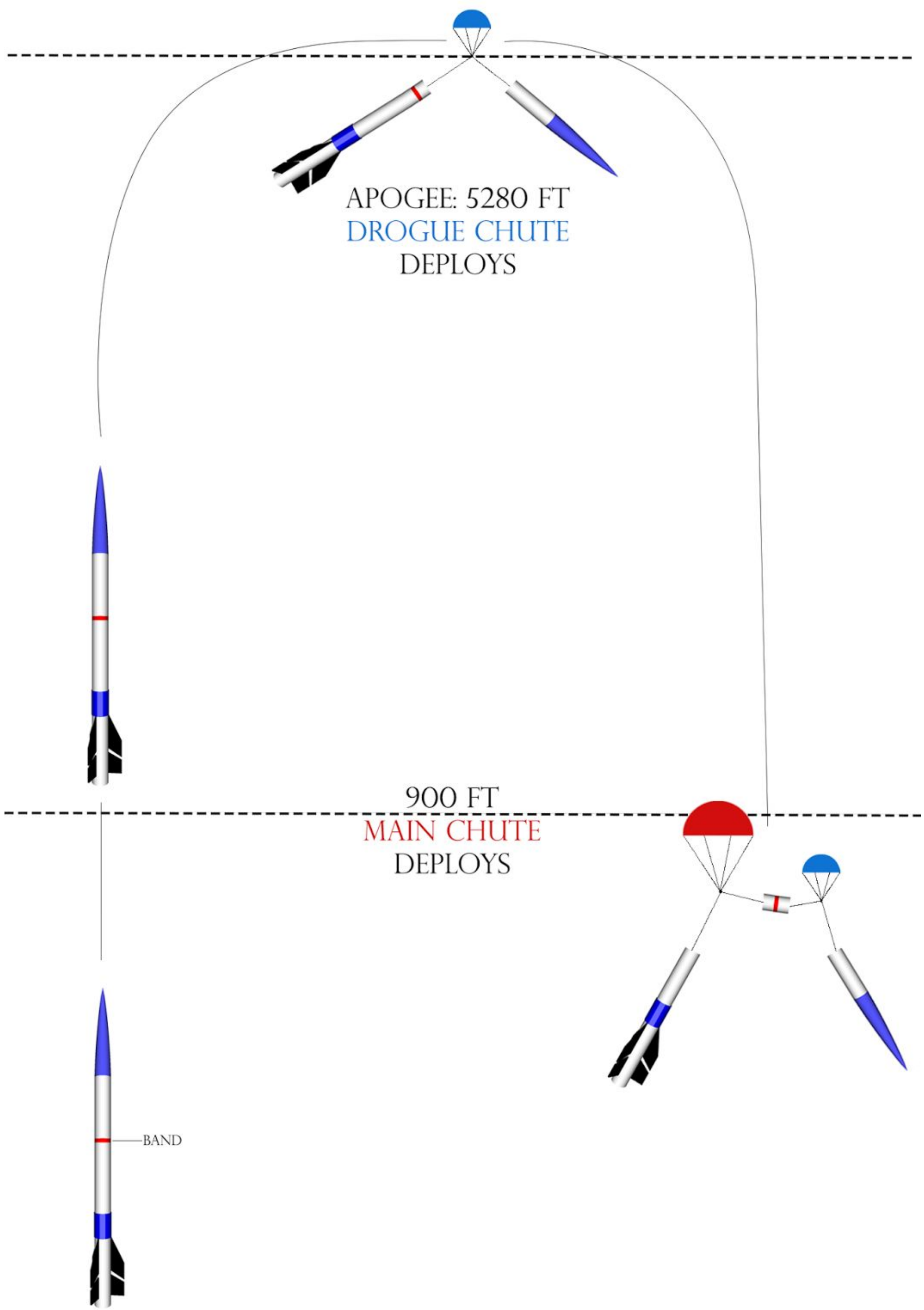
Generally:

- Keep work area orderly and clean; neatly arrange all equipment and material. Put all tools and materials back where they belong.
- Always think through an entire task before starting it, and never rush a process or take chances.
- If you are unsure about safety operation or process, ask for assistance from a program manager or mentor.
- At all times when using chemicals, X-Acto knives, electrical tools, or any tool that creates a danger of fumes or particles entering your eyes, wear safety glasses.
- Flammable liquids such as paints, solvents, and thinners must be stored in their original containers or in approved safety cans with flame arresters.
- If there are any unsafe conditions, report them to a program manager or mentor right away. Rely on the best of your own judgment and knowledge of safety to guide you.
- When lifting a heavy object, lift with your legs and not with your back; keep your back straight.
- Do not use an air hose for cleaning or dusting yourself off. Never point it towards anyone.
- If you have long hair, you must tie it back or keep it from falling down so it won't be caught in rotating tools.
- Horseplay of any kind is not allowed.
- Heavy glues and household chemicals should only be used in well ventilated areas; heavy sanding, painting, and use of chemicals are to be done outdoors.
- For documents that require work with potentially hazardous tools or operations, specific sections will be marked with the following: HAZARDOUS OPERATION – SEE SAFETY PLAN

Electrical Tools

- Do not work with power tools unless there is at least one other person in proximity.
- Before operating any machine or equipment, make sure that all safety guards are in place. The guards must be replaced as soon as repairs or servicing on a machine has been completed and put into operation.
- Never oil, remove guards, or attempt to repair machinery while it is on or in motion.
- Never use a rag near moving machinery.
- It is prohibited to tie down, block out, or otherwise make inoperative of any type of safety device, attachment method, or guard.
- Before energizing or operating any equipment, be sure to verify the safety of all personnel.
- When a machine is de-energizing for the purpose of changing the setup or making a minor adjustment, turn off the machine and pull the plug. Allow the machine to come to a complete stop before proceeding with your task.
- Do not handle electrical equipment while standing on damp or wet surfaces or when your hands are wet.
- Wear suitable clothing for the work that you are doing. Loose clothing, neckties, rings, watches, and even gloves can create a hazard when operating tools. Long sleeves or non-synthetic clothes should be worn when sparks or hot metal is present.

Appendix E: Flight Diagram



Appendix F: Material Safety Data Sheet (MSDS)

MSDS Outline

MSDS is an important document that states the health risks for an item in case an accident happens and the proper procedures that need to be undertaken just in case the health of the affected is at risk.

Fiberglass

Product Name(s): Woven Unidirectional Fiberglass Fabric (A-Style Warp Unidirectional), Stitchbonded Fiberglass Fabric, Woven Fiberglass Fabric
Manufacturer: Owens-Corning, World Headquarters, One Owens-Corning Parkway Attn. Product Stewardship, Toledo, OH, 43659, Telephone: 1-419-248-8234 (8am-5pm ET weekdays). OC Fabrics, 1851 S. Sequin Ave., New Braunfels, TX, 78130 Telephone: 1-210-629-4009 (8am-5pm CT weekdays).
Emergency Contacts: Emergencies ONLY (after 5pm ET and weekends): 1-419-248-5330, CHEMTREC (24 hours everyday): 1-800-424-9300, CANUTEC (Canada- 24 hours everyday): 1-613-996-6666. Health and Technical Contacts:
Health Issues Information: (8am-5pm ET):1-419-248-8234, Technical Product Information (8am-5pm ET): 1-800-GET-PINK.

Common Name	Chemical Name	CAS No.	Wt. %
Fiber Glass Continuous Filament (non respirable)	Fibrous Glass	65997-17-3	94-100
Size	Size	None	0-2
Polyester Yarn	Polyester Yarn	None	0-4

Appearance and Odor: White/off-white colored solid with no odor.
Primary Route(s) of Exposure: Inhalation, skin, eye
Potential Health Effects:

- **Acute (short term):** Fiber glass continuous filament is a mechanical irritant. Breathing dusts and fibers may cause short term irritation of the mouth, nose and throat. Skin contact with dust and fibers may cause itching and short term irritation. Eye contact with dust and fibers may cause short term mechanical irritation. Ingestion may cause short term mechanical irritation of the stomach and intestines. See Section 8 for exposure controls.

- **Chronic (long term):** There is no known health effects connected with long term use or contact with this product. See Section 11 of MSDS for more toxicological data.

Medical Conditions Aggravated by Exposure: Long term breathing or skin conditions that are aggravated by mechanical irritants may be at a higher risk for worsening from use or contact with this product.
Inhalation: Move person to fresh air. Seek medical attention if irritation persists.
Eye Contact: Flush eyes with running water for at least 15 minutes. Seek medical attention if irritation persists.
Skin Contact: Wash with mild soap and running water. Use a washcloth to help remove fibers. To avoid more irritation, do not rub or scratch affected areas. Rubbing or scratching may force fibers into skin. Seek medical attention if irritation persists.
Ingestion: Ingestion of this material is unlikely. If it does occur, watch the person for several days to make sure that intestinal blockage does not occur.
Flash Point and Method: None
Flammability Limits (%): None
Auto Ignition Temperature: Not Applicable
Extinguishing Media: Water, foam, CO2 or dry chemical.
Unusual Fire and Explosion Hazards: None known
Fire Fighting Instructions: Use self contained breathing apparatus (SCBA) in a sustained fire.
Hazardous Combustion Products: Primary combustion products are carbon monoxide, carbon dioxide and water. Other undetermined compounds could be released in small quantities.
Land Spill: Scoop up material and put into suitable container for disposal as a nonhazardous waste.
Water Spill: This material will sink and disperse along the bottom of waterways and ponds. It can not easily be removed after it is waterborne; however, the material is non-hazardous in water. **Air Release:** This material will settle out of the air. If concentrated on land it can then be scooped up for disposal as a non-hazardous waste.
Storage Temperature: Not applicable
Storage Pressure: Not applicable
General: No special storage or handling procedures are required for this material.

Black Powder 4F

Hazardous Components

Material or Component	%	CAS no.	TLV	PEL

Potassium Nitrate	70-76	007757-79-1	NE	NE
Sodium Nitrate	70-74	007631-99-4	NE	NE
Charcoal	8-18	N/A	NE	NE
Sulfur	9-20	007704-34-9	NE	NE
Graphite	Trace	007782-42-5	15 mppct (TWA)	2.5 mg/m^3

Physical Data

Boiling Point: N/A
Vapor Pressure: N/A
Vapor Density: N/A
Solubility in Water: Good
Specific Gravity: 1.70 - 1.82 (mercury method) and 1.92 - 2.08 (pycnometer)
pH: 6.0-8.0
Evaporation Rate: N/A
Appearance and Odor: Black granular powder. No odor detectable.

Hazardous Reactivity

Instability: Keep away from heat, sparks, and open flame. Avoid impact, friction, and static electricity.
Incompatibility: When dry, black powder is compatible with most metals; however, it is hygroscopic, and when wet, attracts all common metals except stainless steel. Black powder must be tested for compatibility with any material not specified in the production/procurement package with which they may come in contact. Materials include other explosives, solvents, adhesives, metals, plastics, paints, cleaning compounds, floor and table coverings, packing materials, and other similar materials, situations, and equipment.
Hazardous Decomposition: Detonation produces hazardous overpressures and fragments (if confined). Gases produced may be toxic if exposed in areas with inadequate ventilation.
Polymerization: Will not occur.

Fire and Explosion Data

Flashpoint: N/A
Auto Ignition Temperature: Approximately 464 C (867 F)
Explosive Temperature (5sec): Ignites at approximately 427 C (801 F)
Extinguishing Media: Water
Special Fire Fighting Procedures: ALL EXPLOSIVES: DO NOT FIGHT EXPLOSIVES FIRES. Try to keep fire from reaching explosives. Isolate area. Guard against intruders.

- Division 1.1 Explosives (heavily encased): Evacuate the area for 5000 feet (1 mile) if explosives are heavily encased.
- Division 1.1 Explosives (not heavily encased): Evacuate the area for 2500 feet (½ mile) if explosives are not heavily encased.
- Division 1.1 Explosives (all): Consult the 2000 Emergency Response Guidebook, Guide 112 for further details.

Unusual Fire and Explosion Hazards: Black powder is a deflagrating explosive. It is very sensitive to flame and spark and can also be ignited by friction and impact. When ignited unconfined, it burns with explosive violence and will explode if ignited under even slight confinement.

Health Hazards

General: Black powder is a Division 1.1 Explosive, and detonation may cause severe physical injury, including death. All explosives are dangerous and must be handled carefully and used following approved safety procedures under the direction of competent, experienced persons in accordance with all applicable federal, state, and local laws, regulations, and ordinances.

Carcinogenicity: None of the components of Black powder are listed as a carcinogen by NTP, IARC, or OSHA.

First Aid

Inhalation: Not a likely route of exposure. If inhaled, remove to fresh air. If not breathing, give artificial respiration, preferably by mouth-to-mouth. If breathing is difficult, give oxygen. Seek prompt medical attention.

Eye and Skin Contact: Not a likely route of exposure. Flush eyes with water. Wash skin with soap and water.

Ingestion: Not a likely route of exposure.. If ingested, induce vomiting immediately by giving two glasses of water and sticking finger down throat.

Injury from Detonation: Seek prompt medical attention.

Spill or Leak Procedures

Spill/Leak Response: Use appropriate personal protective equipment. Isolate area and remove sources of friction, impact, heat, low level electrical current, electrostatic or RF energy. Only competent, experienced persons should be involved in cleanup procedures. Carefully pick up spills with non-sparking and non-static producing tools.

Waste Disposal: Desensitize by diluting in water. Open train burning, by qualified personnel, may be used for disposal of small unconfined quantities. Dispose of in compliance with federal regulations under the authority of the Resource Conservation and Recovery Act (40 CFR Parts 260-271).

Special Protection Information

Ventilation: Use only with adequate ventilation.

Respiratory: None

Eye: None

Gloves: Impervious rubber gloves
Other: Metal-free and non-static producing clothes

Ammonium Perchlorate Composite Propellant (APCP)

Product Name: Ammonium Perchlorate
Other/Generic Names: AP, ammonium salt of perchloric acid
Product Use: Analytical chemistry, oxidizer in various propellant or explosive mixtures, various industrial uses involving need for oxidizing or ionization in aqueous solution properties.
Manufacturer: American Pacific Corporation, Western Electrochemical Co. 10622 West 6400 North, Cedar City, UT 84721
For More Information Call: (435) 865-5000
In Case of Emergency Call: (435) 865-5044

Ingredient Name	CAS no.	Einecs no.	Wt. %
Ammonium Perchlorate	7790-98-9	232-235-1	100

OSHA Hazard Communication Standard: This product is considered hazardous under the OSHA Hazard Communication Standard. The stated hazards classifications are applicable to the ammonium perchlorate as manufactured by AMPAC and as delivered in the DOT/UN approved shipping containers. Any rework, modification, amending or additional processing of the ammonium perchlorate may change the hazards classification and may require further hazards classification testing to determine the appropriate classification. AMPAC will not be responsible for personnel or property damage caused by a failure to conduct or provide adequate safe measures needed due to any individual company's production activities.
Emergency Overview: An odorless white crystal material. Perchlorate is an Oxidizing Agent; there is a risk of explosion if heated under confinement. As with any toxicant, dose and exposure are critically important variables to understand any potential treatment. Harmful if swallowed or inhaled in large doses.
Potential Health Effects:

- **Acute (short term):** Eye contact causes irritation, redness, and tearing. Skin contact causes irritation to mucous membranes and skin. Inhalation may cause respiratory tract irritation such as coughing, and shortness of breath; high concentrations may cause more significant respiratory effects. Ingestion: may cause gastrointestinal irritation; larger doses may cause nausea and vomiting.
- **Chronic (long term):** Perchlorates act to reversibly and competitively inhibit iodine uptake by the thyroid gland. Perchlorate is soluble in water, so exposure to ammonium perchlorate can be via water contaminated with ammonium perchlorate or inhalation in the workplace. With chronic exposure given sufficient dose (see NRC, 2005) and

duration, ammonium perchlorate can cause thyroidal stores of iodine to be reduced, which may lead to hypothyroidism. For those individuals that live in areas of the world where endemic iodine deficiency occurs, it is important that these people receive adequate iodine in the diet or are supplemented with iodine.

May be explosive when mixed with combustible material. Risk of explosion if heated under confinement.

Routes of Exposure	Signs and Symptoms of Exposure:	Emergency and First Aid Procedures:
Skin:	May cause local irritation or stinging effect.	Wash exposed area immediately with plenty of water. Remove contaminated clothing and footwear.
Inhalation:	Airborne concentrations of ammonium perchlorate can aggravate pre-existing respiratory problems.	If experiencing breathing difficulties, move to fresh air. Administer oxygen if exposed person is unconscious such as mouth to mouth resuscitation. Never give anything by mouth to an unconscious person.
Ingestion:	Ingestion of large quantities has been reported to cause staggering in small mammals. Chronic ingestion of sufficient quantities may interfere with uptake of iodine by the thyroid.	Give water. Induce vomiting, keep airway clear. Seek medical attention.
Eyes:	Irritation of the eyes will cause stinging effect.	Flush eyes with fresh water for at least 15 minutes and move exposed person to a non-contaminated area.

Flash Point: Not flammable
Flash Point Method: Not applicable
Autoignition Temperature: Not applicable. Ammonium perchlorate decomposes spontaneously at 300o C in its pure state. Contaminants may cause decomposition at lower temperatures typically down to 2700C but decomposition temperature has been listed as low as 240oC in one case
Upper Flammability Limit (volume % in air): Not applicable.
Lower Flammability Limit (volume % in air): Not applicable.
Extinguishing Media: Water - other extinguishing materials are ineffective

Unusual Fire and Explosion Hazards: Ammonium perchlorate is an oxidizing agent and may cause rapid combustion or explosions if mixed with fuels, including organic materials or powdered metals. This does not include DOT shipping containers if intimate mixtures are not present and the shipping container is not inordinately contaminated. Plastic containers have been observed to burn and leave standing cylinders of ammonium perchlorate. Molten metal from aluminum containers may contribute fuel in an instance hot enough to melt aluminum.
Special Fire Fighting Precautions/Instructions: Do not fight fires involving mixtures of ammonium perchlorate and fuels. Ammonium perchlorate is an oxidizing agent and may cause rapid combustion or explosions if mixed with fuels. Burning ammonium perchlorate may produce chlorine, chlorine dioxide, hydrogen chloride, and oxides of nitrogen as well as mixtures with any other compounds involved in the combustion. These are common by-products of combustion and are likely to be serious health concern; thus, keep upwind or wear self-contained breathing apparatus when attempting to rescue.
In Case of Spill or Other Release: (See section 8 for recommended personal protective equipment.) Sweep up material and containerize. Clean contaminated floor surface with water. Ammonium perchlorate is water soluble; thus, manage water to avoid release into the environment. Dispose of in accordance with local, state, and federal regulations.
Normal Handling: (See section 8 for recommended personal protective equipment.) Avoid contact with skin, eyes and clothing. Avoid breathing dust. Wash thoroughly after handling and follow good personal hygiene and good housekeeping practices. Keep containers closed. Handle in a manner to minimize dusting. Use of containers that meet the requirements to be DOT approved shipping containers which are managed in a manner to inhibit intimate mixtures of the container material with the product is recommended. Materials such as plastic drums, steel drums, flexible intermediate bulk containers, and fiberboard containers approved or constructed to the same specifications as DOT requirements are normally safe. FIBC are normally constructed of plastic materials in which intimate contamination soaked into the plastic is difficult to achieve. If in doubt wet and wash the FIBC and manage the water used to wash in accordance with good environmental principles to avoid contaminating drinking water sources or organic materials more subject to intimate mixtures.
Storage Recommendations: Store away from combustibles and flammables. Keep container closed when not in use. Control static electricity and other ignition sources. Store in dry areas away from sources of extreme heat.
Special Mixing and Handling Instructions: Ground and bond process equipment. Mixing ammonium perchlorate with fuels of any type may result in rapid combustion or explosions. When handling materials contaminated with ammonium perchlorate such as dust collector bags or any other combustible material, thoroughly wet the bags with water before handling, keep the bags wet while handling, and use non-sparking tools or tools coated with non-sparking material if non-sparking tools are not available. AVOID friction, impact, or static electricity ignition sources when organic materials are contaminated with ammonium perchlorate. Fire resistant

fabrics do not reduce the hazard. Finely powdered metals are frequently as combustible with ammonium perchlorate as are organics.

Engineering Controls: Ventilate as necessary to minimize dust exposures. Inspect and clean ventilation systems regularly.

Personal Protective Equipment Skin Protection: Wear impervious aprons or rain gear to reduce contamination of cotton or other fiber clothing. Plastic, rubber or latex gloves are recommended. Leather or cotton gloves should not be used unless a management program is implemented to ensure detection of contamination and immediate cleaning and change in case of contamination. Cotton clothing may be used if chance of contact is minimal or if clothing is monitored for contamination and changed if contamination occurs. In any case where combustible protection is used, a strong management system must be in place to monitor contamination and ensure appropriate removal and cleaning or severe risk of fire and personal injury or death exists. There are no known cloth materials that will not combust vigorously with perchlorates including nomex, Kevlar based materials, or clothing that is normally considered fire retardant or resistive. Observation and management of contamination is the only practicable safety measure. See additional recommendations below.

- **Eye Protection:** Under normal conditions, wear safety glasses. Under dusty conditions, wear chemical safety goggles.
- **Respiratory Protection:** Under normal conditions, not required. Where dusty conditions develop, use a NIOSH approved respirator for dusts.
- **Additional Recommendations:** Avoid contamination of cotton or other absorbent material. As in any industrial working environment, workers should routinely wear clean clothes to work. Do not wear any work clothing that has become contaminated with ammonium perchlorate. Remove contaminated clothing immediately and keep wet until thoroughly washed. Keeping contaminated clothing wet minimizes hazards until the laundering is completed. Showering is recommended after handling any industrial chemical. Smoking of tobacco should not be permitted while wearing contaminated clothing. Leather boots may become contaminated and could be a source of combustion damaging feet. Rubber boots are recommended unless a very strict management program to detect contaminated leather boots is in place much as listed on the glove section above.

Appearance: White Crystal	**Physical State:** Solid	**Molecular Weight:** 117.50	**Chemical Formula:** NH4ClO4	**Odor:** None
Specific Gravity (water = 1.0): 1.95	**Solubility in Water (weight %):** 20.8 g/100 ml at 20 C	**pH:** Materials is a solid however, dissolved in water the pH is slightly acidic	**Boiling Point:** None, rather it decomposes	**Melting Point:** Decomposes at 300 C in its pure state, impurities may lower the decomposition

				temperature significantly.
Vapor Pressure: Solid, none	**Vapor Density (air = 1.0):** At 20 C, None	**Evaporation Rate:** None		
Flash Point: Not flammable				

Normally Stable (Conditions To Avoid): Stable under normal conditions. Do not mix with organic materials, reducing agents, metal powders or powdered carbon. Avoid elevated temperatures over 270°C, which can cause spontaneous exothermic decomposition. Cloth fabric of any type including dust collector bags intimately contaminated with ammonium perchlorate is subject to ignition through friction or impact. High-energy static electricity may also serve as an ignition source when contamination or combustibles are intermixed.
Incompatibilities: Sulfuric acid, powdered metals, and intimate mixtures with organics.
Hazardous Decomposition Products: Chlorine, chlorine dioxide, oxygen, nitrogen oxides, hydrogen chloride.
Hazardous Polymerization: Will not occur.
As with any toxicant, dose and exposure are critically important variables to understand any potential toxicity. It is always advisable to minimize dusting and use respiratory protection for environments where substantial dust is generated or where there may be exposure to water with high concentrations of perchlorate. Ammonium perchlorate acts to reversibly and competitively inhibit iodine uptake by the thyroid gland. The half-life of ammonium perchlorate ranges from 8 to 12 hours. Ammonium perchlorate does not bioaccumulate. Perchlorate is not metabolized and is excreted from the kidneys. Harmful if swallowed or inhaled in large doses. In the early 1960s another salt of perchlorate, potassium perchlorate, given in very high doses for weeks of exposure as an oral therapeutic agent to treat hyperthyroidism was reported to be associated with a few cases of aplastic anemia and agranulocytosis (National Research Council, 2005). Since that time, there have been no known reports of aplastic anemia. There have been no reports of ammonium perchlorate associated with aplastic anemia or agranulocytosis.
Immediate (Acute) Effects: Oral LD50: rat; 4200 mg/kg Rat-par-LDLo = 3500 mg/kg Oral LD50: rabbit; 1900 mg/kg Rabbit-par-LDLo = 750 mg/kg Inhalation LC50: No references found. Skin sensitization: not reported to be a skin sensitizer
Delayed (Subchronic And Chronic) Effects:

- **Thyroid:** No long-term health effects have been reported with exposure to ammonium perchlorate. Perchlorate is water soluble, so exposure to ammonium perchlorate can be via water contaminated with ammonium perchlorate or inhalation in the workplace. With chronic exposure, sufficient dose, and duration, ammonium perchlorate may cause thyroidal stores of iodine to be reduced, which may lead to goiter (enlarged thyroid gland) and hypothyroidism. Occupational studies indicated no adverse health effects on workers exposed for 3 years or more to perchlorate. These studies also demonstrate that blood chemistry and hormone values are not altered with occupational exposures as high as 0.48 mg per kilogram body weight (Braverman et al., 2005; Lamm et al., 1999). In 2005, a National Academies of Science Committee reviewed the literature and oral exposures to perchlorate and identified a no-observable-adverse-effect-level 0.4 mg/kg/day in humans. That dose is inhibits iodide uptake by nearly 70 percent without effecting thyroid hormones or thyroid stimulating hormone. The NAS also identified a no-observed-effect-level of 0.007 mg/kg/day in humans, based on Greer, et. al. 2002, which is a dose that does not cause inhibition of iodide uptake. For those individuals that live in areas of the world where endemic iodine deficiency occurs, it is important that these people receive adequate iodine in the diet or are supplemented with iodine.