Noctua Technical Report

Team Rice Eclipse Noctua Technical Report for the 2018 SAC

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Rice Eclipse is a four year old undergraduate rocketry club at Rice University. Due to the organizations young age, 2018 is the first year it has competed in the Spaceport America Cup. For the team's first year in the competition, the project goals were fairly conservative, seeking primarily to reach the target altitude and learn more about higher altitude rockets. As of May 2018, the highest altitude ever achieved by Rice Eclipse is just over 3,700 feet, so the attempt for 10,000 feet in June will be a monumental step for the club. Along with reaching the target altitude, a primary goal for the year has been to create custom carbon fiber body tubes that can be reused on multiple rockets. In most cases, when a rocket is assembled the fins, motor mount, and other components are permanently affixed to the lower body tube of the vehicle. This renders the entire assembly unusable if the fin size or motor size were to change, forcing a team to roll another body tube from scratch. This can cost hundreds of dollars and take hours of work for roll, epoxy, sand, and polish all over again. For Eclipse's first carbon fiber flight vehicle, a primary goal has been to reuse the body tube on future rockets and develop completely removable motor mounts and fins.

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Section I: Design Summary

1.1 Purpose and Goal

Noctua is an in-house high powered rocket designed by Rice Eclipse to participate in Spaceport America Cup 2018. Noctua will enter competition under the 10’000-ft AGL Apogee COTS solid rocket propulsion system category. Eclipse has participated in SEDS competition with a two-stage design in the past, where staging designs were explored. Moving forward, we are hoping to gain more experience in designing heavier and larger scale rockets. Noctua will test our ability to manufacture such rockets, create our own carbon fiber body tubes, and gain experience in performing better flight predictions. Since Noctua is our first rocket to enter the 10,000-ft range, we have taken a simplistic approach in most designs to ensure success. The project details are outlined below.

1.2 Overall design

Noctua is powered by a single solid COTS motor of category L. Standard two body tube configuration is adopted, each with an OD of 4” for easy avionics and motor installation. 4-fin design at the end of lower body tube is chosen to maintain high stability. A standard Ogive-shaped nose-cone is used for aerodynamics consideration.

Material-wise, body tubes are constructed completely with layered carbon-fiber, while the fins are made with carbon-fiber reinforced fiberglass. Lastly, a fiberglass nose cone tops off the rocket.
The length of the rocket and size of fins are optimized so that rocket is expected to hit 10,000 ft in simulation. However, as team progressed throughout the year, many changes were made to the design. While rocket’s stability and safety remains a high priority, rocket’s efficiency was traded to ensure successful recovery. The targeted apogee for Noctua has dropped from the original 10,000 ft to 9,200 ft but with increased factor of safety in design.

Design Considerations:

1. Stability- all design criteria are adjusted to ensure stability of the rocket first
2. Reusability- a separable motor mount design was implemented in order to have to ability to reuse the lower body tube and experiment with various fin shapes and motor sizes in the future
3. Efficiency- careful construction and fine sanding is done to reduce aerodynamic drag

Table 1: Key Specifications of Noctua

Motor Impulse/ Burn-time/ Average Thrust	4214 Ns | 3.49 s | 1207 N
Rocket Length/ Weight	83.75 in | 33.6 lb
Max Velocity/ Acceleration	845 ft/s | 302 ft/s^2
Expected Apogee	9258 ft

Figure 1: Overview of Noctua

Section II: Design Criteria

2.1 Airframe

2.1.1 Airframe

The lower body tube will be constructed from a 44” custom carbon fiber tube. This length minimizes the amount of additional weight needed to keep stability under 2 caliber while still allowing for the payload in the coupler and a 36” motor-ejected drogue chute. The upper body tube will be 24” long and will contain the main parachute and the remainder of the payload.

The team considered using a boat tail on the end of the rocket, but determined that the extreme difficulty of manufacture greatly outweighed the nominal benefit it would have provided.

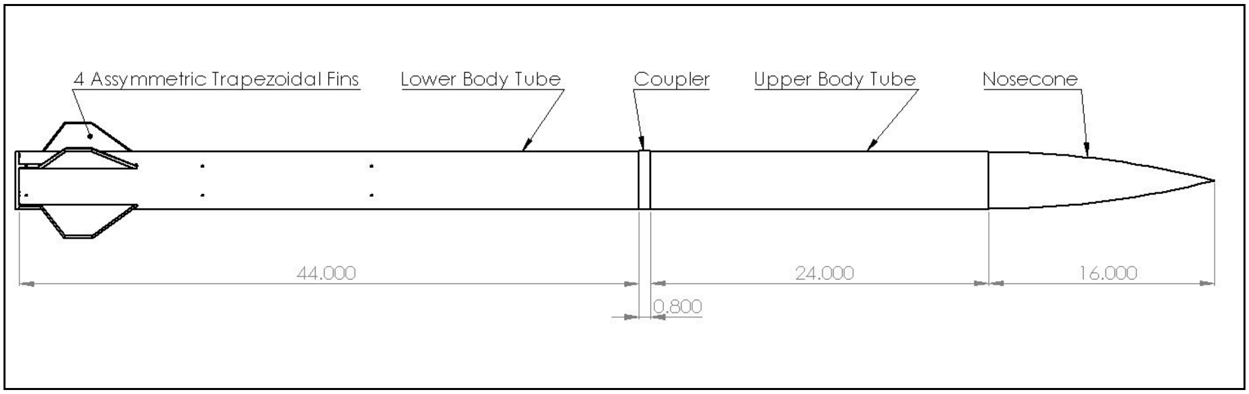

Figure 2:. Overall Airframe Drawing

2.1.1.1 Airframe Stability

The numbers given in table below are up-to-date, and resulting CG/ CP locations are measured and are comparable to simulation in section 2.6.

Table 2: Mass Sheet for CP/CG Calculation

Component	Mass /lb	CG /in
Nose Cone without boiler plate weights	2.31	16 from tip of nose cone
Upper Body Tube	0.88	center
Main Parachute Assembly (shock cord, quick links, parachute protector, main parachute)	1.51	center
Drogue Parachute Assembly	0.676	center
Coupler Assembly (without	3.44	center

boiler plate weights)		
Lower Tube Assembly (with motor tube and fins)	4.976	17 from bottom of body tube
Nose Cone Weight	2.2	17 from tip of nose cone
Middle Coupler Weight	6.6	3 from top side of coupler

2.1.2 Nose Cone

After running simulations in Openrocket, the team decided to use an Ogive nose cone profile due to its superior drag characteristics at both subsonic and transonic speeds and its availability from commercial sellers(see Table 1 of Appendix ii for decision matrix). A fiberglass nose cone is selected as it provides necessary stiffness without hindering radio transmissions for the avionics that will be held in the nose cone (see Figure 1 of Appendix viii for engineering drawing).

2.1.3 Fin Design

The team decided to use an asymmetrical trapezoidal fin shape because of its optimal apogee and stability, especially in comparison to the symmetrical trapezoidal design. Back slanted fins were ruled out due to the structural integrity risk of breaking upon landing. Rounded fins yielded the highest apogee, however the difficulty in creating perfect rounded fins caused the team to decide against this option.

The specifics of the fin shape were decided through copious simulation testing. After creating many different designs and systematically manipulating variables, the asymmetrical trapezoid was shown to be the optimum design. The dimensions of the fin are as follows(see Figure 2 of Appendix viii for drawing):

Root Chord: 7”
Tip Chord: 2”
Thickness: 0.3”
Height: 2.6”
Sweep Angle: 55º

2.1.3.1 Number of Fins

The team decided to have four fins via the parameters of ease of construction and aerodynamics. Increasing the number of fins led to a higher drag coefficient and higher stability. This resulted in a trade off of stability for maximum height. Furthermore, increasing the number of fins past five increased the stability to over 2 cal. This was not ideal, as it could make the rocket overstable and prone to weather cocking. Hence, to maintain simplicity for construction, and avoid overstability, four fins were chosen (see Table 3 of Appendix ii for decision matrix).

2.1.3.2 Fin Material

The fins were constructed from a base of ¼” G10 Fiberglass with two layers of carbon fiber on each side. The fiberglass-carbon fiber combination creates a lightweight, strong structure of fins that has a similar appearance to the rest of the body tube. Having a fiberglass core also means the fins have a different resonant frequency than the body tube and resists against flutter. Once two layers of carbon fiber were added to the fiberglass core, the overall fin thickness increased to 0.3”.

2.1.3.3 Airfoil Design

A symmetric airfoil with sharp leading and trailing edges, or double-diamond airfoil, was picked for our rocket fins. The airfoil must be symmetric as asymmetry would induce spin and hence reduce apogee. As the rocket only reached transonic speeds at its max velocity, a rounded leading edge provided the best drag coefficient values. However, a sharp leading edge provided slightly worse drag coefficient values but greatly increased the ease of manufacturing. The sharp trailing edge created high pressure behind the fin that helped cancel out the drag created by the leading edge.

Other possible airfoil designs were not chosen due to the difficulty of manufacturing using the selected materials. An airfoil with a round leading edge would be the optimal design for our max velocity, however it was decided against during the fabrication process

2.1.3.4 Fin Flutter

In order to ensure the stability of our fin design, the team decided to calculate the fin flutter velocity (V_f) with MatLab. The fin flutter velocity is the maximum velocity the fin can travel without fluttering. V_f is calculated at the altitude at which we reach maximum velocity in order to ensure fin stability. Fin flutter needs to be avoided because flutter will cause the fins to fail structurally. The value calculated from the fin flutter equation is the over 8000 ft/s (see Appendix i for calculation). This value for velocity is over eight times greater than our actual theoretical maximum velocity. Therefore, our fin design should be structurally sound for our rocket launch.

2.1.4 Nose-cone Avionics

Although carbon fiber is a great composite material for the construction of body tubes, it is not a good material for facilitating data transmission due to its ability to block radio frequencies. Therefore any GPS unit placed within the body tubes would be unable to send and receive radio signals. To accommodate for this, an additional avionics bay was created within the nose cone. The fiberglass of the nose cone does not interfere with the radio signals of the GPS unit.

The main concern throughout the design process was twofold: how to securely attach the bay to the nose cone itself, and how to ensure it remains stable throughout flight. Twelve rings were lazer cut out of wood with 4 through-holes spaced 90 degrees apart from each other. They were then epoxied together with all the through-holes lined up to form one long tube with 4 radially symmetrical through-holes going down the length of the tube wall. A tube was created to maximize the surface area that is in contact with the inside of the nose cone so it could be secured with epoxy.

Threaded rods with a nut on one end were then placed into each through-hole of the tube and used to bolt on a fiberglass bulkhead to the bottom of the nose cone. The bulkhead creates an airtight compartment for the avionics stored inside the nose cone and decreases the total volume that is required to be displaced by the ejection charges during recovery. Two threaded rods are bolted to this nose cone bulkhead. The threaded rods run up into the nose cone itself and create a mounting surface for the avionics bay and scientific payload.

To keep the avionics bay stable during flight, above the avionics bay a disc of fiberglass is mounted. The disc is slightly smaller than the nose cone at the point at which it is mounted. Bolted to this disc is a piece of 1.5” thick foam that is slightly larger than the diameter of the nose cone so that when the avionics bay is fully inserted, the foam is compressed against the nose cone. This serves to secure the bay in the center of the nose and also dampens some of the vibrations to minimize their effects on the avionics and the scientific payload.

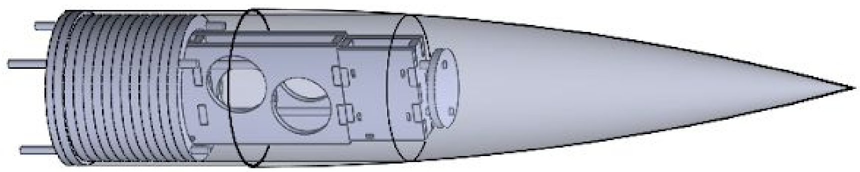

Figure 3: Assembled Nose Cone Avionics Bay

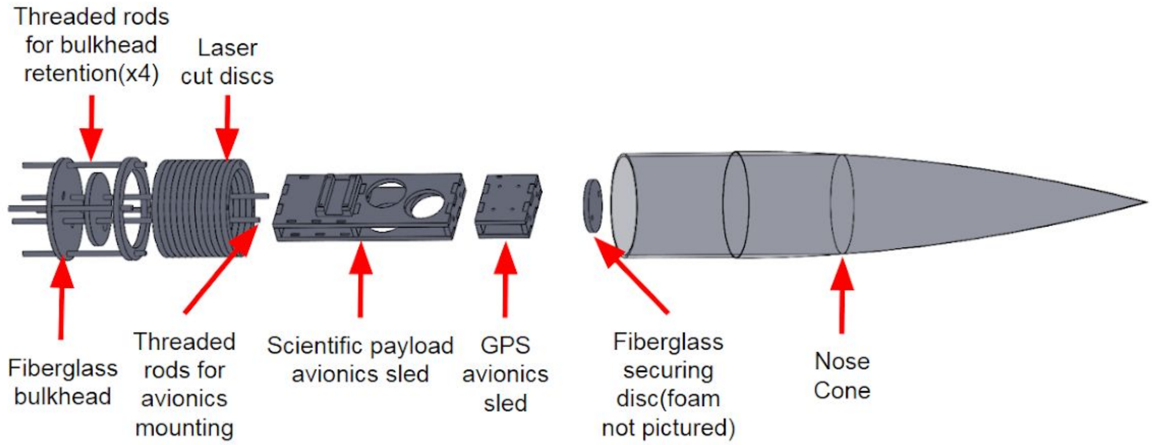

Figure 4: Exploded View of Nose Cone Avionics Bay

2.2 Composites

2.2.1 Composite technique and prototypes

2.2.2.1 Fiberglass Prototype

A fiberglass tube of 3 layers was built in order to practice Jim Jarvis technique. The composite was made up of the fiberglass and epoxy on a 24” mandrel with mylar and tape protecting the inside. Peel ply was used on the outside to remove excess epoxy from the tube and create an even finish. The epoxy was cured for 24 hours and the tube, which was 0.22 inches thick, was pulled off the mandrel. 6 additional layers of epoxy were added and mostly sanded down. Lastly the tube was polished for a shiny finish.

2.2.2.2 Carbon Fiber Prototype

A 50” tube was fabricated using a similar technique as the fiberglass prototype. 6 layers of 2x2 twill carbon fiber were wrapped, but this time the epoxy was mixed with milled glass before application. After drying, the tube was sanded and more epoxy was applied until it was ready to be polished. The polished tube was cut into two segments, a 33” lower body tube and a 17” upper body tube. Fin slots were cut into the tube for fin mounting.

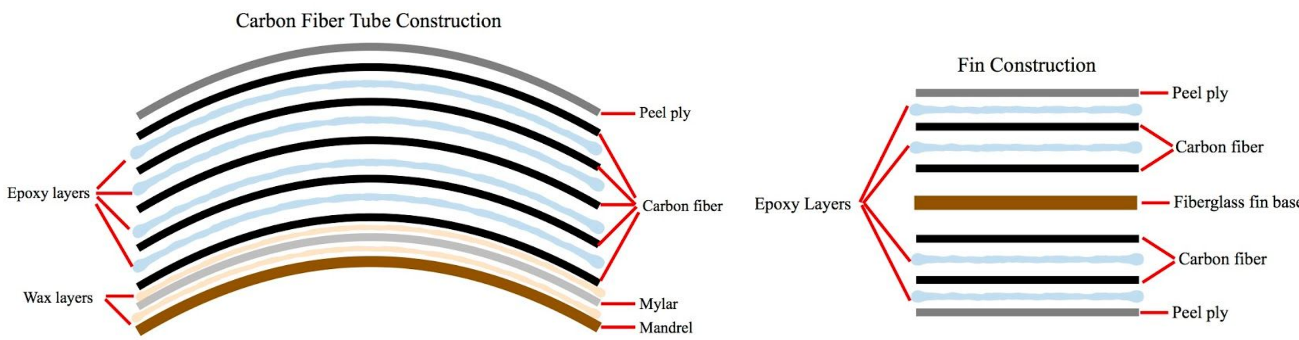

Figure 5: Tube and fin composition with layers shown

2.2.3 Weight calculation

Using OpenRocket Simulator ©, the weight was estimated using the value for density of a carbon fiber-epoxy composite as 1.60[1] grams/cubic centimeter. For a 40" lower body tube and a 24" upper body tube, plus estimating the nose cone as being fiberglass and the fins as carbon fiber composite, the calculated mass of these components was 38.6 ounces, or 1094 grams. The estimated weight of just the 40" tube was 20.2 ounces (573 grams), not far off from Jim Jarvis's actual weight of his tube of the same length was 529 grams.

2.2.4 Construction of final rocket body

For the rocket intended to launch at the 2018 Spaceport America® Cup, two 50" carbon fiber body tubes were built using the same procedure as the carbon fiber prototype, with the only difference that 5 layers of 2x2 twill carbon fiber were used instead of 6 for these two tubes. The construction was done in series. The same epoxy-milled glass mixture was applied to each tube and the same sanding and additional layers of epoxy and then polish were applied. One tube was cut down to 44" for the lower body tube, and the other was cut to 24" to be the upper body tube. The excess sections of the tubes will be used for strength and compression tests.

The fins were made of a G10 fiberglass core with 2 layers of carbon fiber on each side. The 2x2 twill carbon fiber was the same as used for the body tube, and the procedure of laying the fiber onto the fins layer by layer while adding epoxy was the same. Peel ply was also used to create the finish, and clamps were used to apply pressure while drying. After the epoxy was cured, a dremel was used to sand the fins into shape and sandpaper was used to create a smooth bevel on the edges.

2.3 Recovery

2.3.1 Recovery technique

The recovery system is composed of a dual deployment separation method with two altimeters and a GPS system in the nose cone of Noctua. The system deploys the drogue parachute at apogee and the main parachute at 700 ft. Two black powder charges are used to separate the rockets and deploy the parachutes. Further details of this system are listed below.

2.3.1.1 Separation mechanism and parachute release

Once target apogee (10,000 ft) is achieved, the altimeter will initialize the ejection charge via pyrotechnic gas generation. After a short delay while the charge diffuses, the built-up pressure in the body tube will separate the rocket into two sections by ejecting the coupler from the lower body tube and releasing the drogue. Once the drogue parachute is deployed, the altimeter will initialize a second ejection charge for a given altitude after apogee; after the second charge goes off, the built-up gas in the chamber will deploy the main parachute which will significantly decelerate the rocket and carry it towards the ground for the remaining duration of the flight.

A variety of separation methods were researched and the results are summarized in the following tables. Ultimately, we chose black powder as our separation method because it is the most reliable method (see Table 4,5 of Appendix ii for decision matrices).

2.3.2 Parachutes and Shock Cords

2.3.2.1 Parachute sizing

When calculating the parachute size, we chose to exceed the minimum sizing calculations to make sure our rocket does not hit the ground with a greater speed than 9.14 m/s, which is in accordance with the 2017 Tripoli RSO safety guidelines. Our drogue chute diameter size is 36in and our main chute diameter size is 96in (see Appendix i for calculation) (see Table 6,7 for decision matrices).

2.3.2.2 Shock Cords

The shock cords should be roughly three the length of body tube section: 6 feet for the drogue parachute and 16 feet for the main parachute. Two types of shock cords were used on Noctua, both capable of withstanding 1500 lbf maximum tension loads[2][3]. Calculations for safety factor were made with the assumption that all loads from main deployment will be exerted onto one shock cord. This is the maximum load shock cords will experience and the factor of safety is over 4 (see Appendix i for calculation).

2.3.2.3 Parachute Protector

We decided to use a parachute protector to protect the parachute from black power charge damage because we have experience with using them and they maintain their durability well. The device will protect the parachutes from the black powder blast by preventing severing of reefing lines and burning holes in the parachute. We will use a 12in x 12in parachute protector for the drogue and an 18in diameter parachute protector for the main parachute.

2.3.3 Avionics Setup

We decided to use a GPS to easily find our rocket after launch. The GPS we decided on was the TeleGPS because of its incredible range and high reliability. It is also one of the lightest and smallest GPS systems on the market making it the optimum choice (see Table 8,9 of Appendix ii for decision matrices).

The recovery avionics bay is composed of a rectangular, plywood, single-panel avionics sled housed in an 12-inch long, 3.8” diameter fiberglass coupler, contained by two ¼” fiberglass bulkheads. The bulkheads are held together by 4 ⅜” forged steel eye nuts along 2 ⅜” threaded rod which also function as the mounting surface for the avions sled. The eye nuts also attach the sustainer’s main and drogue parachute shock cords to the airframe. The sled is 4.5” long and 3.25” wide, and houses the following components:

- Two 9-volt batteries, mounted to the sled by battery clips and strapped down with zip ties
- Missileworks RRC3 Dual-Deploy Altimeter screwed into the board (primary altimeter)
- PerfectFlite StratoLogger screwed into the board (secondary / competition altimeter)

(see Figure 3 of Appendix viii for avionics schematics)

2.3.4 Vent Holes

Vent ports are necessary along the avionics coupler and the corresponding airframe section because the primary altimeters will need to read changes in air pressure to provide altitude readings during flight. The holes were sized according to the primary RRC3 altimeter, which requires larger holes than the Perfectflite altimeter. Three ⅛ inch vent holes were drilled 120 degrees apart through the wall of the coupler housing the avionics bay (see Appendix i for calculation).

2.3.5 Black Powder Setup

The separation mechanism will consist of four black powder charges. Two will be used for main parachute deployment and two will be used for drogue parachute deployment. We are utilizing two black powder charges to provide redundant systems in the event of an anomaly. The capsules can hold up to 2 grams of black powder each and we are using E-matches as the igniters shown in the image below:

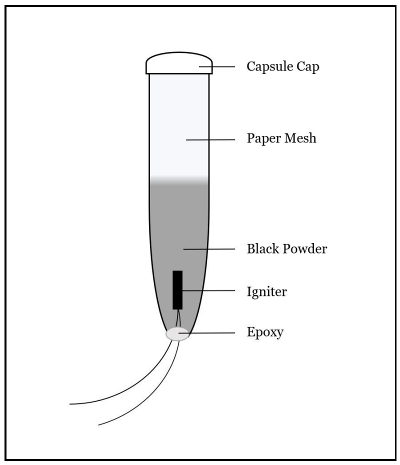

Figure 6: BP Capsule Diagram

We have two methods of calculating the amount of black powder needed for separation charges. First, we calculated the amount of black powder needed to separate the rocket based on accepted formulas. Second, we calculated the amount of black powder needed by multiple tests on the ground and in flight. After the completion of these tests, we concluded that we need at least 1.5 grams of black powder for each separation charge. We will be using 2 grams of black powder for each charge to account for uncertainty (see Recovery Calculations section of Appendix i for calculation).

We will be using two black powder capsules for each ejection charge with a total of four black powder charges for added redundancy. The extra black powder charge will be used as a safety net to reduce the likelihood of recovery system failure such as severed power connections or damage to the altimeters during flight.

2.4 Internal Structures

2.4.1 Motor Mount Design

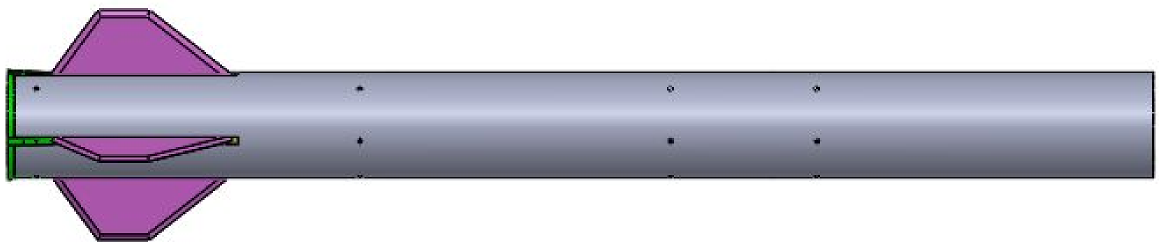

Figure 7: Lower Body Tube Assembly

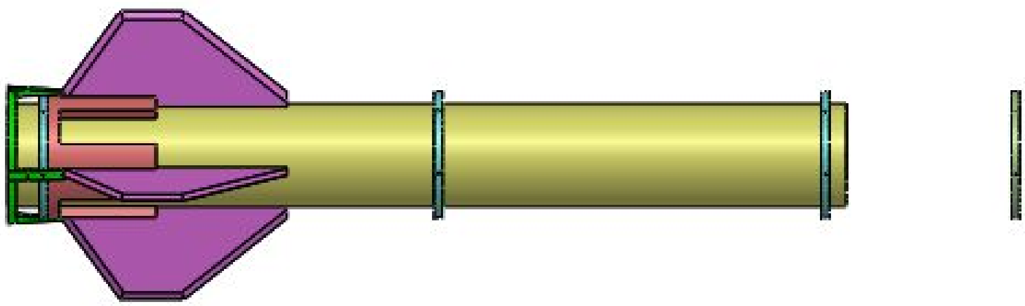

Figure 8: Lower Body Tube Assembly: Hidden Body Tube

The motor mount is designed to keep the L motor centered inside the rocket and structurally connect the motor to the rocket. The motor mount is composed of a cardboard motor tube which holds the L motor, three fiberglass centering rings spaced equally throughout the length of the motor tube, and a slotted fin-attachment ring. The three fiberglass centering rings act as the mechanism to center the motor within the rocket, while securing the motor mount with the carbon fiber body tube. Each centering ring contains six tapped holes equally spaced around the ring, normal to the motor tube. Each centering ring contains six #2-56 tapped holes in the radial direction, with each set of six holes spaced equally throughout the ring. On the carbon fiber body tube are corresponding holes in which #2-56 flat head screws secure the body tube with the motor mount, with the exception of three rail guide buttons, which are inserted into modified tapped holes (detailed in section 2.4.3).

The bottom centering ring contains two tapped #6 holes parallel with the length of the motor tube in between two pairs of #2-56 holes. The 3-D printed cap attaches to the motor mount through these holes. Directly above the bottom centering ring is the slotted fin-attachment ring, which lies flush against the bottom centering ring. The 3-D printed cap and slotted fin-attachment ring act as the key components to creating a detachable fin-attachment mechanism (detailed in section 2.4.4). The centering rings and slotted fin-attachment rings are epoxied onto the motor tube, normal against the tube.

2.4.2 Fiberglass Bulkhead

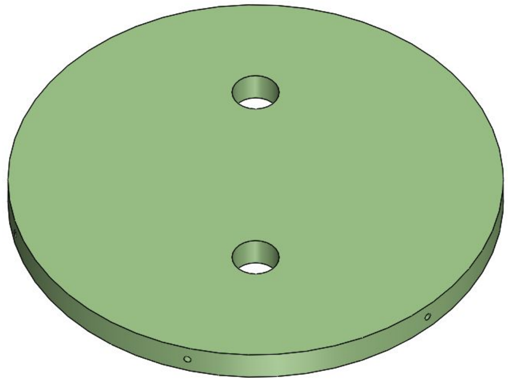

Figure 9: Fiberglass Bulkhead

Located above the motor mount assembly in the lower body tube is a fiberglass bulkhead. The fiberglass bulkhead acts as the connecting structure between the lower body tube and the drogue parachute, which connects to the rest of the rocket. Similar to the fiberglass centering rings, the fiberglass bulkhead contains six #4-40 tapped holes equally spaced around the disk to screw it with the carbon fiber body tube. Two ⅜" holes are placed in the middle of the fiberglass bulkhead, in which two ⅜" welded eye-bolts are inserted. The parachute is then attached to the eyebolts by tying a bowline knot on each of the eyebolts and connecting to a single line which leads to the parachute via quicklink and more bowline knots. Any clearance space between the bulkhead and the body tube is filled with epoxy, thus sealing the section and providing extra structural support.

2.4.3 Rail Guide Attachment

In order to mount the rocket onto the launch rail, there are three rail buttons bolted to the side of the lower body tube. These rail buttons are 3D printed to fit the mold of the rail and are attached using a #4-40 screw that runs through the rail button and into the centering ring. The top and bottom centering rings have one of the #2-56 tap holes adjusted on each of them to accommodate a #4-40 screw.

2.4.4 Fin-fixing Method

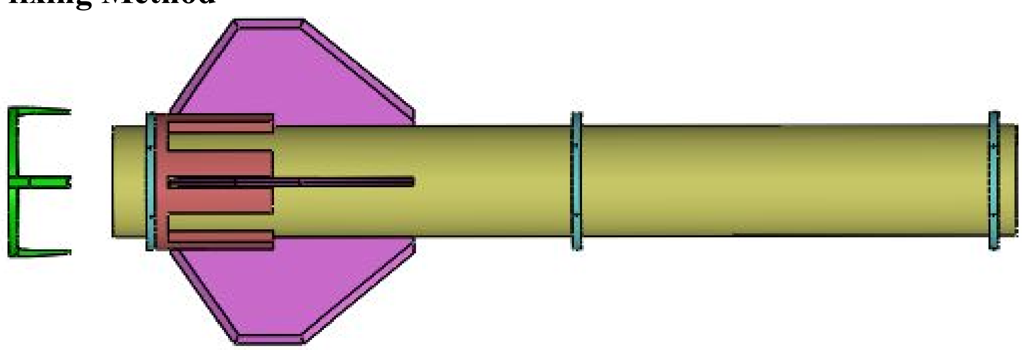

Figure 10: Internal Motor Mount Side View

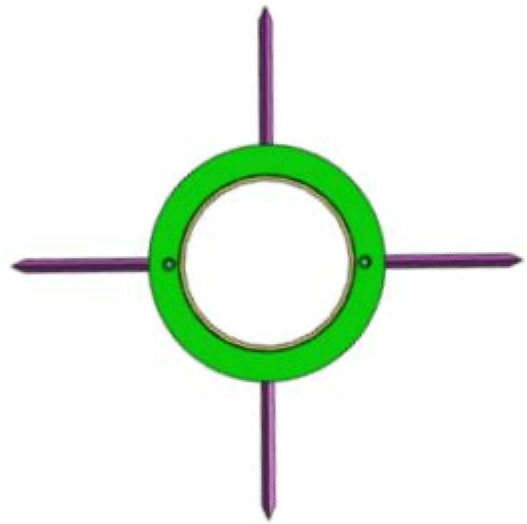

Figure 11: Internal Motor Mount Bottom View

The rocket utilizes a detachable fin attachment mechanism in order to test different fin designs without the need for creating a new carbon fiber body tube for every iteration, saving time and expenses. The four fins are epoxied onto the motor mount in the slots discussed in section 2.4.1. The motor mount/fin assembly slides into four open-ended slots located at the bottom of the lower body tube. At the bottom of the assembly is a 3-D printed cap to close off the motor mount assembly.

The 3-D printed cap has an outer diameter of 4.100 inches so it lies flush with the carbon fiber body tube, and has an inner diameter 3.220 inches to create a lip so the motor tube can lie flush against it and provide extra support during flight. The cap contains four protrusions which hold each of the four fins in, with tapped #2-56 holes on two of the four protrusions. On the bottom of the cap are two vertical tapped #4-40 holes on opposite sides, alternating between the #2-56 holes. The horizontal #2-56 holes allow #2-56 screws to connect the bottom cap into the fiberglass centering rings, maintaining the six-screw centering structure throughout the assembly. The vertical tapped #6 holes allow two #6 screws to further strengthen the connection between the bottom cap and the motor mount assembly.

2.4.5 Bolt Size Calculations

Shear stress calculations (see Appendix i) were done to ensure that the #2-56 bolts would be strong enough to mount the motor. In doing this calculation, we made the conservative assumption that all the thrust load was transmitted through one centering ring and only three bolts on the centering ring transmitted the load (because a minimum of three points are needed to define a plane). Thus, the maximum thrust force of 1489 Newtons from the L1170 motor is transmitted to be 496.3 Newtons on one bolt. In addition, the minor diameter of a #2 bolt is 0.0635 inches (0.001613 meters). While stress concentration due to the thread pattern is not considered, any additional effect will be negligible due to our conservative assumptions. The maximum transverse shear stress is found to be approximately 243 MegaPascals. Therefore, given the ultimate tensile strength of steel is 585 MegaPascals[4], the safety factor is calculated to be 2.41.

Similarly, a calculation was also performed to ensure that the shear stress in the fiberglass centering ring or the carbon fiber body tube did not exceed the material's limitations. With the #2-56 bolts that are 1/4 inches in length, 1/16 (0.001588 meters) inches of the bolt interfaces with the carbon fiber body tube and 3/16 inches (0.004763 meters) of the bolt interfaces with the fiberglass centering ring.

Thus, the bearing area stresses for the fiberglass centering rings and the carbon fiber body tube are 64.6 MegaPascals and 193.8 MegaPascals, respectively.

Given the tensile strengths of fiberglass (3500 MegaPascals) and carbon fiber (4000 MegaPascals)[5], the safety factors of the two components are 54.18 and 20.64, respectively.

Thus, our limiting safety factor is for the bolt design. While keeping the bolt size small brings us close to a factor of safety of 2, it gives us the benefit of a smaller bolt head sticking out on the lower body tube which can reduce drag. In addition, the conservative assumptions discussed err on the side of caution. As expected, the safety factors for the fiberglass centering ring and carbon fiber body tube are not a concern due to the outstanding material properties of the composites (see Structures Calculations section of Appendix i for more detailed calculations).

2.5 Scientific Payload

2.5.1 Payload

The scientific payload has been selected in collaboration with the Lou Lab Group at Rice university. The payload consists of non-toxic and non-volatile 2-D crystals of iron oxide that have been grown through the process of chemical vapor deposition. These crystals have been deposited on silicon and mica substrates, and are not able to seen by the naked eye. These crystals have immense value in the field of 2-D magnetism. Current challenges of the field are demonstrating room temperature at the 2-D regime. These crystals are an attempt at getting closer to bridging the gap between 2-D materials and magnetism.

The aim of this payload is to the test the phase stability of these crystals under the pressures, temperatures and inertial forces that the crystals will experience over the flight of the rocket. In terms of potential applications, these crystals are significant in the field of spintronics. This is a new way of computing that uses the spin degree of freedom in electrons to create faster and more energy efficient electronics devices. The crystals would allow for the development of better spin readers and transporters that would help propel the field further.

2.5.2 Payload Preparation

A total of eight substrates (4 mica and 4 silicon) that the crystals have been grown on will be included in the payload. Before the crystals are launched in the rocket, the surface of both the mica and silicon substrates will be mapped through the use of an optical microscope. This will allow us to identify specific crystal sites that correspond to the phase of iron that we are interested in. Optical images of these crystals will be taken before and then compared to new images that will be taken after the launch.

The substrates will separated into two categories: covered and uncovered. 2 silicon substrates will be placed in a petri dish and then covered and sealed with parafilm, the same process will occur for the mica substrates. For the uncovered samples, double sided tape will be used to hold the substrate to the bottom of the petri dish. This will be done for two mica substrates and two silicon substrates.

2.5.3 Payload Housing

All scientific payload setup will be housed inside nose cone. Data collection on acceleration, pressure during flight and potentially temperature and humidity will be gathered. The main components of this scientific payload include a wood avionics bay that slides onto the two M5 threaded rods and the altimeter that is fixed on the bay. Lock washers are used to fix the avionics bay in place and prevent vibrations from excessive movements. The general setup is shown in the CAD image below.

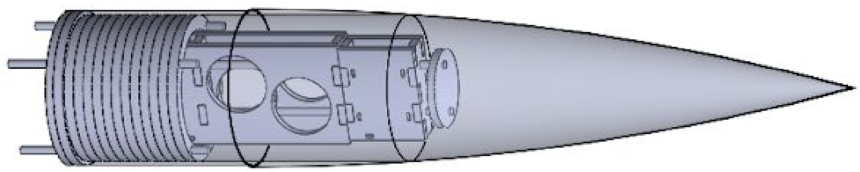

Figure 12:Assembled Nose Cone Avionics Bay

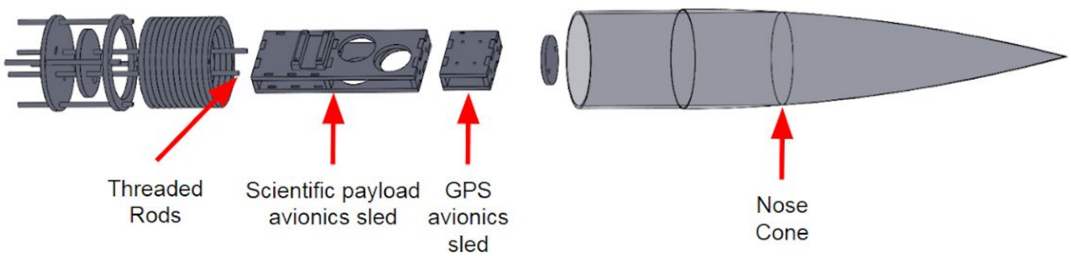

Figure 13: Exploded View of Nose Cone Avionics Bay

2.6 Simulations

2.6.1 OpenRocket Simulation

The team primarily used OpenRocket to design and simulate Noctua. OpenRocket is a free and open-source rocketry simulation program. Airframe designs as detailed in section 2.1 are imported. The following data was produced in OpenRocket. Launch parameters such as temperature, air pressure, and average wind conditions are tuned so as to best represent conditions at Spaceport America.

Table 3: Openrocket Simulation Results

Simulation Results:	**Values:**
Velocity off Launch Rail	95.1 ft/s
Apogee	9258 ft
Static Margin	1.77 *cal*
Max Velocity	845 ft/s
Max Acceleration	302 ft/s^2
Descent Speed (Drogue)	66.8 ft/s
Descent Speed (Main)	23.4 ft/s

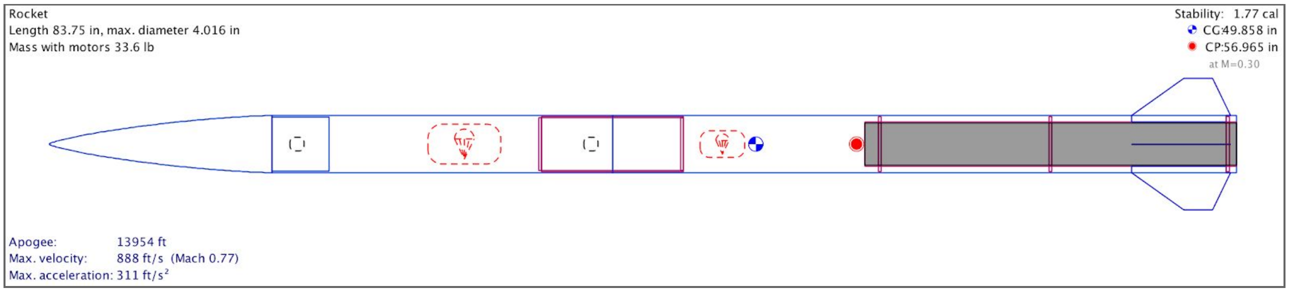

Figure 14: Noctua Airframe Modelled in OpenRocket

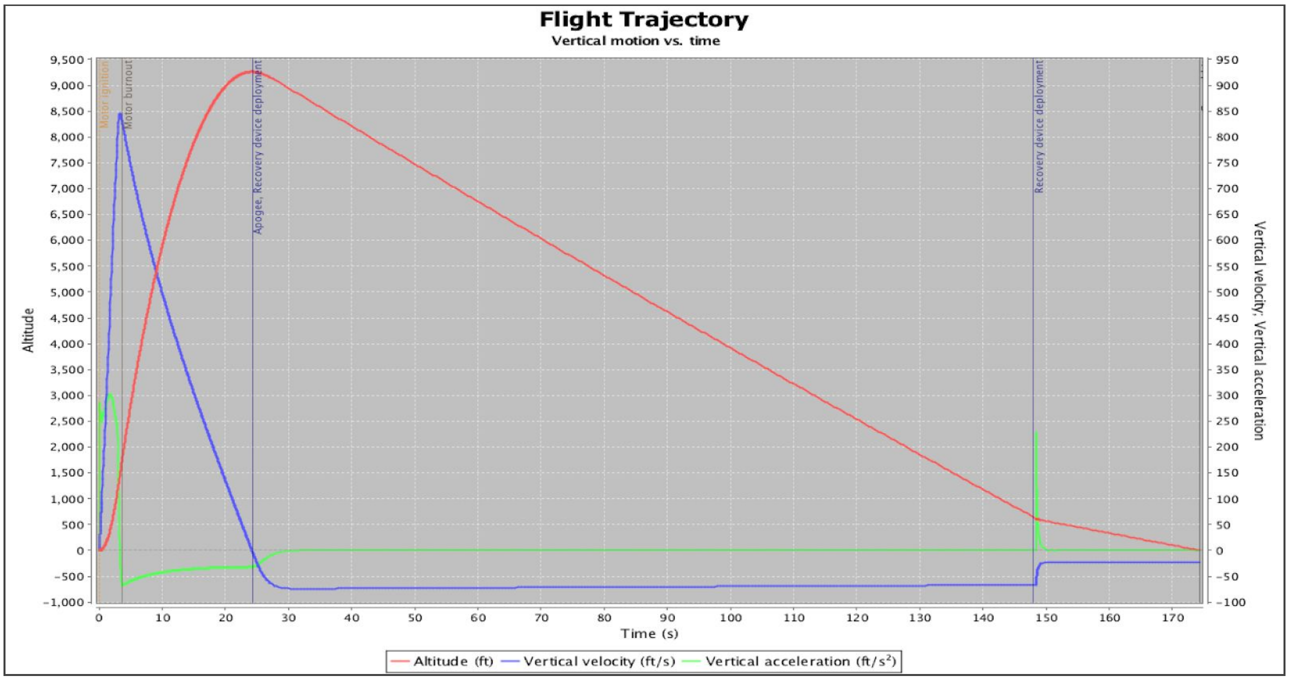

Figure 15: Simulation data of Noctua showing altitude, velocity, and acceleration.

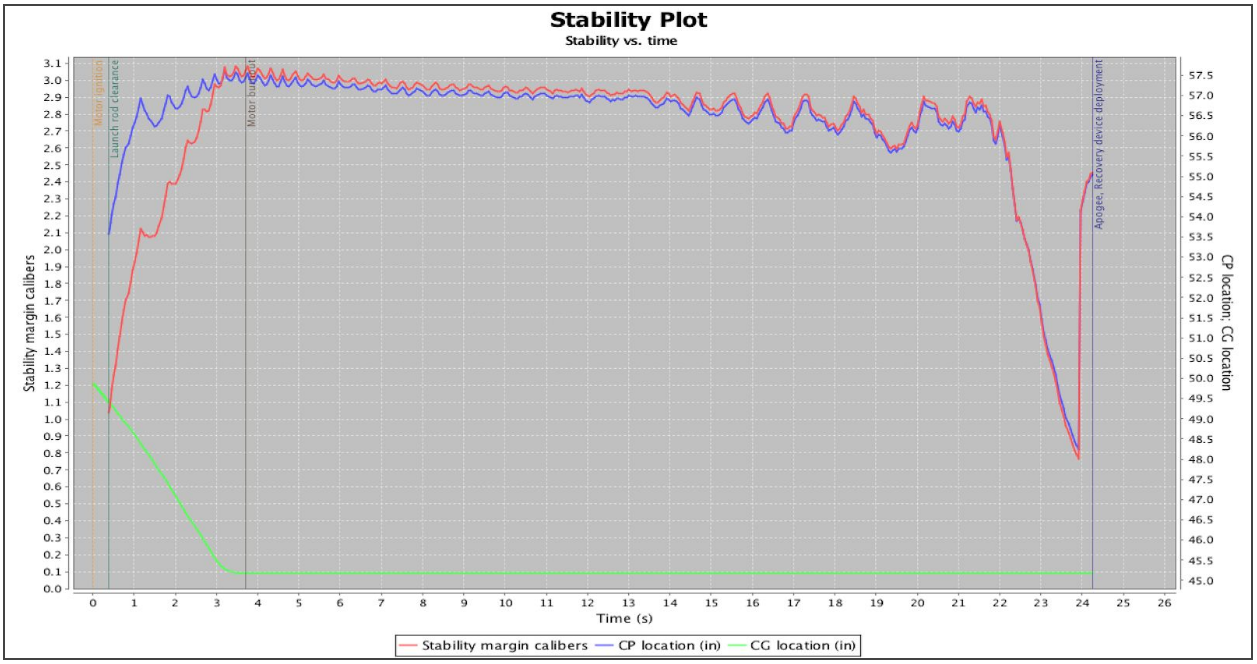

Figure 16: Simulation data of Noctua showing Stability.

Section III: Mission Concept of Operations Overview

An overall flight trajectory can be found in simulation section 2.6, where key events are highlighted.

		Sub systems		
Mission Phases	**Transition**	**Airframe**	**Recovery**	**Structures**
Pre-flight	N/A	• Check GPS and scientific payload	• Pack parachutes • Assemble/ wire BP charges • Secure parachutes and shock chords	• Insert motor • Assemble motor retainer
Mount Rocket	All system check	• N/A	• N/A	• Rail buttons catch rail guide and hold rocket in place
System Check	Rocket successfully mounted onto rail guide	• Bluetooth connection with nose-cone altimeter	• Altimeters arm and beep continuity • GPS successfully connects	• Ignitors correctly inserted and secured • Continuity on the pad
Ignition	Fire signal sent to launch pad	• N/A	• N/A	• Ignition
Boost (on launch rail)	Motor starts burning	• Static margin at 1.78	• Altimeter senses acceleration and start detecting for apogee	• Rail buttons provide guidance • Motor boosts velocity to 101 ft/s
Boost (left rail)	Motor continues burning, rocket tail leaves launch rail	• Fins provide stabilizing lift during flight	• N/A	• Motor continues to provide thrust
Coasting	Motor burnout	• Fins provide stabilizing lifts during flight	• Velocity starts decrease, altimeters get ready for drogue deployment	• N/A
Apogee and Drogue Parachute Deployment	Rocket reaches zero velocity	• Nose-cone altimeter records apogee	• Altimeters sense apogee and e-matches to drogue ignite • Black powder capsules ignite • Shear pins break on lower body tube • Lower body tube	• Shock cords, bulkheads and eye-bolts withstand shock at deployment, holding separated lower body tube together with

			separate, bring out drogue chute ● Drogue chute deploys fully	upper body assembly
Descent (drogue)	Drogue chute deployed successfully	● N/A	● Drogue chute reduce descent speed to 60 ft/s	● Shock cords continue holding rocket attached
Main Parachute Deployment	Reach 700-ft	● N/A	● Altimeters senses 700-ft and e-matches to main ignite ● Black powder capsules ignite ● Shear pins break on upper body tube ● Nose-cone separate from upper body tube, bring out main chute ● Main chute deploys fully	● Shock cords, bulkheads and eye-bolts withstand the shock at deployment, holding rocket attached
Descent (main)	Main chute deployed successfully	● N/A	● Drogue and main chutes reduce descent speed to 20 ft/s	● Shock cords continue holding rocket attached
Ground Hit	Rocket hit ground	● GPS continues to send location signal to laptop station	● N/A	● Rocket body withstands ground impact
Recovery	Reach landing site	● Record GPS and altimeter data and shut down	● Switch off altimeters ● Retrieve rocket	● N/A

Section IV: Conclusions

The airframe team gained great experience in the design process, taking an idea from creation to fabrication. In the research phase of the project, the team learned a lot about the choices made in rocket design. We learned the varying impacts and uses of the different airfoils. We tested the effects of different shapes of nose cones. We grasped the many concepts required to create reliable rockets with well researched data. Overall, bringing Noctua to fruition was extremely rewarding. Our team's hard work paid off just by being able to have a physical rocket that we could hold. Furthermore, the experiences that we gained from working on Noctua this school year have given us great insight for our future projects.

The composites team learned the technical skills and attention to detail required to build a carbon fiber body tube. By generally following the standards of the Jim Jarvis procedure while making adjustments, the team learned how to respond to mistakes and produce a functional rocket body and fins in a high stakes situation. The team now has significant experience precisely laying carbon fiber and epoxy in multiple layers as well as sanding and polishing the surface. The team learned that carbon fiber is quite painstaking and time-consuming but with teamwork and care a beautiful and strong rocket body tube can be constructed. Moving forward, the team will take the technical experience gained and build improve efficiency so that the club can continue to produce carbon fiber rockets. The team will also seek to implement tip-to-tip carbon fiber in the future as to improve strength.

In the process of developing the recovery system for Noctua, the recovery team researched, designed, and tested many different ways to recover the rocket. The team learned the importance of safety checks and documentation to ensure an effective and safe test of all systems. Furthermore, the team increased their technical writing skills and streamlined the process of developing a simple, yet effective, recovery system. Since many aspects of the recovery system needed to be integrated with aspects from multiple teams, the recovery team learned the importance of collaboration not only within the team but also across teams. This increased collaboration helped teach the importance of proper communication and time management. The team documented all research, testing, and analysis to pass onto future generations of the team and to maintain a high level of innovation and development.

Throughout the year, the structures team has gained experience in mechanical design through the work we have done for the rocket. Working with other subteams, we have learned the importance of collaboration and clear communication in order to make the final design come together. In addition, the requirements of structural tasks pushed team members to innovate in their design and confirm success through calculations processes learned in class. Even when certain aspects of the design did not perform as planned, each opportunity allowed for a learning moment that taught us how to better design, fabricate, and test components. In the end, we learned to bring together design and engineering for a successful rocket.

Section V: Appendices

i. Calculations
ii. Decision Matrices
iii. Appended 3rd Progress Update
iv. Project Test Reports
v. Hazard Analysis
vi. Risk Assessment
vii. Assembly Checklists
viii. Engineering Drawings

Appendix i: Calculations

Airframe Calculations

Fin Flutter Calculations:

Variables:
Cr = Root Chord (7 in)
Ct = tip chord (2 in)
t = Thickness (0.25 in)
b = Semi-Span (2.6 in)
G = Shear Modulus (1160340 psi)
h = Height of Maximum Velocity (1950 ft)
[The following values were used in our fin flutter equation. However, these values are according to our initial design and not exact to the most current dimensions.]

Surface Area of Fin:
S = $((Cr + Ct) * b)/2$
Aspect Ratio (ratio of the semi-span to the mean chord length of a wing):
AR = b^2/s
Ratio of tip chord to root chord:
λ = Ct/Cr
Temperature (T_0 is base temp):
T= $T_0 - 0.00356 * (h)$
Speed of Sound
α = $\sqrt{1.4 * (1716.59)(T + 460)}$
Pressure:
P = $(2116/144) * ((T + 459.7)/518.6)^{5.256}$

$$V_f = a\sqrt{\frac{G/(1.337AR^3P(\lambda+1))}{2(AR+2)(t/c)^3}} = 8591.17\,ft/s$$

Recovery Calculations

Parachute Sizing Calculations:

Variables:
g = gravitational constant (9.81 m/s^2)
m = mass of the rocket minus propellant (13777.87 g)
p = density of air at sea level (1225 g/m^3)
C_d = drag coefficient (1.34 for drogue and 1.4 for main)
v = descent velocity (selected as 18.5 m/s for drogue and 6.5 m/s for main with drogue)
S = parachute canopy surface area (in m^2)
D = parachute canopy diameter (in m)

$S = \frac{2gm}{pC_d v^2}$

$0.866D^2 = \frac{2gm}{pC_d v^2}$

($0.866D^2$ is the area of a hexagonal parachute)

$D = \sqrt{\frac{2gm}{pC_d v^2 (0.866)}}$

Drogue Parachute:

$D = \sqrt{\frac{2(9.81)(13777.87)}{(1225)(1.34)(18.5^2)(0.866)}}$

$D = 0.745m \text{ or } 29.3in$

Main Parachute:

$D = \sqrt{\frac{2(9.81)(13777.87)}{(1225)(1.4)(6.5^2)(0.866)}}$

$D = 2.08m \text{ or } 81.9in$

Shock Cords Stress Calculations[9]*:*

Variables:

U_{drogue} = terminal velocity with drogue ($67\ ft/s$) [see section 2.6]

A_{main} = main parachute surface area ($54.28\ ft^2$)

ρ = air pressure[6] ($20.48\ slug/ft^3$)

C_d = drag coefficient (1.4)

T_{max} = max tensile load[2][3] (1500 lbf)

η = factor of safety

Maximum total tension experienced:

$Max\ Tension = Drag = 1/2 * C_d * A_{main} * U_{drogue}{}^2 * \rho = 349\ lbf$

Factor of safety for shock cords:

$\eta = T_{max} / Max\ Tension = 1500\ lbf / 349\ lbf = 4.3$

Vent Port Sizing Calculations:

Variables:

V = avionics bay volume (in^3)

R = avionics bay radius (in)

L = avionics bay length (in)

n = number of vent ports (3)

D = diameter of each port, for multiple ports (in)

[Consolidated vent port diameter formula obtained from Missileworks RRC3 Altimeter manual[7]]

For cylindrical avionics bays with $V < 100\ in^3$:

$V = \pi R^2 L$

$$D = 2 * \sqrt{\frac{V^2}{n * 800^2}}$$
$$D = 2 * \sqrt{\frac{(\pi R^2 L)^2}{n * 800^2}}$$
$$D = 2 * \sqrt{\frac{(\pi 1.95^2 12)^2}{3 * 800^2}}$$
D = 0.207" (rounded to the nearest drill bit size)

Black Powder Calculation:

Variables:
P = absolute pressure in the airframe (psi)
V = airframe volume (in^2)
m = mass of black powder (grams)
R = converted ideal gas constant (265.92 in*lbf/lbm)
T = temperature inside airframe during combustion (3307°R)
F = force on separation (lbf)
τ_{max} = max shear load on #2-56 Nylon screws[8] (□35 lbf)
η = factor of safety

Black powder mass needed:
$$PV = mRT$$
$$m = \frac{PV}{RT}\left(\frac{453.592g}{1\ lbm}\right)$$

Sustainer Drogue Charge:
$$m = \frac{(15)(\pi(2^2)(10))}{(265.92)(3307)}\left(\frac{453.592g}{1\ lbm}\right)$$
$$m = 0.97g$$

Sustainer Main Charge:
$$m = \frac{15 * \pi * 2^2 * 15}{265.92 * 3307}\left(\frac{453.592g}{1\ lbm}\right)$$
$$m = 1.46g$$

Verification on successful separation with 2 shear pins:
Assumed standard pressure of 15 psi
$$F = \pi * 2^2 * 15 = 188.5\ lbf$$
$$\eta = 188.5\ lbf / (35\ lbf * 2) = 2.7$$

Structures Calculations

Maximum Shear Stress Calculation:

Variables:
τ_{max} = maximum shear stress (MPa)
F = force exerted on each bolt (N)

A = bolt cross-sectional area (m^2)
D_{bolt} = bolt diameter (m)

$$\tau_{max} = \frac{F}{A} = \frac{Thrust/3}{\pi(D_{bolt})^2/4} = \frac{496.3N}{\pi(0.001613m)^2/4} = 242.88MPa$$

Factor of Safety for Shear Stress Calculation:

Variables:
η = factor of safety
UTS = ultimate tensile strength (MPa)
τ_{max} = maximum shear stress (MPa)

$$\eta = \frac{UTS}{\tau_{max}} = \frac{585MPa}{242.88MPa} = 2.41$$

Maximum Bearing Stress Calculation:

Variables:
$B_{t,fiberglass}$= maximum fiberglass bearing stress (MPa)
$B_{t,carbon\ fiber}$= maximum carbon fiber bearing stress (MPa)
F = force exerted on interface area (N)
t = thickness of interface area (m)
D_{bolt} = bolt diameter (m)

$$B_{t,fiberglass} = \frac{F}{td} = \frac{Thrust/3}{t_{fiberglass}D_{bolt}} = \frac{496.3N}{0.004763m * 0.001613m} = 64.6MPa$$

$$B_{t,carbonfiber} = \frac{F}{td} = \frac{Thrust/3}{t_{carbonfiber}D_{bolt}} = \frac{496.3N}{0.001588m * 0.001613m} = 193.76MPa$$

Factor of Safety for Bearing Stress Calculation:

Variables:
η = factor of safety
UTS = ultimate tensile strength (MPa)
$B_{t,fiberglass}$= maximum fiberglass bearing stress (MPa)
$B_{t,carbon\ fiber}$= maximum carbon fiber bearing stress (MPa)

$$\eta_{fiberglass} = \frac{UTS}{B_{t,fiberglass}} = \frac{3500MPa}{64.6MPa} = 54.18$$

$$\eta_{carbonfiber} = \frac{UTS}{B_{t,carbonfiber}} = \frac{4000MPa}{193.76MPa} = 20.64$$

Appendix ii: Decision Making Charts

Airframe Decision Charts

* The following tables were made with the aid of simulations in openrocket, with only one independent variable changing in each table.
* Mass was not up to date, therefore overall apogees are higher.

Table 1: Nose Cone Decision Matrix

Design	**Apogee** (ft)	**Max Acceleration** (ft/s^2)	**Max Velocity** (ft/s)	**Mach Number**	**Stability** (Cal)
Von Karman	10054	329	918	0.83	1.70
Conical	9393	328	910	0.82	1.82
Ogive	10029	329	917	0.83	1.67
Ellipsoid	9591	327	907	0.82	1.58
Power Series	10045	329	917	0.83	1.71
Parabolic Series	10042	329	917	0.83	1.68

Table 2: Decision Matrix for Fin Shape

Design	**Drag**	**Apogee** (ft)	**Stability** (cal)
Asymmetrical Trapezoidal	0.38	10053	1.70
Symmetrical Trapezoidal	0.38	9981	1.68
Back Slanted	0.39	9890	1.75
Rounded	0.39	10214	1.80

Table 3: Decision Matrix for Number of Fins

# of Fins	**Apogee** (ft)	**Max Acceleration** (ft/s^2)	**Max Velocity** (ft/s)	**Mach Number**	**Stability** (cal)
3	10219	331	926	0.83	0.76
4	10056	328	918	0.83	1.7
5	9903	326	910	0.82	2.2

Recovery Decision Charts

Table 4: Separation Method pros and cons list

Separation Method	Pro	Con
Servo Release	• No combustibles used • Easy to test • Occupies minimal space • Multi-use	• Difficult to implement • Possibility of failure due to high accelerations
Pyrotechnic Bolt	• Reliable • Cheap	• Difficult to manufacture • Requires wiring to bolt • Possibility of damaging coupler • Single use
Pyrotechnic Gas Generation (Black Powder)	• Highly effective • Easy to obtain • Previous team experience	• Combustible • Requires wadding protection • Single Use
Carbon Dioxide Release	• Safe to handle • Reliable at high altitudes	• Expensive • Large components • Heavy • Single Use

Table 5: Separation Methods, 10 is most desirable

Separation Method	Ease of Fabrication	Reliability	Experience	Cost	Total
Weighted Score	**0.2**	**0.4**	**0.2**	**0.2**	**1**
Servo Release	1	1	1	2	1.2
Pyrotechnic Bolt	2	8	6	6	6
Pyrotechnic Gas (Black Powder)	9	10	10	10	9.8
Carbon Dioxide	10	9	1	5	6.8

Table 6: Parachute Type pros and cons list

Parachute Type	Pro	Con	Drag Coefficient
Crossfire Parachute	• Ripstop Nylon • Cheaper	• Melts at high temperatures	<60” = 1.34 >60” = 1.40

	● Lightweight ● Strong		
B2 Classic II	● Chute Spin Technology ● Controls Rocket descent well	● Largest parachute is 60”	24”-1.16 36”-1.34 60”-1.89
Cert-3	● 80” coord ● Chute spin technology ● 2000lbs cord strength	● Smaller drag coefficient ● All parachutes are >96”	CD: 1.26
Fruity Chutes: Iris Ultra Parachute	● Premium parachute ● Reinforced suspension line attachment ● Tubular nylon bridle and barrel swivel ● Reinforced circular opening ● Heat shrink tube	● Very pricy ● Parachute may not slow descent to speed we want	CD: 2.2

Table 7: Parachute Selection, 10 is most desirable

Parachute Type	**Drag Coefficient**	**Materials**	**Sizing Selection**	**Cost**	**Total**
Weighted Score	**0.2**	**0.2**	**0.1**	**0.5**	**1**
Crossfire Parachute	6	8	10	8	7.8
B2 Classic II	6	8	5	5	5.8
Cert-3	5	8	5	9	7.6
Fruity Chutes: Iris Ultra Parachute	9	8	1	2	4.6

Table 8: GPS Systems pros and cons list

GPS System	**Pro**	**Con**	**Range**

BeeLine GPS	● 2+ hours of GPS data ● Rechargeable battery	● Amateur Radio License Required ● Requires $125 purchase of additional equipment ● Requires computer	15 miles
BRB900 TX/RX Base GPS	● All inclusive ● No computer required ● 1 to 1/2hrs of GPS data	● Higher price	6 miles
Eggfinder	● 20 grams ● Real time data ● Tracks height in real time	● $20 additional equipment to double range ● Requires software program ● Assembly required	1.5+ miles
TeleGPS	● 12.19 grams - very light ● Chargeable ● Inexpensive compared to other GPS systems	● Requires computer ● Requires $107 purchase of additional equipment ● Requires license	20+ miles
MissileWorks RTS/GPS Standard	● 7 flights at 1 hr 8 min each of data ● Delay for up to 30 min while prepping launch	● Requires $25 in additional equipment	9 miles
MissileWorks T3 GPS Tracking	● Rechargeable ● 7 flights can be stored	● Android App required ● Additional equipment required	9 miles

Table 9: GPS Selection, 10 is most desirable

GPS System	**Lowest Total Price**	**Range**	**Reliability**	**Does not require additional parts/software**	**Total**
Weighted Score	**0.1**	**0.3**	**0.5**	**0.1**	**1**
BeeLine GPS	1	10	6	5	6.6

BRB900 TX/RX Base GPS	2	8	5	10	6.1
Eggfinder	10	6	5	8	6.3
TeleGPS	2	9	10	6	8.5
MissileWorks RTS/GPS Standard	3	10	6	6	6.9
MissileWorks T3 GPS	7	10	6	4	7.8

Appendix iii: Appended Progress Update

Appended to the end of this document.

Appendix iv: Test Reports

Table 1: Major Noctua Tests

Date	**Test**	**Description**
1/28/18	Ground Recovery Test	Team conducted ground test to find optimal amounts of black powder needed for recovery system.
3/10/18	First Prototype Test	Team flew first prototype with J-motor to test prediction methods.
5/6/18	Full Scale Launch Test	Team flew Noctua in competition-ready configuration to further test recovery systems.

Ground Recovery Test

Tests were conducted at South Annex in Houston on 1/28/2018.
The goal is to ascertain the amount of black powder required for successful body tube separations.
Because of time constraint, only a number of black powder tests were conducted.
Setup: coupler is clamped down and a body tube section is fixed to coupler with two shear pins.
Lesson learned: there is likely to be discrepancy between calculation and testing results. To compensate for variations, larger amounts of black powder should be used.

Table 2: Ground recovery test results

Tube Length	**Charge (in grams)**	**Success (Y/N)**	**Anomaly (Y/N)**	**Explanation:**
8”	0.6g	Y	Y	Unsuccessful separation. Shear pins did not shear.
8”	0.8g	Y	N	Separation successful. Body tube landed ~30 ft away from the rocket. Might be able to separate with less BP.
19”	1.4g	N	Y	Black powder charge did not ignite, possibly because of faulty igniter.
19”	1.0g	Y	N	Separation successful, shear pins broke as expected. 0.85 grams less than calculation, check for math errors.

First Prototype Test

Test was conducted at Apache Pass in Rockdale TX on 3/10/2018.
The main goal of this test was to verify the predictions team simulated in openrocket.
First prototype had slight variations in design from the final Noctua design detailed in this technical report. These differences reflect the changes team had made after the test.
The main differences are:

1. length of lower body tube was 33 in compared to 44 in on Noctua
2. Launched on a J-425
3. Weights only 8.1lb with motor

The projected flight path matches with the test result with margin of error about 3%, with expected apogee at 3360 ft.

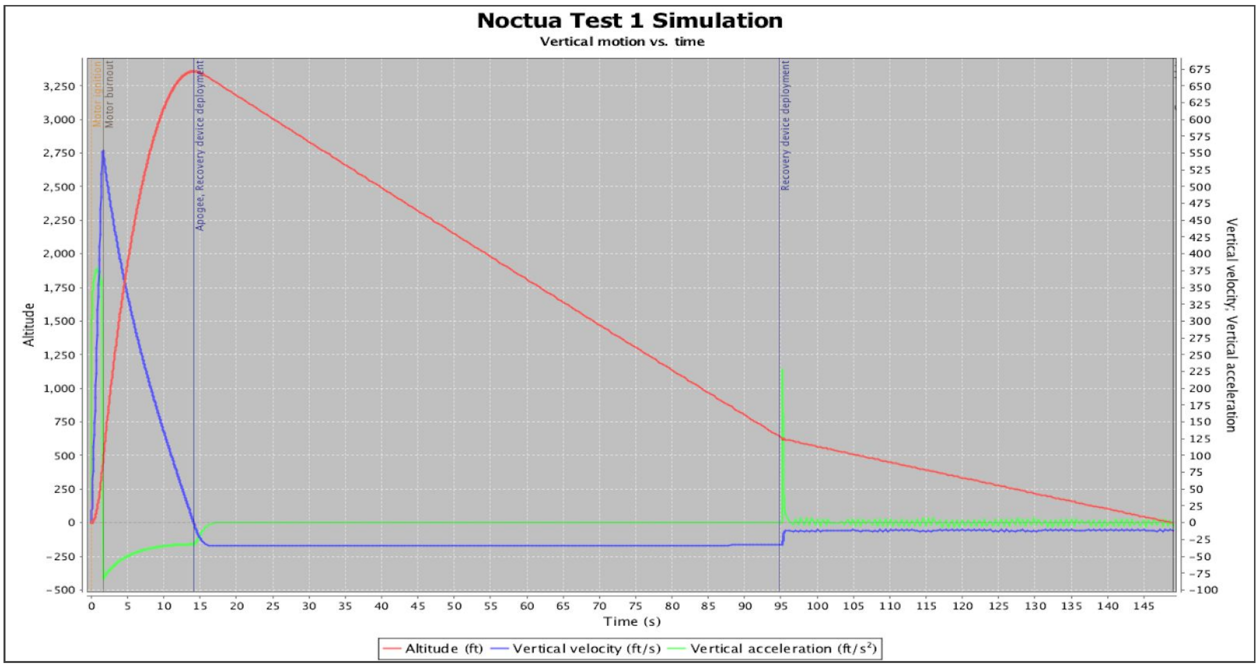

Figure 1:A Simulated Flight Trajectory

The altimeter data is shown below:

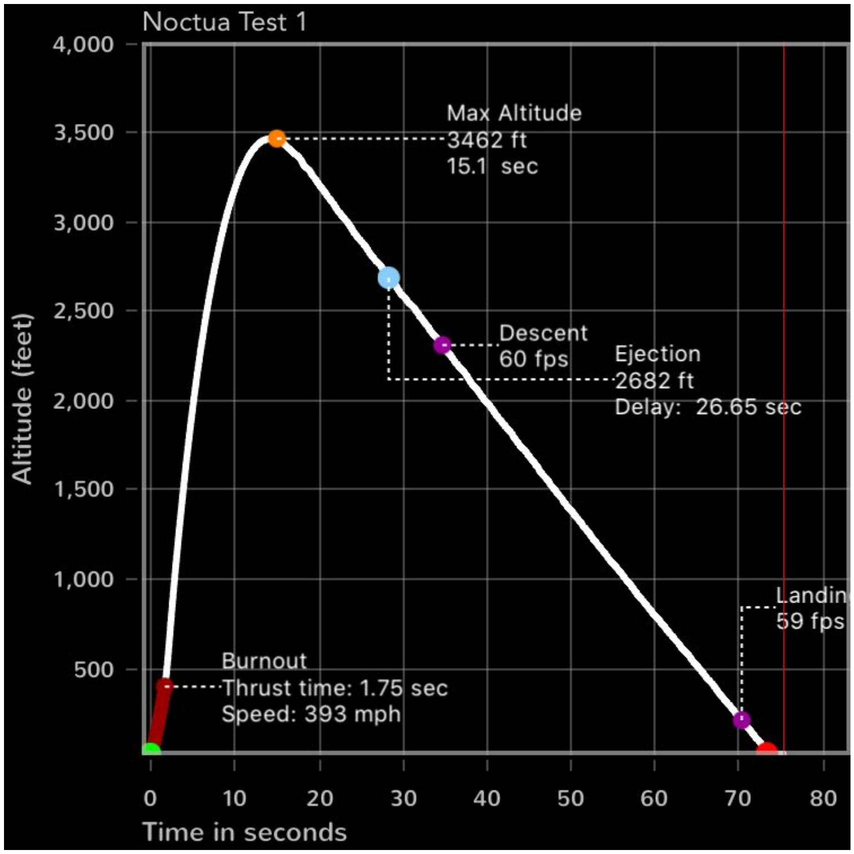

Figure 1: B Altimeter Data from First Prototype Launch

However, recovery system was not successful, after retrieving the rocket, it was discovered that one of the ejection charges did not ignite.
Ignitor tests later conducted showed that a high voltage, around 12V, is required to guarantee successful charge deployment.
The results, tabulated below, propelled the team to adopt E-matches for recovery charge deployment and introduce redundancy into recovery system.

Table 3: Black Powder Flight Testing

Body Tube	**Charge (in grams)**	**Success (Y/N)**	**Anomaly (Y/N)**	**Explanation:**
Lower Body Tube (Drogue Chute)	0.8g	Y	Y	The charge ignited, but only sheared one pin and did not separate the rocket.

Upper Body Tube (Main Parachute)	1.5g	N	Y	Charge did not ignite. Not enough voltage to ignite igniter. Will be using e-matches in the future.

Full-Scale Prototype Test

Test was conducted at Apache Pass in Rockdale TX on 5/6/2018.
The team decided to fly Noctua in competition-ready configuration for a full system test. Recovery systems were the main focus for this test, as safety is the most important aspect of a successful launch. The main changes made to ensure successful recovery include:

1. Redundancy from employing two altimeters
2. E-matches to ignite black powder capsule
3. ⅜" forged eyebolts and fiberglass bulkheads to sustain shock during main deployment

Drogue parachute deployed at apogee and main parachute was later deployed at 700 ft as expected. The flight trajectory from altimeter is shown below:

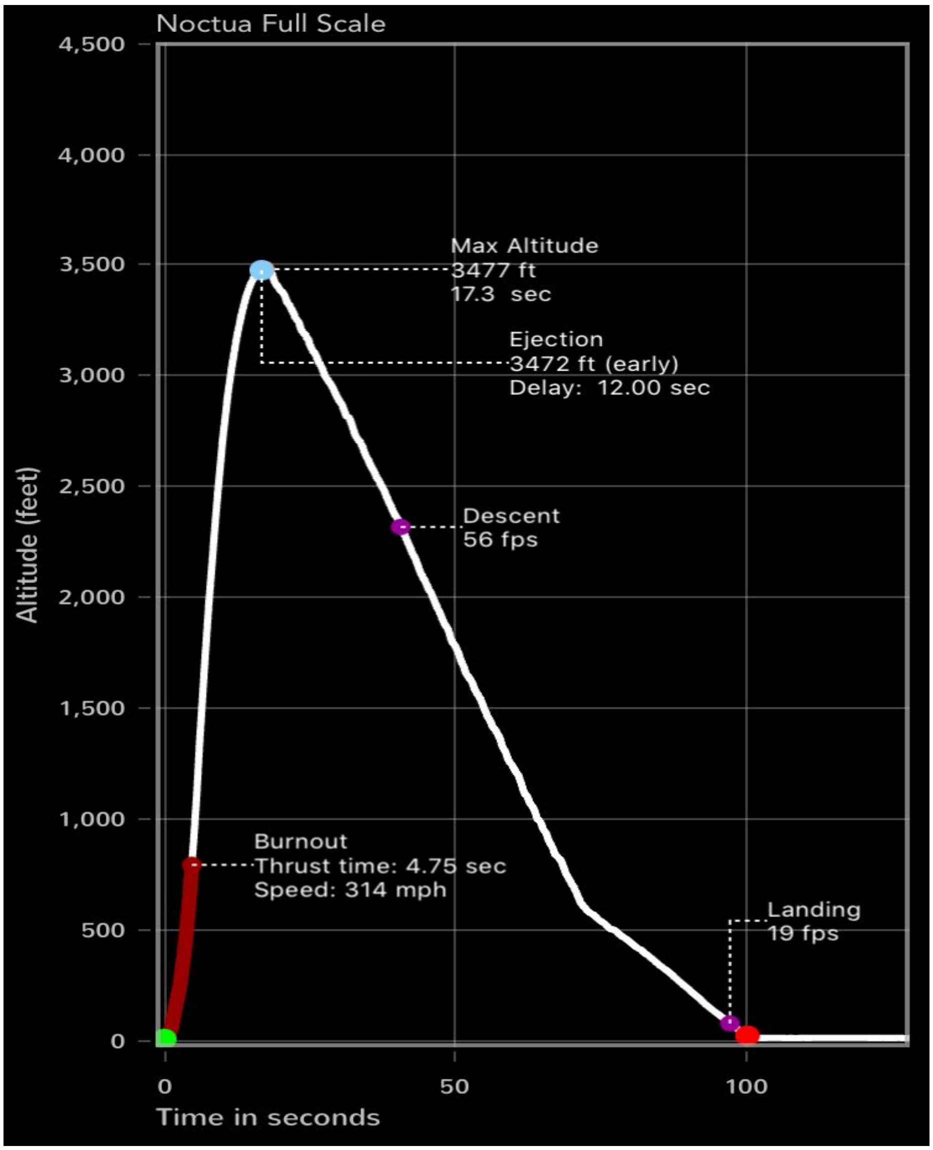

Figure x. B Altimeter Data from First Prototype Launch

From this test, team verified the recovery system's separation mechanism and verified the parachutes provide enough drag to decrease descend speed as expected.

Appendix v: Hazard Analysis

Appended to the end of this document

Appendix vi: Risk Assessments

Appended to the end of this document

Appendix vii: Assembly, Preflight and Launch Checklists:

Assembly

Structures

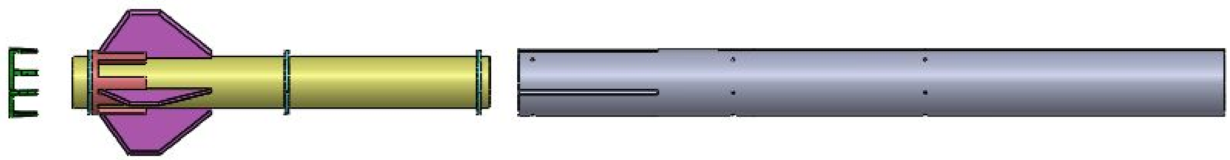

Figure x: Lower Body Tube Pre-Assembly

Lower Body Tube Assembly

1. Align motor mount assembly centering ring holes with corresponding holes on lower body tube by matching the numbers assigned to each hole
2. Maintain this alignment while inserting motor mount assembly into lower body tube
3. Slide motor mount assembly up into the lower body tube until fins lie flush with the top of the fin slots in the lower body tube
4. Secure motor mount assembly into lower body tube at each centering ring with five #2-56 bolts that go through the body tube and into the centering ring and one #4-40 bolt that goes through a rail guide, the body tube, and the centering ring for a total of fifteen #2-56 bolts and three #4-40 bolts
5. Align tabs of bottom cap with the fin slots on the lower body tube such that the retaining holes align with those on the motor mount assembly
6. Slide bottom cap into the lower body tube until the inside face of the cap is flush with the base of the lower body tube
7. Secure the bottom cap with a #2-56 bolt through the tabs of the cap with holes in them and the centering ring for a total of two #2-56 bolts

Recovery

Coupler

1. Slide avionics sled onto threaded rods
2. Secure sled with nuts and washers on both sides
3. Slide weight discs onto threaded rods
4. Secure weight discs with nuts and washers
5. Screw on a nut and washer 1 inch onto each threaded rod on the side with the weight discs
6. Slide the wiring tube through the central hole in the weight discs and avionics sled
7. Slide upper bulkhead onto the threaded rods so its bottom surface is flush with the nuts from **step 5**
8. Using a wrench to secure outside of the bulkhead with a lock washer and an eye nut on each rod
9. Partially insert the avionics bay into the coupler and wire each switch to the respective altimeters
10. Slide the avionics bay into the coupler so that the upper bulkhead seats into the top of the coupler

11. Power cycle both altimeters individually and listen to the altimeter report to ensure system is running optimally
    a. If electronics not functioning properly:
        i. Ensure proper power line connection
        ii. Ensure proper switch connection
        iii. Ensure switch is operating as designed
        iv. Check for damaged components
        v. Ensure board is clear of debris

Assembly for parachutes and shock cords

Lower body tube to coupler(drogue parachute)

1. Holding shock cord attached to lower body tube taut, slide a parachute protector down the shock cord until parachute protector is level with the top of the lower body tube
2. Tie parachute protector in place to the shock cord
3. Tie shock cord attached to lower body tube to a quick link with a bowline knot
4. Attach drogue parachute to quick link
5. Close quicklink
6. Tie another length of shock cord from the quick link to a second quick link using bowline knots
7. Use bowline knots and 2 foot long sections of shock cord to attach the second quick link to the two eye nuts on the bottom bulkhead of the coupler
8. Close second quick link
9. Duct tape both quick links closed

Coupler to nose cone(main parachute)

1. Use bowline knots and 2 foot long sections of shock cord to attach a quick link to the two eye nuts on the top bulkhead of the coupler
2. Tie a third length of shock cord to the quick link using a bowline knot
3. Close the quick link and duct tape it
4. Insert the upper half of the coupler into the bottom of the lower body tube
5. Ensure the coupler fits into the upper body tube snuggly so there is no wobble
    a. If the fit is wobbly, add winds of electrical tape to the lower coupler shoulder until the fit is snug
6. Align retaining screw holes between the coupler and the body tube by matching the corresponding numbers
7. Put an M3 bolt through both holes to secure the coupler to the upper body tube for a total of three M3 bolts
8. Pull the free end of the shock cord taut out of the top of the upper body tube
9. Continuing to hold the shock cord taut, slide a parachute protector down the shock cord until parachute protector is level with the top of the upper body tube
10. Tie parachute protector in place to the shock cord
11. Tie free end of the the shock cord to a quick link using a bowline knot
12. Attach main parachute to quick link
13. Close quicklink and duct tape it
14. Tie another length of shock cord from the quick link to the eyebolt connected to the bottom of the nose cone using bowline knots on both ends

Pre-Flight Checklist

Structures

1. Ensure that the motor mount assembly is secure. Check for tight bolts along the centering rings as well as in the bottom cap and the lower bulkhead.
2. Slide the motor casing into the motor tube until the lip of the motor casing sits flush against the motor tube.
3. Ensure that the motor is safely housed inside the motor casing, double checking the motor model and specifications.
4. Use the metal retaining ring to secure the motor from the bottom.
    a. The metal retaining ring is secured using two #4-40 screws that are drilled through the bottom and into centering rings at the bottom of the motor mount.
5. Check rigidity of the entire motor mount system. Ensure that the fins are secure in their positions.

Recovery

*Top side points up (towards nose cone)

Assembly for the middle coupler

1. Power cycle both altimeters individually and listen to the altimeter report to ensure system is running optimally
    a. If electronics not functioning properly:
        i. Ensure proper power line connection
        ii. Ensure proper switch connection
        iii. Ensure switch is operating as designed
        iv. Check for damaged components
        v. Ensure board is clear of debris
2. Use multimeter to check empty BP charge continuity
    a. If there is no continuity replace empty BP charge and check new empty BP charge for continuity
3. Pour 2g of BP into each of the 4 capsules
4. Pack paper mesh in capsules for airtight seal
5. Close and tape each capsule shut
6. Remove avionics bay from coupler
7. Insert BP charge lead into corresponding through holes on lower and upper bulkhead until the charge is flush with the top of the bulkhead and sits inside the pvc housing
8. Add a small amount of epoxy to the inside of each bulkhead where the BP charge wires come through to make the bulkheads airtight
9. After letting the epoxy dry, seal the top of the pvc housings with tape
10. Feed the BP charge leads from the upper bulkhead through the wiring tube into the avionics bay sled
11. Bring one ignitor lead up to the top altimeter and wire it to the “main” terminal of the board
12. Bring the other ignitor lead down to the bottom altimeter and wire it to the “main” terminal of the board
13. Leaving some slack, secure the excess BP charge wiring with zip ties
14. Wire one of the BP charge leads from the lower bulkhead to the “drogue” terminal of the top altimeter
15. Wire the remaining BP charge lead from the lower bulkhead to the “drogue” terminal of the bottom altimeter

16. Bring the lower bulkhead onto the threaded rods so that the top of the rods are flush with the top face of the bulkhead
17. Gather the slack from each BP charge lead into neat blundles
18. Zip tie the bundles
19. Secure the bundles to the inside of the coupler with zip ties and duct tape
20. Slide the lower bulkhead down the threaded rods until the bulkhead seats into the bottom of the coupler
21. Slide a lock nut onto each threaded rod and screw on an eye nut on each
22. Tighten the eye nuts with a wrench until they cannot be tightened anymore
    a. If coupler weight needs to be adjusted:
        i. Unbolt eye nuts from lower bulkhead
        ii. Disconnect the BP charge leads on both altimeters from lower bulkhead
        iii. Slide out the avionics bay carefully (out from top side). **Do not to disconnect altimeters from the switches**
        iv. Unbolt the two ¼" lock nuts facing top side and take out or add weight discs as needed
        v. Screw the lock nuts back on

Airframe (nose-cone assembly):

1. Load crystal dishes
2. Secure specimen dishes in place with superglue and zipties
3. Turn on GPS
    a. Plug in LiPo battery to GPS
    b. Connect RF cable to antenna and plug into computer
    c. Open GPS computer software
    d. Press begin to monitor flight in the software
    e. Check status for GPS
4. Turn on altimeter
5. Use the app to check altimeter status
6. Insert nose-cone avionics bay into nose cone so the upper face of the bulkhead lies flush with the bottom of the nose cone
7. Secure avionics bay with 4 M5 bolts and 4 lock washers

System Integration

1. Inspect bowline knots in every shock cord
2. Give each length of shock cord a good tug and observe if there is slipping in any knot
    a. If the knot slips:
        i. Retie the knot and check for slipping again
3. Ensure each quicklink is closed and taped shut
    a. If the a quick link is not secured properly:
        i. Close the quick link and tape it
        ii. If the quick link is faulty, replace the quicklink
4. Pack main parachute into the upper parachute protector
5. Insert the packed main parachute into the top of the upper body tube
6. Insert the shock cord leading from the main parachute to the nose cone on top of the packed main parachute in careful coils to avoid tangling and facilitate easy deployment
7. Line up the shear pin holes between the nose cone and the upper body tube tube by matching the corresponding numbered holes

8. Secure the nose cone to the upper body tube with a 4-40 nylon bolt in each hole for a total of two 4-40 nylon bolts
9. Pack drogue parachute into the lower parachute protector
10. Insert the packed drogue parachute into the top of the lower body tube
11. Insert the shock cord leading from the drogue parachute to the lower bulkhead of the coupler on top of the packed drogue parachute in careful coils to avoid tangling and facilitate easy deployment
12. Line up the shear pin holes between the lower shoulder of the coupler and the lower body tube tube by matching the corresponding numbered holes
13. Secure the lower shoulder of the coupler to the lower body tube with a 4-40 nylon bolt in each hole for a total of two 4-40 nylon bolts

Electronics Check

1. Holding rocket ends away from people, power cycle both altimeters individually and listen to the altimeter report to ensure system is running optimally
    a. If electronics not functioning properly:
        i. Remove shear pins between coupler and lower body tube
        ii. Separate lower body tube from coupler
        iii. Remove retaining bolts between coupler and upper body tube
        iv. Separate coupler from upper body tube
        v. Unscrew eye nuts on lower bulkhead with a wrench
        vi. Remove lower bulkhead
        vii. Disconnect BP charges
        viii. Troubleshoot altimeter:
            1. Ensure proper power line connection
            2. Ensure proper switch connection
            3. Ensure switch is operating as designed
            4. Check for damaged components
            5. Ensure board is clear of debris
        ix. Reassemble coupler following **Recovery** procedures above
2. Check GPS status
3. Check nosecone altimeter status
4. Check igniters for continuity

Launch Checklist

1. Slide the rocket onto the launch rail
2. Check launch rail angle
    a. If launch rail deviates significantly from recommended angle:
        i. Adjust launch rail angle until angle is within recommended range
3. Turn on one recovery altimeter at a time and listen for positive reporting
4. Get permission from range manager to instal ignitors
5. Check to ensure firing line is not active by touching the leads together and observing no sparks
    a. If there are sparks:
        i. Coordinate with launch control to deactivate the firing line
6. Insert igniters all the way into the top of the motor
7. Secure igniters to the launch rail
8. Connect the igniters to the launch control system
9. Check control system for continuity

   a. If there is no continuity:
      i. Check igniter connections
      ii. Radio launch control
      iii. Ask range manager for help
10. Radio over to indicate rocket is ready for launch
   a. If rocket reeds to be removed:
      i. Disconnect firing line
      ii. Remove igniters
      iii. Shunt igniters
      iv. Turn off recovery altimeters
      v. Remove rocket from launch rail
11. Leave launch area

Appendix viii: Engineering Drawings

Airframe Drawings

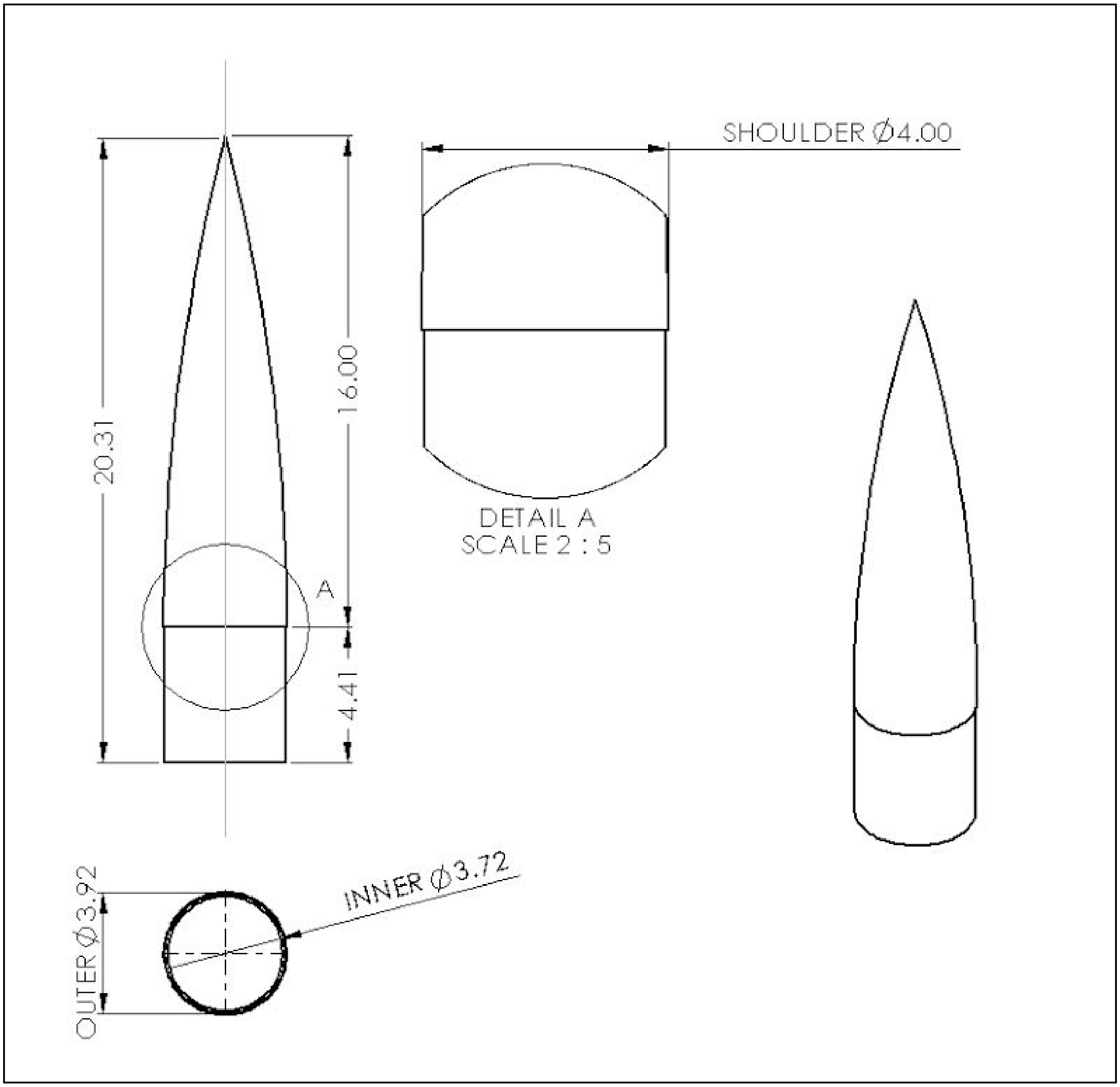

Figure 1: Nose-cone Drawing

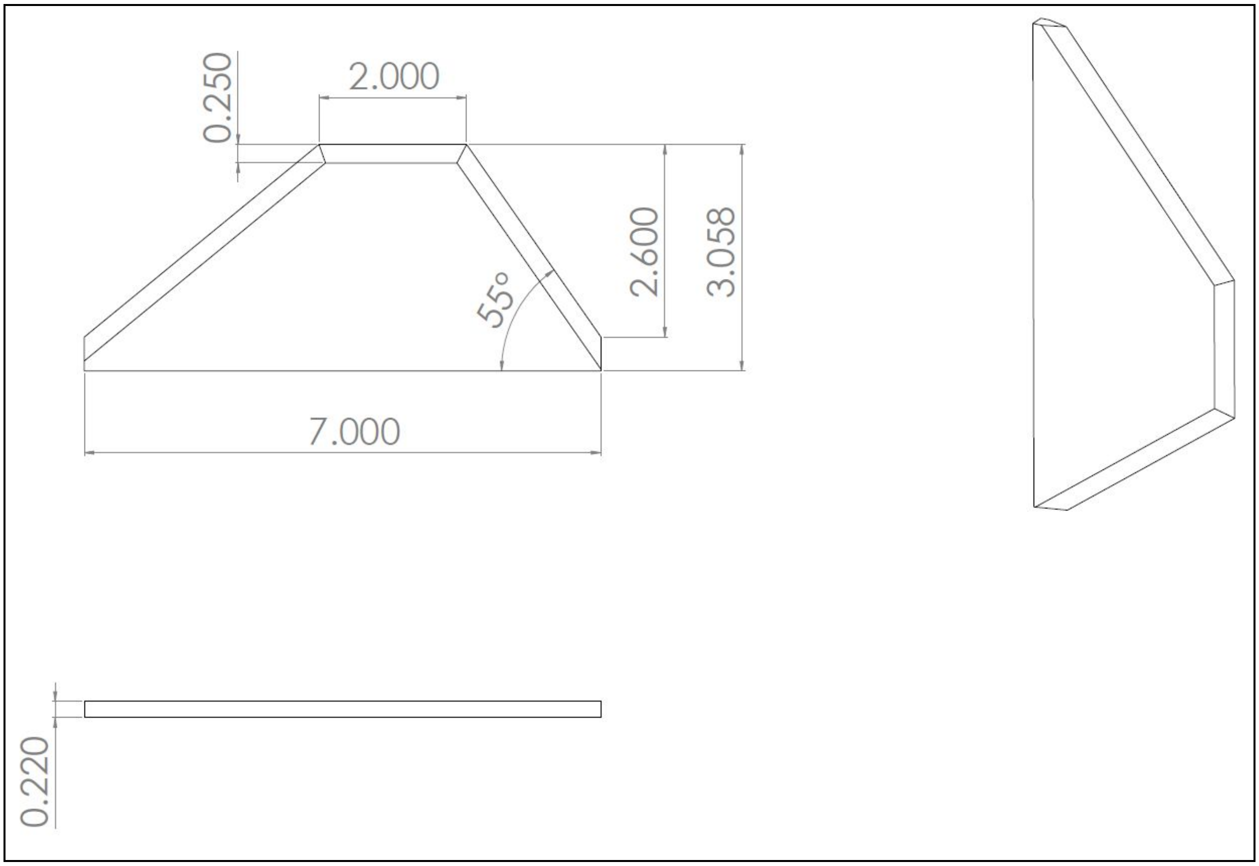

Figure 2: Fin Detailed Drawing

Recovery Drawings

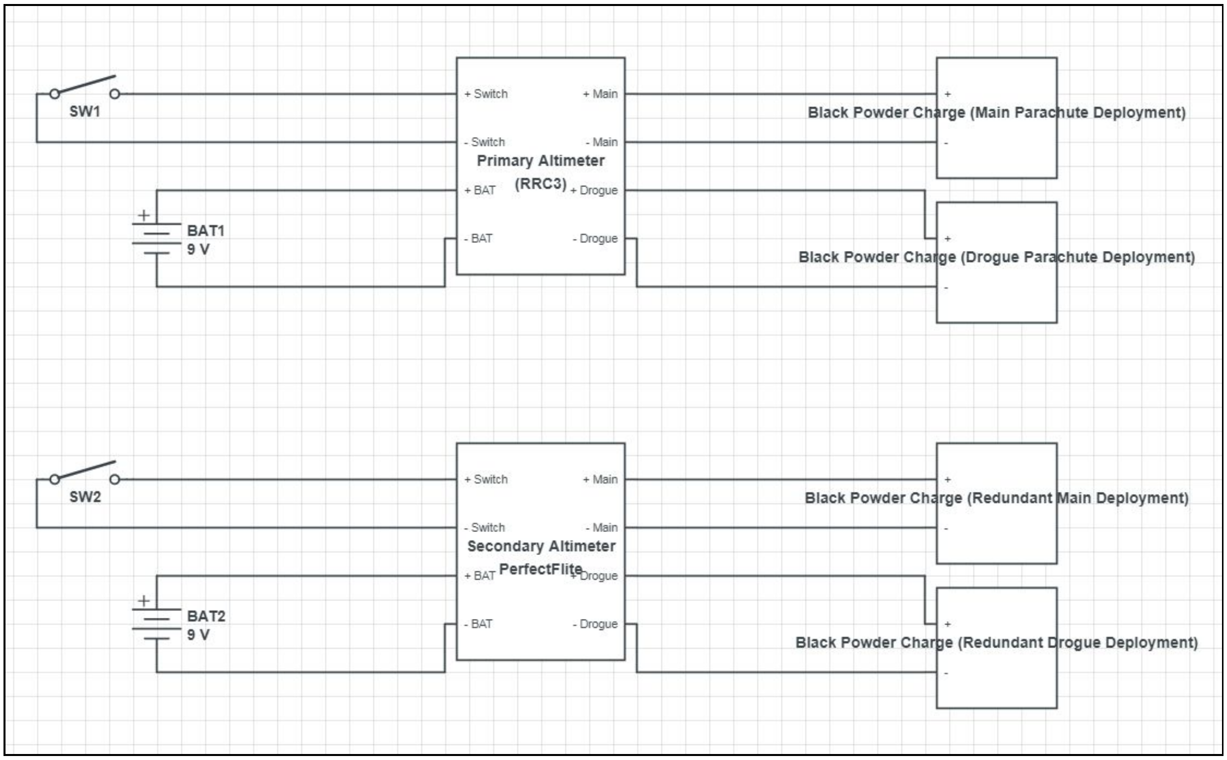

Figure 3: Recovery Circuits

Structures Drawings

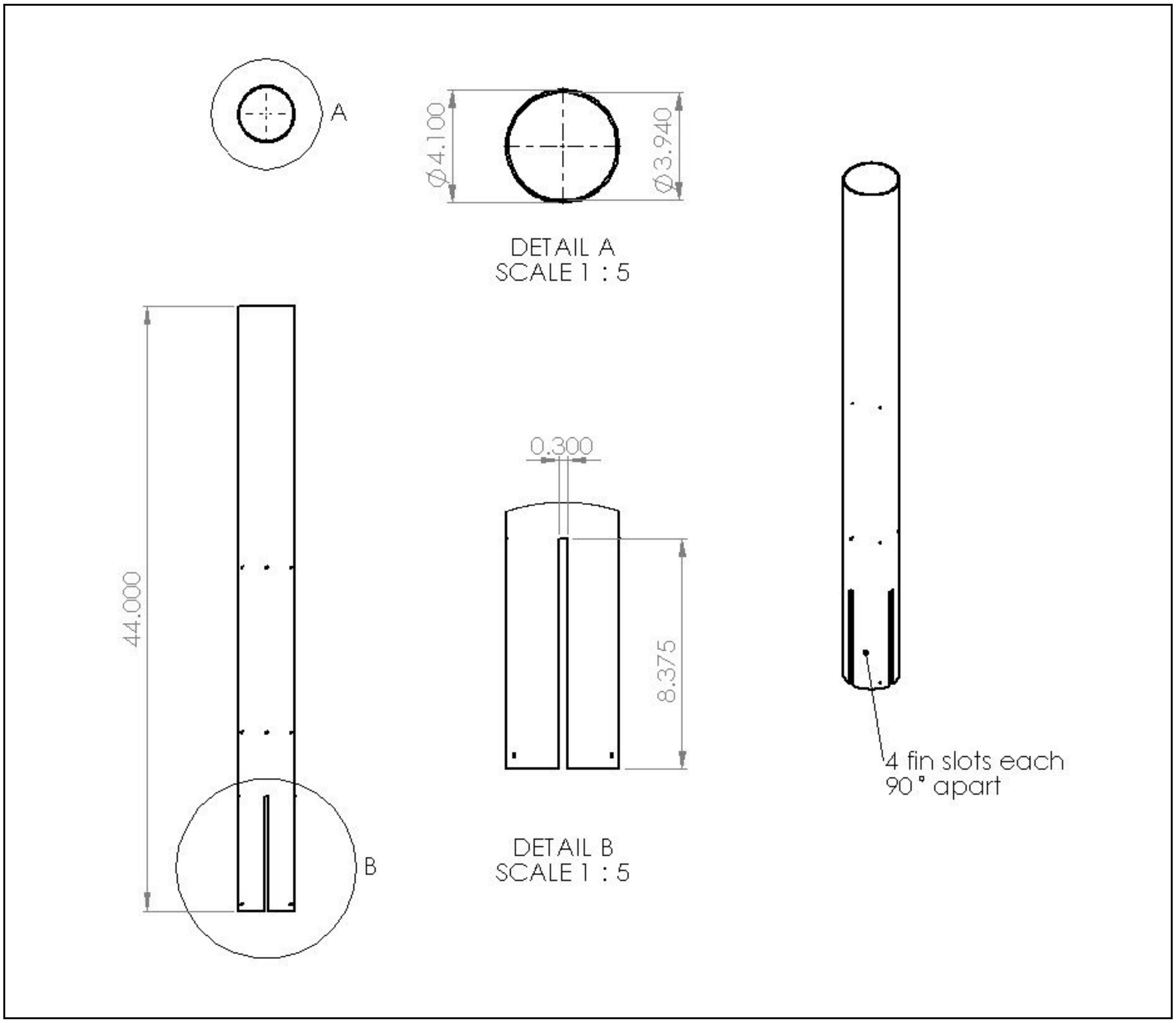

Figure 4: Lower Body Tube Detailed Drawing

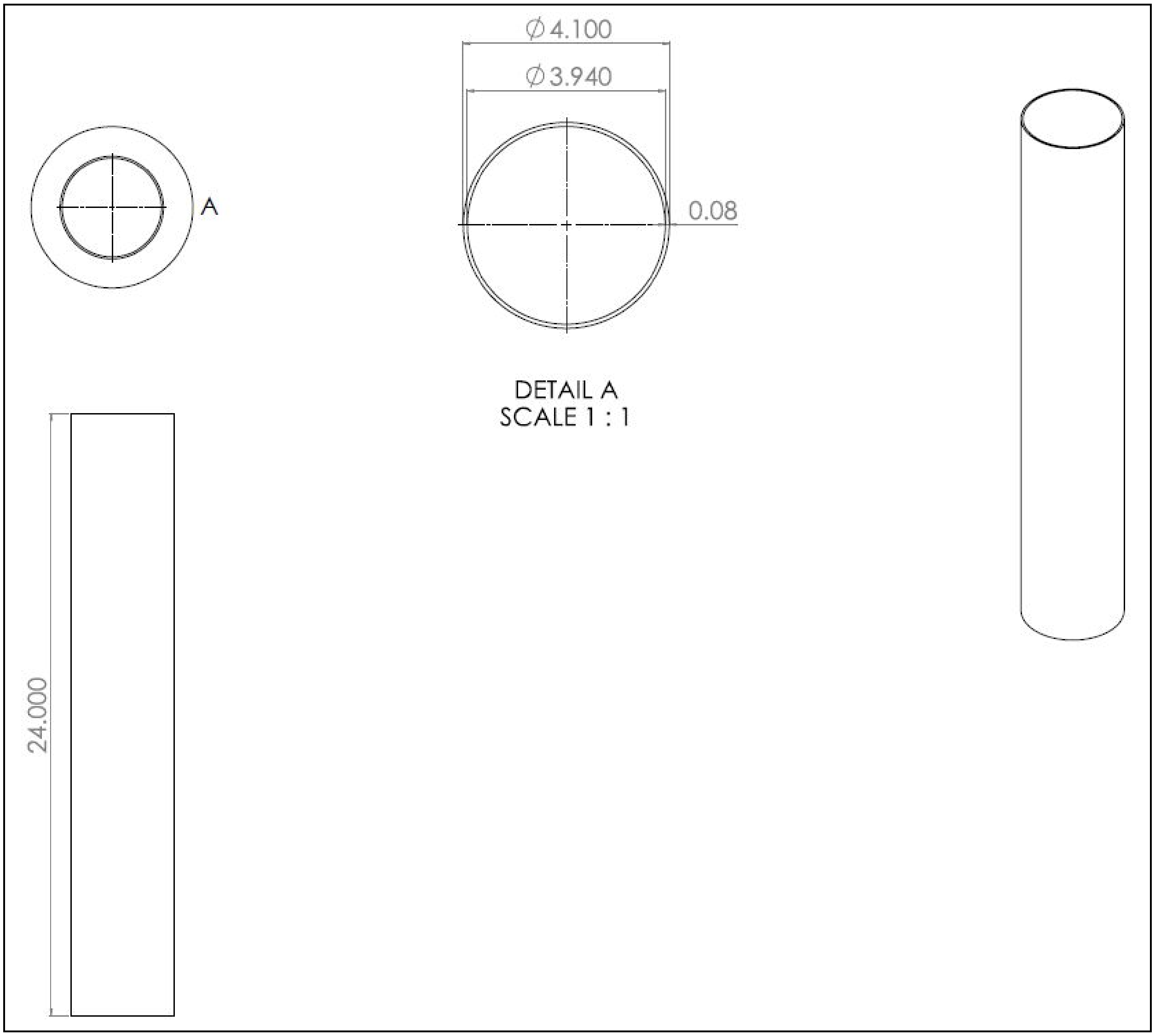

Figure 5: Upper Body Tube Detailed Drawing

Section VI: References

1.Carbon fiber material properties, assuming standard carbon fiber fabric:
www.performance-composites.com

2.Braided kevlar shock cord properties:
https://www.amazon.com/emma-kites-Braided-Creative-Projects/dp/B01850OST0/ref=redir_mobile_desktop?_encoding=UTF8&dpID=51O1akR5TfL&dpPl=1&keywords=kevlar%2Bshock%2Bcord&pi=AC_SX236_SY340_QL65&qid=1527202878&ref=plSrch&ref_=mp_s_a_1_1&sr=8-1&th=1&psc=1

3. 9/16” Tubular Nylon Shock cord properties: https://www.madcowrocketry.com/tubular-nylon-9-16/

4. Ultimate tensile strength of steel:
https://www.engineeringtoolbox.com/engineering-materials-properties-d_1225.html

5. Carbon fiber material properties: https://www.engineeringtoolbox.com/polymer-composite-fibers-d_1226.html

6. US pressure data by altitude: https://www.engineeringtoolbox.com/standard-atmosphere-d_604.html

7. Missile Works RRC3 User Manual:
https://www.missileworks.com/app/download/965482691/RRC3+User+Manual+v1.60.pdf

8. Nylon screw max shear load:
http://www.rocketryfiles.com/files/FlightSimulation/BP_sizing/Black%20Powder%20Sizing.htm

9. Equation for shock cord stress:
http://www.cusf.co.uk/category/rocket-calculations/

Spaceport America Cup

Intercollegiate Rocket Engineering Competition

Entry Form & Progress Update

Color Key — Student — v18.1

Must be completed accurately at all time. These fields mostly pertain to team identifying information and the highest-level technical information.

Should always be completed "to the team's best knowledge" , but is expected to vary with increasing accuracy / fidelity throughout the project.

May not be known until later in the project but should be completed ASAP, and must be completed accurately in the final progress report.

Date Submitted: 5/25/2018

Country: United States

Team ID: 92 — * You will receive your Team ID after you submit your 1st project entry form.

State or: Texas

State or

Team Information

Rocket/Project Name:	Noctua
Student Organization Name	Rice Eclipse
College or University Name:	Rice University
Preferred Informal Name:	Eclipse
Organization Type:	Club/Group
Project Start Date	10/1/2017
Category:	10k – COTS – All Propulsion Types

Projects are not limited on how many years they take

Member	Name	Email	Phone
Student Lead	Andre Sushchenko	as153@rice.edu	609-334-0639
Alt. Student Lead	Jeremy Palmer	jjp6@rice.edu	908-514-5849
Faculty Advisor	Kazimir Karwowski	karwowski@rice.edu	713-348-2359
Alt. Faculty Adviser			

For Mailing Awards:

Payable To:	Sam Zorek
Address Line 1:	6350 Main St.
Address Line 2:	Houston, TX 77005
Address Line 3:	
Address Line 4:	
Address Line 5:	

Demographic Data

This is all members working with your project including those not attending the event. This will help ESRA and Spaceport America promote the event and get more sponsorships and grants to help the teams and improve the event.

Number of team members

High School	0	Male	15
Undergrad	15	Female	0
Masters	0	Veterans	0
PhD	0	NAR or Tripoli	Tripoli

Just a reminder the you are not required to have a NAR, Tripoli member on your team. If your country has an equivelant organization to NAR or Tripoli, you can cant them in the NAR or Tripoli box. CAR from Canada is an example.

STEM Outreach Events

- Ran rocket day for local Boy Scouts and Cub Scouts to launch hobby rockets and earn a merit badge
- Mentored two groups of high school students through their rocketry projects
- Spoke to middle school students visiting Rice to learn about studying STEM
- Presented at the Houston Maker Faire

Rocket Information

Overall rocket parameters:

	Measurement	Additional Comments (Optional)
Airframe Length (inches):	83.75	
Airframe Diameter (inches):	4	
Fin-span (inches):	3	
Vehicle weight (pounds):	13.8	

Propellent weight (pounds):	11	
Payload weight (pounds):	8.8	
Liftoff weight (pounds):	33.6	
Number of stages:	1	
Strap-on Booster Cluster:	No	
Propulsion Type:	Solid	
Propulsion Manufacturer:	Commercial	
Kinetic Energy Dart:	No	

Propulsion Systems: (Stage: Manufacturer, Motor, Letter Class, Total Impulse)

```
COTS Format - [Stage1]: [Aerotech],      [L1170FJ-P],  [L], [4214Ns]
```

Total Impulse of all Motors: 4214 (Ns)

Predicted Flight Data and Analysis

The following stats should be calculated using rocket trajectory software or by hand.

Pro Tip: Reference the Barrowman Equations, know what they are, and know how to use them.

	Measurement	Additional Comments (Optional)
Launch Rail:	ESRA Provide Rail	
Rail Length (feet):	17	
Liftoff Thrust-Weight Ratio:	8.22	
Launch Rail Departure Velocity (feet/second):	95.1	
Minimum Static Margin During Boost:	1.77	*Between rail departure and burnout
Maximum Acceleration (G):	9.39	
Maximum Velocity (feet/second):	845	
Target Apogee (feet AGL):	10K	
Predicted Apogee (feet AGL):	9258	

Payload Information

Payload Description:

The scientific payload has been selected in collaboration with the Lou Lab Group at Rice university. The payload consists of non-toxic and non-volatile 2-D crystals of iron oxide that have been grown through the process of chemical vapor deposition. These crystals have immense value in the field of 2-D magnetism. Current challenges of the field are demonstrating room temperature at the 2-D regime. These crystals are an attempt at solving getting closer to bridging this gap between 2-D materials and magnetism.

The aim of this payload is to the test the phase stability of these crystals under the pressures, temperatures and inertial forces that the crystals will experience over the flight of the rocket.

All scientific payload setup will be housed inside nose cone. Sensors and petri dishes containing crystals will be strapped down onto a wood slide that is fixed in nose cone.

Recovery Information

Recovery mechanism: one drogue and one main, altimeter triggered black powder capsule for parachute release.
COTS Altimeters for dual deployment and altitude recording: RRC3, StratoLogger altimeter, with separately wired E-matches to ensure redundancy. They will be placed in the rocekt's coupler.
GPS: TeleGPS. It will be implemented in the nose cone avionics bay to prevent carbonfiber from blocking the signal.
Aiming for 6.5m/s ground impact speed:
Main parachute size: 96in
Drogue chute size: 36in
Black powder usage: 1.8g for drogue separation, 2g for main deployment

Planned Tests

* Please keep brief

Date	Type	Description	Status	Comments
1/28/18	Ground	Black powder test	Minor Issues	Target: find optimal amount of black powder needed for recovery system. Experimental calculation were off and thus calibrated.
2/3/18	In-Flight	Structure & simulation test	Major Issues	Target: test retractable rail buttons on pre-existing rocket flights and measure altitude and gps to compare to our custom simulations. Retractable rail button was not finished in time, some simulation results were lost due to avionics issue.
3/10/18	In-Flight	First prototpye testing	Minor Issues	Launched with J class motor; Carbonfiber body tube; Preliminary Avionics. Recovery system failure. Debugged recovery system after failed deployment.
4/2/18	Ground	Retractable rail guide test	Successful	Fly-away rail guide was tested with 3D printed launch rail. Successful detachment and guidance under light weight. Does not support large weights
4/11/18	Ground	Various avionics test: GPS, altimeters	Successful	GPS and altimeter in nose cone both functional.

4/14/18	In-Flight	Full-size prototype testing	Successful	Launched on K class motor; Full size carbon fiber body tube; Full Avionics. All system performed as expected. Excessive weathercocking was observed.

Any other pertinent information:

Please help us to help you, by filling this box out as completely as possible. The more information we have the better we can help you.
(Tip: [Alt] + [Enter] for new line)

End of File

Rice Eclipse SA Cup 2018 - Hazard Assessment Matrix

											Post-Mitigation Analysis (See Mitigation Plan for Rationale)	
Number	Hazard	Cause(s)	Effect(s)	Probability of Occurance (1-5) & Rationale	Personnel Severity (0-5) & Rationale	Equipment Severity (1-5) & Rationale	Personnel Risk Index (Probability * Severity)	Equipment Risk Index (Probability * Severity)	Acceptable?	Mitigation Plan	Personnel Severity (0-5) With Mitigation Plan	Equipment Severity (1-5) With Mitigation Plan
1	Solid motor ignites during transporation to the launch site	Igniter is left in the motor during transport, and igniter comes into contact with a battery; fire in the car	Motor emits hot exhaust gases and flame; risk of burning equipment and people	1 Motor is packaged inside a containment cylinder to prevent contact with ignition sources	4 Severe burns due to exhaust gases likely; exhaust gases will expand to area around motor, so large hazard area	4 Motor exhaust gases can burn, melt, or otherwise thermally damage nearby equipment in the pickup truck bed or trailer bed	4	4	Yes	Motor used for the rocket will be bought on-site at the launch, rather than transported by Eclipse team members, which removes this failure mode from the team's operations	0	1
2	Solid motor ignites during assembly of the rocket	Ignition sources (ex. ignitiers, batteries, flammable chemicals, lighters, live wires) present near the rocket assembly table come into contact with the motor's fuel grain	Hot, high-pressure exhaust gases from motor can damage equipment and hurt Eclipse team members; if motor is loaded into rocket's motor mount, the rocket could shoot forward at high velocity and injure people downrange	1 The solid motor must come into direct contact with an active ignition source in order for this event to occur	5 Exhaust gas will severely injure Eclipse team members assembling the rocket; people downrange of the rocket will be severely injured if the rocket impacts them	4 The gas and flame emitted from motor could burn and deform other necessary rocket components	5	4	Yes	All possible ignition sources will be removed from the table where the rocket is assembled; integrating the motor with the rocket's motor mount is on of the the last steps in the assembly procedure; igniter won't be inserted into the motor until the rocket is mounted on the launch rail	1	1
3	Solid motor fuel grain ignites during assembly of motor	Ignition sources (ex. ignitiers, batteries, flammable chemicals, lighters, live wires) present near the rocket assembly table come into contact with the motor's fuel grain	Hot, high-pressure exhaust gases from motor can damage equipment and hurt Eclipse team members	1 The solid motor must come into direct contact with an active ignition source in order for this event to occur	5 Exhaust gas will severely injure Eclipse team members assembling the motor	4 Motor will be unusable if the fuel grain is ignited and spent before the flight	5	4	Yes	All possible ignition sources will be removed from the table where the motor is being assembled	1	1
4	Solid motor fuel grain damaged, cracked, or crushed during assembly of motor	Heavy equipment or tools are dropped on the motor fuel grains while the motor is being assembled; motor fuel grains are dropped from a large height; motor fuel grains are damaged while being inserted into motor	Fuel grains can no longer be used in the motor; possibility of propellant fragments or powder being ejected from the motor to the assembly area, which poses a fire hazard	2 Nature of motor assemby demands direct handling of fuel grains, but careful handling can reduce much of the risk	3 Fragments of solid propellant are a fire risk to Eclipse members if not immediately located and cleaned up	4 Motor will be unusable if the fuel grain is damaged	6	8	Yes	Motor will be assembled on a table clear of any heavy objects that can damage the fuel grains; Eclipse members will assemble the motor carefully to so the grains aren't dropped or otherwise impacted with a large force	1	1
				1	3	3				Black powder charges in the		

5	Black powder ignites during transportation to launch site	Ignition sources (ex. ignitiers, batteries, flammable chemicals, lighters, live wires) are stored with the black powder during tranportation and ignite	Black powder capsules explode; can injure Eclipse members nearby or damage equipment being transported near the black powder container	Under existing safety regulations, ignition sources are never stored with the black powder during transportation	Exploding black powder capsules will injure Eclipse members if transported near people	Black powder will be wasted before the launch; exploding black powder capsules could damage nearby equipment due to concussive force of the explosion	3	3	Yes	Black powder charges in the rocket itself won't be loaded with black powder until the final assembly; black powder is transported to the launch site in small, separate, sealed capsules to minimize the chance and magnitude of an accidental explosion; these capsules will be attached to the site of a vented container so an accidental explosion can be safely controlled	1	1
				1	4	3						
6	Altimeters trigger ignition of the black powder charges during assembly of the rocket	Altimeters are prematurely attached to the wire leads of the black powder charges; altimeters are turned on and a sudden pressure decrease or an altimeter malfunciton causes the ignition signal to be sent pre-flight	Black powder capsules explode; force and hot gases from explosion will injure Eclipse members assembling the rocket; explosion could launch a segment of the airframe or a coupler away from the rocket at high speed. injuring anyone downrange	Pre-launch procedures dictate that the rocket's avionics systems won't be turned on until the rocket is mounted on the launch rail	Exploding recovery charges will eject hot gas, airframe segments, and couplers at high speeds, which will injure any Eclipse members in the way	Recovery system charges will have to be replaced; possible damage to parachutes, shock cords, avionics bay, and payload	4	3	Yes	Black powder charges in the rocket itself won't be loaded with black powder until the final assembly; all avionics switches will be turned off until the rocket is mounted on the launch pad to stop any false ignition signals due to electronics malfunctions	1	1
				1	5	3						
7	Black powder used for recovery system charges ignites while being loaded into the charge capsules on the rocket	Ignition sources (ex. ignitiers, batteries, flammable chemicals, lighters, live wires) are stored black powder charges during rocket assemby.	Black powder ignites fuel grain, resulting in the rocket firing prematurely, which could cause damage to team members and other equipment	Assembly procedures require that all ignition sources are removed from the assembly area when the black powder is poured into the charge capsules	Black powder container will be in the hands of an Eclipse member while loading, so accidental ignition will cause severe burns or tissue damage to fingers and hands	Black powder explosion will release hot gas that could damage the airframe, parachutes, shock cords, avionics bay, or payload of the rocket	5	3	Yes	Loading black powder into the recovery system's capsules will be one of the last steps of the assembly procedure; black powder will be loaded on a table clear of any possible ignition sources by a trained Eclipse member	2	1
				2	2	4						
8	Rocket airframe crushed by other equipment during transportation to launch site	Equipment not secured properly within rocket or truck bed, rough terrain during transportation	Unable to use airframe, resulting in inablility to participate in competition	Rocket airframe will be secured in-place inside the transportation vehicle, and will be packed away from any heavy equipment that could damage it	Crushed or cracked carbon fiber composite tubes will expose raw carbon fiber and release microfibers into the air, which can irritate skin and respiratory passages without proper protective equipment	Rocket airframe would be unusable, and the rocket could not be launched at the competition	2	8	Yes	Airframe will be stored securely and will not be stored underneath any other components.	0	2
				1	4	5						

9	Driver falling asleep at wheel	Lack of sleep or stimulation	Possible accident; damage to drivers, passengers, and equipment	Trip to New Mexico will be planned with adequate rest stops, and all vehicles will have passengers to monitor the drivers	Transportation vehicle will got out of control and a crash could severly injure Eclipse members	Transportation vehicle will go out of control, and a crash would damage necessary equipment and rocket components beyond repair	4	5	Yes	There will be a passenger in the car with the driver at all times to ensure alertness. Additionally, the driver will take adequate breaks to avoid exhaustion.	2	1
10	Forgetting necessary equipment	Lack of preparation	Unable to participate in competition	1 Equipment checklists will be prepared pre-departure to verify that all parts and equipment are accounted for	0 Lack of equipment doesn't pose a direct hazard to the health and safety of Eclipse members	4 Missing equipment will render the rocket unusable unless replacement tools or components can be found	0	4	Yes	Following extremely detailed SOP with itemized list of travel materials	0	1
11	Transportation vehicle involved in a car crash during transportation to launch site	Inattentive or unsafe driving practices	Damage to driver, passengers, and equipment	2 Vehicle drivers will be experienced and well-rested because of planned rest stops, but uncontrollable external variables like weather and other drivers leave open the possiblity	5 Crash could severely injure or kill Eclipse members in the vehicle	5 Crash will damage equipment necessary for the rocket likely beyond repair; unable to participate in the competition	10	10	Yes	Driver employs safe and cautious driving practices, passengers assist driver in navigation	2	2
12	Equipment falls out of the vehicle while under way to launch site	Equiment not properly secured to truck bed	Unable to participate in competition	1 Equipment will be restrained with ratchet straps or placed in secured containers, so these security measures will have to fail for anything to fall out	0 Equipment falling out of the vehicle doesn't pose a direct hazard to the health and safety of Eclipse members	5 Any equipment that falls out of the vehicle will likely be damaged beyond repair and could damage other vehicles on the road	0	10	Yes	Use rachet straps and containers to properly store equipment and ensure that no loose materials are present in the truck bed.	0	1
13	Transportation vehicle gets a flat tire or breaks down en route to the launch site	Uneven terrain, excessive speed while driving	Unable to transport rocket to launch site	1 Vehicles and tires used for the trip will be well-maintained and in good condition before departure	0 Assuming the vehicle can be safely brought to the side of the road, a breakdown doesn't directly threaten the health and safety of Eclipse members	3 Transportation vehicle itself is necessary equipment for the competition; if it breaks down and isn't repariable in time, Eclipse cannot particpate in the competition	0	3	Yes	Take two cars to the launch site, bring spare tires and emergency kit; all vehicles will have at least one cell phone to call other vehicle or a towing service for help	0	1

				1	1	5						
14	Theft of equipment during transportation	Equiment not properly secured and locked in truck bed and rocket trunk	Unable to participate in competition due to lack of necessary equipment	Equipment and the vehicle will be secured against theft; vehicles will only stop at pre-determined safe rest locations	Theft isn't a direct hazard to Eclipse members, but someone could be injured if they are in the vehicle during a robbery	Necessary equipment will be missing, which will prevent participation in the competition unless it is replaced	1	5	Yes	Lock valuable equipment in trunk of vehicle and cover equipment when unable to transport it inside the vehicle so that it is not visible	1	3
				3	1	1						
15	Cars become separated en route from Houston to launch site	Lack of communication between vehicle, different driving speeds	Unsure of location of other rocket	Traffic patterns and different driving styles will likely separate the transportation vehicles for brief periods during the trip	Vehicle seperation isn't a direct risk to Eclipse members as long as it is for a short period and the other vehicles are aware of their location	Vehicle seperation isn't a direct risk to the rocket or support equipment	3	3	Yes	Passengers of each vehicle will be in communication with each other over phone as necessity dictates for the entire drive	0	1
				1	5	5						
16	Propane tank (for use with portable grill) vents gas during transportation to launch site or during use	Propane tank is damaged during transportation; propane tank valve is accidentally left open	Propane gas could explode in either the truck bed or during use, causing injury to team members and damage to equipment	Propane tank will be properly secured and inspected before transportation and during use to make sure the correct valves are closed and no leaks are present	Gas tank explosion will severely injure or kill Eclipse members nearby	Gas tank explosion will damage nearby equipment or the transportation vehicle beyond repair	5	5	Yes	Propane will be transported in the truck bed and secured to the vehicle. While at the launch site, the propane will be out of direct sunlight and away from equipment	1	1
				3	3	1						
17	Dehydration while team searches for rocket after launch or while assembling the rocket	Not bringing sufficient quantity of water, extended exposure to extreme heat	Discomfort of team members	Extreme desert temperatures mean dehydration is likely, though sun safety measures and adequate hydration will act as safeguards (see Mitigation Plan)	Dehydration can cause long-term health problems for Eclipse members if left untreated, and prevent them from participating in the competition	Dehydration could mentally impair Eclipse members and cause misuse of equipment	9	1	Yes	Team members will bring hats, sunglasses, and sunscreen. They will also assemble two pop-up canopies at the launch site to provide shade and bring two 10-gallon coolers filled with bottled water to ensure hydration.	2	1
				2	5	1						

18	Heat stroke while team searches for rocket after launch	Not bringing sufficient quantity of water, extended exposure to extreme heat	Possible illness or death of team members	Extreme desert temperatures make heat stroke likey, though less likely than dehydration; sun safety mesures and adequate hydration will act as safeguards (see Mitigation Plan)	Heat stroke can severely injure or even kill Eclipse members if left untreated, and will prevent them from participating in the competition	Heat stroke will mentally impair affected Eclipse members and could cause misue of equipment	5	1	Yes	Team members will bring hats, sunglasses, and sunscreen. They will also assemble two pop-up canopies at the launch site to provide shade and bring two 10-gallon coolers filled with bottled water to ensure hydration.	3	1

Risk Indexing Matrix

		Probability of Occurance				
		1	2	3	4	5
Severity	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	6	9	12	15
	4	4	8	12	16	20
	5	5	10	15	20	25

Key:	
19-25	Unacceptable
14-18	Undesirable: Written and reviewed decision required to proceed
6-13	Acceptable upon completion of quality assurance review
1-5	Acceptable without review

Equipment Severity Scoring Key

Severity Rating	Failure Effect
1	Minor malfunction; easily resolved or quickly fixed at test site
2	Malfunction fixable at test site, but will delay engine test and assembly

Personnel Severity Scoring Key

Severity Rating	Failure Effect
0	Failure mode is present, but only affects engine performance during test and poses no physical danger to members present
1	Extremely minor risk to Eclipse members; even minor physical injuries are extremely unlikely

Probability Scoring Key

Probability Rating	Probability of Occurance
1	Extremely unlikely; failure mode will not occur based on safety factors calculated during design review
2	Unlikely; engine system designed to prevent failure, but failure mode is dependent on a variable that cannot be completely controlled during test

3	Testing procedures must cease and malfunctioning system must be reevaluated before test can continue	2	Minor risk to Eclipse members; any physical injuries easily treatable at test site using Eclipse first aid kit	3	Possible; external variables affecting failure mode can't be fully controlled
4	Engine test must be ended prematurely	3	Moderate risk to Eclipse members; risk is contained by safety protocols in place	4	Probable; more likely than not to occur during a test
5	Engine test must be terminated, and likely damage to engine systems	4	Major risk to Eclipse members; failure could cause severe injury	5	Extremely likely; will almost certainly happen during a test
		5	Failure mode will cause severe injury to Eclipse members; existing safety protocols cannot fully contain failure effects; emergency services must be contacted if failure occurs and causes severe injury		

Rice Eclipse SA Cup 2018 - Risk Assessment Matrix & FMEA

Number	Potential Failure Mode	Cause(s)	Effect(s)	Probability of Occurance (1-5) & Rationale	Personnel Severity (0-5) & Rationale	Equipment Severity (1-5) & Rationale	Personnel Risk Index (Probability * Severity)	Equipment Risk Index (Probability * Severity)	Acceptable?	Mitigation Plan	***Post-Mitigation Analysis (See Mitigation Plan for Rationale)*** Personnel Severity (0-5) With Mitigation Plan	Equipment Severity (1-5) With Mitigation Plan
Pre-Flight												
SEE HAZARD ASSESSMENT MATRIX												
General (Could Occur Throughout Flight Plan)												
1	Payload retaining structures are damaged or break during flight (most likely during: boosting, parachute deployment, or ground impact)	Rocket experiences greater than expected acceleration or deceleration due to trajectory instability, sudden impact, parachute deployment; payload retainers designed with inadequate factor of safety	Petri dishes of crystal samples will break loose in the coupler; possible damage to crystal samples, invalidating the experiment	1 Payload retainers designed with ample factor of safety, in case the rocket experiences extreme forces due to off-nominal flight events	0 Payload damage poses no direct risk to Eclipse team members or other personnel	3 Damaged retainers will likely damage the payload itself and invalidate the experiment; retainers will have to be repaired or replaced before next flight	0	3	Yes	Payload retainers are designed with sufficient factor of safety to survive extreme forces due to sudden velocity changes; crystal samples are also secured inside petri dishes for added protection	0	1
2	Avionics batteries become dislodged from their clips during flight (most likely during: boosting, parachute deployment, or ground impact)	Sudden velocity changes or extreme forces on the rocket due to off-nominal flight events (ex. early parachute deployment) knock batteries loose; batteries are incorrectly installed during assembly of avioincs bay	Altimeter connected to that battery becomes inactive, disabling the primary or backup recovery system black powder charges; if all batteries are dislodged, rocket's recovery system becomes inoperative	1 Standard 9-volt battery clips aren't designed to withstand forces expected by rocket during flight, but added steel brackets will hold batteries in place as long as the avionics bay is structurally intact	2 Dislodged batteries will affect rocket's recovery system; one dislodged battery will be compensated for by the redundant altimeter, but two dislodged batteries could put rocket on ballistic trajectory, endangering everyone downrange	2 Dislodged batteries will affect rocket's recovery system; if both batteries dislodge, the rocket won't have a functioning recovery system and will impact ground ballistically or at high velocity, causing damage	2	2	Yes	Batteries are secured in place with steel brackets as well as battery clips; rocket has a redundant avionics system (battery, altimeter, and switch) wired to a redundant set of black powder charges, so both batteries will have to dislodge to deviate rocket from flight plan	1	1
				2	2	2				Wires used are		

3	Avionics wiring is severed during flight (most likely during: boosting, parachute deployment, or ground impact)	Sudden velocity changes or extreme force on rocket due to off-nominal flight events (ex. ballistic ground impact) severs avionics wiring or rips wiring from avionics terminals; wiring becomes tangled with itself or other internal structures in the rocket; wires improperly screwed or soldered into terminals	One or more recovery system black powder charges will become inactive; rocket has redundant drogue and main parachute charges, but if both primary and redundant charges for a parachute fail, that parachute won't deploy (see Drogue & Main Parachute Deployment sections of this matrix for analysis of failed parachute deployment)	Wires used are thick-enough gauge to prevent severing unless rocket's airframe fails catastrophically; all wire connections and terminals are secured with either solder or screw terminals	Severed wiring will affect rocket's recovery system; depending on wires cut, one or more of the rocket's parachutes could fail to deploy, posing a danger to anyone near the rocket at ground impact	Severed wiring will affect rocket's recovery system; depending on wires cut, one or more of the rocket's parachutes could fail to deploy, causing damage to the rocket or other nearby equipment due to high-velocity ground impact	4	4	Yes	Wires used are thick-enough gauge to prevent severing from expected forces during flight plan; all wire connections are secured using solder or screw terminals; wires are clipped together and organized on a main channel along the rocket's body to prevent tangling or pinching; wires are run through the rocket body with enough slack to limit tension on wires during flight or parachute deployment	1	1
				1	3	2						
4	Black powder capsules crack or open during flight	Sudden velocity changes or extreme force on rocket due to off-nominal flight events (ex. ballistic ground impact) fractures the plastic capsule, breaks off the cap, or rips out the igniter epoxied in the bottom of the capsule	Cracked black powder capsule could become inactive if enough black powder leaks out; leaked black powder will distribute inside the rocket airframe segments, including into parachute; loose black powder could ignite later or more slowly after avionics trigger recovery charge ignition, burning parts of the airframe and recovery system, impairing rocket's descent	Black powder capsule's plastic and epoxy is strong enough to withstand forces if rocket's flight plan goes off-nominal, proven by prototype test flight experience	Loose black powder could damage rocket's parachutes if ignited, causing the rocket to descend unstabily and at high velocity, endangering anyone near the ground impact site; loose black powder in rocket's airframe is a safety hazard to the recovery team	Loose black powder could burn or otherwise damage rocket's parachutes and the inside of airframe segments	3	2	Yes	Black powder charges sit inside plastic housings on coupler bulkheads to protect them from impact and direct the shockwave after ignition; capsule design is flight-proven to withstand extreme forces caused by unexpected flight conditions like high-velocity ground impact	1	1
						Mounting Rocket						
				1	0	2						

1	Rail buttons do not align with launch rail	Launch rails not correctly measured; user error in drilling rail button holes	Rocket cannot be mounted to launch rail and therefore cannot be launched	Without prior access to the launch rail, it is possible that the buttons do not align with the rail provided, but is unlikely	Team members are not directly endangered by this failure	The rail button holes must be redrilled, causing a change in the aerodynamics of the body tube, as well as creating open holes	0	2	Yes	Measure the line where the holes will be drilled multiple times to ensure the lines will be straight and therefore will align with the rail guide	0	1
				1	4	3						
2	Recovery system black powder charges ignite while mounting the rocket	Altimeter calibrated incorrectly, black powder is exposed to an ignition source (ex. igniters, batteries, flammable chemicals, lighters, live wires)	Drogue and/or main parachutes deploy prematurely; rocket airframe segments forcibly separate apart, possibly causing injury to team members; rocket rendered unusable until recovery system and black powder charges are repacked	Avionics programming will be inspected and verified before turning on altimeters; black powder charges are protected and secured inside rocket airframe; launch rail is located in an isolated area away from any ignition sources, save for the launch controller leads	Black powder explosions near Eclipse team members or other personnel will likely cause injury, either from the hot gases, shockwave, or ejected airframe segments	Premature black powder ignition could damage rocket's rail buttons, recovery system, or launch rail; black powder and recovery system will have to be repacked before rocket launches	4	3	Yes	Avionics switches won't be turned on until the end of the Systems Check, after the rocket is fully mounted on the launch rail and oriented vertically, minimizing the likelihood and impact of an accidental ignition; launch controller wire leads will be kept away from the interior of the rocket's airframe	2	2
				1	2	3						
3	Rocket falls from launch rail during or after mounting	Rail buttons not fully secured to launch rail; sudden wind gust or other perturbation of launch rail	Falling rocket could cause damage to components and injury to nearby team members; rocket might remain connected to launch controller, opening possibility of an accidental horizontal launch	Rail buttons will be attached securely to rocket body tube and unlikely to detatch	Could fall and hit team members mounting rocket, but not inflict serious damage due to relative light weight of rocket; greater risk of injury if fallen, horizontal rocket's motor igniter remains wired to launch controller	Fall could cause damage to body tube and internal structures such as avionics	2	3	Yes	Carefully secure the rail buttons using a screwdriver and manually test the security of rail buttons after installation; multiple rail buttons provide redundancy	1	1
				1	5	4						

4	Solid-propellant rocket motor (hereafter refered to as the "motor") ignites while rocket is being mounted and handled by Eclipse team members	Ignition source (ex. live igniter, electrical leads from launch controller, spark, flammable chemicals, etc.) comes into contact with motor fuel grain during mounting process	Eclipse team members or other personnel handeling the rocket will be injured by the motion of the rocket body or the motor's exhaust gases; possibility of an unstable trajectory if the rocket isn't fully mounted on the launch rail during ignition	Only motor ignition source present will be the igniter wired to the launch controller; launch controller contains electrical safety switches to prevent accidental ignition during mounting	Any personnel injuries will be severe due to proximity to the motor's exhaust gases and the high speed of the rocket; unstable rocket could fly into nearby crowds an injure onlookers; rocket motor burn cannot be stopped until fuel is expended	Unstable trajectory off the launch rail will cause severe damage to the rocket if it impacts the ground or anything else at high velocity	5	4	Yes	Launch rail will be isolated from any possible ignition sources beyond the launch controller wire leads; Eclipse members mounting the rocket will wear protective equipment, including safety glasses; inserting and wiring the motor's igniter won't occur until last step of Systems Check, so risk of accidental ignition with team members present is minimized; launch controller contains electrical safety switches to prevent accidental ignition during mounting	1	1
Systems Check												
1	Motor ignites during systems check	Motor comes in direct contact with an ignition source, such as ignitiers, batteries, flammable chemicals, lighters, or live wires; ignition signal is sent to launch controller early	Motor emits hot exhaust gases and flame in attempt to propel rocket; risk of burning nearby equipment and people performing systems check and final inspection of rocket	1 Motor's igniter won't be inserted until the last step of the system's check, after all other rocket components and avionics are verified to be functional	5 Any personnel injuries will be severe due to proximity to the motor's exhaust gases and the high speed of the rocket	4 Avionics systems might not be activated or verified before motor ignition, rendering parts of the rocket's recovery system inactive, causing possible damage to rocket upon ground impact	5	4	Yes	Inserting and wiring the motor's igniter is the last step of the systems check, after the avionics have been activated and and verified; launch rail is isolated from accidental ignition sources and launch controller contains electronic safety switches to prevent accidental ignition	1	1

2	Explosion of the motor during systems check	Motor ignites prematurely during systems check (see Systems Check Failure Mode #1), and motor is damaged due to manufacturing error or Eclipse team member error, including: cracks in fuel grain, fuel grain piece becoming disoldged and clogging the nozzle, fuel grain debonds with phenolic liner, motor casing structural failure, or gaps between propellant fuel grain segments	Motor explosion will catastrophically damage the rocket's airframe, preventing the launch; motor explosion will severely injure any Eclipse members or personnel near the rocket performing systems check and final inspection	1 Motor explosion at this stage would only occur if motor accidentally ignites early - several safeguards in place to prevent accidental ignition; motor casing and fuel grains are inspected as part of the assembly procedure	5 Systems check requires that Eclipse team members be near the rocket to activate the altimeters, verify their funcitonality, and insert the igniter; motor explosion at this close proximity will cause severe injury or death	5 Motor explosion will likely cause complete loss of the bottom segement of the airframe, making the rocket unusable	5	5	Yes	Motor fuel grains and casing will be inspected as part of motor assembly procedure; igniter will be inserted into motor as last step of systems check procedure to minimize risk of accidental ignition or explosion; see Systems Check Failure Mode #1 for mitigation plan against accidental ignition	1	1
3	One or more avionics components or rocket structures are found to be inoperative during systems check	Error in assembling rocket; manufacturer error; lack of power to avionics systems	Rocket must be removed from launch rails so problem can be assessed and the faulty component repaired or replaced; launch is delayed	3 In a complex system, it is likely that at least one component is not initially fully functional, which is the purpose of the systems check	0 Team members are not directly threatened by this failure	1 Usually, probems that arise during the systems check are ones that can be readily resolved by repairs or replacement parts	0	1	Yes	All avionics components will be tested for funtionality and proper programming before assembly of avionics bay; replacement altimeters, wires, and batteries will be available to fix faulty parts	0	1
			Drogue and/or	1	4	3						

4	Recovery system black powder charges ignite during activation and systems check of avionics	Altimeters malfunction from manufacturer error sends ignition signal early; altimeters are incorrectly programmed, causing ignition upon activation	main parachutes deploy prematurely; rocket airframe segments forcibly separate apart, possibly causing injury to team members; rocket rendered unusable until recovery system and black powder charges are repacked	Black powder capsules are isolated from ignition sources inside the airframe, so only altimeter signal will trigger ignition; altimeters used have been flight-tested and have never fired prematurely	Black powder explosions near Eclipse team members or other personnel will likely cause injury, either from the hot gases, shockwave, or ejected airframe segments	Premature black powder ignition could damage rocket's rail buttons, recovery system, or launch rail; black powder and recovery system will have to be repacked before rocket launches	4	3	Yes	Avionics switches will be activated as the second to last step of the systems check (only before inserting the motor igniter), removing the only ignition source until the last possible moment	1	1
Ignition												
				1	4	5						
1	Motor explodes during ignition	Motor is damaged due to manufacturing error or Eclipse team member error, including: cracks in fuel grain, fuel grain piece becoming disoldged and clogging the nozzle, fuel grain debonds with phenolic liner, motor casing structural failure, or gaps between propellant fuel grain segments	Motor emits hot exhaust gases and flame, as well as flying, possibly flaming, debris, which could cause injury to team members	The motor is designed and manufactured to reduce the risk of explosion; motor fuel grain and casing inspection is part of the motor assembly procedure	Flying debris and flames can cause significant injury to any nearby personnel, though the launch rail will be vacated before launch as part of range standard operating procedure	A motor explosion would cause an explosion of the rocket itself, causing irreparable damage to the body tube as well as other components	4	5	Yes	Assemble motor carefully and inspect parts before assembling rocket, and if there are anomalies, replace with different part; as per range standard operating procedure, rocket will have a large safety radius during the launch, so any explosion will be far enough away to prevent injury to personnel	1	2
				3	3	1				Attach igniter		

2	Motor fails to ignite when ignition signal is sent to launch controller	Inactive igniter due to manufacturing anomoly; igniter head not in contact with motor fuel grain; igniter leads improperly wired to launch controller; inactive motor fuel grains due to manufacturing error	Rocket will not launch; motor could also ignite when team members approach the rocket for troubleshooting if igniter or motor was smoldering, causing potential injuries	Igniter failures are fairly common because it is difficult to ensure that the igniter head is in perfect contact with the motor fuel grain	If team members approach hot wires, burns could occur, as well as injury from the rocket launching unexpectedly	Igniters can be easily exchanged and are inexpensive to replace, and do not cause damage to the rocket	9	2	Yes	Attach igniter securely to motor fuel grain and make sure that no power is running to the igniters before approaching rocket; any team members approaching the rocket to troubleshoot an igniter will follow range safety procedures and wear protective equipment, including safety glasses	1	1
				1	3	5						
3	Motor ignites and breaks free from rocket's motor mount; begins unrestrained burn through rocket body	Rocket motor mount improperly assembled or installed in the airframe; motor mount designed with inadequate safety factor; motor casing ruptures and ejects hot gas sideways into motor mount, causing internal damage and breaking the mount	Motor will fly uncontrollably through the rocket's airframe, possibly with enough force to push out of the rocket and fly through the air without control or stability; inside of rocket's airframe, recovery system, and payload could be badly burned or melted	Motor mount is designed with ample factor of safety for expected stresses during motor burn; motor will be inspected for casing or fuel grain damage as part of assembly procedure	If motor ejects out of rocket's airframe, it will fly unstably and could injure onlookers if it flies far enough from the launch rail	Motor's burn inside the rocket airframe will almost certainly burn or melt critical rocket components such as the parachute or the payload, making the rocket unlaunchable	3	5	Yes	Motor mount is designed with significant factor of safety, so it will be able to retain the motor even if thrust is higher than expected due to transient combustion effects; as per range procedures, rocket will have large safety radius around it, so a free-flying motor will have a big distance buffer between it anyone it could hurt	1	1
Boosting (On Launch Rail)												
				1	4	4				Carefully secure		

1	Rail buttons break off from body of rocket during boost phase	Rail buttons not properly secured to airframe or are misaligned on launch rail, causing extra stress on rail buttons or rocket's airframe	Rocket does not leave launch rail on desired trajectory, could possibly collide with people or objects, causing damage or injury	With careful drilling and installation of the rail buttons, the rigidity of the tube should secure the rail buttons to the frame	If the rocket deviates from the normal flight path it could come in contact with observers, causing injury	If the rocket deviates from the nominal flight path it could crash into the ground, seriously damaging the equipment	4	4	Yes	Carefully secure the rail buttons using a screwdriver and manually test the security of rail buttons after installation; testing rail button security is part of both rocket assembly and systems check procedures; rocket will have a large safety radius around it, protecting anyone nearby from a deviant trajectory	1	1
				1	4	5						
2	Explosion of motor during boosting on launch rail	Motor is damaged due to manufacturing error or Eclipse team member error, including: cracks in fuel grain, fuel grain piece becoming disoldged and clogging the nozzle, fuel grain debonds with phenolic liner, motor casing structural failure, or gaps between propellant fuel grain segments	Motor emits hot exhaust gases and flame, as well as flying, possibly flaming, debris, which could cause injury to onlookers	The motor is designed and manufactured to reduce the risk of explosion; motor fuel grain and casing will be inspected as part of motor assembly procedure	Flying and flaming debris could cause significant injury if they come into contact with personnel	A motor explosion would cause an explosion of the rocket itself, causing irreparable damage to the body tube as well as other components	4	5	Yes	Assemble motor carefully and inspect parts before assembling rocket, and if there are anomalies, replace with different part; rocket will have a large safety radius around it for the launch, so the damage radius of any motor explosion will not endanger spectators	1	1
Boosting (Free Flight)												
				1	2	4						

1	Drogue and/or main parachute deploys early, during boosting	Altimeter programmed incorrectly; black powder is exposed to an ignition source (ex. ignitiers, batteries, flammable chemicals, lighters, live wires) during the boosting phase of flight; rocket somehow becomes unstabled during flight and tumbles, releasing parachute	Boosting is hindered by parachute, rocket will not reach desired altitude; parachute(s) may light of fire from firing motor; rocket airframe and payload will likely experience structural damage due to sudden increase in drag force	Carefully program the altimeter and confirm programming with other teammates during both avionics assembly and systems check; package black powder slowly, gently, and carefully to ensure that it is packaged securely; altimeters used will be flight-proven to decrease risk of electrical malfunctions	The parachute deployment could cause the rocket to deviate from the nominal flight path and possibly come in contact with and cause injury to bystanders	The deployment will cause significant damage to the rocket airframe (a "zipper" failure) and could possibly ignite the parachute	2	4	Yes	Carefully program the altimeter and confirm programming with other teammates during both avionics assembly and systems check; package black powder slowly, gently, and carefully to ensure that it is packaged securely; altimeters used will be flight-proven to decrease risk of electrical malfunctions	1	1
				1	4	5						
2	Explosion of solid-propellant rocket motor during boosting	Motor is damaged due to manufacturing error or Eclipse team member error, including: cracks in fuel grain, fuel grain piece becoming disoldged and clogging the nozzle, fuel grain debonds with phenolic liner, motor casing structural failure, or gaps between propellant fuel grain segments	Motor emits hot exhaust gases and flame, as well as flying, possibly flaming, debris, which could cause injury to team members	The motor is designed and manufactured to reduce the risk of explosion; motor fuel grains and casing will be inspected for damage as part of motor assembly procedure	Flying debris and flames can cause significant injury	A motor explosion would cause an explosion of the rocket itself, causing irreparable damage to the body tube as well as other components	4	5	Yes	Assemble motor carefully and inspect parts before assembling rocket, and if there are anomalies, replace with different part; rocket will have large safety radius around it for duration of launch, so all spectators will be outside the damage radius of a motor explosion and the resulting debris field	1	1
				1	4	5						
										Observe		

3	Rocket does not maintain its trajectory and deviates from nominal flight path	Rocket is aerodynamically unstable; fins are incorrectly aligned or weights shift during flight; fins or rocket airframe damaged in-flight by external projectiles or internal structural failures; sudden extreme wind gusts	Rocket could impact the ground prematurely, causing damage to the rocket, or hit the ground outside of the safety radius, causing damage to people and equipment	The rocket is designed so that the fins provide adequate stability. Also, competition safety officials will not allow the rocket to launch in high winds	The rocket could hit observers or hit the ground at high velocity, causing injury to anyone nearby	When deviating from the nominal flight path, the rocket could eventually crash, which will result in significant damage to the rocket	4	5	Yes	weather and not launch rocket in high winds; test fins to ensure they are securely attached to body tube as part of rocket assembly procedure; verify center of gravity and center of pressure locations on rocket to ensure stability	1	1
				1	0	2						
4	Motor stops firing prematurely	Defect within the motor; wrong size motor used; error in constructing the motor - ex. not all fuel grain segments are loaded into casing	Desired apogee is not reached; drogue parachute will deploy below desired altitude; main parachute could deploy at apogee if rocket doesn't reach at least 800 ft at apogee	Team members are knowledgeable of the type of motor required for rocket; motor manufacturing defect is unlikely, and should be noticed in pre-assembly inspection	Team members are not directly affected by this failure	Chance that drogue and main parachutes deploy simultaneously if rocket doesn't reach 800 ft altitude, increasing chance of tangled parachutes and high-velocity descent	0	2	Yes	Verify impulse class and thrust rating of motor before purchase; construct the motor deliberately and carefully, inspecting the fuel grain for damage; install all fuel grain segments into casing during assembly	0	1
						Coasting						
				1	2	3						

1	Drogue and/or main parachute deploys early, during coasting	Altimeter calibrated incorrectly, black powder is exposed to an ignition source (ex. ignitiers, batteries, flammable chemicals, lighters, live wires) while coasting	Coasting is hindered by parachute; rocket will not reach desired apogee; rocket airframe and payload will likely experience structural damage due to sudden increase in drag force	Minimal risk of the black powder coming in contact with an ignition source due to the design of the black powder container, but as the altitude increases, the altimeter is more likely to be triggered incorrectly; altimeter is flight-proven and uses a barometer-triggered design, so altimters will have to internally malfunction to send an early deployment signal	If the parachute deploys early, the rocket will drift far from the launch site, making it more difficult to find for the recovery team to find	The deployment could cause significant damage to the rocket airframe (a "zipper" failure), though this is less likely to happen during coasting than during boosting	2	3	Yes	Carefully program the altimeter and confirm programming with other teammates during both avionics assembly and systems check; package black powder slowly, gently, and carefully to ensure that it is packaged securely; altimeters used will be flight-proven to decrease risk of electrical malfunctions	1	1
				1	4	5						
2	Rocket does not maintain its trajectory and deviates from nominal fliight path	Rocket is aerodynamically unstable; fins are incorrectly aligned or weights shift during flight; fins or rocket airframe damaged in-flight by external projectiles or internal structural failures; sudden extreme wind gusts	Rocket could impact the ground prematurely, causing damage to the rocket, or hit the ground outside of the safety radius, causing damage to people and equipment	The rocket is designed so that the fins provide adequate stability. Also, competition safety officials will not allow the rocket to launch in high winds	The rocket could hit observers or hit the ground and explode, causing injury	When deviating from the nominal flight path, the rocket could eventually crash, which will result in significant damage to the rocket	4	5	Yes	Observe weather and not launch rocket in high winds; test fins to ensure they are securely attached to body tube as part of rocket assembly procedure; verify locations of center of gravity and center of pressure to ensure stability	1	1
Apogee and Drogue Parachute Deployment												
				1	3	3				Rocket has		

1	Drogue parachute fails to deploy	Black powder charge does not ignite, altimeter calibrated incorrectly	Rocket will assume a high-velocity ballistic trajectory; could result in a nosecone-first hard collision with the ground if main parachute doesn't deploy, severely damaging components of the rocket and injuring any people near the impact site	Presence of a redundant altimeter with redundant black powder charges makes a failed main parachute deployment very unlikely	If the drogue parachute does not deploy, the rocket will assume a ballistic trajectory and will continue on it if the main parachute doesn't deploy, which could injure bystanders at the impact site	Failed drogue parachute deployment will put the rocket under extreme decceleration when the main parachute deploys, likely damaging the airframe	3	3	Yes	Rocket has redundant altimeters and black powder charges to compensate for an avionics or black powder failure; carefully calibrate the altimeter and confirm calibration with other teammates; package black powder slowly, gently, and carefully to ensure that it is packaged securely	1	1
				1	2	3						
2	Shock cords, bulkheads, or eyebolts do not withstand shock during drogue deployment	Cords, bulkheads, and/or eyebolts chosen have inadequate safety factor for expected stresses; these parts were damaged during assembly or flight; higher-than-expected pressure generated by black powder charges during drogue parachute deployment	Upper body tube separates from lower body tube; airframe segments without attached parachutes will hit the ground at high velocities, causing structural damage to the rocket and potentially the payload	Equipment chosen for this rocket has been picked specifically to withstand the black powder deployment and has been tested in the past	Airframe segments could hit the ground at high speeds, causing injury to people near the crash site	Airframe segments without parachutes will hit the ground at high speeds, causing damage	2	3	Yes	Selected components have ample factor of safety for expected stresses during deployment based on calculations and simulations; components are flight-proven to withstand deployment stresses from prototype launches	1	1
				2	2	2						

3	Main parachute deploys prematurely at apogee	Altimeter calibrated incorrectly; black powder is exposed to an ignition source (ex. ignitiers, batteries, flammable chemicals, lighters, live wires) at apogee	Rocket will drift well beyond expected recovery area, could pose a hazard to inhabitants of area and also makes the rocket more difficult to successfully recover	Minimal risk of the black powder coming in contact with an ignition source due to the design of the black powder container, but as the altitude increases, the altimeter is more likely to be triggered incorrectly; altimeter is flight-proven and uses a barometer-triggered design, so altimters will have to internally malfunction to send an early deployment signal	If the rocket drifts into an area inhabited by people, it could land on someone and injure them; large drift distance will make recovery very difficult and increase chance of dehydration or heat stroke in the recovery team	The rocket could land on different terrain than expected, which could cause damage to the airframe	4	4	Yes	Carefully program the altimeter and confirm programming with other teammates during both avionics assembly and systems check; package black powder slowly, gently, and carefully to ensure that it is packaged securely; altimeters used will be flight-proven to decrease risk of electrical malfunctions	1	1
Descent under Drogue Parachute												
				1	3	3						
1	Drogue parachute canopy tears, burns, or is otherwise damaged during descent	Recovery wadding doesn't protect parachute from black powder charge's hot gases; parachute canopy becomes snagged on an internal structure of the rocket during deployment; parachute canopy impacts another flying object during descent	Drogue parachute will be partially or fully compromised, providing less drag force and causing the rocket to descend faster than expected; higher velocity will cause sudden deceleration when main parachute deploys, possibly damaing the rocket's airframe	Parachute is packed with enough wadding to fully seal it from the black powder gases; inside of airframe is smooth and clear of any prominent structures the parachute can snag on	Damaged drogue parachute will cause a high-speed descent if the main parachute fails to deploy, giving less time for onlookers to clear the ground impact site and possibly injuring someone on impact	Higher speed descent will cause a sudden decceleration when the main parachute deploys, likely damaging the airframe upon main deployment; higher speed ground impact could damage parts of the rocket	3	3	Yes	Parachute will be packed with enough wadding to fully seal it from the black power explosion; rocket design leaves the airframe interior above the parachutes clear of any outcroppings so parachute won't snag; airspace around the rocket during launch will be clear of other flying vehicles (ex. photography drones)	1	1
				1	3	3						

2	Drogue parachute suspension lines snap during descent	Lines become snagged on an internal structure of the rocket during deployment; lines impact another flying object during descent; parachute deploys at higher velocity than expected (ex. due to failed drogue deployment)	Drogue parachute will be partially or fully compromised, providing less drag force and causing the rocket to descend faster than expected; higher velocity will cause sudden deceleration when main parachute deploys, possibly damaging the rocket's airframe	Interior of airframe is smooth and clear of any outcroppings the parachute lines can snag on; drogue parachute's suspension lines designed to withstand larger forces than expected during deployment	Damaged drogue parachute will cause a high-speed descent if the main parachute fails to deploy, giving less time for onlookers to clear the ground impact site and possibly injuring someone on impact	Higher speed descent will cause a sudden decceleration when the main parachute deploys, likely damaging the airframe upon main deployment; higher speed ground impact could damage parts of the rocket	3	3	Yes	Rocket design leaves the airframe interior above the parachutes clear of any outcroppings so parachute won't snag; airspace around the rocket during launch will be clear of other flying vehicles (ex. photography drones)	1	1
				1	3	3						
3	Drogue parachute becomes tangled with shock cords or rocket itself during descent	Rocket tumbles while descending under drogue parachute, due to drogue parachute deployment, sudden wind gusts, or impact with another flying object	Drogue parachute will be partially or fully compromised, providing less drag force and causing the rocket to descend faster than expected; higher velocity will cause sudden deceleration when main parachute deploys, possibly damaging the rocket's airframe; tangled drogue and shock cords could prevent main parachute deplyoment	Rocket is designed with long enough shock cords to prevent interaction between the drogue parachute and the ariframe during descent	Resulting high-speed descent will give onlookers less time to clear the ground impact site, and could injure someone on impact	Higher speed descent will cause a sudden decceleration when the main parachute deploys, likely damaging the airframe upon main deployment; main deployment could be hindered by tangled shock cords; higher speed ground impact could damage parts of the rocket	3	3	Yes	Rocket's shock cords are long enough to prevent interaction between drogue parachute and airframe even if the airframe tumbles; rocket won't be launched if wind speeds are too high, at the discretion of the range safety officer; airspace around rocket during launch will be clear of other flying vehicles (ex. photography drones)	2	2
Main Parachute Deployment												
				1	4	4				Rocket has		

1	Main parachute fails to deploy	Black powder charge and redundant charge do not ignite; altimeter calibrated incorrectly	Rocket descends at higher than intended velocity, which could result in a hard collision with the ground, damaging components of the rocket	Presence of a redundant altimeter with redundant black powder charges makes a failed main parachute deployment very unlikely	Failed main parachute deployment will cause rocket to impact ground at high velocity, injuring anyone near the impact site	Failed main parachute deployment will cause rocket to impact ground at high velocity, likely damaging rocket components	4	4	Yes	redundant altimeters and black powder charges to compensate for an avionics or black powder failure; carefully calibrate the altimeter and confirm calibration with other teammates; package black powder slowly, gently, and carefully to ensure that it is packaged securely	1	1
				1	2	3						
2	Shock cords, bulkheads, or eyebolts do not withstand shock during main deployment	Cords, bulkheads, and/or eyebolts chosen have inadequate safety factor for expected stresses; these parts were damaged during assembly or flight; higher-than-expected pressure generated by black powder charges during main parachute deployment	Airframe separates; airframe segments without attached parachutes will hit the ground at high velocities, causing structural damage to the rocket and potentially the payload	Equipment chosen for this rocket has been picked with ample factor of safety to withstand the black powder deployment and has been tested in the past	Airframe segments could hit the ground at high speeds, causing injury to people near the crash site	Airframe segments without parachutes will hit the ground at high speeds, causing damage	2	3	Yes	Selected components have ample factor of safety for expected stresses during deployment based on calculations and simulations; components are flight-proven to withstand deployment stresses from prototype launches	1	1
Descent under Main Parachute												
				1	3	3						

1	Main parachute canopy tears, burns, or is otherwise damaged during descent	Recovery wadding doesn't protect parachute from black powder charge's hot gases; parachute canopy becomes snagged on an internal structure of the rocket during deployment; parachute canopy impacts another flying object during descent	Main parachute will be partially or fully compromised, providing less drag force and causing the rocket to descend faster than expected; high-velocity ground impact could damage rocket components or injure bystanders	Parachute is packed with enough wadding to fully seal it from the black powder gases; inside of airframe is smooth and clear of any prominent structures the parachute can snag on	Damaged main parachute will cause a high-speed descent, giving less time for onlookers to clear the ground impact site and possibly injuring someone on impact	Higher speed descent will cause a higher speed ground impact, which could damage parts of the rocket	3	3	Yes	Parachute will be packed with enough wadding to fully seal it from the black power explosion; rocket design leaves the airframe interior above the parachutes clear of any outcroppings so parachute won't snag; airspace around the rocket during launch will be clear of other flying vehicles (ex. photography drones)	1	1
				1	3	3						
2	Main parachute suspension lines snap during descent	Lines become snagged on an internal structure of the rocket during deployment; lines impact another flying object during descent; parachute deploys at higher velocity than expected (ex. due to failed drogue deployment)	Main parachute will be partially or fully compromised, providing less drag force and causing the rocket to descend faster than expected; high-velocity ground impact could damage rocket components or injure bystanders	Interior of airframe is smooth and clear of any outrcroppings the parachute lines can snag on; main parachute's suspension lines designed to withstand larger forces than expected during deployment	Damaged main parachute will cause a high-speed descent, giving less time for onlookers to clear the ground impact site and possibly injuring someone on impact	Higher speed descent will cause a higher speed ground impact, which could damage parts of the rocket	3	3	Yes	Redudant altimeters and charges ensure the drogue will be deployed at apogee, minimizing risk of a high-velocity main parachute deployment; rocket design leaves the airframe interior above the parachutes clear of any outcroppings so parachute won't snag; airspace around the rocket during launch will be clear of other flying vehicles (ex. photography drones)	1	1
				1	3	3				interaction between drogue and main parachutes		

3	Main parachute becomes tangled with drogue parachute during descent	Rocket tumbles while descending under main parachute, due to main parachute deployment, sudden wind gusts, or impact with another flying object	Both main and drogue parachutes will be impaired and possibly fully compromised, causing the rocket to descend at high velocity; high-velocity impact could damage rocket components and inure bysanders	Rocket is designed with long enough shock cords to prevent interaction between the drogue and main parachutes during descent	Resulting high-speed descent will give onlookers less time to clear the ground impact site, and could injure someone on impact	Higher speed descent will cause a higher speed ground impact, which could damage parts of the rocket	3	3	Yes	parachutes even if the airframe tumbles; rocket won't be launched if wind speeds are too high, at the discretion of the range safety officer; airspace around rocket during launch will be clear of other flying vehicles (ex. photography drones)	2	2
Ground Impact												
				2	2	2						
1	Rocket hits ground at higher than expected velocity	Parachutes do not adequately slow descent of rocket, parachutes do not deploy correctly or at the correct altitude	Rocket components are damaged, possibly preventing future flights, or, if hitting ground in an inhabited area, impact could cause damage to people or equipment	Parachutes may deploy slightly late or not exactly when expected due to varying flight conditions, so the rocket may hit the ground at a different speed than expected	People in the immediate area of the landing could be hit, causing injury	Rocket components could be damaged from the larger force on impact	4	4	Yes	Rocket has a primary and backup altimeter as well as redundant charges so parachutes will deploy if primary systems fail; take steps described in Main & Drogue Parachute Deployment sections to ensure that parachutes deploy correctly	1	2
				1	5	5						
2	Rocket undergoes a ballistic ground impact	Both main and drogue parachutes fail to deploy, or both parachutes sever from rocket during descent, completely eliminating the recovery system	Rocket components and payload severely damaged; rocket will likely be unflyable; ground impact will cause damage to equipment or injury to people near the impact site	Unlikely that both parachutes will fail in the same flight thanks to redundant altimeters and black powder charges	With no recovery system, the rocket will crash at a very high speed, causing injury to people in the vicinity	The rocket will embed itself into the ground, causing severe damage to all parts	5	5	Yes	Rocket has a primary and backup altimeter as well as redundant charges so parachutes will deploy if primary systems fail; take steps described in Main & Drogue Parachute Deployment sections to ensure that parachutes deploy correctly	1	1
Recovery												

1	GPS fails to transmit a signal during flight and after the rocket's ground impact	GPS power supply is depleted before rocket can be recovered; GPS signal not picked up by receiver due to poor connection; GPS deactives unexpectedly during flight due to an electrical malfunction or loss of power	Team members cannont determine where the rocket is located, making it significantly more difficult to recover the rocket	1 GPS will be tested before flight to ensure it works, but it could stop transmitting for several reasons, especially if the recovery efforts takes a long time	2 Without GPS, team members will have to spend a significantly longer time searching for the rocket and endure more sun exposure, which could become a health hazard	1 Other than the GPS, no parts of the rocket will be directly damaged by this failure	2	2	Yes	Test the GPS before launching to confirm that it is fully functional and has proper battery power; GPS functionality will be verified as part of avionics assembly procedure and systems check; rocket will be recovered promptly after launch to minimize chance of GPS running out of battery	1	1
2	Eclipse team members become dehydrated or experience heat stroke while recovering the rocket	Not bringing sufficient quantity of water, extended exposure to extreme heat	Possible illness or death of team members; recovery effort must be abandoned and the rocket may not be found	2 Extreme desert temperatures make dehydration and heat stroke probable; sun safety mesures and adequate hydration will act as safeguards (see Mitigation Plan)	5 Heat stroke can severely injure or even kill Eclipse members if left untreated, and will prevent them from participating in the competition	3 Risk of being unable to recover the rocket if the recovery search effort has to be called off to keep team members safe	5	1	Yes	Team members wear hats, sunglasses, and sunscreen during recovery operations; team members will bring more than enough water for several hours of searching during the recovery operation; team members will stay together throughout the search effort; search team will have at least one cell phone or radio to call for help in an emergency	3	1

Risk Indexing Matrix

		Probability of Occurance					
		1	2	3	4	5	
	1	1	2	3	4	5	Key:
	2	2	4	6	8	10	19-25 Unacceptable

	3	3	6	9	12	15	14-18	Undesirable: Written and reviewed decision required to proceed
	4	4	8	12	16	20	6-13	Acceptable upon completion of quality assurance review
Severity	5	5	10	15	20	25	1-5	Acceptable without review

Equipment Severity Scoring Key	
Severity Rating	Failure Effect
1	Minor malfunction; easily resolved or quickly fixed at test site
2	Malfunction fixable at test site, but will delay engine test and assembly
3	Testing procedures must cease and malfunctioning system must be reevaluated before test can continue

Personnel Severity Scoring Key	
Severity Rating	Failure Effect
0	Failure mode is present, but only affects engine performance during test and poses no physical danger to members present
1	Extremely minor risk to Eclipse members; even minor physical injuries are extremely unlikely
2	Minor risk to Eclipse members; any physical injuries easily treatable at test site using Eclipse first aid kit

Probability Scoring Key	
Probability Rating	Probability of Occurance
1	Extremely unlikely; failure mode will not occur based on safety factors calculated during design review
2	Unlikely; engine system designed to prevent failure, but failure mode is dependent on a variable that cannot be completely controlled during test
3	Possible; external variables affecting failure mode can't be fully controlled

4	Engine test must be ended prematurely		3	Moderate risk to Eclipse members; risk is contained by safety protocols in place		4	Probable; more likely than not to occur during a test
5	Engine test must be terminated, and likely damage to engine systems		4	Major risk to Eclipse members; failure could cause severe injury		5	Extremely likely; will almost certainly happen during a test
			5	Failure mode will cause severe injury to Eclipse members; existing safety protocols cannot fully contain failure effects; emergency services must be contacted if failure occurs and causes severe injury			