Preliminary Design Review

Measurement of Aerosols in Lower Atmosphere Using Optical Detection

NASA Student Launch for Middle and High School

Madison West High School

ATTN: Ms. Christine L. Hager

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Summary of PDR Report

Team Summary

Name:	Madison West Rocket Club
Mailing Address:	Madison West High School Attn: Ms. Christine L. Hager 30 Ash Street Madison, WI. 53726
Mentor Name:	Pavel Pinkas, Ph. D.
NAR Number:	73307 Level 2 Certified
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Launch Vehicle Summary

Size:	4 in diameter construction. Size: 90.47” x 10” x 10”
Mass:	23.2 lbs
Motor Choice:	75mm diameter motor CTI K2000
Target Altitude:	5350 ft
Recovery System:	Dual Deploy: 56 cm drogue @ Apg | 305 cm Main @ 500 ft AGL.

Flysheet: http://westrocketry.com/sli2019/MSRFS_PDR_MadisonWest2019_Aerosols.pdf

Payload Summary

Payload Title: Measurement of Aerosols in Lower Atmosphere Using Optical Detection

Payload Summary: The payload is designed to analyze particle concentration and size distribution at specific altitudes. During vehicle ascent, the vehicle will allow air and particles to enter into the payload. These particles will be imaged by a camera and LED light and the concentration recorded. The data will then be relayed back to the ground via a telemetry interface.

Changes Since Statement of Work

Changes in Vehicle

- Added selection rationale for nosecone, airframe, motor mount and fins
- Added fin flutter analysis
- Updated vehicle design
- Updated propulsion selection
- Performed analysis of target altitude (select 5,350*ft* at the target)
- Updated recovery system design and analysis

Changes in Payload

- Changed number of payload units from three to two
- Updated payload design
- Updated design of the telemetry module
- Designated telemetry module as Payload #2 (in flysheet)

Changes in Project Plan

- Update list of outreach events
- Completed Wisconsin Science Festival outreach event
- Completed Homecoming Parade outreach event
- Started annual fundraising raking campaign

General Information

Educators

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https://sites.google.com/view/qcrs

Team Leader

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Safety Officer

Matilda
Safety Officer
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The safety officer is supervised by Dr. Pinkas, who carries all accountability.

Student Participants

Vehicle Team: Responsible for vehicle design, flight safety parameters, altitude target, propulsion, and launch operations.

Ryley
Lead Vehicle Engineer

Grant
Vehicle Safety Engineer

Ella
Construction Engineer

Kyle
Vehicle Design Specialist

Sultani
Construction Engineer

Payload Team: Responsible for payload design, payload preflight preparations and activation and postflight payload data analysis.

Mason
Lead Payload Engineer

Kab
Payload Function Specialist

Nicholas
Software Technician

Norlha
Social Media Coordinator

Telemetry Team: Responsible for maintaining wireless contact with the rocket, receiving data from onboard GPS, avionics and payload, tracking and locating the rocket.

Ben
Lead Telemetry Engineer

Hyun-seok
Team Leader, Software Engineer

Daniel
Chief Hardware Engineer

Modelling Team: Responsible for 3d modelling for Payload and Vehicle teams.

Michael H.
Lead Payload Modelling

Michael M.
Lead Vehicle Modelling

Edwin
Payload Technician

Project Management and Safety: Responsible for following safety procedures and updating safety documentation.
 **Matilda** *Chief Safety Officer*  **Maya** *Details Coordinator*

Table 1: Team members and proposed duties

Vehicle Criteria

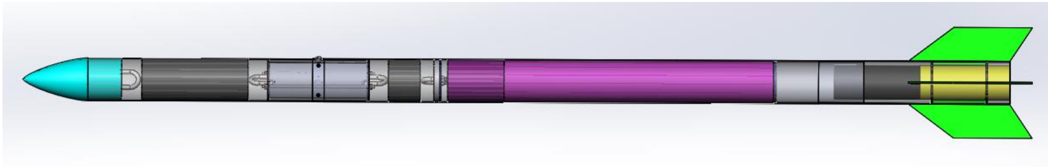


Figure 1: SolidWorks model of the proposed vehicle

Vehicle Selection, and Rationale

Mission Statement

The vehicle design team's mission is to design, test and construct a delivery vehicle capable of sending itself, and its integrated payload to an altitude of 5350 ft and back to the ground safely in an effort to measure aerosol concentrations in the lower atmosphere using optical detection.

Mission Success Criteria

The criteria for determining a successful vehicle design are as follows :

1. Vehicle exits launch rail at a velocity of 16 m/s (52 fps).
2. The flight is stable.
3. The vehicle reaches an altitude between 1220 meters (4,000 ft) and 1,675 meters (5,500 ft) and within 5% accuracy of the 5350 ft.
4. The descent is safe and both main and drogue parachutes deploy properly (landing has kinetic energy less than 102 J or 75 ft-lbf).
5. There are no unplanned or out of sequence events.
6. The vehicle sustains no damage and is able to fly in the same day.
7. The rocket is recovered and returned within 2 hours after the launch.

Nosecone System Analysis

Nosecone Shapes

Ellipsoid

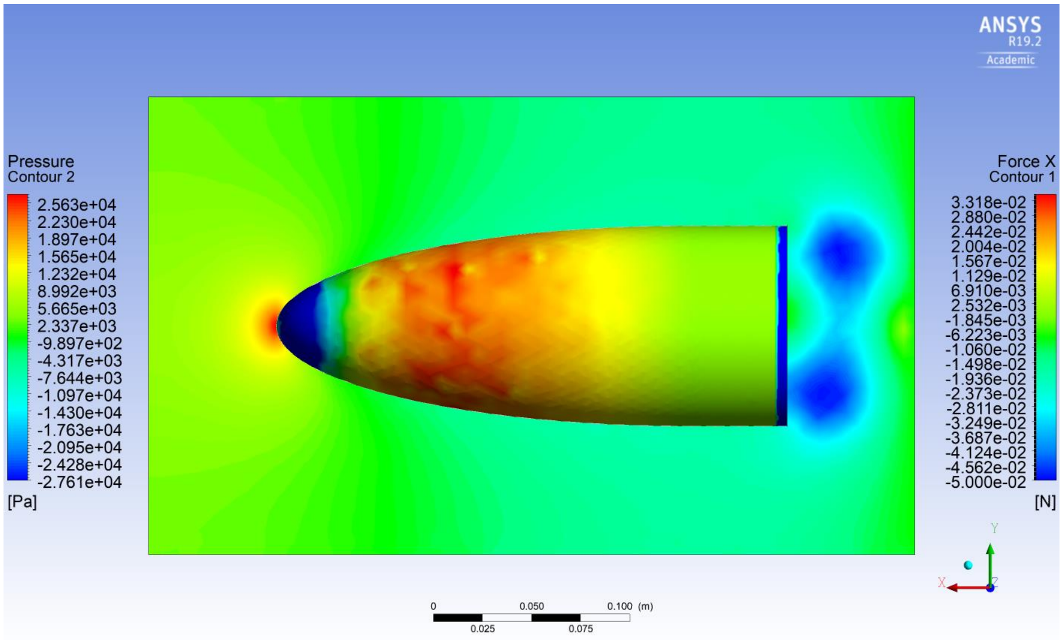


Figure 2: Pressure analysis for elliptical nosecone

The ellipsoid nosecone has a profile of an ellipsoid that is cut in half and is often used in low powered rocketry. The bluntness of the nosecone, as well as the fact that it is tangent to its base, theoretically gives it good performance in low velocity flights, but causes it to suffer during high velocity flights. However, simulations show that an ellipsoid nosecone performs poorly compared to other nosecone designs. The design was generated by using the following mathematical formula:

$$y = R\sqrt{\frac{x^2}{L^2}}$$

Equation 1: Elliptical nosecone outline formula

Where R is the radius of the base, L is the overall length of the nosecone, and y is the radius of the nosecone at a given point x, which is zero at the top of the nosecone and L at the base of the nosecone.

Half Power

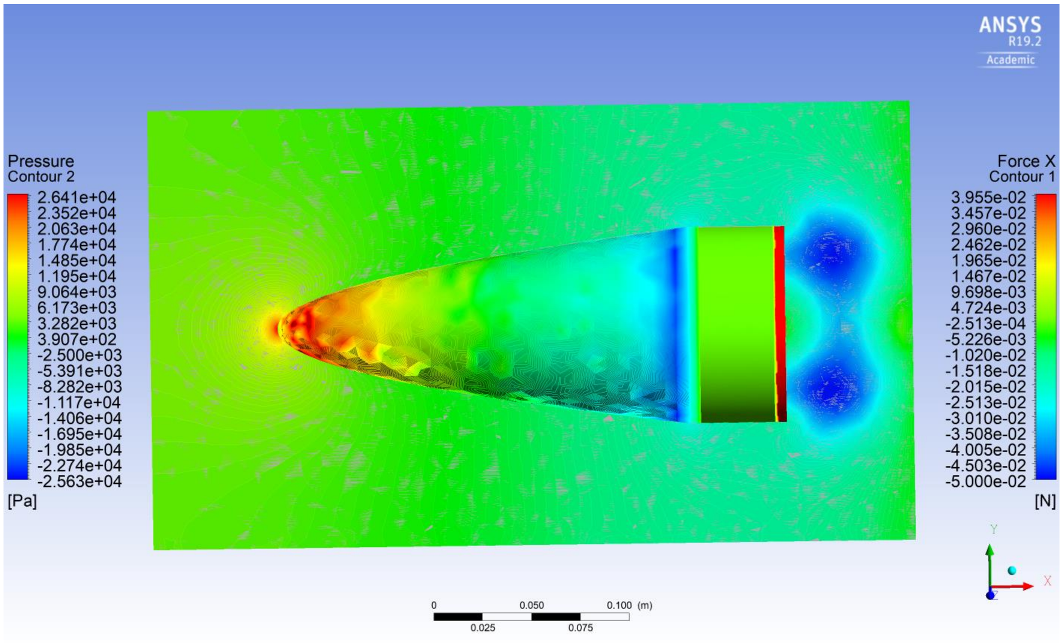


Figure 3: Power series nosecone pressure analysis

The power series of nosecones has a profile that is similar to the conical nosecone but more smoothed out. This design is blunt at the tip and is not tangent to the base. The design was generated by using the following mathematical formula:

$$y = R\left(\frac{x}{L}\right)^n$$

Equation 2: Power series nosecone outline formula

Where R is the radius of the base, L is the overall length of the nosecone, n corresponds the the bluntness of the nosecone (in this case, ½) and y is the radius of the nosecone at a given point x, which is zero at the top of the nosecone and L at the base of the nosecone.

Parabolic

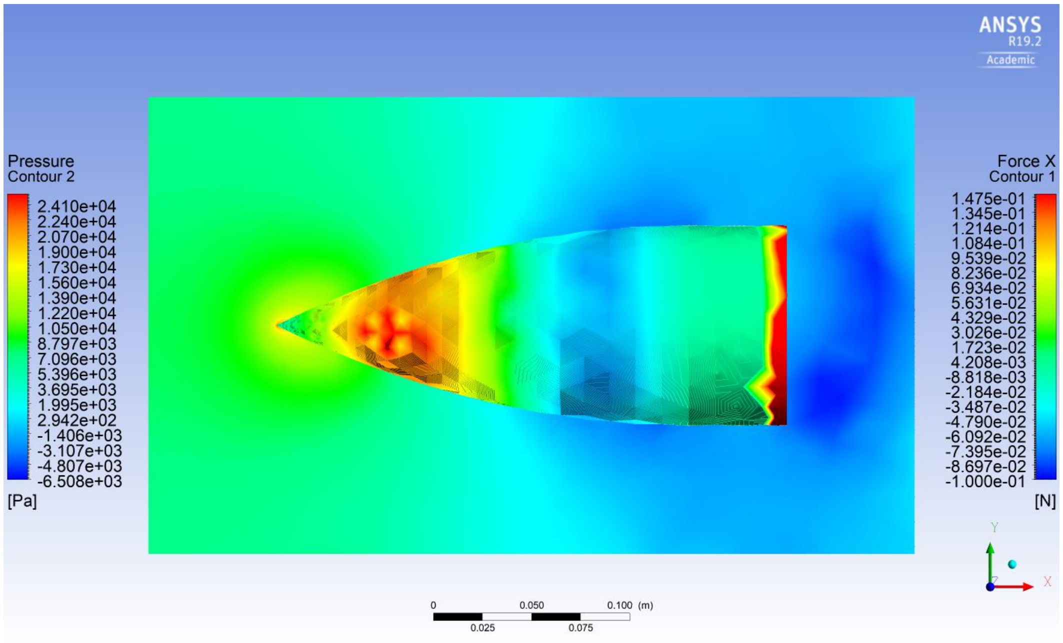


Figure 4: Parabolic nosecone pressure analysis

The parabolic series of nosecones has a profile that is similar to the conical nosecone but more smoothed out. This design is blunt at the tip and is not tangent to the base. The design was generated by using the following mathematical formula:

$$y = R\left(\frac{x}{L}\right)^n$$

Equation 3: parabolic nosecone outline formula

Where R is the radius of the base, L is the overall length of the nosecone, n corresponds the the bluntness of the nosecone (in this case, ½) and y is the radius of the nosecone at a given point x, which is zero at the top of the nosecone and L at the base of the nosecone.

Von Karman

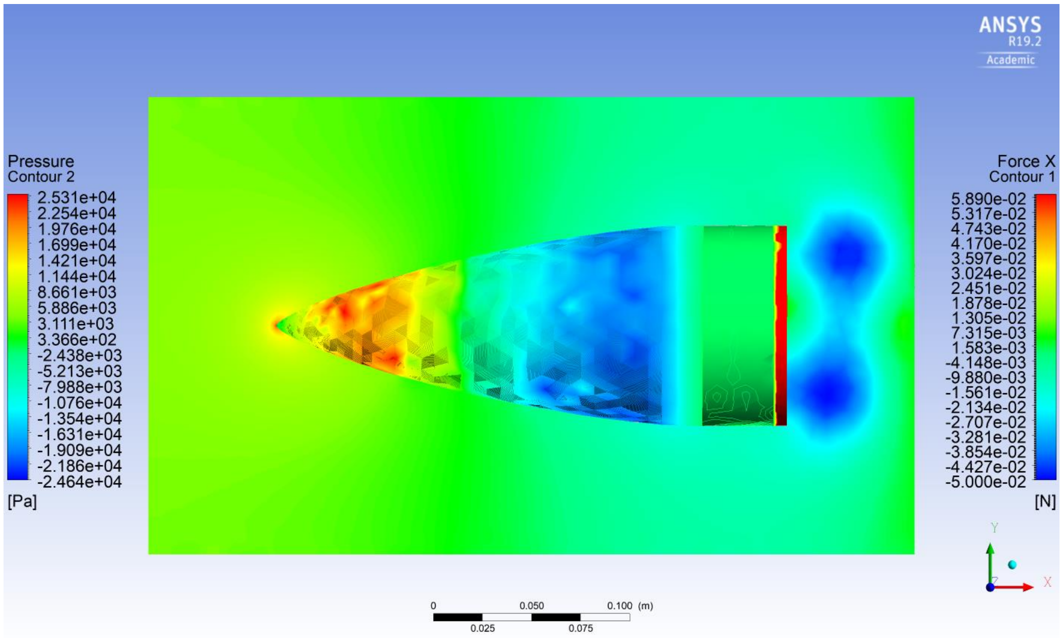


Figure 5: von Karman nosecone pressure analysis

The LD-Haack or Von Karman nosecone is mathematically designed in order to minimize drag for a given length and diameter. The design was generated using the following equation.

$$y = \frac{R\sqrt{\frac{\theta - sin(2\theta)}{2}}}{\sqrt{\pi}}$$

Equation 4: von Karman nosecone outline formula

Where θ is defined as follows:

$$\theta \ = \ arccos(1 - \frac{2x}{L})$$

Equation 5: von Karman θ factor

Where R is the radius of the base, L is the overall length of the nosecone, and y is the radius of the nosecone at a given point x, which is zero at the top of the nosecone and L at the base of the nosecone.

Nosecone Verification Matrix

		Von Karman		Parabolic		Ellipsoid		½ Power	
Criteria	Weight	Value	Score	Value	Score	Value	Score	Value	Score
Drag	50.00%	10	5	10	5	5	2.5	7	3.5
Altitude Change	40.00%	10	4	10	4	3	1.2	10	4
Aesthet-ics	10.00%	10	1	8	0.8	4	0.4	5	0.5
	Total:	10.00		9.80		4.10		8.00	

Table 2: Nosecone decision matrix

Nosecone designs were scored based on their simulated drag coefficients determined by ANSYS, and simulated changes in apogee determined by OpenRocket. The tie caused by the almost negligible difference between the performance of the Von Karman and parabolic nosecones was broken through the nosecones aesthetic appeal.

Nosecone Length

While the optimum length of the nosecone would be 51 cm or a 5:1 nosecone length to body diameter ratio (also called the fineness ratio), due to design constraints of the 3D printer that will be used to manufacture the nosecone, the current design stands at around 21 cm, providing 2:1 nosecone length to body diameter ratio. Further design constraints may require an even shorter nosecone.

Airframe Material Analysis

Candidate Materials

Kraft-Phenolic Tube

Kraft-Phenolic tubing is the impregnation of regular kraft paper cardboard tubing with phenolic resin. This gives the tube a higher strength and resistance to heat than its cardboard counterpart. It is the most affordable of the options at $21.32 per meter of 98 mm tubing and only behind carbon fiber in terms of lightness. However, Kraft-Phenolic tubing is quite brittle and needs special preparation such as filling in the groves for a smooth surface.

Blue Tube

Blue Tube is a material that was initially made for military ammunition but has since seen widespread use in high powered rocketry. It is stronger than phenolic due to it being less brittle and is marketed as 36% less dense than fiberglass. Additionally, it is quite affordable at $31.93 per meter of 98 mm tubing. However, Blue Tube has a tendency to warp, especially in humid conditions, making painting more involved.

Fiberglass Tube

G12 fiberglass tubing is the stable of the club's high powered vehicles in the past. It is a very strong material that has a smooth surface finish and thus is very easy to paint and work with. Additionally, due to this material's long history with the club, there is a wealth of knowledge about its use. However, disadvantages to fiberglass include its high density and its relatively high price at $76.61 per meter of 98 mm tubing.

Carbon Fiber Tube

Carbon fiber tubing is both the material with the highest strength and the lowest density of all the materials examined, making it an excellent choice. However, carbon fiber is prohibitively expensive with a hefty price tag of $157.48 per meter of 98 mm tubing. Additionally, carbon fiber is quite toxic when it is being cut, even more so than fiberglass tubing, which adds an extra level of consideration to this otherwise excellent material.

Airframe Material Decision Matrix

Material	Available in 152.4 cm lengths	Able to withstand flight forces
Kraft-Phenolic	X	✓
Blue Tube	✓	✓
Fiberglass	✓	✓
Carbon Fiber	✓	✓

Table 3: Airframe Material Requirement Table

Requirements of the airframe tubing include its availability in at least 152.4 cm (5 ft) lengths due to the design of the vehicle and its ability to withstand flight forces. Examination of the manufacturer recommendations and the stress forces exerted on the vehicle (6.24 G) show that all materials have the ability withstand flight forces. However, no Kraft-Phenolic tubing sold in lengths over 152.4 cm were discovered by the team, eliminating Kraft-Phenolic as a possible airframe material choice.

		Kraft-Phenolic		Blue Tube		Fiberglass		Carbon Fiber	
Criteria	Weight	Value	Score	Value	Score	Value	Score	Value	Score
Cost	20.00%	10	2	8	1.6	6	1.2	2	0.4
Strength	35.00%	2	0.7	6	2.1	8	2.8	10	3.5
Mass	10.00%	10	1	6	0.6	4	0.4	8	0.8
Work-ability	35.00%	4	1.4	8	2.8	10	3.5	6	2.1
	Total:	5.10		7.10		7.90		6.80	

Table 4: airframe material decision matrix

Airframe materials were also scored based on cost, strength, mass, and workability. For the purposes of the analysis, strength was determined as the likelihood that the material will break under the stresses of building, testing, transportation, flight and landing of the vehicle and workability was determined as the ease of measuring, cutting, and painting the airframe. Analysis of the candidate materials show fiberglass as the optimal airframe material.

Motor Retention Analysis

Candidates

Clip System

This system of motor retention uses kaplow clips to secure the motor within the motor mount. This method has been verified to work on rockets that run on K-class motors by the club due to its widespread use in the Rockets For Schools program. Advantages of this system include its low cost and easy replaceability. Disadvantages include a higher likelihood of the retention system being damaged during transportation and low aesthetic appeal.

Screw On Motor Retention

The screw on motor retainer system consists of two components, one of which is glued to the end of the motor mount and the other which screws on top of it to retain the motor. Advantages of this system include its ease of implementation and clean look. However, it is much more expensive to implement than the clip system.

Plate Retention

The plate retention system involves bolting an plate to the back of the motor to prevent its movement during flight. This is probably the strongest and least failure prone method of all the systems discussed. However, plate retention is not available on the commercial market in the sizes needed and is also the heaviest of the options.

Motor Retention Verification Matrix

Retention System	Capable of handling ejection forces	Is not a form of friction retention
Clip	✓	✓
Screw-On	✓	✓
Plate	✓	✓

Table 5: Motor retention feature matrix

Requirements for the proper motor retention system include a system that is capable of handling ejection forces and - pursuant to section 2.24.6 of the handbook - and cannot be classified as a form of friction retention. All candidates meet the requirements

		Clip		Screw-On		Plate	
Criteria	Weight	Value	Score	Value	Score	Value	Score
Cost	15.00%	10	1.5	7	1.6	5	0.8
Availability	20.00%	5	1.0	7	1.4	1	0.2
Mass	10.00%	10	1.0	7	0.7	3	0.3
Strength	35.00%	4	1.4	9	3.2	10	3.5
Ease of Implementation	20.00%	4	0.8	10	2.0	9	1.8
	Total:	5.70		8.90		6.60	

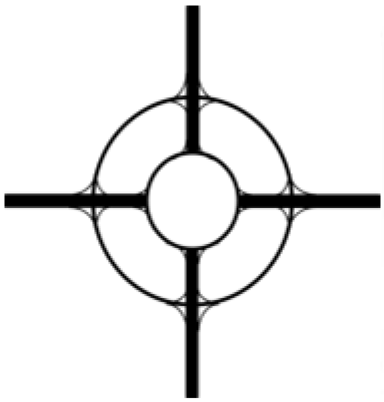
Table 6: Motor retention decision matrix

Each system was ranked according to its cost, availability, mass, strength, and ease of implementation. The screw on motor retention system was chosen as the best candidate because it is easy to implement, widely available, and quite strong.

Fin System Analysis

Fin Mounting System

A number of fin mounting systems were considered for the current design. However, the through the wall (TTW) fin mounting ultimately was decided upon. The TTW mounting system consists of gluing the fin through the wall of the airframe and onto the motor tube. Additionally, the fin tab will be sandwiched in with centering rings. This method is the strongest and lightest of all the possible options. However, this method is permanent and any damage to the fins or the joint cannot easily be replaced. Alternatives, allow for the easy removal and replacement of such damage but are heavier and are much more difficult to acquire. The team therefore decided to adopt the TTW fin mounting system for the vehicle in order to reduce the weight of the fin system, adding to the stability of the vehicle. Furthermore, it was determined proper implementation of the TTW would greatly reduce the chances of fin breakage and thus is not a big concern. The airframe is tang slotted to allow for the stronger attachment of fins.



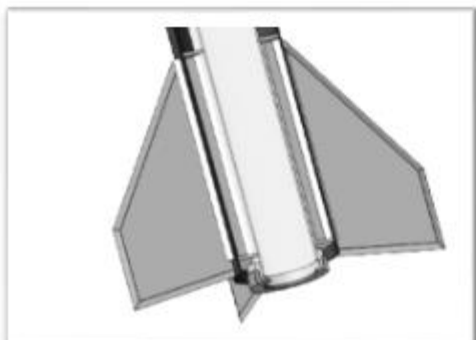


Figure 6: Through-the-wall fin mounting technique

Fin Materials

G10 Fiberglass

G10 fiberglass has often been used in the past by the club for the construction of fins. While it is not the strongest or lightest of the materials considered, it is more flexible and affordable than carbon fiber.

Carbon Fiber

Carbon fiber has high strength and extreme stiffness, all of which comes in a very lightweight package. However, carbon fiber is more expensive to work with and its high strength may not be necessary.

Fin Thickness Analysis

1.59 mm (1/16”) Thickness Fins

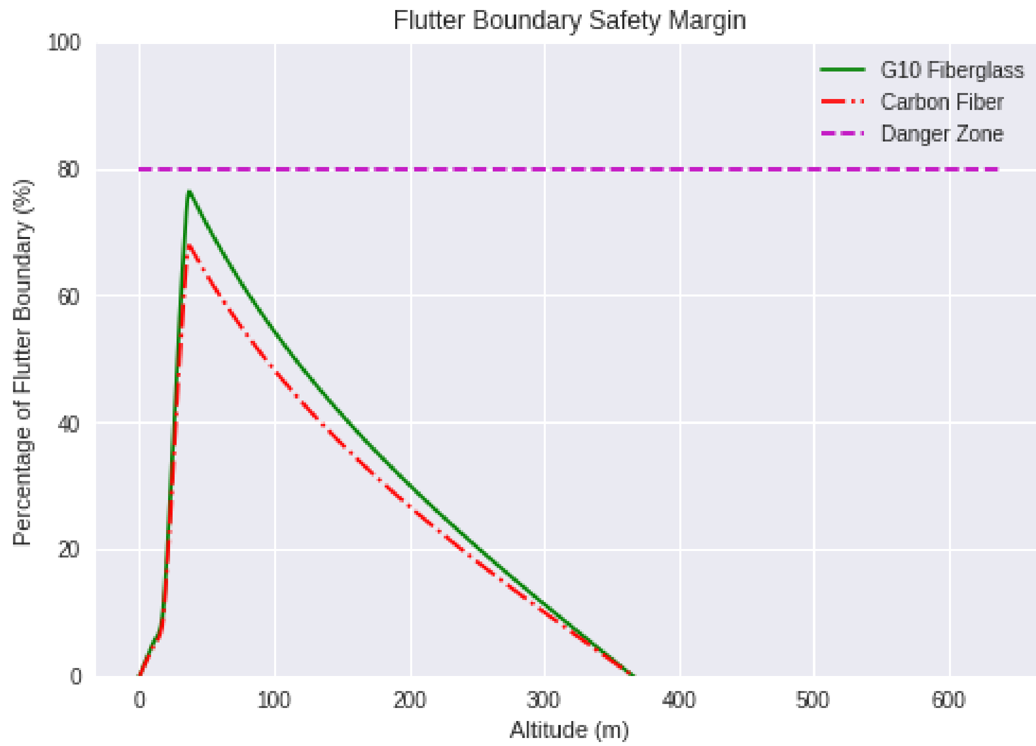


Figure 7: 1/16” (1.59 mm) fin flutter safety margin analysis

Fin Flutter calculations project fins with 1.59 mm thickness to reach 77% of the flutter boundary for g10 fiberglass and 66% of the flutter boundary for carbon fiber at an altitude of 66 meters. Projected total mass of fin sets of this thickness is 196 g for g10 fiberglass and 164g for carbon fiber.

2.38 mm (3/32”) Thickness

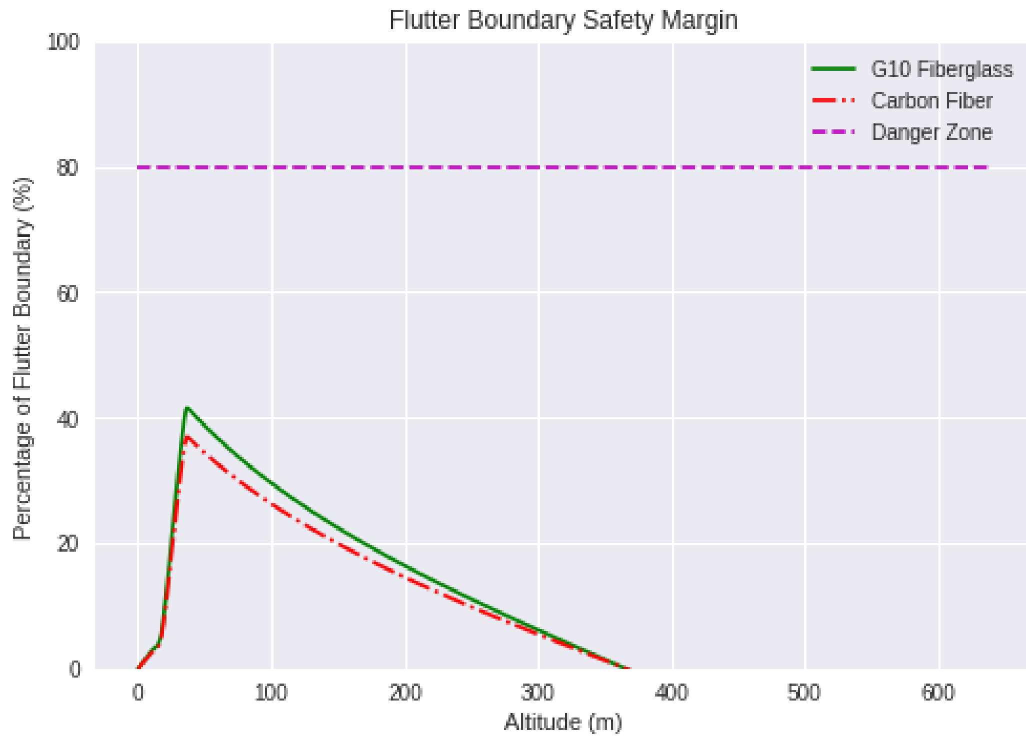


Figure 8: 3/32” (2.38 mm) fin flutter safety margin analysis

Fin Flutter calculations project fins with 2.38 mm thickness to reach 40% of the flutter boundary for g10 fiberglass and 38% of the flutter boundary for carbon fiber at an altitude of 66 meters. Projected total mass of fin sets of this thickness is 294 g for g10 fiberglass and 246 g for carbon fiber

3.18 mm (1/8")Thickness

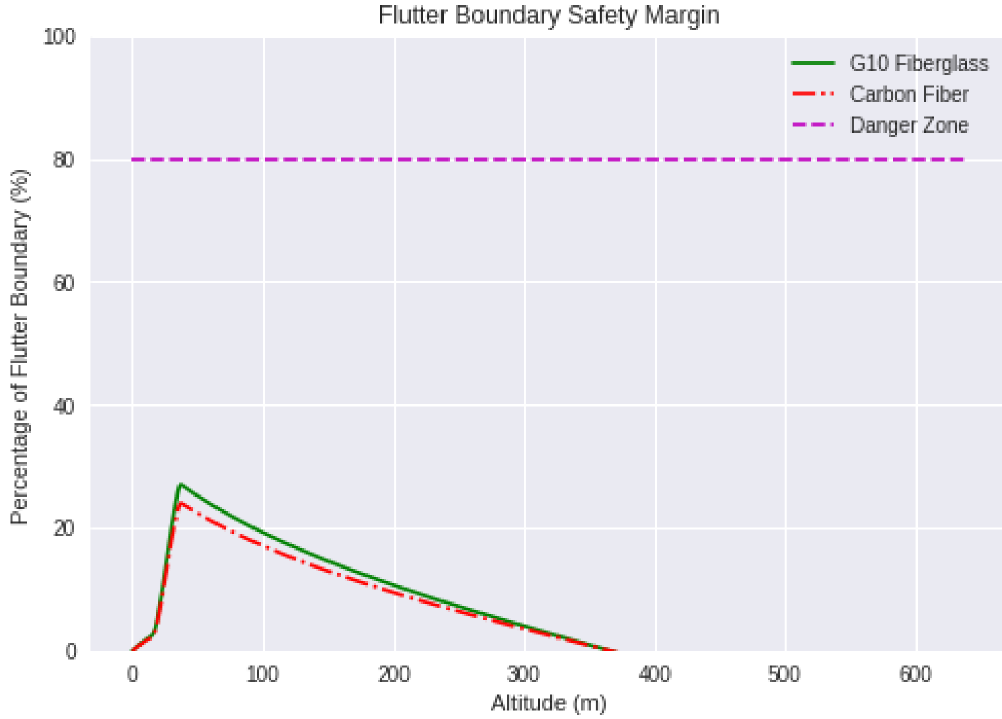


Figure 9: 1/8" (3.18 mm) fin flutter safety margin analysis

Fin Flutter calculations project fins with 1.59 mm thickness to reach 24% of the flutter boundary for g10 fiberglass and 22% of the flutter boundary for carbon fiber at an altitude of 66 meters. Projected total mass of fin sets of this thickness is 392 g for g10 fiberglass and 329 g for carbon fiber.

Fin Decision Matrix

Fin	Flutter Boundary Safety Margin < 50%	Stability > 2.0 cal
1.59 mm - G10	✗	✓
1.59 mm - CF	✗	✓
2.38 mm - G10	✓	✓
2.38 mm - CF	✓	✓
3.18 mm -G10	✓	✓
3.18 mm - CF	✓	✓

Table 7: Fin requirements table

Requirements for the fin include a flutter boundary safety margin of less than 50% and a stability greater than 2.0 cal to ensure proper safety margins. Thus, 1.59 mm (1/16”) fin thickness of both g10 fiberglass (G10) and carbon fiber (CF) material was ruled out.

		2.38 mm - G10		2.38 mm- CF		3.18 mm - G10		3.18 mm - CF	
Criteria	Weight	Value	Score	Value	Score	Value	Score	Value	Score
Cost	30.00%	10	3	5	1.5	7	2.1	2	0.6
Strength	50.00%	6	3	7	3.5	9	4.5	10	5
Mass	20.00%	8	1.6	10	2	3	0.6	5	1
	Total:	7.60		7.00		7.10		6.60	

Table 8: Fin decision matrix

Analysis of the candidate materials show 2.38 mm (3/32”) G10 fiberglass as the optimal material for fins due to its low mass, low cost, and relatively high flutter boundary safety margin.

Leading Vehicle Design

Summary

A single stage, K-class vehicle will be used to deliver our payload to the target altitude of 5350 ft. The proposed project will investigate the concentration of aerosols in the planetary boundary layer.

The vehicle will be 230 cm long, will be constructed from 98mm fiberglass tubing. Fins will be constructed using 2.38mm (3/32") G10 fiberglass. The vehicle will be constructed to launch from a standard size, 8 ft launch rail.

With an estimated liftoff mass of 10.726 kg (including 30% of simulated weight increase), the primary propulsion choice is the K class CTI K2000. This motor has a total impulse of 2329.9 Ns, and requires a 75mm motor casing.

The rocket will use dual deployment to minimize drift.

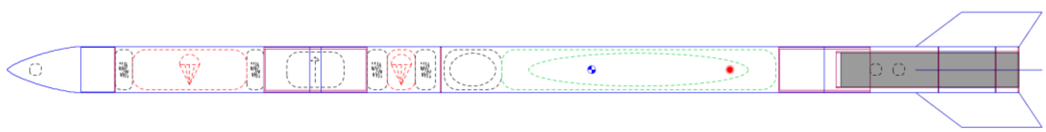
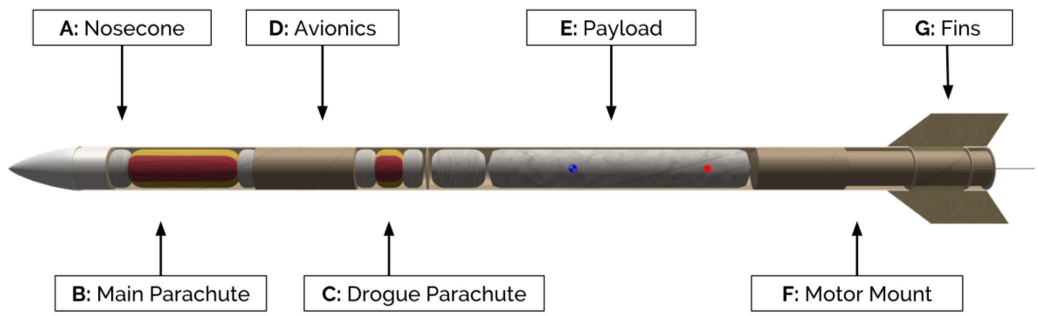


Figure 10: A two-dimensional schematic of the vehicle

Length	Mass	Diameter	Motor Selection	Stability Margin	Thrust to Weight Ratio
86.5 in	23.3 lbs	4.0 in	CTI K2000	2.48 cal	23.9

Table 9: Vegicle parameters

Sectional Overview



(A)	Nosecone
(B)	Main parachute
(C)	Drogue Parachute
(D)	Avionics
(E)	Payload
(F)	Motor mount
(G)	Fins

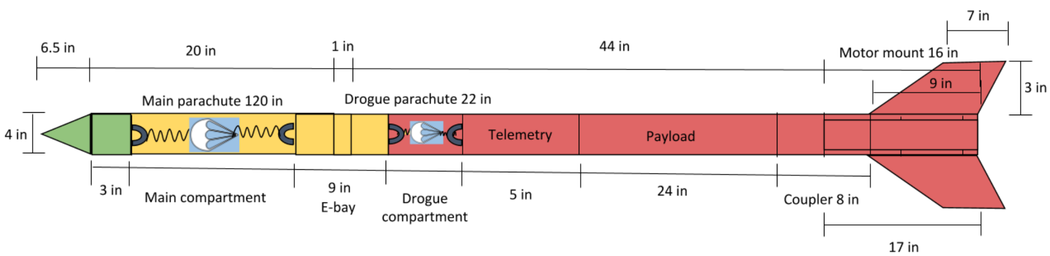
Figure 11: A three-dimensional schematic of the vehicle

The table and diagram above outlines the major components and parts of the rocket. The main parachute is packed in the fore of the rocket, directly under the nose cone. The avionics bay, which houses the flight electronics will be located under the main parachute and on top of the drogue parachute. A bulkhead separates the recovery section from the rocket's payload section, which houses both the telemetry bay and the payload. Finally, the vehicle finishes off with a motor mount and fins to facilitate in its propulsion and stability.

Mass Statement

Total Weight of Rocket: 23.3 lbs.
Weight of Propulsion Subsystem: 5.4 lbs.
Weight of Payload Subsystem: 4 lbs.
Weight of Telemetry Subsystem: 1.5 lbs.
Weight of Structure Subsystem: 12.4 lbs.

Vehicle Dimensions



Part	Size
Overall length	86.5 in
Body diameter	4 in
Avionics Bay (E-bay) length	9.0 in
Main compartment length	13.0 in
Drogue compartment length	3.0 in
Fin foot cord	9.0 in
Fin tip cord	7.0 in

Figure 12: A dimensioned drawing of the vehicle

The fully assembled vehicle will have a length of 86.5 in and a body diameter of 4.0 in. The booster section (colored red), containing the telemetry, payload, motor mount, fins and drogue parachute compartment will span 60 in with 24 in dedicated for the payload and 5 inches dedicated to the telemetry system. The upper vehicle section (yellow) consists of the avionics bay and the main parachute compartment and will span 24 in. Finally the nose cone section (green), which will be ejected at main deployment, consists of a 6.5 in Von Karman nose cone with a 3 in shoulder.

Material Selection

Fiberglass is the primary choice of material for most of the rocket. Fiberglass can be precisely machined, has the desired strength to weight ratio and can be easily finished.

Simulations show that a K-class motor has enough impulse to reach between 4000 and 5,500 feet in a 4.0 inch diameter fiberglass rocket. 3D printing can create sturdy custom nosecones at little cost. Other materials are selected with prior successes in mind.

Rocket Part	Material
Nosecone	3D printed PLA plastic, Von Karman shape
Tubing	Fiberglass tubing, 4 in diameter
Fins	3/32 in G10 fiberglass
Parachutes	Ripstop nylon
Couplers	Fiberglass 4 in coupler tubing
Motor Mount	Fiberglass 75 mm tubing
Centering Rings	1/8 in G10 fiberglass
Anchors	1/4 in stainless steel U-bolts
Tie Rods	#10/24 stainless steel threaded rods
Motor Retention	Aeropack aluminium flange mounted retainer

Table 10: Materials for rocket construction

Forward Airframe Subassembly

Nosecone

A 16.4 cm Von Karman nosecone with a 7.6 cm shoulder will be used for the vehicle. A 3D rendering of the nosecone is shown below.

Figure 13: Von Karman nosecone

Main Parachute Bay

The main parachute bay is located just aft of the nosecone with anchors for the parachute on the nosecone and the Ebay. A variety of different lengths for the main parachute bay was tested but a length of 33 cm was determined based in measurement data from a fully packed 120 in parachute with nomex shielding and shock chords as well as experience from past projects.

E-Bay Subassembly

E-Bay Design

The E-bay is constructed from a length of coupler tubing and will serve to connect the booster and forward airframe sections of the vehicle. The current location of the Ebay subassembly allows for an easy separation of the vehicle sections without complex wiring and minimizes the risk of ejection failure.

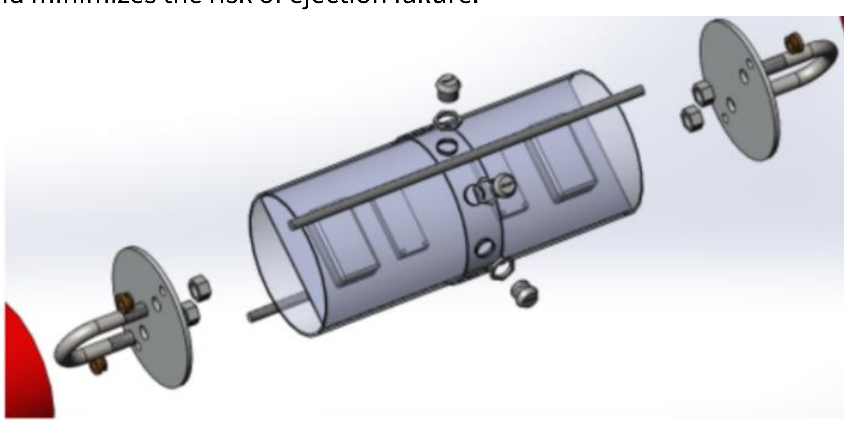


Figure 14: Solidworks model of the electronics bay

Booster Subassembly

Payload Bay

Location

Many different designs for the location of the payload bay were discussed during the initial design phase. Initial designs put the payload bay just behind the nosecone in order to allow for the capturing of air through the nosecone. However, changing payload design configurations and strict interpretation of requirement 2.22 in the handbook, which requires any structural protuberances to be located aft of the center of gravity has placed the payload bay in the current location: just above the motor mount assembly. A bulkhead will be used to shield the payload from the heat generated by the motor.

Design and Rationale

The payload bay system is fully discussed in the payload section of the report.

Aft Bulkhead

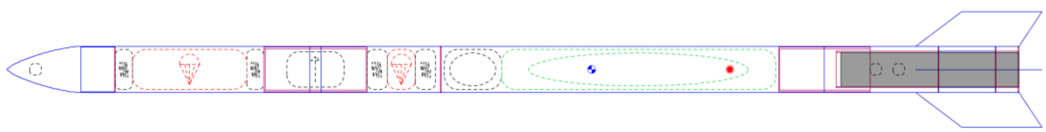


Figure 15: Detachable Aft Booster Section Design

The initial design of the vehicle as presented in the Statement of Work proposed an aft coupler tube that would allow the detachment of the section of the vehicle containing the motor mount and fins. The purpose of this design was to facilitate the loading of the payload into the vehicle and to prevent the payload from resting on the motor casing. However, the team has now opted to remove this coupler as it negatively affects the weight and stability of the vehicle. The new design removes the coupler and keeps the booster section as a single unified body. To separate the payload from the motor and more evenly distribute flight forces, an aft bulkhead will either be epoxied or screwed to the lower section of the vehicle. While the new setup complicates payload integration into the vehicle by requiring the removability of the drouge bay bulkhead, it has been done successfully in the past and deemed worth the reduced mass and increased stability of the vehicle.

Removable Forward Bulkhead

The vehicle booster section features a removable forward bulkhead that serves to shield the payload bay from the ejection gases that result from drogue deployment and to provide an anchor point for the drogue parachute. This system is held into place with T nuts and #5 steel screws and can be easily removed and installed at the launch site. The system will be constructed so that the load bearing force acts against the bulkhead lip, thus causing it to fail safe. The whole assembly has a calculated load bearing capacity of 4,400 lbs.

Drogue Bay

The drogue parachute is located aft of the e-bay with anchors for the parachute located on the e-bay and a removable bulkhead that separates the drouge bay from the payload bay and is 7.6 cm in length. The size of the drogue parachute bay was determined through empirical measurements of packed parachute configurations and past experience.

Fin Design

The fins of the vehicle are designed with a root chord of 22.9 cm, a tip chord of 17.8 cm and a semi span of 7.62 cm. The fins are swept back at an angle of 53 degrees and extend 5 cm past the end of the airframe tube. A swept fin design was chosen to lower the CP of the vehicle and allow for a more stable flight. Fin flutter analysis indicates that the design will not undergo fin flutter.

Motor Mount

Both 54 mm and 75 mm diameter motors were examined during the design of the vehicle. 54 mm motors were preferred due to their use in past projects which would cut down on costs due to existing materials. Additionally, 54 mm motors are both slightly more affordable and reliable than their 75 mm counterparts. However, during the design of the vehicle it quickly became apparent that the long length of 54 mm K-class motors would take up large amounts of space in the vehicle and would seriously affect the flight characteristics and recovery profile of the rocket. Therefore a 75 mm motor mount will be used in the design.

Centering Rings

The vehicle will use commercially available 75 mm - 98 mm fiberglass centering rings. These centering rings have been used in past projects by the team and are flight tested.

Motor Retainer

A flange mounted 75 mm areopack screw-on motor retainer will be used to hold the motor casing in place. The motor casing will be placed on the aft end of the motor casing and will be secured with both epoxy and screws.

Propulsion Selection

A total of five motors were analyzed as potential candidates for the vehicle. Of the motors analyzed, the CTI K2000 was chosen as the primary motor for the vehicle. This was due to its high thrust to weight ratio and stability which ensures a straight and proper flight of the vehicle. The CTI K1085 was chosen as the secondary motor choice due to its compatibility with Cesaroni motors systems and similar flight metrics.

Motor	Avg Thrust	Total Impulse	Burn Time	Stability Margin	Thrust to Weight Ratio
K1000	1066.0 N	2511.5 Ns	2.5s	2.47 cal	10.3
K510	514.0 N	2486.0 Ns	4.8s	2.40 cal	4.9
K661	660.5 N	2436.5 Ns	3.7s	2.44 cal	6.3
K2000	2036.1 N	2329.9 Ns	1.2s	2.48 cal	19.6
K1085	1113.0 N	2412.0 Ns	2.1s	2.50 cal	10.1

Table 11: Propulsion Candidates Table

Recovery Subsystem Analysis

Parachute Retention System

Two Compartment Deployment

This parachute retention system consists of two compartments with the e-bay, containing the deployment electronics, is placed between these two compartments. Each parachute deploys independently of each other. The benefits of this system include its simplicity, reduced wiring complexity, and low setup time. The main drawback of this system is that it translates its complexity to the payload integration system as the payload must be separated and shielded from the aft parachute compartment via a bulkhead or other device.

One Compartment Deployment

This parachute deployment system consists of a single compartment that contains both the drouge and main parachutes. Deployment at apogee causes both the main parachute and the drogue parachute to come out of the compartment. The drogue parachute is then allowed to fully deploy at apogee while the main parachute is inhibited in some way until a charge allows it to deploy at a lower altitude. The main advantage of this system is that it allows the recovery system to be contained in a single compartment, reducing the space used and allowing for a more graceful payload integration scheme. The drawbacks of this system include its increased complexity with both wiring and setup, as well as greater impact kinetic energies due to a decrease in the number of sections used.

Parachute Retention System Decision

A two compartment deployment system was chosen due to the simplicity of the design and the allowance for greater impact speeds. The payload integration issue was resolved with a removable aft bulkhead which would allow the insertion of the payload during launch setup and protect the payload from ejection forces during deployment.

Recovery Altimeter System

Altimeter Candidates

Featherweight Raven 3

Figure 16: Featherweight Raven 3

The Featherweight Raven 3 is equipped with both an accelerometer and a barometric sensor that works up to 100,000 ft of altitude. It is relatively small and has a form factor of 4.56 cm x 2.03 cm x 1.40 cm and weighs around seven grams. Features include up to four software programmable pyro controls, and enough memory to internally store up to five flights, all with a price of around $155 per unit. While a number of these altimeters are owned by the team, these are no longer manufactured due to part obsolescence and the software that is used is only compatible with Windows.

Perfectflite Stratologger CF

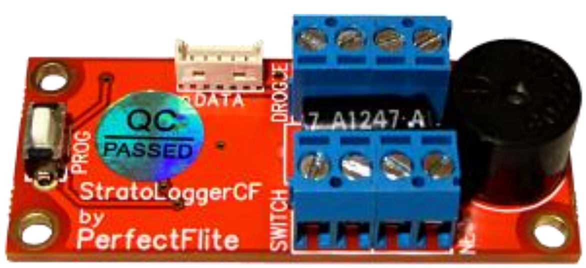


Figure 17: Perfectflite Stratologger CF

The Perfectflite Stratologger CF is equipped with a barometric sensor that allows it to read altitudes up to 100,000 ft. It has a mid-range form factor of 5.08 cm x 2.13 cm x 1.27 cm and weighs around 11 grams. The Stratologger CF comes with two software programmable pyro controls and the ability to store up to 16 flights in its memory with a cost of around $55.

Missile Works RRC3 Sport

The Missile Works RRC3 Sport is a barometric pressure altimeter that works up to 40,000 ft, has a rather large form factor of 9.96 cm x 2.35 cm x 1.27 cm and weighs about 17 grams. This altimeter comes with three software programmable pyro controls, can store the data up to 15 flights internally and costs around $70.

Altimeter System Decision Matrix

Altimeter	Reads Altitudes up to 10,000 ft	2 or more programmable pyro controls	Operates on 9v batteries
Raven 3	✓	✓	✓
Stratologger CF	✓	✓	✓
RRC3 Sport	✓	✓	✓

Table 12: Altimeter Requirements Table

Requirements for the altimeter includes the ability for it to read altitudes up to 10,000 feet, have 2 or more programmable pyro controls, and compatibility with commercially available 9v batteries.

		Raven 3		Stratologger CF		RRC3 sport	
Criteria	Weight	Value	Score	Value	Score	Value	Score
Cost	10.00%	3	0.3	10	1.0	8	0.8
Availability	20.00%	2	0.4	10	2.0	7	1.4
Mass	30.00%	10	3	5	1.5	2	0.6
Size	30.00%	10	3	8	2.4	4	1.2
Memory	10.00%	4	0.4	9	0.9	10	1.0
	Total:	7.10		7.80		5.00	

Table 13: Altimeter Decision Matrix

Analysis of the candidate altimeters show the Stratologger CF is the optimal altimeter due to its low cost and wide availability as well as acceptable size, mass and memory characteristics.

Parachute Sizing

Parachute Sizing Analysis Equations

The parachute sizing was calculated using the drag force equation determined from a circle shown as follows:

$$F_D = \frac{\rho v^2 C_D \pi d^2}{8}$$

Equation 6: The Drag Force Equation

Where F_D is the drag force of the parachute, ρ is the density of air, C_D is the drag coefficient of the parachute, d is the diameter of the parachute and v is the velocity.

Drag force was set to equal the force of gravity to find out when the force of gravity comes to equilibrium with the drag force:

$$F_D = \frac{\rho v^2 C_D \pi d^2}{8} = m_t g$$

Equation 7

Where F_D is the drag force of the parachute as determined by equation Equation 7, m_t is the total mass of the vehicle, and g is the gravitational constant. This equation can be rearranged or combined with other equations to determine the parachute sizes needed for certain requirements such as a desired kinetic energy or drift. The following equations were used in making that possible:

$$E_k = \frac{1}{2} m {v_d}^2$$

Equation 8: The Kinetic Energy Equation

$$x_d = \frac{v_w}{v_d} \times \Delta x$$

Equation 9: The Drift Equation

Where E_k is kinetic energy, m is mass, v_d is the descent velocity, v_w is the wind velocity, and Δx is the change in altitude.

Equation 8 can be rearranged and substituted for *v* to yield the required diameter of a parachute given a desired kinetic energy requirement:

$$d = \sqrt{\frac{4m_s m_t g}{\rho E_k C_D \pi}}$$

Equation 10

Where *d* is the desired diameter of the parachute, m_s is the mass of the heaviest independent section of the vehicle under the parachute, m_t is the total mass under the parachute, *g* is the gravitational constant, ρ is the density of air, E_k is the desired kinetic energy, and C_d is the drag coefficient of the parachute.

Similarly, we can find the required diameter of a parachute given a desired drift distance:

$$d = \sqrt{\frac{8m_t \times {x_d}^2 \times g}{\rho \times {v_w}^2 \times \Delta x^2 \times C_D \times \pi}}$$

Equation 11

Where *d* is the desired diameter of the parachute, x_d is the drift of the rocket, v_w is the velocity of the wind, Δx is the change in altitude over which drift is measured, and ρ, *d*, *g*, C_D and m_t have the same definition as previously.

Equation Equation 11 can then be rearranged to find the amount of drift for a parachute with a given diameter:

$$x_d = \sqrt{\frac{\rho \times {v_w}^2 \times \Delta x^2 \times C_D \times \pi \times d^2}{8 \times m_t \times g}}$$

Equation 12

Where x_d is the drift of the rocket, v_w is the velocity of the wind, Δx is the change in altitude over which drift is measured, and ρ, *d*, *g*, C_D and m_t have the same definition as presented previously.

Main Parachute Sizing Analysis

The primary concern for the main parachute was the 101 joules (75 ft-lbf) impact energy requirement presented in the handbook, section 3.3. The following metrics for the minimum diameter main parachute was determined by the equations presented above, where the change altitude is from main parachute deployment to landing, the density of air is set at 1.225 kg/m^3, the gravitational constant is set at 9.81 m/s^2, the drag coefficient is set at 1.2 and drift is calculated in 20 mph winds (8.9 m/s). For the equations, the total descent mass of the vehicle used was 8.9 kg (19.7 lb) and the mass of the largest independent section as defined by requirement 2.8 in the handbook was set at 6.4 kg (14.1lb).

Parachute	Diameter	∆ Altitude	Drift under 20mph wind	Kinetic Energy
Main Parachute	120 in (304.8 cm)	500 ft (152.4 m)	575.4 ft (175.4 m)	80 J (58.9 ft-lbf)

Table 14: Main Parachute Minimum Diameter Stats

Drogue Parachute Sizing Analysis

The primary concern for the drogue parachute was the drift requirement 3.9 which limits the drift to a 762 m (2500 ft) radius from the launch pad. The following metrics for the maximum usable drogue parachute is presented below, where the change in altitude measured from apogee to main parachute deployment , the density of air is set at 1.225 kg/m^3, the gravitational constant is set at 9.81 m/s^2, the drag coefficient is set at 1.2 and drift is calculated in 20 mph winds (8.9 m/s). For the equations, the total mass of the vehicle used was 8.9 kg (19.7 lb) and the mass of the largest independant section as defined by requirement 2.8 in the handbook was set at 6.4 kg (14.1lb).

Parachute	Diameter	∆ Altitude	Drift under 20mph wind	Kinetic Energy
Drogue Parachute	22 in (55.88 cm)	4850 ft (1478.3 m)	2390.1 ft (728.5 m)	2995 J (2209 ft-lbf)

Table 15: Drogue Parachute Maximum Diameter Stats

Ejection Charge Sizing

Ejection Charge Equations

The sizes of the ejection charges needed were calculated using a modified version of the universal gas law:

$$m_c = \frac{Pd^2\pi h}{4RT} \times a$$

Equation 13: Ejection charge size formula

Where m_c is the mass of the ejection charge, *P* is the desired pressure, usually 1 atmosphere or 101325 Pa; *d* is the diameter of the body tube in which the ejection charge resides in, in this case 98 *mm*; *h* is the height of the given ejection bay; *R* is the universal gas constant, 8.314 J mol^{-1} K^{-1}; and T is the temperature of the gas, set to 1840 K for the ignition point of black powder; and *a* is the amount of black powder needed to produce a given amount of gas, a value that is set at 67.53 grams of black powder / mol and is derived via stoichiometry from the following chemical equation:

$$2KNO_{3\,(s)} + S_{(s)} + 3C_{(s)} \rightarrow K_2S_{(s)} + N_{2\,(g)} + 3CO_{2\,(g)}$$

Equation 14: Black powder combustion

Where the gases are identified as N_2 and CO_2 and the formula for gunpowder is simplified into just saltpeter, sulfur and pure carbon without impurities.

Ejection force is calculated as follows:

$$F_e = \frac{1}{4}Pd^2\pi h$$

Equation 15: Ejection force

Where F_e is the ejection force, *P* is the pressure provided by the ejection charge, *d* is the diameter of the bay tube housing the parachute and h is the height of the bay tube housing the parachute.

Ejection Charge Sizing Analysis

The values calculated using this method will be verified through ground ejection tests before flight. The primary charge was calculated using the equations presented in the section above. The backup charges follow Jefferies' Redundancy Scheme and are 25% larger than the primary charges. The calculated ejection charge sizes are shown below.

Setup	Primary Charge Mass	Backup Charge Mass
Main	1.265 g	1.58 g
Drouge	0.633 g	0.8 g

Table 16: Ejection charge sizes

Leading Recovery Design

The main parachute is 120 inches and the drogue parachute is 22 inches. These parachutes are packed like an accordion in both directions with baby powder to ensure the parachute opens. The main and drogue parachutes are ejected with 0.63 grain and 1.27 grain charges respectively. These charges are connected to the altimeter via a wire that goes through the caps of the ebay. Other wires connect a button to the altimeter; this button turns the altimeter on. When turned on the altimeter is able to track the altitude of the rocket and once the appropriate height is reached the charges are ignited. The following timeline for the recovery system is shown below.

Sequence	Charge	Altitude	Trigger
1	Drouge	Apogee	Primary Altimeter
2	Drouge Backup	Apg + 1 sec	Backup Altimeter
3	Main	500 ft	Primary Altimeter
4	Main Backup	450 ft	Backup Altimeter

Table 17: Flight Events

Recovery Redundancy

If either the drogue or main charges fail to deploy the parachutes, a second, larger charge will go off. If the error lies within the first altimeter, a second altimeter controls the backup chargers and runs on a seperate battery. The two altimeters circuits are completely independent of each other.

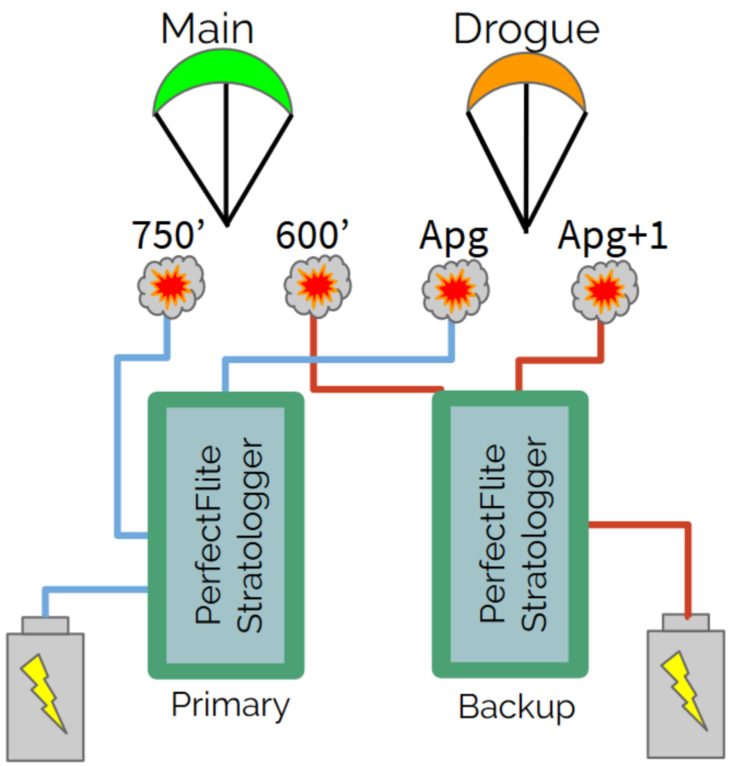


Figure 18: Redundant deployment setup

Mission Performance Predictions

All performance predictions were made using OpenRocket v15.03.

Altitude Declaration

The team declares a target altitude of 5350 ft for launch day.

Altitude Profile

The graph below shows the simulated flight profile for the CTI K2000 motor. The vehicle reaches the apogee of 5350 feet around 17.6 seconds after ignition. For the purpose of this preliminary simulation, and based on prior experiences with single diameter rockets, the average coefficient of drag was set at 0.7 for simulations. The entire flight duration is estimated at 97.2 seconds and the drift under 15 mile per hour wind conditions is simulated at 1736 feet.

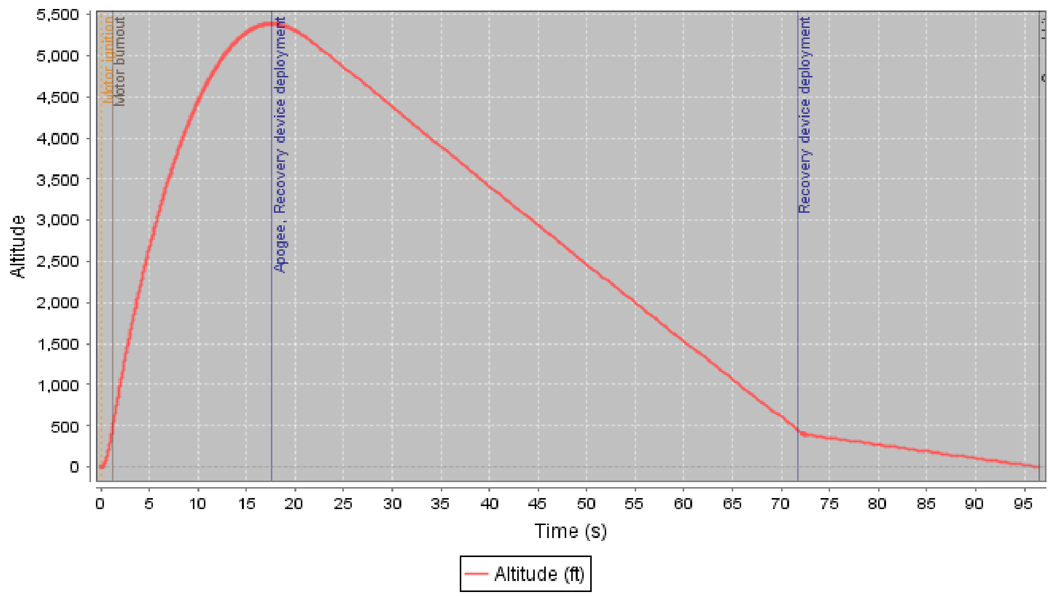


Figure 19: Altitude vs. Time Simulation

Simulations are not a final indication for the performance of the vehicle. The team will refine the projections and make accurate ballast decisions after the test flights of the scale model and full scale vehicle. The final test flight will use the same motor as we will use for our flight in Huntsville to ensure that the rocket will not exceed the target altitude.

Wind Speed vs. Altitude

The effect of the wind speed on the apogee of the entire flight is was simulated and is shown in the table below. A launch of the vehicle in 20 mile per hour winds, the max wind speed allowed for launches under NAR rules, will see the apogee change by 0.7%

Wind Speed	Apogee	Δ Apogee
0 mph	5350 ft	0.00%
5 mph	5347 ft	0.1%
10 mph	5338 ft	0.2%
15 mph	5326 ft	0.4%
20 mph	5310 ft	0.7%

Table 18: Wind Speed vs. Altitude

Velocity Profile

The velocity profile projects that the rocket will reach maximum velocity of 7.2 feet per second (0.62 mach) shortly before burnout, which is simulated at 1.1 seconds after liftoff. The rocket remains subsonic for the entire duration of its flight.

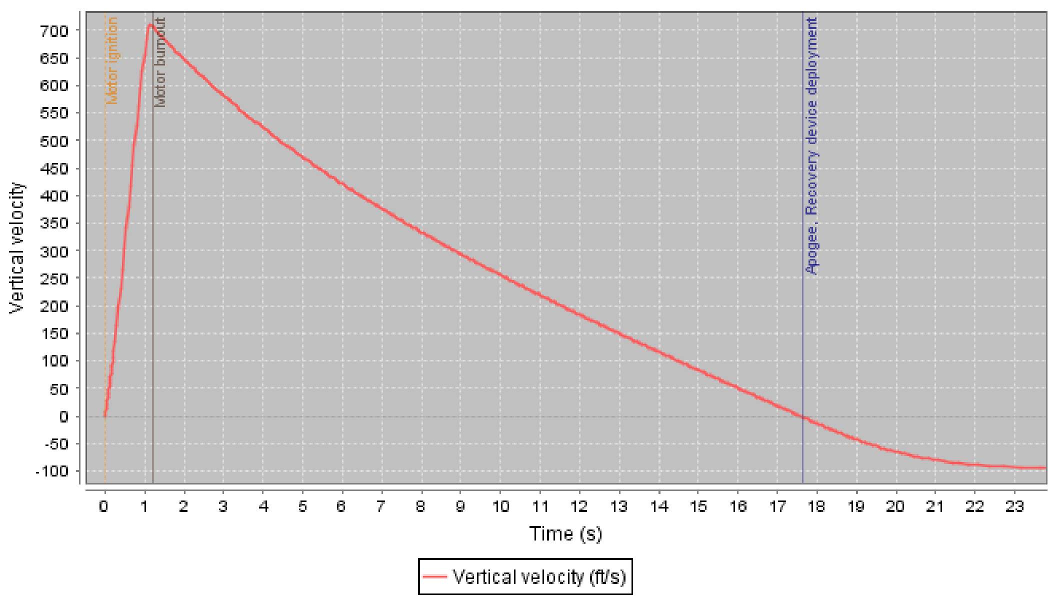


Figure 20: Velocity vs. Time Simulation

Acceleration Profile

The graph below shows that the rocket will experience maximum acceleration of about 23.4 g (752.77 ft/s^2). The vehicle will be robust enough to endure the acceleration shocks associated with rocket flight.

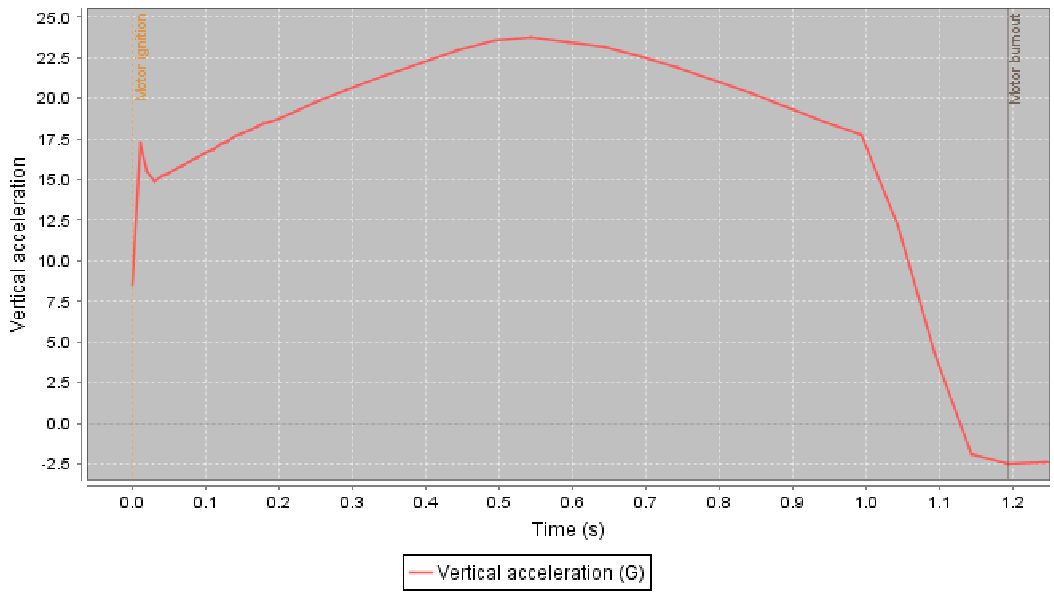


Figure 21: Acceleration vs. Time Simulation

Thrust Profile

The graph below shows the thrust profile for the CTI K2000 motor. The motor reaches its maximum thrust of 2481*N* after 0.55*s* and burns at approximately constant thrust level for about 1.0*s*. The thrust to weight ratio of the vehicle when using this motor's average thrust is 23.9, while the thrust to weight ratio of the rocket at maximum is 10.1. The rocket is projected to launch from an eight foot rail with the velocity of 69.5 feet per second (47.4 mph).

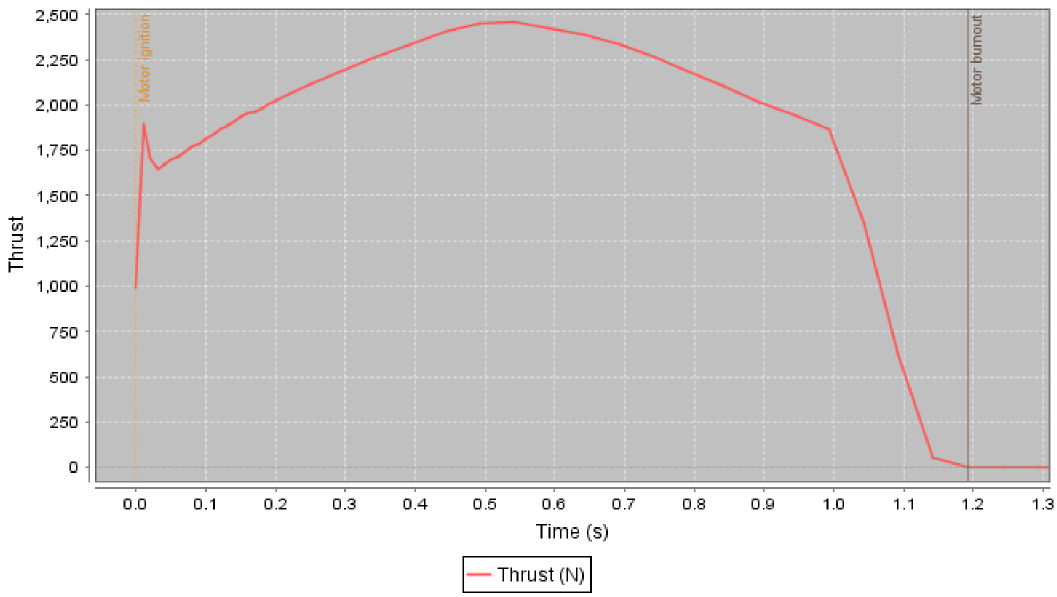


Figure 22: Thrust vs. Time Simulation

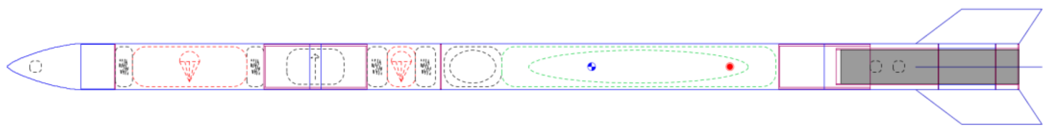
Vehicle Strength Verification

The vehicle will be built to withstand the maximum flight forces exerted on it. Many of the components proposed have been successfully tested and used in past Student Launch vehicles that have exceeded 20 g. The quick-links, which are the weakest part of the vehicle, require a 800 lbs of force to fail, which is far greater than the maximum effective force of 543 lbs of force experienced by the vehicle. A table of the materials used follows:

Component	Material	Strength
Nosecone	3D printed PLA plastic	Flight Tested
Tubing	1/16” x 4” Fiberglass	Flight Tested
Fins	3/32” Fiberglass (TTW mounted)	Flight Tested
Main Parachute	Ripstop Nylon	1400 lbs/shroud line 5600 lbs totals
Couplers	1/16” x 4” Fiberglass	Flight Tested
Motor Mount	1/16” x 75 mm Fiberglass	Flight Tested
Centering Rings	1/16” Fiberglass	Flight Tested
Bulkhead	⅛” Fiberglass with 1/16” Lip	Flight Tested
Anchors	¼” Stainless Steel U-Bolts	2000 lbs
Quick-Links	¼” Zinc Plated Steel QuickLinks	800 lbs
Tie-rods	¼” Stainless Steel Threaded Rods	3200 lbs per tierod 2 tie rods used
Motor Retention	Aeropack Screw-On Retainer	Flight Tested
T-nuts, Screws	¼” Threaded T-nuts. #5 Screws	1100 lbs per T-nut 4400 lbs per connection

Table 19: Material strength analysis

Vehicle Stability



Situation	Stability Margin	Simulated CG	Simulated CP
Launch Config	3.11 cal	50.765 in	63.208 in
Burnout	5.25 cal	42.196 in	63.208 in

Table 20: Vehicle Stability Table: Simulated CG and CP are measured from the top of the vehicle. The ballast consists of 2.43 lbs of nose weight.

The vehicle is simulated with a stability of 3.11 calibers in its full launch configuration. The vehicle will remain stable from ignition to apogee. The graph below shows the simulated stability of the vehicle as well as the location of the CG and CP in inches from the top of the vehicle.

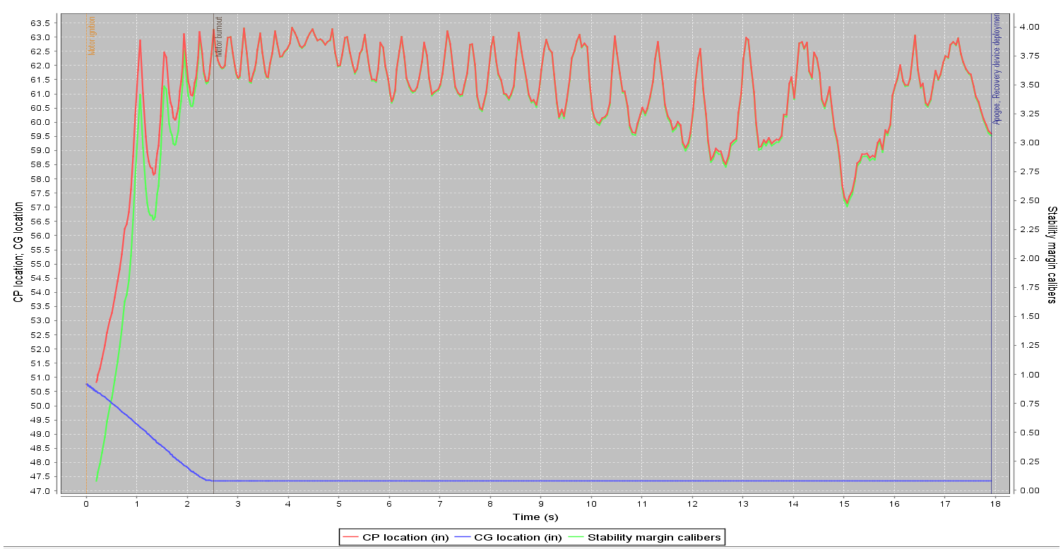


Figure 23: Vehicle stability analysis

Descent and Landing Profiles

The vehicle will separate into three tethered sections:

1. A nose cone section that weighs 2.80 lbs and constitutes 14.2% of the descent weight
2. An upper vehicle section weighing 2.80 lbs and constitutes 14.2% of the descent weight
3. A booster section weighing 14.1 lbs and constitutes 71.5% of the descent weight. This section will also hold the telemetry and payload for the rocket.

The table below shows the estimated parachute sizes, descent rates, ejection charge sizes, deployment altitudes and landing impact energy for the proposed parachute system. The upper vehicle section and nose cone section will remain connected during the decent under the drogue parachute, with the sections separating during main parachute deployment.

Parachute	Diameter	Alt. Deployed	Decent Rate	Descent Time	Descent Weight		Impact Energy
Drouge	22 in	Apogee	91.7 fps	79.74 s	2.80 lbs	14.2%	366 ft-lbf
					16.9 lbs	85.8%	2209 ft-lbf
					--	--	--
Main	120 in	700 ft	16.4 fps	25.94 s	2.80 lbs	14.2%	11.7 ft-lbf
					2.80 lbs	14.2%	11.7 ft-lbf
					14.1 lbs	71.5%	58.9 ft-lbf

Table 21: Descent and Landing Analysis

Vehicle Mission Profile

The vehicle flight sequence is shown on the figure below. The rocket is a standard dual deployment rocket that will be recovered as three tethered sections. The drogue parachute deploys at apogee and the main parachute is set to deploy at 500 ft. The payload does not separate from the rocket at any point during flight. Total decent time is projected at 78.9 seconds. Total flight time is projected at 97.6 seconds.

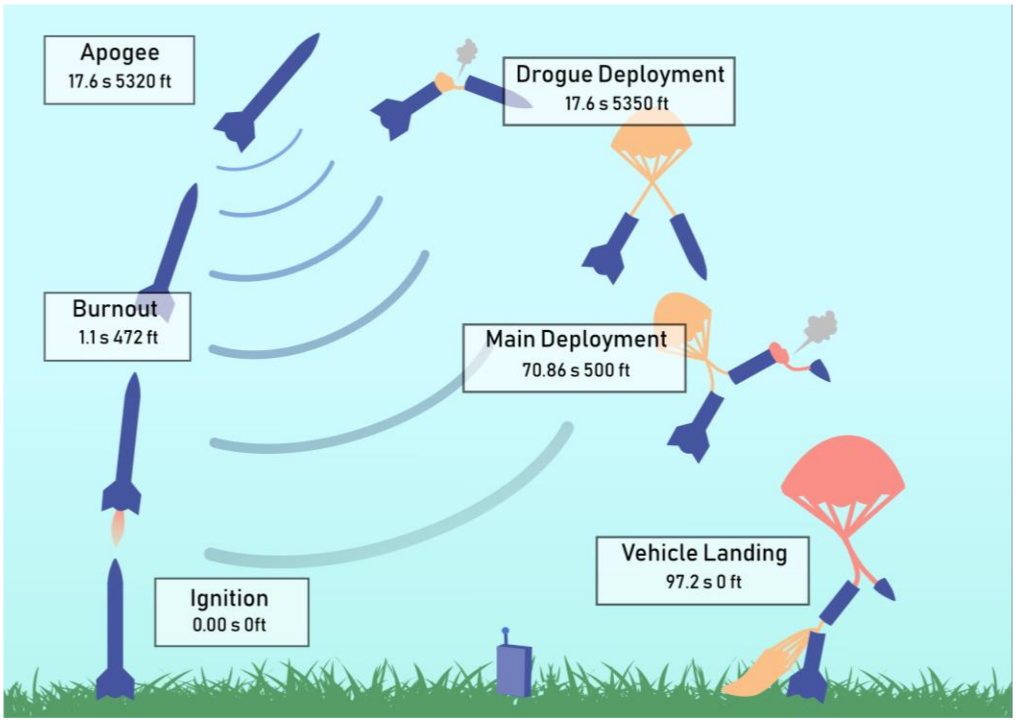


Figure 24: Mission profile chart

The table below summarizes the flight events for the entire mission.

Sequence	Event	Time	Altitude	Trigger
1	Ignition/Boost	0.00 s	0 ft	Launch Control
2	Burnout	1.1 s	1280 ft	--
3	Apogee	17.6 s	5350 ft	--
4	Drogue deployment	17.6 s	5350 ft	Altimeter
5	Main deployment	70.8 s	500 ft	Altimeter
6	Vehicle Landing	97.6 s	0 ft	--

Figure 25: Flight Events

Drift

The following table shows the estimated drift of the rocket considering the descent rates in the table above. A flight with 20 mile per hour winds will still remain within 2,500 feet from the launchpad. Calculations are made based on the assumption that the apogee event occurs directly above the launch pad.

Wind Speed	Drift (ft)	Drift (mi)
0 mph	0 ft	0.000 mi
5 mph	579 ft	0.110 mi
10 mph	1157 ft	0.220 mi
15 mph	1736 ft	0.329 mi
20 mph	2314 ft	0.438 mi

Table 22: Drift Predictions

Safety

Preliminary Failure Modes and Effects Analysis

FMEA Table 1 = low; 10 = high

Subsystem	Potential Failure Mode	Effects of this Failure Mode	Effect Severity	Occurrence rarity	Controls	Control Effectiveness
Vehicle	Parachute tangles	Rocket plunges to Earth dangerously/high energy	6	4	Follow proper procedures for inspecting and folding parachute and lines	8
Vehicle	Motor impulse too high/low	Altitude target over/under run	2	9	Scale launch and full-scale tests	5
Vehicle	Ejection charge too small	Failure to deploy, rocket plunges to Earth dangerously/high energy	8	3	On-ground ejection test with same ejection charge	8
Vehicle	Parachute does not deploy	Rocket plunges to Earth dangerously/high energy	8	4	Use redundant deployment system	9
Vehicle	Ejection charge too large	Potential damage to recovery system	2	3	On-ground ejection test with same ejection charge	8
Vehicle	Motor fails to ignite	Rocket does not leave launch pad	4	5	Properly insert igniter, run continuity test prior to launch	10
Vehicle	Motor fails explosively	Destruction of rocket	10	1	Choose known/proven motor suppliers Store motors carefully and use promptly after purchase	9
Vehicle	Motor retainer fails to retain motor	Potential destruction of rocket and internal damage	9	1	Choose proven motor retainer suppliers, inspect motor retainer prior to use	10
Vehicle	Altimeter fails to operate	Failure to deploy, loss of flight data, dangerous energy on ground	8	2	Use redundant deployment system	9
Vehicle	Rocket strikes foreign object in flight	Rocket knocked off flight path, rocket and foreign object sustain damage	9	1	Ensure skies are clear before launch, do not launch around birds or other rockets	10
Vehicle	Altimeter battery runs out on the launchpad	Parachutes fail to deploy, rocket plunges	8	3	Replace batteries for each flight, do	9

		to Earth dangerously/high energy			not leave rocket sitting on launchpad for an extended period of time, test batteries prior to use	
Vehicle	Shock cord breaks	Sections separate, some plunge to Earth dangerously/high energy, others descend too slowly and land outside the launch field	10	1	Use new shock cord in rocket construction, inspect shock cord for signs of wear before use	10
Vehicle	Tracker fails to locate rocket	Rocket is lost	6	6	Ensure tracker batteries are charged, ensure tracker has a reliable GPS and cellular connection	8
Vehicle	Rocket snags launch rail during takeoff	Rocket is knocked off flight path, rail buttons potentially torn off	7	2	Ensure launch rail is clean and there are no nicks or bumps prior to takeoff	10
Vehicle	Vehicle structure fails mid-flight	Rocket debris falls to Earth dangerously/high energy, destruction of rocket	10	2	Ensure parts are sturdy, examine parts for signs of wear prior to usage	10
Payload	Battery runs out of power on launchpad	Payload does not work	9	5	Ensure any rechargeable batteries are fully charged, do not leave rocket sitting on launchpad for an extended period of time, test batteries prior to use	8
Payload	Water vapor condenses inside compartment	Picture comes out fuzzy, payload fails to collect usable data	5	7	Launch in favorable weather conditions	3
Payload	Air vent separates from rocket wall	Sampling air does not enter rocket, payload does not collect usable data	6	3	Ensure air vents are securely attached to rocket wall	9
Payload	Camera Lens is shifted out of alignment	Samples particles out of focus or not visible	5	4	Ensure lens is securely held in place during flight, test to make sure that payload does not shift in flight	8

Payload	Air vent becomes obstructed	Sample particles do not enter rocket, no airflow through payload	7	3	Ensure air vents are unobstructed prior to launch, avoid launching when large airborne debris such as corn husk shreds are present	10
Payload	Camera connector disconnects from rest of payload	Camera is out of alignment, particles out of focus or not visible	5	4	Ensure camera is securely held in place during flight, test to make sure that payload does not shift in flight	8
Payload	LED fails to flash	Particles not illuminated for picture, picture comes out black	8	4	Ensure connection to LED is secure and that LED works properly	9
Payload	Camera fails to take picture	Data from payload is not collected	8	4	Ensure connection to camera is secure and that camera works properly	9
Payload	LED reflects off surface causing back scatter	Potential false positives from reflection, particles are washed out by LED reflection	5	6	Use light absorbing paint on surfaces inside payload	8
Payload	Electronics short together	Electronics fail to operate properly and payload does not work properly	7	2	Ensure that payload is properly assembled, test on the ground prior to flying	9
Payload	Firmware fails to execute properly	Electronics fail to operate properly and payload does not work properly	7	3	Test firmware on the ground prior to flying	9
Payload	Unanticipated light source present	Particles appear as lines due to overexposure, particles potentially obscured by unintended light source	6	2	Ensure chamber is fully sealed and materials are opaque	10
Telemetry	Data not transmitted properly	Data not collected in flight, collected on the ground	6	5	Ensure transmitter and receiver can communicate with each other throughout the entire flight	7
Telemetry	SD card does not record data	Data is not backed up if it does not transmit properly	7	3	Test payload prior to flight, ensure connection	10

					between SD card and rest of payload is secure	
Telemetry	Telemetry is unable to communicate with payload	Data from payload is not received or transmitted to ground	5	4	Ensure connection between payload and telemetry is secure	10
Telemetry	Data from sensors is missing/corrupted	Sensor data is not received or transmitted to ground	4	3	Ensure connection between sensors and telemetry is secure	10
Telemetry	Telemetry firmware fails to execute properly	Telemetry unit does not run properly,	7	3	Test firmware on the ground prior to flying	9
Telemetry	Battery runs out of power on launchpad	Telemetry unit does not function, no data transmitted or stored	8	5	Ensure any rechargeable batteries are fully charged, do not leave rocket sitting on launchpad for an extended period of time, test batteries prior to use	8

Table 23: FMEA

Project Risk Analysis

Risk	Mitigation	Impact	Likelihood
Workshop Inaccessible	Work with landlord to ensure availability; have alternate facilities available if necessary	High	Low
Classrooms Unavailable	Have a number of backup classrooms and meeting locations	Med	Med
Launch Site Unavailable	Schedule redundant launch dates; work with launch service providers to	Med	Med

	ensure launch site availability		
Project behind Schedule	Extend working hours if necessary	Low	Med
Key Team Member Unavailable	All duties are shared between multiple team members in the event one becomes unavailable	Low	Low
Unsolvable Technical Problem	Ensure payload is feasible, have alternate designs available	Med	Low
Unresolvable Personal Disagreements	Educators step in to protect project progress, regardless of personal interests	Low	Low
Part Unavailability	Purchase parts as soon as practically possible, work with multiple vendors to ensure availability	Med	Med
Budget Overrun	Set fundraising goal at 140% of expected project expense	Med	Med
Repeated Test Flight Failure	Perform tests on all vehicle subsystems prior to launch to prevent failures	Med	Low
Vehicle Lost/Irreparably damaged during test flight	A time reserve has been built into the schedule to allow a vehicle to be rebuilt	Med	Med

Propellant Unavailability	Purchase propellant as soon as practically possible, explore alternative motors, work with several vendors to ensure availability	Med	Med
Final Vehicle Heavily Overweight, Unable to Reach Target Altitude	Vehicle is simulated with a 30% weight surplus to ensure motors are powerful enough to reach target altitude	Low	Low
Payload/Telemetry Construction Falls Behind Schedule	Begin construction as soon as possible, check progress against list of milestones	Med	Med
Coding Deficiencies/ Libraries Not Maintained	Feasibility review prior to beginning construction, all libraries are maintained by the product developers and the community	Low	Low
Transmission Interference	Use Xbee modules specifically designed for minimal interference, if problems persist, use additional shielding	Low	Med
Physical Injury	Personal Protective Equipment usage is mandatory, adult supervision is provided, and the	Med	Low

	use of headphones or earbuds is prohibited during club activities		
Toxicity	SDS documentation for all chemicals is provided, dangerous chemicals are avoided as much as possible	Low	Low

Table 24: Project Risk Analysis

Written Safety Plan

The following risks could endanger the successful completion of the proposed project (listed with proposed mitigations):

Facility Risks

- **Workshop inaccessible:** A rental agreement is in place between the landlord and the team. Should it become temporarily inaccessible, the team will work with the landlord to resolve the issue in a timely manner. Events scheduled in workshop will be migrated temporarily to Mr. Lillesand's house while the issue is being resolved.

- **Classrooms unavailable:** The classrooms are provided by Atmospheric Oceanic Space Sciences Dept. with several choices available should the primary classroom become inaccessible. Other options in the event of classroom unavailability include meeting at a local public library meeting room, or meeting at a team member's residence.

- **Launch site unavailable / inclement weather:** Redundant launch windows are routinely scheduled to ensure that enough opportunities are available to carry out all necessary flights. The team is currently working with three rocketry organizations (NAR Section WOOSH, TRA WI and TRA QCRS) to maximize our launch opportunities.

Project Risks

- **Project behind schedule:** Project progress is constantly compared against a list of required milestones and working hours are extended as necessary to meet all milestones. All deadlines are considered hard.

- **Key team member unavailable:** No task is assigned to a single team member; all tasks are carried out by a pair or a small group of equally knowledgeable students. Students will be required to spread their participation past a single area of expertise.

- **Unsolvable technical problem:** A thorough feasibility review is conducted before the Statement of Work is submitted. Alternative solutions will be sought.

- **Unresolvable personal disagreements:** Should the students involved fail to reach an acceptable compromise; the educators will protect the progress of the project, regardless of the individual interests of the parties in the dispute. All students were informed of this rule before their admission to the program.

- **Part unavailability:** All purchasing is conducted as soon as practically possible. The team also works with several vendors to maintain part availability.

- **Budget overrun:** The initial fundraising goal is set at 140% of estimated project expense.

Vehicle Risks

- **Repeated test flight failure:** Rocket design review, performance prediction evaluation, static stability check and static ejection tests will be carried out before each test flight. A due consideration will be given to weather conditions to maximize the probability of safe flight and successful recovery. All flight data will be analyzed to identify problems before next flight.

- **Vehicle lost/irreparably damaged during test flight:** A sufficient time reserve will be built into project schedule to allow for vehicle replacement. All team members will participate in additional workshop hours. The airborne vehicle will be tracked using three different methods: CAT (Cloud Aided Telemetry), onboard RF telemetry and sonic beacon. A GPS device will also be used to locate the rocket after launch.

- **Propellant unavailability:** All purchasing is conducted as soon as practically possible and motor alternatives are thoroughly investigated during the vehicle design. The team also works with several vendors to maintain propellant availability.

- **Final vehicle heavily overweight, unable to reach target altitude:** 30% of total vehicle weight is added to the initial estimate of vehicle weight and all initial simulations are carried out with coefficient of drag (Cd) set to 0.7 (reasonable estimate for a single diameter, cylindrical vehicle). This prevents overly optimistic estimates of vehicle performance and also simulates the vehicle weight increase accurately.

Payload Risks

- **Construction falls behind the schedule:** A significant amount of 3D printing will be necessary to build the payload. The team will begin fabrication as soon as the payload design is finalized to ensure that all parts are completed on schedule

Telemetry Risks

- **Construction falls behind schedule:** Construction and and assembly of the telemetry module will begin as soon as possible. Progress is constantly compared against a list of required milestones and test flights and working hours are extended as necessary to meet all milestones.

- **Coding deficiencies/Libraries not maintained:** A thorough feasibility review of the coding required for the telemetry was conducted before the submission of the SOW. All libraries that will be used are maintained by the vendors of the sensors, and have sufficient community support among developers, ensuring that code maintenance will be a minimal issue at worst.

- **Transmission interference:** Xbee modules will be used in the telemetry unit. The very design of the Xbee transmission sequence allows for minimal interference. Additional shielding will be used if it is deemed necessary after test flights

Personal Risks

- **Physical injury:** The use of Personal Protective Equipment is mandated during all construction tasks and preparation of the rocket for flight or static test. Adult supervision is provided at all times. The use of headphones and personal electronics during rocketry activities and workshop hours is strictly prohibited

- **Toxicity:** SDS documentation is available for all chemicals used in the project and dangerous chemicals are avoided as much as possible. Adult supervision is provided at all times, PPE (Personal Protection Equipment) use is mandated.

NAR/TRA Personnel

Dr. Pavel Pinkas (L2 certified, NAR and TRA member) is the mentor for the team and designated owner of the rocket for liability purposes. Dr. Pinkas will accompany the team to Huntsville, AL.

All hazardous materials will be purchased, handled, used, and stored by Mr. Lillesand (L3 certified, NAR and TAR member, LEUP holder) or project educators (Dr. Pinkas or Ms. Hager). Dr. Pinkas and Mr. Lillesand will be the only people purchasing and handling energetics. The use of hazardous chemicals in the construction of the rocket, will be carefully supervised by NAR mentor and project educators.

In the construction of our vehicle, only proven, reliable materials made by established manufacturers will be used under the supervision of the mentor and educators. We will comply with all NAR standards regarding the materials and construction methods. Reliable, verified methods of recovery will be exercised during the retrieval of our vehicle. Motors will be used that fall within the NAR HPR Level 2 power limits as well as the restrictions outlined by the SL program.

Additionally, All HPR flights will be conducted only at public launches covered by an HPR waiver (mostly the WOOSH/NAR Section #558 10,000 ft MSL waiver for Richard Bong Recreation Area launch site and 15,000 ft MSL waiver for Princeton, IL, TRA QCRS site). We will be assisted by members of hosting section (WOOSH, TRA WI or TRA QCRS) and follow all instructions issued by their range personnel and our mentors.

All LMR flights will be conducted only at the launches with the FAA notification phoned in at least 24 hours prior to the launch. NAR and NFPA Safety Codes for model rockets and high power rockets will be observed at all launches.

Team Members Safety Briefing

Mentor, educators and experienced rocketry team members will take time to teach new members the basics of rocket safety. All team members will be taught about the hazards of rocketry and how to respond to them; for example ground fires, errant trajectories, and environmental hazards. Students will attend mandatory meetings and pay attention to pertinent emails prior participation in any of our launches to ensure their safety. A mandatory safety briefing will be held prior each launch. During the launch, adult supervisors will make sure the launch area is clear and that all students are observing the launch. The NAR mentor will ensure that any electronics included in the vehicle are disarmed until all essential pre-launch preparations are finished. All hazardous and flammable materials, such as ejection charges and motors, will be assembled and installed by our NAR-certified mentor, complying with NAR regulations. Each launch will be announced and preceded by a countdown (in accordance with NAR safety codes).

Safety Documentation Procedures

In all working documents, all sections describing the use of dangerous chemicals will be highlighted. Proper working procedure for such substances will be consistently applied, including the required PPE (Personal Protective Equipment), such as using protective goggles and gloves while working with chemicals such as epoxy. MSDS sheets will be on hand at all times to refer to for safety and emergency procedures. All work done on the building of the vehicle will be closely supervised by adult mentors, who will make sure that students use proper protection and technique when handling dangerous materials and tools necessary for rocket construction.

Compliance with Federal, State and Local Laws

All team members and mentors will conduct themselves responsibly and construct the vehicle and payload with regard to all applicable laws and environmental regulations. Extreme care will be taken to minimize the effects of the launch process on the environment. All recoverable waste will be disposed properly. No effort will be spared when recovering the parts of the rocket that drifted away. Properly inspected, filled and primed fire extinguishers will be on hand at the launch site.

The team is cognizant and will abide with the following federal, state and local laws regarding unmanned rocket launches and motor handling:

- **Use of airspace:** FAR 14 CFR, Subchapter F, Part 101, Subpart C
- **Handling and use of low explosives:** Code of Federal Regulation Part 55
- **Fire Prevention:** NFPA 1127 Code for High Power Rocket Motors

All of the publications mentioned above are available to the team members and mentors via links to the online versions of the documents (see: List of External Applicable Resources).

Energetics Purchase, Storage, Transport and Use

NAR/TRA mentor, Dr. Pinkas, holds a Level 2 HPR certification. Mr. Lillesand has Low Explosives User Permit (LEUP). If necessary, the team can store propellant with Mr. Goebel (Level-3 certified), who owns a ATF approved magazine for storage of solid motor grains containing over 62.5 grams of propellant. In most cases, the motors and electrical matches are purchased from the on-site vendor, Mr. Tim Lehr of Wildman Rocketry and used on the same day. Dr. Pinkas and Mr. Lillesand will be the only people to purchase and handle energetics (motors, ejection charges and igniters). Mr. Lillesand will be responsible for depositing unused propellant with Mr. Goebel should the need arise. Only NAR/TRA certified motors will be used.

Written Safety Statement

All team members and educators understand and will unconditionally abide by the following safety regulations

Range Safety Inspection

Range safety inspections of each rocket shall be carried out before the rocket is flown. The team shall comply with the determination of the safety inspection.

RSO Ruling Compliance

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.

Mentor Approval Compliance

The team mentor, that is, Dr. Pavel Pinkas, is ultimately responsible for the safe flight and recovery of the team's rocket. The team will not fly a rocket until the mentor has reviewed the design, examined the build and is satisfied the rocket meets established rocketry design and safety guidelines.

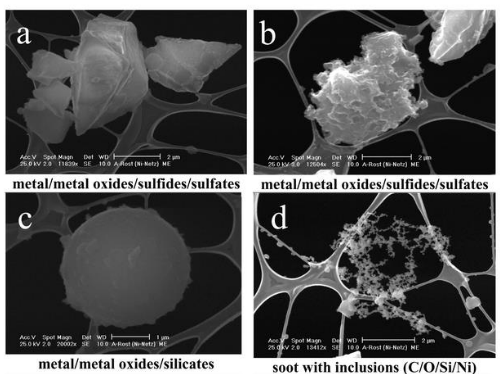
Team Compliance with Safety Requirements

Should the team fail to comply with the safety requirements they will not be allowed to launch their rocket.

Payload Criteria

Motivation

Aerosols are abundant in Earth's Atmosphere and heavily influence air quality and public health. It is important to understand the size and concentration of these particles specifically in the lower atmosphere because they influence cloud composition and cloud formation. Cloud presence changes absorption and reflection of sunlight directly affecting Earth's energy budget and weather patterns. The Cloud-Aerosol LIDAR and Infrared Pathfinder Satellite Observation (CALIPSO) satellite has been collecting data on aerosol concentration in the atmosphere using active LIDAR instrument with passive infrared and visible images. However, this method is less accurate when collecting data near the Earth's surface where there is increased cloud composition. Our project aims to use optical detection to measure aerosol concentration and size distribution in the lower atmosphere.



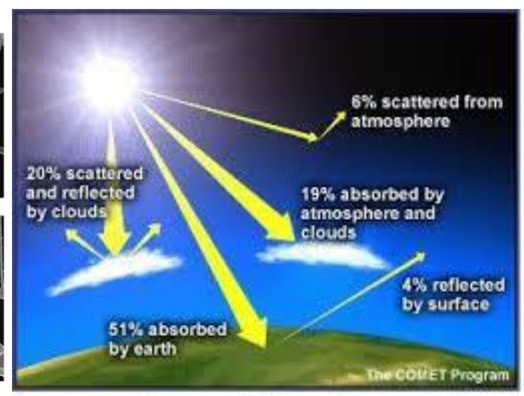


Figure 26: Microscopy of example aerosols (left).
Figure 27: Diagram explaining solar ray scatter on Earth (right).

Objective

Our project's objective is to analyze particle concentration and size distribution at specific altitudes. During vehicle ascent, air and particles will enter the payload. Each chamber will have a camera and LED light in order to perform optical detection. The particles will continuously flow out of the exit tube at the end of each chamber throughout the vehicle's ascent in order to circulate air from the current altitude. A continuous circulation allows us to collect the most accurate data from each altitude.

Hypothesis

Because the atmosphere decreases in density as altitude increases, we hypothesize that as the vehicle ascends, particle size will decrease, and the concentration of smaller aerosols will increase relative to the concentration of larger aerosols due to the tendency of smallers aerosols to be carried higher into the atmosphere. Our hypothesis is summarized in the figures below.

Payload Design And Experimental Setup

To capture images during vehicle ascent, a Raspberry Pi Camera will be used. Air input/output ducts will be used to direct air into the interior of the vehicle. The airflow will be confined between two glass plates, allowing for the camera and LED system to capture an image. Each of the two payload units will contain its own Raspberry Pi computer that will control the LED and camera, and store the images taken.

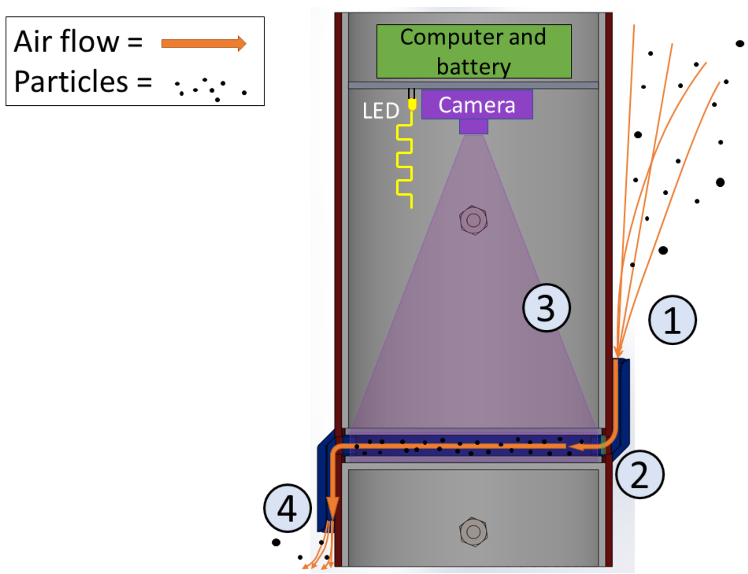


Figure 28: Payload unit for measuring air particle concentration

1. Air and particles enter the payload through the external air intake
2. The air and particles enters an air channel between 2 glass plates
3. The led flashing in time with the camera reflects light off the particles into the camera, the camera captures this as images
4. Air and particles exit the payload through the external air outtake

Payload Assembly

A 3d model of one of two independently functioning payload units is shown in the following image.

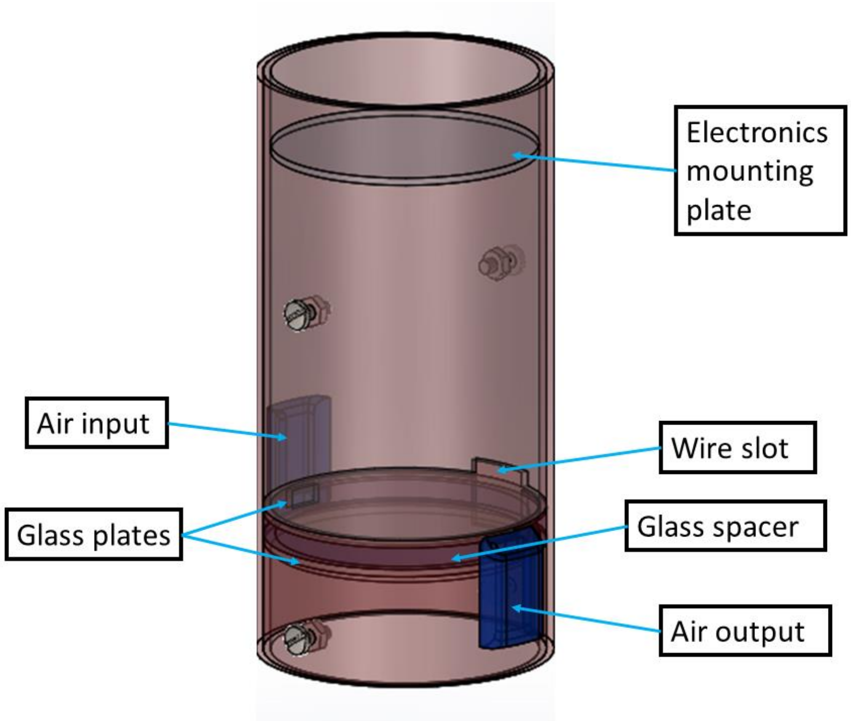


Figure 29 3D model of a single payload unit (one of two)

The data from each of the cameras is collected using a Raspberry Pi computer. The raspberry pi computer also controls the timing on the LED and camera.

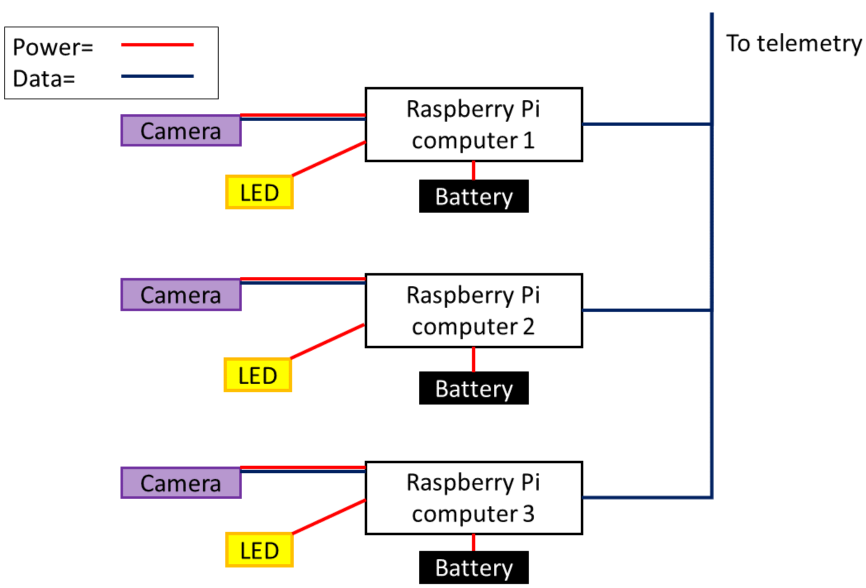


Figure 30: Payload Block Scheme

Experimental Sequence

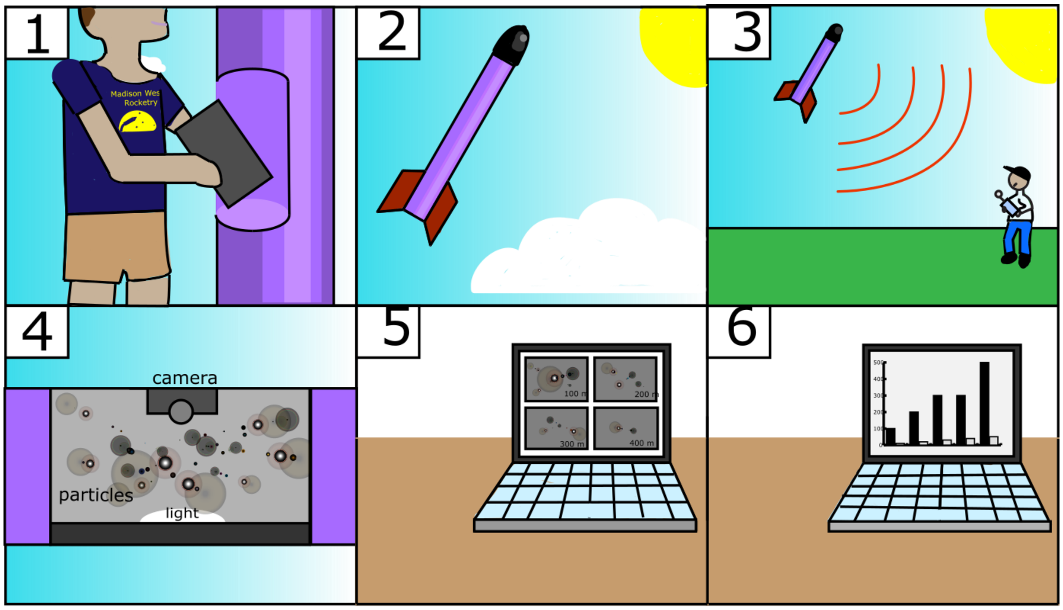


Figure 31: Experimental Sequence

1. We will load and turn on the payload prior to launch.
2. The vehicle will be launched.
3. Throughout rocket flight, telemetry information will be relayed to the ground.
4. During vehicle ascent, particle images will be taken by onboard cameras.
5. During flight, images will be analyzed for particle concentration and data will be sent to telemetry module for transmission to the ground.
6. Finally, we will write the post-launch assessment report.

Data Analysis

The data analysis is outlined in the section below. For each image we will use a python algorithm to identify particles and record the concentration of each size of particles. Data from the image will be matched to a specific altitude based on an image timestamp recorded by the Raspberry Pi computer and transmitted to the ground by the telemetry unit for further analysis.

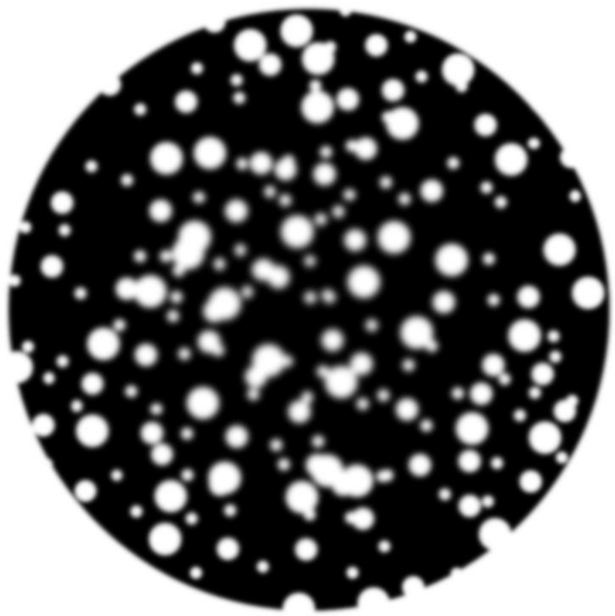


Figure 32: Example image that the camera will produce

On the ground, the data will be visualized using graphs and histograms showing the concentrations and sizes of particles at different altitudes. Sample visualizations of what these graphs might look like follow:

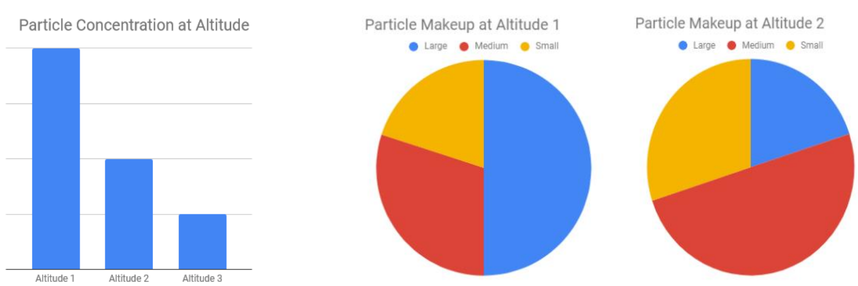


Figure 33: Example graph showing particle concentrations at different altitudes (left).

Figure 34: Example graphs showing the concentrations of different particle sizes at different altitudes (right)

Correlations will then be measured using statistical analysis. The following figure outlines the independent variables and dependant variables that will be used to measure correlations.

Independent Variables:	Dependent Variables
• A - Altitude • h - Humidity • T - Temperature	• C_a - Aerosol Concentration • S_p - Particle Size Range

Correlations Measured:

- $C_a = f(A)$ - Concentration as a function of altitude
- $C_a = f(h)$ - Concentration as a function of humidity
- $C_a = f(T)$ - Concentration as a function of temperature
- $S_p = f(A)$ - Particle size as a function of altitude
- $S_p = f(h)$ - Particle size as a function of humidity
- $S_p = f(T)$ - Particle size as a function of temperature

Table 25: Summary chart of data analysis

Telemetry Criteria

Objective

The telemetry module of the project seeks to prepare the team for the unlikely situation where the local data inside the rocket becomes corrupted or lost (eg. the rocket cannot be located/recovered after the flight), increasing the chance of successful payload data recovery. The secondary objective of the telemetry module is to collect data on the trajectory, speed, orientation, acceleration and altitude of the vehicle while it is in the air, providing the team with a better understanding of the rocket's design, functionality, and safety.

In addition to standard rocket metrics, the telemetry unit also seeks to collect and transmit atmospheric data from a variety of other sensors. This will aid in augmenting our understanding of the data collected from our primary payload.

Telemetry Success Criteria

The criteria for a successful telemetry flight is as follows:

1. The telemetry unit required no more than 30 min to integrate into the rocket at the launch field
2. The telemetry unit transmitted all collected data the ground control station for the entire duration of the flight without errors.
3. Data collected from the telemetry unit is accurate
4. The telemetry unit was not damaged and can be flown on the same day with a simple battery replacement.

Leading Telemetry Design

Overview

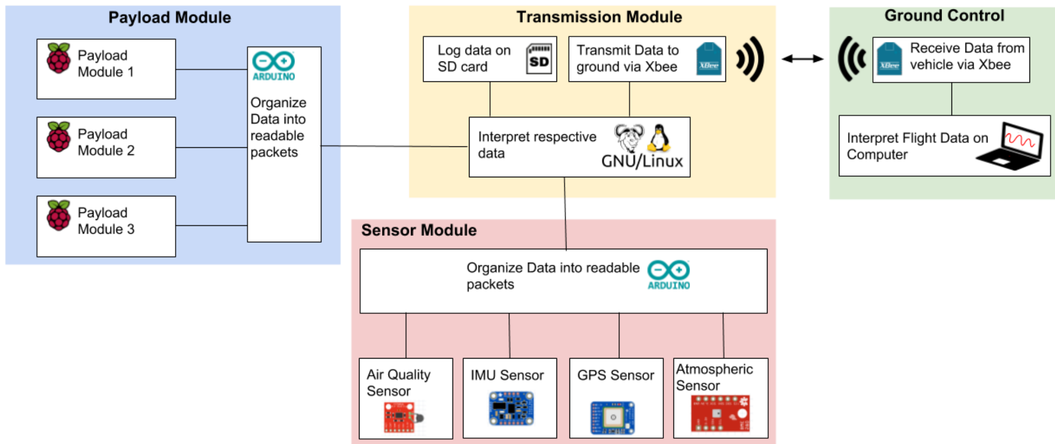


Figure 35: Payload Integration Block Scheme

The telemetry payload will be comprised of multiple modules: the payload integration module. which will collect data on the particulate matter (aerosols) in the atmosphere; the sensor module, which will collect specific data on the rocket flight and environmental conditions; and the transmission module, which will organize data from both the sensor and the payload module and will subsequently transmit the data back to the ground.

The data will be received on the ground using another wireless Xbee RF transmitter and will be interpreted, in real time, on a computer.

Payload-Telemetry Data Staging

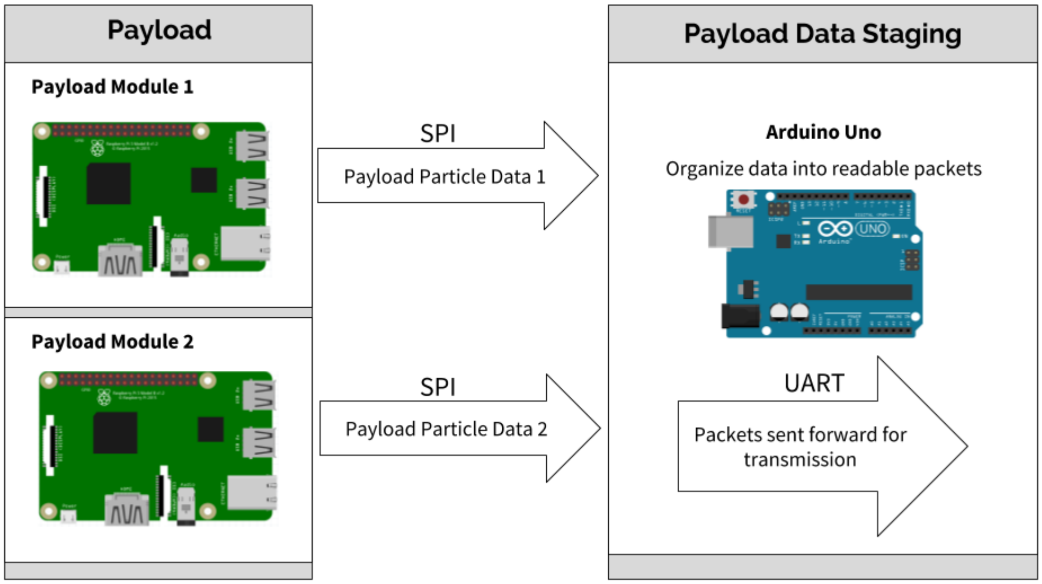


Figure 36: Payload Block Scheme

The payload module will integrate with the telemetry unit to provide redundancy for the data collected. Each payload module will communicate data to a data relay Arduino via SPI. This Arduino will then organize the data into readable packets which will subsequently transferred to the transmission module via a UART interface.

SPI was chosen over the I2C protocol due to its faster transmission speeds and larger data processing capacities.

Sensor Module Overview

The table below outlines which instruments will be used in the sensor modules. An Adafruit Metro M4 was selected to be the microcontroller for the telemetry unit, due to its high amount of flash memory and RAM compared with the traditional Arduino Uno.

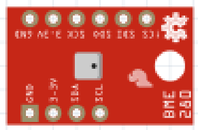
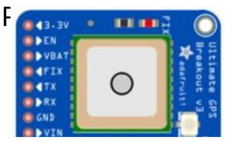
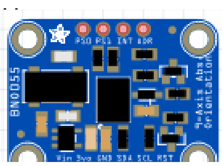
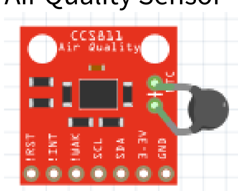
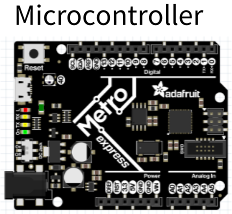
Instrument	Device	Data Rate/Second	Max. Sampling Rate	Data
Atmospheric Data Logger 	BME280	106 bytes	180 Hz	Temperature (°C)
				Humidity (% RH)
				Barometric Pressure (Pa)
				Altitude (m)
GPS 	MTK3339	73 bytes	10 Hz	GPS Coordinates (long, lat, altitude)
IMU 	BNO055	77 bytes	100 Hz	Absolute Heading (Euler Angles, Quaternions)
Air Quality Sensor 	CCS811	36 bytes	4 Hz	Total Volatile Organic Compounds (TVOC)
				Equivalent Calculated CO_2 Levels (ECO_2)
				Metal Oxide Levels (MOX)
Microcontroller 	Metro M4	N/A	N/A	Data Collection

Table 26: Sensor Module Components Table

Sensor Module Block Scheme

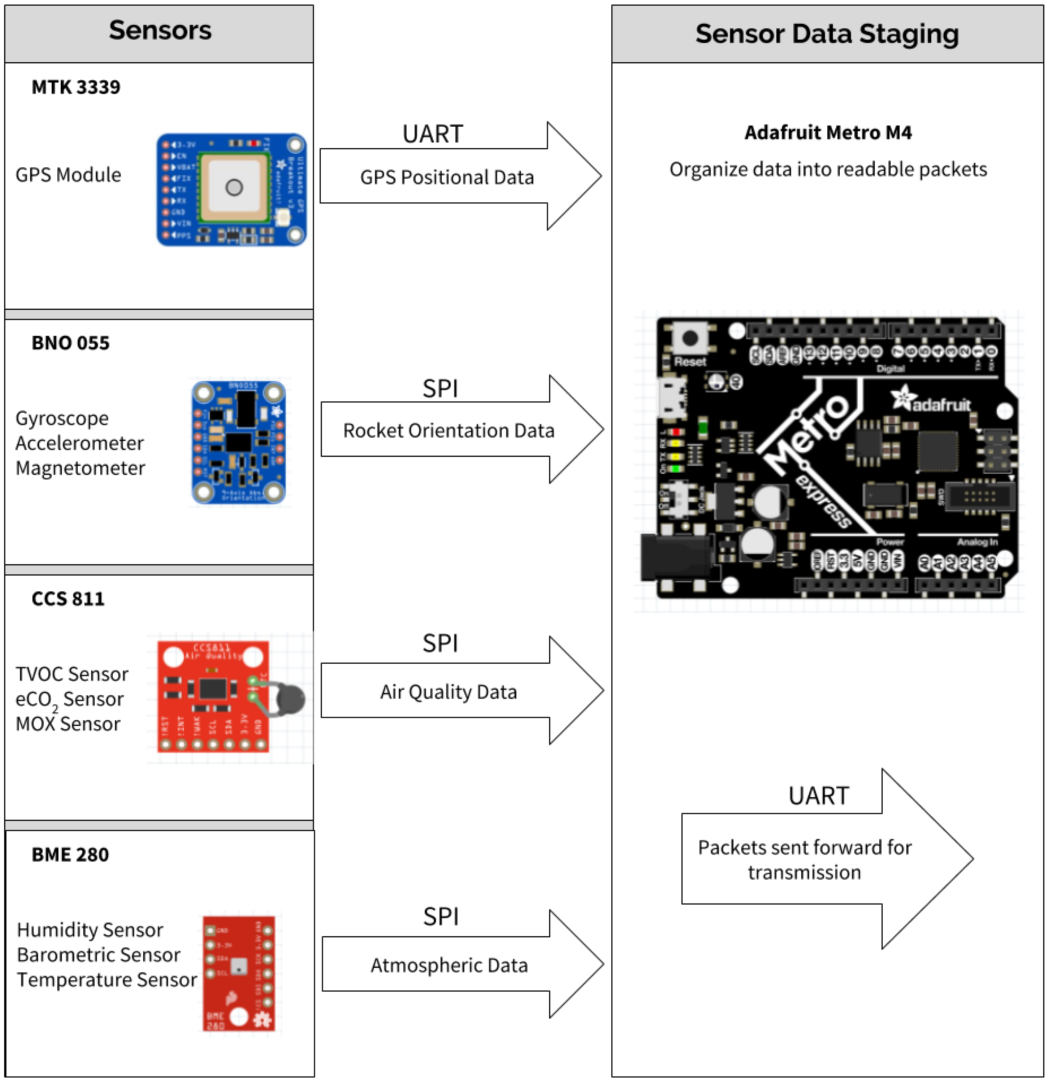


Figure 37: Telemetry Block Scheme

Each individual sensor will forward its data to a microcontroller that will process the data using a variant of the C programming language and facilitate its transfer into an RF transmission via an Xbee Pro S1 module. Data will also be stored in an SD card to ensure that data pertinent to our experiment is recovered should the transmissions fail. A lithium polymer battery along with a voltage regulator/charger will provide the microcontroller and sensors with power for proper functionality.

Transmission Module

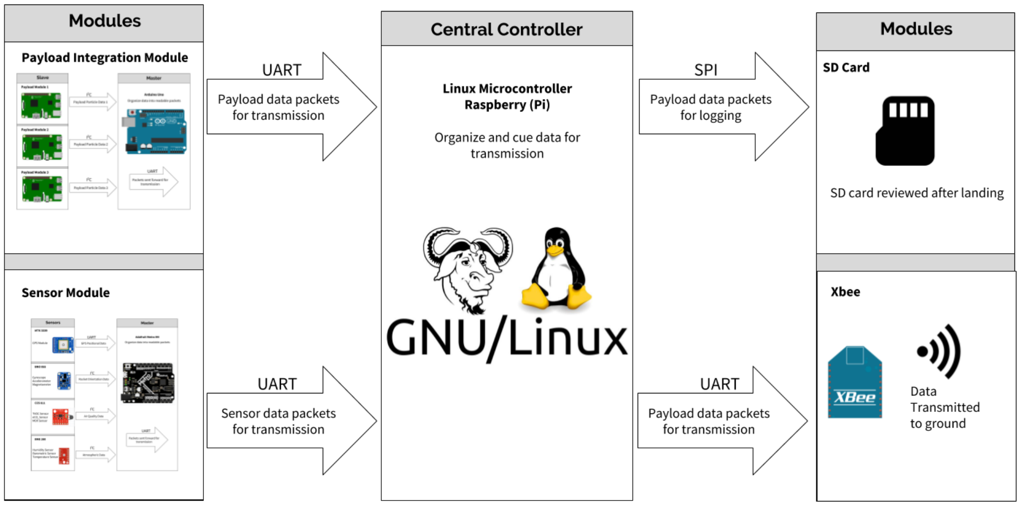


Figure 38: Telemetry Transmission Module Block Scheme

The transmission module will consist of a central single board computer (SBC) which will consolidate the data collected from the payload integration and sensor modules, facilitating its transmission and storage. The Xbee will be connected to the microcontroller via a UART interface. Data will be stored on an SD card in case of transmission failure.

Ground Control

RF transmissions from the rocket will be received on a ground control station consisting of an Xbee hooked up to a portable computer. This computer will then take and process the data into a display showing the heading, GPS location, orientation, altitude, acceleration and atmospheric sensor output from the rocket. Software for the displaying of the data in real time will be written in the C# programming language.

Project Plan

Requirements Verification

Verification Plans

The full verification plan is shown in Appendix A with the bolded items being the requirements and the unbolded text being the verification plan.

Line Item Budget

The estimated project budget for the material costs relating to the proposed SLI project stands at around $4223.83. Prices were calculated from past knowledge and publicly available online prices. The breakdown of prices based on category are shown below. A line item budget is included in the pages thereafter.

Item	Total Costs
Full-Scale Vehicle	$1900.53
Scale Model	$533.24
Payload	$371.18
Telemetry	$390.36
Energetics	$539.96
Taxes, Shipping & Handling, etc.	$500.00
Total Project Budget:	**$4235.27**

Figure 39: Project Budget

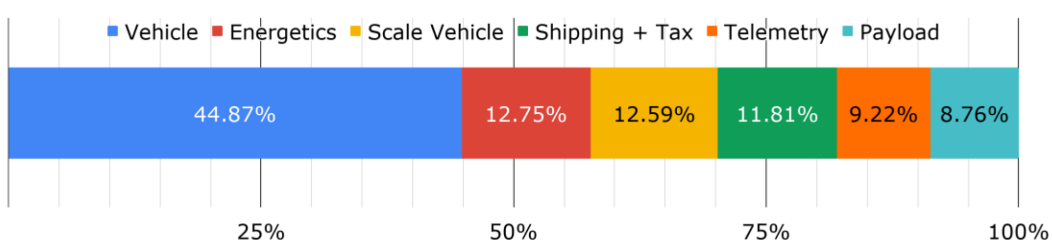


Figure 40: Project expenses breakdown

Vendors

Materials are sourced from a variety of sources. Rocket parts are purchased on an as-needed basis from Wildman Rocketry, an online retailer. Most electronic components are sourced from the hobby vendors Adafruit Industries and Sparkfun Electronics. Various miscellaneous parts such as 3d printer filament and some electronics are sourced from Amazon.com. A large network of other vendors such as local hardware stores (Menards, Home Depot, Ace Hardware), local retail markets (Office Depot, Walgreens, Pick n' Save) and specialized vendors will also be used to acquire materials. These vendors are categorized under the other/various vendors category due to their diversity and range. For the purposes of space, each vendor has been assigned a two letter key that corresponds to the table below.

Key	Vendor	Total Costs
WM	Wildman Rocketry	$1903.74
AZ	Amazon.com Inc.	$358.47
AF	Adafruit Industries	$421.61
SF	Sparkfun Electronics	$121.45
OV	Other/Various vendors	$930.00
ST	Shipping + Tax	$500.00

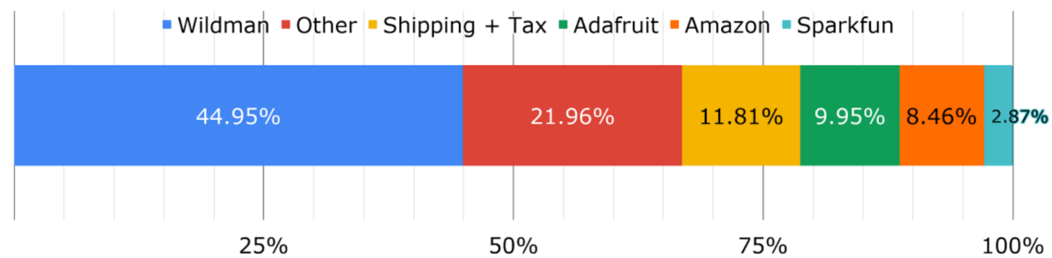


Figure 41: Vendor utilization breakdown

Full -Scale Vehicle

Vendor	Item	Unit Price	Quantity	Price
WM	Motor Casing 752560C	$225.00	1	$225.00
WM	G10 Fiberglass 12 x 12 x 3/32 *in*	$14.00	4	$56.00
WM	Nomex (Main Parachute)	$14.95	1	$14.95
WM	Nomex (Drogue Parachute)	$21.95	1	$21.95
WM	Tubular Kevlar Shock Cord	$42.50	1	$42.50
WM	Fiberglass Coupler Tubing - 20*in* length	$52.00	1	$52.00
WM	Centering Ring	$7.00	3	$21.00
WM	120*in* Parachute (Main)	$169.95	1	$169.95
WM	20*in* Parachute (Drogue)	$39.90	1	$39.90
WM	4*in* Fiberglass Tubing - 9 ft length	$210.15	1	$210.15
WM	75 mm motor mount tube - 2*in* length	$41.02	1	$41.02
WM	PerfectFlite Stratologger CF Altimeter	$61.06	2	$122.12
WM	RA75L Motor Retainer	$44.00	1	$44.00
AZ	Trackimo 3G GPS Tracker	$298.99	1	$298.99
OV	Aesthetics Budget (Primers, Paint, Decals)	--	--	$150.00
OV	Epoxy Budget (Resin, Hardeners, Fillers)	--	--	$100.00
OV	Misc. Supplies (Tools, Wires, etc.)	--	--	$300.00
			Full Scale Vehicle Total:	**$1900.53**

Table 27: Full-Scale Vehicle Budget

Scale Vehicle

Vendor	Item	Unit Price	Quantity	Price
WM	Nomex (Drouge)	$8.95	1	$8.95
WM	Nomex (Main)	$14.95	1	$14.95
WM	12*in* Parachute	$5.95	1	$5.95
WM	40*in* Parachute	$54.95	1	$54.95
WM	G10 Fiberglass 12*in* x 12*in* x 1/16*in*	$10.00	2	$20.00
WM	2.1*in* Fiberglass Tubing - 4 ft length	$57.60	1	$57.60
WM	Centering Rings	$4.75	3	$14.25
WM	38 mm Fiberglass Tubing	$13.09	1	$13.09
WM	Fiberglass Coupler Tubing - 10*in* length	$26.00	1	$26.00
WM	Tubular Kevlar - 3 ft length	$2.50	1	$2.50
WM	38480M 38mm Motor Casing	$115.00	1	$115.00
OV	Aesthetics Budget (Paint and Decal)	--	--	$100.00
OV	Misc. Supplies (Tools, Batteries, Wires, etc.)	--	--	$100.00
			Scale Vehicle Total:	**$533.24**

Table 28: Scale Model Budget

Telemetry

Vendor	Item	Unit Price	Quantity	Price
AF	Adafruit GPS Logger Shield	$44.95	1	$44.95
AF	BNO055 9-DOF IMU	$34.95	1	$34.95
SF	BME280 Atmospheric Sensor	$19.95	1	$19.95
SF	CCS811 Air Quality Sensor	$19.95	1	$19.95
SF	Thermosistors, 3 pk	$0.75	1	$0.75
SF	2.5 Ah Li-poly Battery Pack	$14.95	1	$14.95
AF	Micro-Lipo Battery Charger	$6.95	1	$6.95
SF	Xbee USB connector	$24.95	1	$24.95
SF	Xbee Shield	$26.00	1	$26.00
AF	60 mW Xbee Pro Series 1	$37.95	2	$75.90
AF	Adafruit Metro M4 Microcontroller	$27.50	1	$27.50
AZ	Arduino Uno	$22.00	1	$22.00
AF	Raspberry Pi Zero W	$10.00	1	$10.00
AZ	Gikfun Prototype Shield, 3pk	$11.56	1	$11.56
OV	Miscellaneous Supplies (Wires, Solder, etc.)	--	--	$50.00
			Telemetry Total:	**$390.36**

Table 29: Telemetry Budget

Payload

Vendor	Item	Unit Price	Quantity	Price
AZ	1kg PLA Plastic 3D printing filament	$19.99	2	$39.98
AF	Raspberry Pi 3 B+	$35.00	3	$105.00
AF	Pi Cameras	$29.95	3	$89.85
SF	Li-Poly Battery Packs	$9.95	3	$29.85
AZ	White LEDs, pack of 100	$6.50	1	$6.50
OV	Miscellaneous supplies (Wires, Solder, etc.)	--	--	$100.00
			Payload Total:	**$371.18**

Table 30: Payload Budget

Energetics

Vendor	Item	Unit Price	Quantity	Price
WM	CTI K2000	$159.99	2	$319.98
WM	CTI K661	$139.99	1	$139.99
WM	AT I211W	$49.99	1	$49.99
OV	4F Black Powder	$18.56	1	$18.56
			Energetics Total:	**$528.52**

Table 31: Energetics Budgete

Travel Budget

The following tables show the estimated expenses from traveling to Huntsville. Prices were calculated from past knowledge and publicly available online prices. The total travel cost is currently estimated at $13,015 with a per capita cost of $765.59.

Flight

Cost per Person	Number of People	Flight Cost Total
$345.00	17	$5,865.00

Table 32: Flight Budget

Lodging

Cost per Room per Night	Number of Rooms	Number of Nights	Hotel Cost Total
$119.00	10	5	$5,950.00

Table 33: Hotel Fees Budget

Ground Support

Rental Cost	Gas and Other Costs	Ground Support Total
$900.00	$300.00	$1,200.00

Table 34: Ground Support Budget

Total

Item	Price
Flight	$5,865.00
Lodging	$5,950.00
Ground Support	$1,200.00
Project Budget Total:	**$13,015.00**
Cost Per Team Member:	**$765.59**

Table 35: Total Travel Budget

Funding Plan

Sources of Funding

The Madison West Rocket club has many sources of funding to allow for its steady operation. The main source of project funding is the *Raking For Rockets* fundraising program. Our fundraising services are widely known and highly sought after by the local community and patrons are known to donate over $100 per yard raked in order to support us. The club's Student Launch program is expected to receive over $6,000 dollars from this program alone. Donations from familiers or local companies in rocket club raise on average, an additional $2,500 per year. All travel expenses are covered collectively by the individual members of the club.

Item		Cost
Raking Fundraiser		$6,000.00
Donations		$2,500.00
Travel Funds*		$12,347.00
	Total Expenses:	**$20,847.00**

* Students pay the travel expenses associated with SL launch.

Table 36: Funds Summary

Allocation of Funds

Funds will be allocated mostly for the material cost of the project. For a more detailed overview on the material costs, see the line item budget provided above. Teleconferencing venues and equipment is provided at no cost by UW Madison. The following breakdown of costs is expected for this project:

Item	Cost
Project Cost	$3,460.90
Workshop Rental	$2,400.00
Workshop Insurance	$500.00
Teleconferencing Fees*	$0.00
Outreach Costs	$500.00
Travel Expenses	$12,347.00
Total Expenses:	**$19,207.90**

* Teleconferencing venue and equipment provided for free by the university.

Table 37: Expenses Summary

Material Acquisition

Materials will be acquired through a variety of vendors, as outlined in the line item budget. A majority of materials, including the vehicle airframe, motor mounts, motor casing, shock chords, and motors will be purchased from Wildman Rocketry, either online or at one of their on site vendor booths that are present at launches. Fiberglass for fins will be acquired either through wildman rocketry or through the online vendor McMaster-Carr. Parachutes, nomex, trackers and altimeters will be used from past projects or purchased as necessary. Electronics for the payload and telemetry units will be acquired from the online hobby electronic stores (Adafruit and Sparkfun).

All materials for the subscale model are projected to be acquired by November 10th, which will allow for the purchasing of material at the *Midwest Power* high power rocket launch event hosted at Princeton. Proposed materials for the payload and telemetry units will be acquired no later than December 1st. Materials for the full scale model will be acquired no later than January 12th 2019.

Development Schedule

GANTT Chart

The GANTT chart below shows the sequence, dependencies, overlaps and possible conflicts between different phases of the project. We use this chart to determine optimal schedule that will lead to successful and timely completion of our project. A full timeline of the season is outlined in the next section.

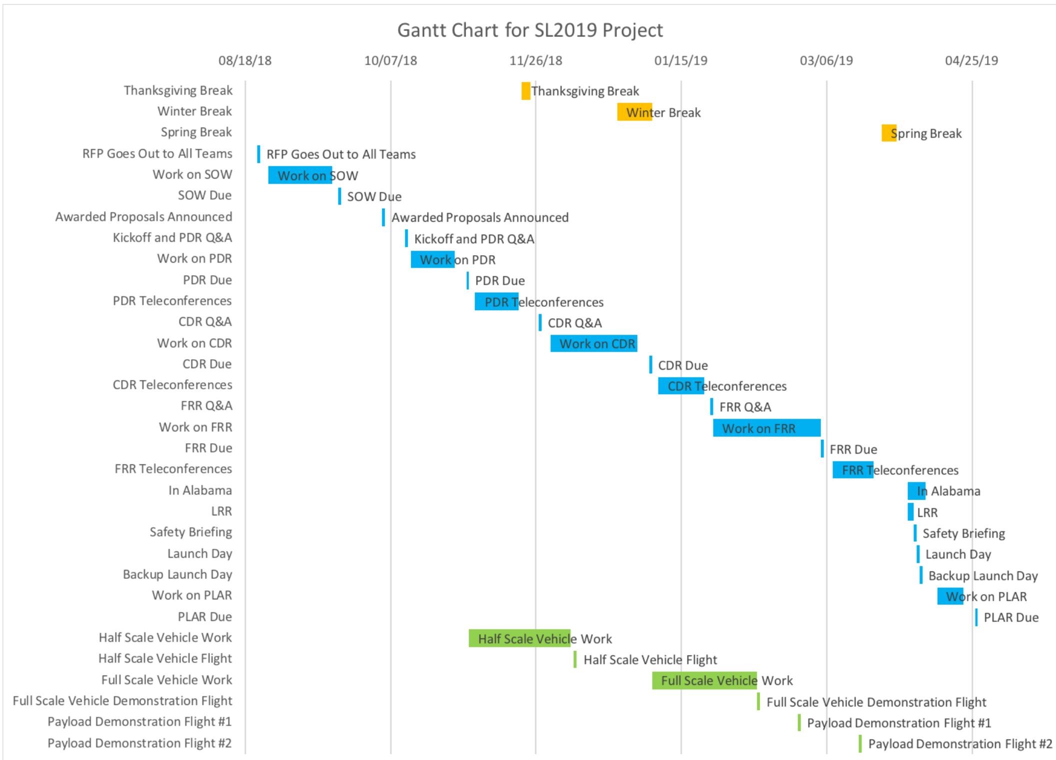


Figure 42: Gantt Chart

Timeline Key

- School
- SLI writing sessions
- Organizational meeting
- Workshop
- Fundraising
- Test launch
- Outreach
- SL Event Dates

Timeline

AUGUST	
Saturday 25	SLI writing session
SEPTEMBER	
Saturday 1	SLI writing session
Wednesday 5	School starts
Friday 7	Workshop
Saturday 8	SLI writing session
Monday 10	Organizational meeting
Friday 14	Workshop
Saturday 15	SLI writing session
Monday 17	Organizational meeting
Wednesday 19	SOW due 3:00 p.m.
Friday 21	Workshop
Saturday 22	SLI writing session
Monday 24	Organizational meeting
Friday 28	Workshop
Saturday 29	SLI writing session
OCTOBER	
Monday 1	Organizational meeting
Thursday 4	Outreach with Boy Scouts
Thursday 4	Accepted Proposals Announced
Friday 5	Workshop
Saturday 6	SLI writing session
Monday 8	Organizational meeting
Thursday 12	Kickoff and Preliminary Design Review (PDR) Q&A
Friday 12	Randall Elementary Outreach
Friday 12	Workshop
Saturday 13	SLI writing session
Sunday 14	Fundraising
Monday 15	Organizational meeting
Friday 19	Workshop
Saturday 20-21	Wisconsin science festival
Saturday 20	SLI writing session
Sunday 21	Fundraising

Monday 22	Organizational meeting
Friday 26	Social media list due 8:00 a.m.
Friday 26	No school
Friday 26	Workshop
Saturday 27	SLI writing session
Sunday 28	Fundraising
Monday 29	Organizational meeting
NOVEMBER	
Friday 2	Workshop
Friday 2	PDR Due by 8:00 a.m.
Saturday 3	SLI writing session
Saturday 3	The stars above
Saturday 3	ACT testing
Sunday 4	Fundraising
Monday 5	Organizational meeting
Monday 5-Monday 19	PDR Video Teleconferences
Friday 9	Workshop
Saturday 10	SLI writing session
Sunday 11	Fundraising
Monday 12	Organizational meeting
Tuesday 13	Mt. Horeb Girl scouts
Friday 16	Workshop
Saturday 17	SLI writing session
Sunday 18	Fundraising
Monday 19	Organizational meeting
Wednesday 21- Friday 23	No school
Saturday 24	SLI writing session
Sunday 25	Fundraising
Monday 26	Organizational meeting
Tuesday 27	Critical Design Review (CDR) Q&A
Friday 30	Workshop
DECEMBER	
Saturday 1	SLI writing session
Sunday 2	Fundraising
Monday 3	Organizational meeting
Friday 7	Workshop
Saturday 8	SLI writing session
Sunday 9	Scale Model flight
Monday 10	No school
Friday 14	Workshop
Saturday 15	SLI writing session
Monday 17	Organizational meeting
Monday 24 - Sunday, Jan. 6	WINTER BREAK
JANUARY	
Friday 4	CDR due by 8:00 a.m.
Friday 4	Workshop
Saturday 5	SLI writing session
Monday 7	Organizational meeting

Monday 7 - Tuesday 22	CDR Video Teleconferences
Friday 11	Workshop
Saturday 12	SLI writing session
Friday 18	Workshop
Saturday 19	SLI writing session
Monday 21	No school
Friday 25	Flight Readiness Review (FRR) Q&A
Friday 25	Workshop
Friday 25	No school
Saturday 26	SLI writing session
Monday 28	Organizational meeting
FEBRUARY	
Friday 1	Workshop
Saturday 2	SLI writing session
Monday 4	Organizational meeting
Friday 8	Workshop
Friday 8	No school
Saturday 9	SLI writing session
Sunday 10	Vehicle Demonstration Flight
Monday 11	Organizational meeting
Friday 15	Workshop
Saturday 16	SLI writing session
Saturday 16	Physics open house
Monday 18	Organizational meeting
Wednesday 20	ACT testing
Friday 22	Workshop
Saturday 23	SLI writing session
Sunday 24	Payload Demonstration Flight
Monday 25	Organizational meeting
MARCH	
Friday 1	Workshop
Saturday 2	SLI writing session
Monday 4	Organizational meeting
Monday 4	Vehicle Demonstration Flight deadline FRR due by 8:00 a.m
Friday 8 – Thursday 21	FRR Video Teleconferences
Friday 8	Workshop
Saturday 9	SLI writing session
Saturday 9	Super Science Saturday
Monday 11	Organizational meeting
Friday 15	Workshop
Saturday 16	SLI writing session
Sunday 17	Payload demonstration flight
Monday 18	No school
Wednesday 20	Wingra Science Night
Friday 22	Workshop

Saturday 23	SLI writing session
Monday 25	Payload Demonstration Flight deadline Vehicle demonstration Re-flight deadline FRR Addendum due 8:00 a.m.
Monday 25-29	No school
Saturday 30	SLI writing session
APRIL	
Wednesday 3	Travel to Huntsville, AL Launch Readiness Reviews (LRR)
Friday 5	Launch Week Activities
Saturday 6	Launch Day
Sunday 7	Backup Launch Day
Monday 8	Organizational meeting
Friday 12	Workshop
Saturday 13	SLI writing session
Monday 15	Organizational meeting
Friday 19	Workshop
Friday 19	MSCR k12 Showcase
Saturday 20	SLI writing session
Monday 22	Organizational meeting
Friday 26	No school
Friday 26	Workshop
Friday 26	Shorewood elementary
Friday 26	Post-Launch Assessment Review due 8:00 a.m.
Saturday 27	SLI writing session
Monday 29	Organizational meeting

Table 38: Detailed project schedule

STEM Engagement

Each year the team participates in numerous outreach events. These events range from single classroom activities at the local elementary schools to large public events that span multiple days and see visitors from around the state of Wisconsin, including but not limited to the Physics Open House at UW Madison or the Wisconsin Science Festival. The team will be returning to these events at the request of the event organizers this year

After a steady building of our reputation through outreaches for nearly a decade, the name Madison West Rocket Club is well recognized and many schools request our participation in their STEM related events. This year, the team expects to reach approximately 10,000 people. All supplies and materials for outreach events are supplied by the club. Minimum cost outreach designs, such as paper pneumatic rockets or surplus items from the workshop are used to ensure that a large number of children can participate in outreach opportunities and witness a meaningful demonstration or rocketry forces.

The team's fundraising efforts, dubbed Raking for Rockets, allows the club to keep in contact with local communities. Last year, the club raked over 120 yards, allowing the team to not only collect funds, but also connect with the local community and spread awareness of the club. Several times during the Raking for Rockets program our raking and yardworking teams helped people who otherwise could not yardwork in the spirit of altruism.

In addition to the programs outlined above, new members for the club are recruited continuously at Madison West High School. This is done through a number of methods, including participation in club fairs at West High School, personal referrals and friendly encouragement. Programs, such as the Spare Parts Airborne program during the summer allow curious members to try out rocketry and attempt an L1 certification flight in the process. These programs not only help with bolstering membership, but also bring exposure to rocketry and STEM fields to those who are either too busy or too intimidated to participate in the main programs of our club.

The table below shows the outreach programs that we have planned for this year. The programs target primarily elementary and middle schools. This list will be continuously updated as requests come in from more schools and event organizers.

Outreach Calendar

Date	Event	Activities	Eval. Criteria	Est. Attendance
10/04	Boy Scouts	Show & tell, static motor firing	Direct Education	50
10/13 - 10/14	Wisconsin Science Festival	Pneumatic rockets, SLI payload	Direct Education	7000
10/22	West High Homecoming	Parade	Indirect Outreach	200
11/03	The Stars Above	Fully functional plasma thruster, 3D printers	Direct Outreach	1000
11/13	Mt. Horeb Girl Scouts	Pneumatic rocket, show & tell, displays	Direct Education	150
02/17	Physics Open House	Displays, pneumatic rockets	Direct Education	530
03/09	Super Science Saturday	Displays, pneumatic rockets	Direct Education	250
03/26	Wingra Family Science Night	Displays, pneurocs	Direct Education	150
04/16	Crestwood Elementary	Displays, pneurocs, 3D printers	Direct Education	170
04/19	MSCR K12 Showcase	Displays, pneurocs, 3D printers	Direct Education	350
04/23	Shorewood Elementary	Displays, pneurocs, 3D printers	Direct Education	150
		Estimated Total Attendance:		**10000**

Table 39: Outreach Calendar

Appendix A - Requirements Verification

1. General Requirements

1.1. **Students on the team will 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). Students will do 100% of work on the project, write the documentation and presentations and present the project during teleconferences.** Inspection: The team will monitor both itself and its mentor, Dr. Pavel Pinkas to ensure that students will do 100% of the work. Dr. Pinkas is the Level 2 mentors for the team and he will handle only motor and ejection charge assembly.

1.2. **The team will 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.** Inspection: The team has been informed of this requirement and will ensure that project plan will be maintained and updated as project progresses. The team leader will delegate tasks accordingly.

1.3. **Foreign National (FN) team members must 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.** Inspection: The team will ensure that a list of foreign nationals is provided to NASA. All foreign nationals have been informed about the situation.

1.4. **The team must identify all team members attending launch week activities by the Critical Design Review (CDR). Team members will include:**

1.4.1. **Students actively engaged in the project throughout the entire year.** Inspection: All team members are identified in the Student Participants section near the beginning of this document. Attendance records are kept to ensure that all students are actively engaged.

1.4.2. **One mentor (see requirement 1.13).** Inspection: Dr. Pavel Pinkas is the mentor for the team. There is only one mentor for the team.

1.4.3. **No more than two adult educators.** Inspection: There are two adult educators on the team. Ms. Christine Hager and Dr. Ankur Desai are the two adult educators for our team.

1.5. **The team will engage a minimum of 200 participants in educational, hands-on science, technology, engineering, and mathematics (STEM) activities, as defined in the STEM Engagement Activity Report, by FRR. To satisfy this requirement, all events must occur between project acceptance and the FRR due date and the STEM Engagement Activity Report must be submitted via email within two weeks of the completion of the event. A sample of the STEM Engagement Activity Report can be found on page 33 of the handbook.** Inspection: Educational engagement forms will be completed and submitted within two weeks of each event's completion. If the minimum of 200 participants is not reached, further outreaches will be scheduled.

1.6. **The team will establish a social media presence to inform the public about team activities**. Inspection: The team will create and update a social media presence update throughout the duration of the project. Norlha, the social media coordinator will ensure that this requirement will be completed.

1.7. **Teams will email all deliverables to the NASA project management team by the deadline specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient.** Inspection: The team has been informed about the major milestone deadlines. Members of the team will cross check each other to ensure that deliverables are emailed on time to NASA project management with either an attachment or a download link.

1.8. **All deliverables must be in PDF format.** Inspection: The team will insure before submission that all deliverables are in PDF format.

1.9. **In every report, teams will provide a table of contents including major sections and their respective sub-sections.** Inspection: The team will ensure that a table of contents with the proper sections is included in every report starting on page two and will cross check it with the respective sections to ensure that all major sections and their respective sub-sections are included.

1.10. **In every report, the team will include the page number at the bottom of the page.** Inspection: The team will ensure that a page number is at the bottom of each page by ensuring that each footer contains the number with the proper page.

1.11. **The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a broadband Internet connection. Cellular phones can be used for speakerphone capability only as a last resort.** Inspection: The Atmospheric and Oceanic Sciences department at UW Madison has graciously allowed us to use their teleconferencing venues.

1.12. **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 [2.4 m 1010 rails], and 12 ft. 1515 rails [3.7 m 1515 rails] available for use. The launch rails will be canted 5 to 10 degrees away from the crowd on launch day. The exact cant will depend on launch day wind conditions.** Test: Test launches will be conducted on an 8ft 1010 rail to ensure that said rail is compatible with the vehicle

1.13. **Each team must 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 must 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 must have flown and successfully recovered (using electronic, staged recovery) a minimum of two 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.** Inspection: The team currently has Dr. Pavel Pinkas as its mentor. He is Level 2 certified and satisfies all requirements listed above. He has pledged to accompany team to the Huntsville launch.

2. Vehicle Requirements

2.1. **The vehicle will deliver the payload to an apogee altitude between 4,000 feet [1,219 meters] and 5,500 feet [1,676 meters] above ground level (AGL) Teams flying below 3,500 feet [1067 meters] or above 6,000 feet [1829 meters] on Launch Day will be disqualified and receive zero altitude points towards their overall project score.** Analysis: The launch vehicle will be constructed to reach an altitude of 5350 ft. Multiple methods of verification, including Openrocket simulations, and hand calculations will ensure that the target altitude is reached to a reasonable degree of accuracy.

2.2. **Teams shall identify their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team's altitude score during Launch Week.** Inspection: The target altitude has been declared in the vehicle criteria section of the report.

2.3. **The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the Altitude Award winner. The Altitude Award will be given to the team with the smallest difference between their measured apogee and the official target altitude on launch day.** Inspection: The vehicle will carry two identical barometric altimeters (PerfectFlite StratoLogger CF), each capable of serving the role of official scoring altimeter. The team will designate and visually identify one of the altimeters as the official scoring altimeter, before the actual flight.

2.4. **Each altimeter will 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.** Inspection: Each altimeter will be armed by an exterior key switch. The switch will be mounted so as not to interfere with the launch rail.

2.5. **Each altimeter will have a dedicated power supply.** Inspection: Each altimeter will be powered by a Duracell 9-volt battery that has been purchased less than 72 hours before launch and was measured to have more than 8.9 volts of charge.

2.6. **Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).** Demonstration: The switches shall be operated by key and be set up so that the key can only be removed when the switch is armed.

2.7. **The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.** Analysis: Openrocket simulations and hand calculations will be used to ensure that the recovery system is robust enough to return the rocket without any damage.

2.8. **The launch vehicle will 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**. Inspection: The team will ensure that the vehicle consists of three tethered sections (nose cone, compartment housing both the payload and main parachute and the booster section).

2.8.1. **Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length** Inspection: All coupler and airframe shoulders located at in flight separation points will be one body diameter in length.

2.8.2. **Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length** Inspection all nosecone shoulders located at in-flight separation points will be at least ½ body diameter in length.

2.9. **The launch vehicle will be limited to a single stage.** Inspection: The launch vehicle will be designed as a single stage rocket and will utilize only a single motor.

2.10. **The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.** Demonstration: The maximum preparation time for the rocket is 2 hours. The team will practice the vehicle preparation in order to assure their ability to ready the vehicle for launch within allocated time.

2.11. **The launch vehicle will be capable of remaining in launch-ready configuration at the pad for a minimum of 2 hours without losing the functionality of any critical on-board components.** Test: Battery capacities and standby times of components will be tested extensively during project development.

2.12. **The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.** Demonstration: The vehicle is using Aerotech motor which is compatible with 12V igniters. Electrical current of 3A is sufficient to fire the igniter. A standard 12-volt direct current firing system will be used in all test launches to ensure that they are compatible with the vehicle.

2.13. **The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).** Demonstration: The test launches will be conducted without any external circuitry or special ground support to ensure that all systems can function without them.

2.14. **The launch vehicle will 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).** Inspection: Only motors satisfying this performance target are used in design, testing and operation of the vehicle. Currently, Cesaroni Technology Inc. K2000 75mm motor is the primary propulsion choice.

2.14.1. **Final motor choices must be made by the Critical Design Review (CDR) milestone.** Inspection: The team will ensure that the propulsion choice is finalized by the Critical Design Review (CDR).

2.14.2. **Any motor changes after CDR must be approved by the NASA Range Safety Officer (RSO), and will only be approved if the change is for the sole purpose of increasing the safety margin. A penalty against the team's overall score will be incurred when a motor charge is made after the CDR milestone, regardless of the reason.** Analysis: Openrocket simulations and calculations will prevent such an occurrence. However, we will comply with all instructions provided by NASA should this situation arise.

2.15. **Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria:**

2.15.1. **The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.** Inspection: The vehicle will not utilize pressure vessels.

2.15.2. **Each pressure vessel will include a pressure relief valve that sees the full pressure of the valve that is capable of withstanding the maximum pressure and flow rate of the tank.** Inspection: The vehicle will not utilize pressure vessels.

2.15.3. **Full pedigree of the tank will 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.** Inspection: The vehicle will not utilize pressure vessels.

2.16. **(...) The total impulse provided by a Middle and/or High School launch vehicle will not exceed 2,560 Newton-seconds (K-class).** Inspection: None of the three motor alternatives considered for this project exceeds the 2,560Ns impulse limit. The primary motor choice has total impulse of 2,436 Ns.

2.17. **The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.** Analysis:

Openrocket simulations and calculations will be used to ensure that the static stability margin exceeds 2.0 calibers at rail exit.

2.18. **The launch vehicle will accelerate to a minimum velocity of 52 fps [15.8 m/s] at rail exit.** Analysis: Openrocket simulations and calculations will be used to ensure that the static stability margin exceeds 52 fps at rail exit.

2.19. **All teams will successfully launch and recover a subscale model of their rocket prior to CDR. Subscales are not required to be high power rockets.** Test: The team will construct, launch, and recover a ½ scale model prior to the CDR.

2.19.1. **The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale will not be used as the subscale model.** Test: The subscale model will be constructed as close as possible to the full scale model. Flight data will be used to evaluate performance.

2.19.2. **The subscale model will carry an altimeter capable of reporting the model's apogee altitude.** Inspection: The subscale model will be equipped by the same altimeter brand as the full-scale vehicle (PerfectFlite StratoLogger CF).

2.19.3. **The subscale rocket must be a newly constructed rocket, designed and built specifically for this year's project.** Inspection: The team will design and build the subscale rocket specifically for this years project.

2.19.4. **Proof of a successful flight shall be supplied in the CDR report. Altimeter data output may be used to meet this requirement.** Demonstration: The team will provide altimeter data as proof of a successful flight. This data will be supplied in the CDR report.

2.20. **All teams will complete demonstration flights as outlined below.**

2.20.1. **All teams will 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:**

2.20.1.1. **The vehicle and recovery system will have functioned as designed.** Inspection: The team will visually verify during descent and landing that the vehicle recovery system will be operated in full configuration on all planned test flights.

2.20.1.2. **The full scale rocket must be a newly constructed rocket, designed and built specifically for this year's project.** Inspection: The full scale rocket will be a newly constructed rocket. It will be designed and built specifically for this year's project.

2.20.1.3. **The payload does not have to be flown during the full-scale test flight. The following requirements still apply:** Test: The team intends to fly the payload during the full scale test flight. However if this is not met, the team will do the following:

2.20.1.3.1. **If the payload is not flown, mass simulators will be used to simulate the payload mass.** Before the payload is ready for flight, payload will be simulated by mass simulators during test flights.

2.20.1.3.2. **The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.** Payload mass simulators, if used, will represent the predicted mass of the payload and will be located at the intended location of the payload within the vehicle to maintain the same mass distribution.

2.20.1.4. **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 will be active during the full-scale demonstration flight.** Test: All changes to the external surface of the vehicle will be active during the full-scale demonstration flight and their effects on the flight recorded and analyzed.

2.20.1.5. **Teams shall fly the launch day motor for the Vehicle Demonstration flight. The RSO may approve the use of an alternate motor if the home launch field cannot support the full impulse of the launch day motor or in other extenuating circumstances.** Inspection: The team intends to fly our demonstration flight with the exactly same motor that will be used for our flight at the SLI launch in Huntsville.

2.20.1.6. **The vehicle must 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. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.** Inspection: The vehicle will be fully ballasted (if ballast is necessary) for the final full-scale test flight.

2.20.1.7. **After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).** Inspection: Except for necessary repairs, there will not be any changes made to the launch vehicle after the full-scale demonstration flight. If any repairs are necessary, the NASA Range Safety Officer will be contacted before making any changes to the vehicle.

2.20.1.8. **Proof of a successful flight shall be supplied in the FRR report. Altimeter data output is required to meet this requirement** Demonstration: The team will provide altimeter data as proof of a successful flight. This data will be supplied in the CDR report.

2.20.1.9. **Full-scale flights must be completed by the FRR submission deadline. If the Student Launch office determines that a re-flight is necessary, then an extension will be granted. This extension is only valid for re-flights, not first-time flights. Teams completing a required re-flight must submit an FRR addendum by the FRR Addendum deadline.** Test: Full scale flights will be completed by the FRR deadline. In the event that a reflight is deemed necessary an FRR addendum will be submitted by the FRR Addendum deadline.

2.20.2. **All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown must be the same rocket to be flown on launch day. The purpose of the payload demonstration flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent, the payload is fully retained during ascent and descent, and the payload is safely deployed on the ground.**

2.20.2.1. **The payload must be fully retained throughout the entirety of the flight, all retention mechanisms must function as designed, and the retention mechanism must not sustain damage requiring repair.** Inspection: The payload will be fully retained throughout the entirety of the flight. All retention mechanisms will be visually examined to see if they have sustained any damage requiring repair.

2.20.2.2. **The payload flown must be the final, active version.** Demonstration: The team will ensure that the payload flown will be the final, active version and meets all set requirements and criteria.

2.20.2.3. **If the above criteria is met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required.** Inspection: The team has been informed of this requirement.

2.20.2.4. **Payload Demonstration Flights must be completed by the FRR Addendum deadline. No extensions will be granted.** Inspection: The team has been informed of this requirement. All effort will be made to ensure that this does not happen.

2.21. **An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA-required Vehicle Demonstration Re-flight after the submission of the FRR Report.**

2.21.1. **Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline will not be permitted to fly the vehicle at launch week.** Inspection: The team has been informed of this requirement. All effort will be made to ensure that this does not happen.

2.21.2. **Teams who successfully complete a Vehicle Demonstration Flight but fail to qualify the payload by satisfactorily**

completing the Payload Demonstration Flight requirement will not be permitted to fly the payload at launch week. Inspection: The team has been informed of this requirement. All effort will be made to ensure that this does not happen..

2.21.3. **Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload at launch week. Permission will not be granted if the RSO or the Review Panel have any safety concerns.** Inspection: The team has been informed of this requirement. All effort will be made to ensure that this does not happen.

2.22. **Any structural protuberance on the rocket will be located aft of the burnout center of gravity.** Analysis: Openrocket simulations and calculations will guide us on where to put the air intakes for our payload and will help ensure that they are located aft of the burnout center of gravity.

2.23. **The team's name and launch day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.** Inspection: Stickers will be printed to attach to the vehicle in a visible location that includes the team name and contact information. The launch checklist will check that such sticker is on the vehicle.

2.24. **Vehicle Prohibitions:**

2.24.1. **The launch vehicle will not utilize forward canards.** Inspection: The vehicle does not have forward canards.

2.24.2. **The launch vehicle will not utilize forward firing motors.** Inspection: The vehicle does not utilize forward firing motors.

2.24.3. **The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)** Inspection: The primary motor choice: CTI K2000, does not expel titanium sponges.

2.24.4. **The launch vehicle will not utilize hybrid motors.** Inspection: Hybrid motors are not used.

2.24.5. **The launch vehicle will not utilize a cluster of motors.** Inspection: Clustered motors are not used.

2.24.6. **The launch vehicle will not utilize friction fitting for motors.** Inspection: A flange mounted, thread secured motor retention system will be used for the vehicle.

2.24.7. **The launch vehicle will not exceed Mach 1 at any point during flight.** Analysis: Both Openrocket and calculations predict that the vehicle remains subsonic during entire flight. The maximum predicted velocity is 0.5 mach.

2.24.8. **Vehicle ballast will not exceed 10% of the total weight of the rocket.** Inspection: The ballast (if used) will not exceed 10% of the vehicle weight.

2.24.9. **Transmissions from onboard transmitters will not exceed 250 mW of power.** Demonstration: All onboard transmitters will be set to broadcast and their power measured to ensure they remain under 250 mW of power. The Xbee S1 Pro is documented by digikey to have a max power output of 250 mW at its highest setting.

2.24.10. **Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of light-weight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.** Inspection: Neither excessive nor dense metal is part of the design of the vehicle. Construction materials will be inspected to ensure that they do not contain dense or excessive metal.

3. Recovery System Requirements

3.1. **The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude. Tumble 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 RSO.** Analysis: Dual deployment recovery method is used for the vehicle (drogue parachute deploys at apogee and main parachute 700 ft (or other predetermined altitude). The vehicle has two fully independent and redundant deployment circuits. The backup charges are 25% larger than primary charges to increase the chance of deployment in the event of primary charge failure.

3.1.1. **The main parachute shall be deployed no lower than 500 feet [152 meters].** Demonstration: The altimeters and the deployment system will be set and the settings verified on the ground via a pressure chamber to ensure that the main parachute at 700 ft and will not be deployed below 500 ft.

3.1.2. **The apogee event may contain a delay of no more than 2 seconds.** Demonstration: The altimeters and the deployment system will be set and the settings verified on the ground via a pressure chamber to ensure that the apogee event does not contain a delay of more than 2 seconds.

3.2. **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.** Test: Static ground ejection tests will be conducted before the launch of both the subscale model and the full scale vehicle.

3.3. **At landing, each independent sections of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf [101 joules].** Analysis: Openrocket simulations and calculations have allowed the selection of parachute sizes so that no section of the rocket lands with kinetic energy greater than 75 ft-lbf.

3.4. **The recovery system electrical circuits will be completely independent of any payload electrical circuits.** Test: All recovery system components will be tested on the ground both with and without the payload electronics to ensure that there is no dependance or interference between the two systems.

3.5. **All recovery electronics will be powered by commercially available batteries.** Inspection: All recovery electronics will be powered by 9V Duracell batteries. Batteries will be installed fresh and only used for one flight. Proper procedure to ensure this will be followed will be included in the checklist.

3.6. **The recovery system will contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more sophisticated flight computers.** Inspection: The recovery system design calls for two commercially available Stratologger CF altimeters. Each altimeter will independently control its own ejection charges. Backup charges are 25% larger than the primary charges to ensure redundancy.

3.7. **Motor ejection is not a permissible form of primary or secondary deployment.** Inspection: The team will ensure that the motor ejection charge is removed from the rocket prior to launch and that all deployment is done with barometric altimeters. Proper procedure to ensure this will be followed will be included in the checklist.

3.8. **Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.** Inspection: Removable shear pins will be used at all separation points. Proper procedure to ensure this will be followed will be included in the checklist. Test: The shear pins will be tested during static ejection tests to assure that they will hold but not interfere with the separation of the corresponding compartment.

3.9. **Recovery area will be limited to a 2500 ft. [762 m] radius from the launch pads.** Analysis: Openrocket simulations and calculations on the rocket will be used to ensure that the rocket will remain within the confines of the launch area even under 20mph wind speed conditions.

3.10. **Descent time will be limited to 90 seconds (apogee to touchdown).** Analysis: Openrocket simulations and calculation on the rocket will ensure that the descent time will be less than or equal to 90 seconds from apogee to touchdown.

3.11. **An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.** Demonstration: A Trackimo GPS tracking device will be used for the vehicle. Each trackimo will be booted up and its location will be verified by the phone app before insertion into the vehicle.

3.11.1. **Any rocket section, or payload component, which lands untethered to the launch vehicle, will also carry an active electronic tracking device.** Inspection: No vehicle section or payload component will land untethered.

3.11.2. **The electronic tracking device will be fully functional during the official flight on launch day.** Inspection: The team will ensure that the tracking device will be fully functional during the official flight on launch day. Proper procedure to ensure this will be followed will be included in the checklist.

3.12. **The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).** Test: All recovery system components will be tested on the ground both to ensure that there is no interference between systems.

3.12.1. **The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.** Inspection: The team will ensure that the recovery system altimeters are housed in a dedicated avionics bay, separate from all other electronics.

3.12.2. **The recovery system electronics will be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.** Test: All electronics will be ground tested for possible interference. Shielding will be used as necessary based on these tests.

3.12.3. **The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.** Inspection: There are no magnetic wave generators onboard.

3.12.4. **The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.** Test: All electronics will be ground tested for possible interference. Shielding will be used as necessary based on these tests.

4. Payload Experiment Requirements

4.1. **High School/Middle School Division – Teams may design their own science or engineering experiment or may choose to complete one of the College/University Division experiment options.**

4.2. **Section Not Applicable**

4.3. **Section Not Applicable**

4.4. **Section Not Applicable**

4.5. **Team-Designed Payload Requirements (High School/Middle School Division)**

4.5.1. **Team-designed payloads must 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.** Inspection: The team has been informed of this requirement. We will follow any modifications or changes that are put forth by NASA.

4.5.2. **Data from the science or engineering experiment will be collected, analyzed, and reported by the team following the scientific method.** Inspection: Close collaboration with the Atmospheric Oceanic Space Sciences department will ensure that the scientific method will be followed and adequate data will be collected. Post Launch Assessment Report will be sent to NASA after our final launch in Huntsville. The hypothesis and analytical methods are described earlier in this document.

4.5.3. **The experiment must 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.** Demonstration: The reusability and recoverability of the payload will be demonstrated by the team during test launches.

4.5.4. **Any experiment element that is jettisoned during the recovery phase will receive real-time RSO permission prior to initiating the jettison event.** Inspection: No elements are planned to be ejected during the recovery phase. However, if such a situation arises, the team will receive real-time RSO permission.

4.5.5. **Unmanned aerial vehicle (UAV) payloads, if designed to be deployed during descent, will be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAV.** Inspection: No UAVs will be used.

4.5.6. **Teams flying UAVs will abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112-95 Section 336; see https://www.faa.gov/uas/faqs).** Inspection: No UAVs will be used.

4.5.7. **Any UAV weighing more than .55 lbs. will be registered with the FAA and the registration number marked on the vehicle.** Inspection: No UAVs will be used.

5. Safety Requirements

5.1. **Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any launch day operations.** Demonstration: Launch and safety checklists will be used to prepare each launch. The efficacy of the checklists will be analyzed and improvements will be made during each test launch. All checklists will be included in our Flight Readiness Review.

5.2. **Each team must identify a student safety officer who will be responsible for all items in section 5.3.** Inspection: Matilda is designated as the team's safety officer. Maya is the deputy safety officer.

5.3. **The role and responsibilities of each safety officer will include, but not limited to:** Inspection: The team leader, mentor, and other members of the team will ensure that the safety officer is present for duty at all events and will aid and abide by the rules set forth by her. Special care will be taken so that the safety officer meets the following requirements:

5.3.1. **Monitor team activities with an emphasis on Safety during:**

5.3.1.1. **Design of vehicle and payload.** The safety officer will insure that the design of the vehicle and payload are safe.

5.3.1.2. **Construction of vehicle and payload.** The safety officer will insure that the construction of the vehicle and payload are sound.

5.3.1.3. **Assembly of vehicle and payload.** The safety officer will supervise assembly and insure that the vehicle and payload are assembled correctly.

5.3.1.4. **Ground testing of vehicle and payload.** The safety officer will attend ground testing and insure it is within safe standards.

5.3.1.5. **Sub-scale launch test(s).** The safety officer will be present at subscale launch tests and insure that they will be carried out safely.

5.3.1.6. **Full-scale launch test(s).** The safety officer will be present at full-scale launch tests and insure that they will be carried out safely.

5.3.1.7. **Launch Day.** The safety officer will be present on launch tests and insure that all safety precautions are kept.

5.3.1.8. **Recovery Activities.** The safety officer will insure that the team remains safe during recovery activities and that all local laws are kept.

5.3.1.9. **Educational Engagement Activities.** The safety officer will insure that educational engagement activities remain safe.

5.3.2. **Implement procedures developed by the team for construction, assembly, launch, and recovery activities.** The safety officer will contribute to, check, and approve procedures and implement them for all activities.

5.3.3. **Manage and maintain current revisions of the team's hazard analyses, failure modes analysis, procedures, and MSDS/chemical inventory data.** The safety officer will take an active leading role in managing the documents outlined above.

5.3.4. **Assist in the writing and development of the team's hazard analyses, failure modes analysis, and procedures.** The safety officer will contribute to, check, and approve the documents outlined above.

5.4. **During test flights, teams will 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.** Inspection: The team will ensure that its intentions are communicated to the host organization prior each launch. The team will abide by the launch rules set by the host organization. Procedures to ensure the proper following of this requirement will be included in the checklist.

5.5. **Teams will abide by all rules set forth by the FAA.** Inspection: All FAA rules will be strictly followed by all team members. See team derived requirements for more details.

Appendix B - Fin Flutter Explanation

The following is an explanation on how the safety margin of fin flutter was calculated based on the simulated altitude and velocity of our vehicle. Calculation are based on the improved fin flutter equation shown below with V_f being the velocity of flutter boundary:

$$V_f = 1.223\, C_s\, e^{0.4 \frac{h}{H}} \sqrt{\frac{G}{p_0}} \sqrt{\frac{2+B}{1+\lambda}} \sqrt{(\frac{T}{B})^3}$$

With constants:

The speed of sound at sea level:	$C_s = 335\ m/s$
Atmospheric pressure at sea level:	$p_0 = 101352\text{Pa}$
Boundary of the troposphere:	$H = 8077\ m$
Shear Modulus of G10 fiberglass:	$G = 5520000000\text{Pa}$

With derived values:

Taper Ratio	$\lambda = \frac{C_t}{C_r}$	$\lambda = 0$
Aspect Ratio	$B = \frac{b^2}{S}$	$B = 0.375$
Normalized Thickness	$T = \frac{t}{C_r}$	$T = 0.00694$

With the fin geometry values:

Root Chord	$C_r = 9\ in$
Tip Chord	$C_t = 7\ in$
Semi Span	$b = 3\ in$
Thickness	$t = 0.0625\ in$
Area	$S = 24\ in$

Figure 11: The Fin Flutter Equation

The tables above outline the values used for the fin flutter equation. The graph was produced with data obtained from Openrocket with altitude (with variable h in the fin flutter calculations) being used as the independent variable and percentage of flutter boundary being calculated by the following equation.

$$Percentage\ of\ Flutter\ Boundary = \frac{V_s}{V_f} \times 100\%$$

Where:

V_f	Flutter boundary velocity as calculated by the fin flutter equation
V_s	Velocity of rocket as simulated by Openrocket

Figure 12: The percentage of flutter boundary equation

Anything above 80% of flutter boundary is considered dangerous.

List of Applicable Outside Resources

Electrical Data Sheets / User Manuals

PerfectFlite Stratologger CF
PerfectFlite Stratologger SL100
Trackimo 3G GPS Universal Tracker
C&K Keylock Switches

Coding Resources

Arduino Language Reference
Python Coding Standards
Python Coding Library
Python Beginner Resources
Typography Standards
Visual Studio Code Manual

West Rocketry Resources

Club Website
Facebook
Instagram
Github

Safety Laws

FAR CFR 14 Chapter F Part 101 Subpart C
CFR 27 Part 55: Explosives In Commerce
NFPA 1127 (2002)

Other Info

Fin Flutter Calculations

Appendix C - List of Applicable Safety Data Sheets

Propulsion and Deployment

Ammonium Perchlorate
Aerotech Reloadable Motors
Aerotech Igniters
M-Tek E-matches
Pyrodex Pellets
Black Powder
Nomex (thermal protector)

Glues

Elmer's White Glue
Two Ton Epoxy Resin
Two Ton Epoxy Hardener
Bob Smith Cyanoacrylate Glue
Super-glue Accelerator
Super-glue Debonder

Soldering

Flux
Solder
Solder Braid

Painting and Finish

Automotive Primer
Automotive Spray Paint
Clear Coat

Construction Supplies

Carbon Fiber
Kevlar
Fiberglass Cloth
Fiberglass Resin
Fiberglass Hardener
Self-expanding Foam

Solvents

Ethyl Alcohol 70%
Distilled Water
Bacto-Peptone
Liquinox
Isopropyl alcohol
Hydrochloric acid
Sodium hydroxide

Payload Materials

Aluminum
Acrylic
Polycarbonate

Payload Chemicals

Copper Sulfate
Glucose
Sucrose
Potassium Phosphate
Agar
Sodium Chloride
Sorensen's Phosphate
Calcium Chloride