IREC Preparation for 2022 SpacePort America Cup

Rowan University Team - “Newton’s Fifth Law”

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Abstract

Rowan University’s 2022-2023 IREC competition team continued to develop the first rocket targeting 30,000 feet in our school’s history. Over the course of the past three years, the previous student teams have attempted to accomplish this but were held back by financial and temporal difficulties, as well as the COVID-19 pandemic. This year’s team looked to continue and improve on the work from the past three years, and rotate to 10,000 feet! With The IREC competition returning this year, many teams had to roll over for their submission, leading to The ESRA gave us a recommendation to switch to the 10,000 foot category

“Newton's Fifth Law” is a minimum diameter rocket, designed to minimize cost and maximize design integrity. Standing at around 7 feet tall, the rocket will be powered by an AeroTech N1975W-PS White Rocket COTS motor. Outside, the rocket is hand wrapped in carbon fiber layers, cured with resin to provide strength through the flight. Inside, the rocket will carry a custom designed payload bay and structure to apogee to measure, collect, and report atmospheric pollutant data. “Newton's Fifth Law” will combine a light, compact build with a powerful rocket motor to provide thrust through the duration of the flight.

During the flight, the payload will be collecting measurements including standard telemetry and air quality data. Along with the payload detector the team will be taking measurements so that the team can create more advanced payloads in the future employing the atmospheric knowledge acquired during this flight. Some measurements required specific temperatures to operate and were, unfortunately, cut from the payload as the required temperature could not be maintained with any level of certainty. This payload will help determine the complexity of the payloads developed in the coming years. The team hopes to have a successful launch and provide a safe recovery to provide a blueprint for future launches.

I. Introduction

Rowan University’s Rocket team was first formed seven years ago with the goal of competing in the International Rocket Engineering Competition. In the first year, the team consisted of five student members with backgrounds in electrical, computer, and mechanical engineering. Four years later, the team had grown to include 24 students with academic backgrounds in electrical engineering, computer engineering, mechanical engineering, civil engineering, and physics. This growth in student members had made this engineering project one of the biggest projects offered by the Rowan College of Engineering. This year’s team features sixteen members with a similarly interdisciplinary set of backgrounds and the project remains one of Rowan’s most popular and ambitious. In the two years leading up to the start of the “Newton's Fifth Law” the team had successfully launched in the 10,000 ft category. In 2018, the team returned to the competition for its third year at the Spaceport America Cup with “The Fifth Day” rocket and placed 23rd out of 129 registered teams after a successful flight to 9,633 feet.

This year’s Rowan University Rocket team is an entirely new team and with a new team there were now new goals for the eventual 2023 flight. The first goal was to solve the issue of not having access to black powder for separation squibs. To get around this we designed a CO2 pressure separation system. Second, the team had to change the direction of the rocket to the 10,000 feet category. The design choice that will give the rocket team the best chance at achieving these goals was to make the rocket’s airframe out of carbon fiber. With the change from 30,000 feet to 10,000 feet, the team had to reevaluate many of the choices previous teams made. The team decided that an appropriate name for this year’s rocket would be “Newton’s Fifth Law” due to the imposing stature and deep shining black from the epoxy covered carbon fiber wrap.

“Newton's Fifth Law” stands at a height of 7.17 feet tall and has a loaded weight of 49.7 lbs. The rocket will fly in the 10K COTS category on an AeroTech N1975W-PS. An avionics bay inside the nose cone contains two COTS flight computers, for data acquisition and GPS location, which transmit a live feed to a ground station. There is one payload bay containing a mix of COTS measuring devices connected to a Raspberry Pi for atmospheric analysis during descent. Current flight simulations (before painting and final rocket assembly) predict a max altitude of 10,925 feet with a maximum velocity of 915.2 ft/s. OpenRocket was the team’s primary simulation tool for general flight trajectory simulation, and the OpenRocket model can be seen below in Figure 1.

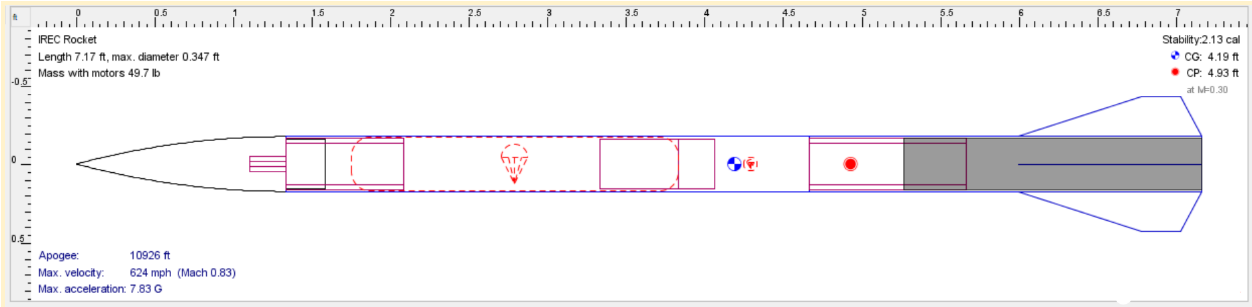

Figure 1. OpenRocket drawing of 2023 launch vehicle (“Newton's Fifth Law”)

A. Engineering Clinic

Rowan University’s College of Engineering offers a hands-on curriculum and early access to lab equipment for undergraduate students. Engineering Clinic perfectly exemplifies this goal of getting students real-world experience in the engineering industry. Every semester, students in the Henry M. Rowan College of Engineering take a clinic class, where they learn how to solve engineering problems in a team setting. Freshman year, students learn about ethics, statistics, economics, universal design, and other concepts related to engineering problems. Sophomore year, the classes focus on effective communication, including technical writing and public speaking in conjunction with hands-on projects and labs. Junior and senior year, students can choose from over 160 different clinic projects, or even start their own. Junior and Senior Clinic can be compared to Senior Design or Capstone courses at other schools, except Rowan offers the unique ability to choose from such a variety of choices and to choose four different projects over your junior and senior years.

These projects cover all disciplines of engineering, allowing students to explore different applications of their engineering degree. Students can serve as consultants for outside companies, solving specific problems that are truly 'real-world’. Students can conduct research with professors, plan outreach projects, or work on hands-on projects for competitions, including IREC. IREC has historically been an exciting project, and students look forward to getting involved with the team, even before their junior and senior years. Underclassmen, especially those in our school’s chapter of AIAA, often join upperclassmen during the clinic period to learn more and work on the project. They can use this knowledge to help lead the team when they are juniors and seniors and continue the project for years at Rowan University.

B. Team Structure

Our team is overseen by faculty advisor Dr. Schmalzel, a professor within the Electrical/Computer Engineering (ECE) department. We are thankful for this opportunity to explore our love for space and rocketry. Schmalzel has historically supervised the IREC project clinic and other aerospace clinics. He provides advice, assists with financial forms, and serves as a liaison between the students and the Engineering department. He is the go-to person for any aerospace questions or interests at Rowan University.

This year, our student team is composed of 16 students from two different majors. Our team includes six electrical/computer engineers, and 10 mechanical engineers. This larger team allowed for more smaller projects to be worked on at once and a larger diversity of skills. Our group chose to split into three subsystems, each pertaining to a system of the rocket requiring completion. These groups were as follows:

- Airframe/Recovery
    - Matthew Charboneaux
    - Brendan Clemenson

    - Kody Deuter
    - Jeffrey Chew
    - Kien Hoang
    - Matt Amato
- Fins
    - Damian Cuevas
    - Ariana Manalac
    - Ian Bain
- Avionics and Payload
    - Nicholas Kreuz
    - Dillon Withers
    - Thomas Nouragas
    - Jesse Cave
- Leadership
    - Daniel Millar
    - Thomas Stanek

C. Team Management Strategies

Our team met at least twice a week during our clinic times, in addition to meeting outside of clinic times if needed. To communicate, our team used Discord, a mobile and desktop instant messaging app. We created multiple channels to keep our information organized. These included a general channel as well as channels specific to each subsystem.

To organize our files, our team used Google Drive. This was useful because team members could access the most updated version of all simulation, modeling, planning, and documentation files. Current members have access to the previous three teams' Google Drives as well, and our Drive will be shared with the next team to help guide them.

D. Project Status as of Dec 1st, 2021

Last semester the rocket body was fully wrapped in carbon fiber, leaving just the fins to be wrapped and attached to the body. Currently, the fins have yet to be wrapped due issues with the oven that was initially used by the previous project team. However, we have been given limited access to the IFrost lab and hope to use their equipment to finish the fin manufacturing early next semester. We are also still attempting to fabricate new couplers out of nylon-fiberglass filament as the aluminum couplers fabricated by earlier teams block RF signals from our payload. Rigorous testing has been conducted in order to properly print using this material, and further testing will be needed going into next semester. The payload team is also planning on taking their Ham Radio certification test December 9, 2021 7pm in Mullica Hill. Once certified, the team will be moving forward with designing the circuitry for the microcontroller and all the parts needed to complete all the tests. All the parts needed for the payload testing are from previous years, so now it is just a matter of putting it all together and getting the code to perform the right measurements.

E. Project Status as of March 26th, 2022

This semester we were able to make substantial progress in multiple areas of the project. The fins team was able to decide on a wrapping method and perform two test wraps with different concentrations of milled fiberglass. The propulsion/Airframe/Recovery test parachutes and reached out to the manufacturer to find a better size. In addition they made substantial progress on creating a black powder policy, testing explosive bolts, and testing the first set of bolts. They also made the decision in conjunction with the payload team to continue with the already machine aluminum couplers, placing antennas externally to avoid the RF suppressing properties of the carbon fiber body tubes and aluminum couplers. The Payload team was now able to use their HAM radio certifications to test the antenna, deciding to place the antenna's externally, and constructing a camera assembly to test a radio transmitted video signal to cover a F.A.R. competition category. In order to finish the rocket, the next year's team needs to continue testing explosive bolts, machine bolt holes, test separation with the charge wells and bolts, create bulk heads, externally mount the antenna, assemble sensor suite, replace flight computers, wire blot fuses and program controller, perform new tests for each subsystem and launch!

F. Project Status as of December 15, 2022

This semester a ton of progress has been made for preparing the entire rocket. The team decided on the final layout of all the components which will be inside the rocket and finalized the design for the recovery system. The separation method is now based on pressurized CO2 which will be released to break shear pins when activated. The team deviated from the previous black powder based separation system due to safety concerns and complications with acquiring the proper certifications for storage and use of black powder. Although, a document has been processed and is currently under review by both Technologist Nick Bovee and the health and safety department for Rowan University so that future Rowan IREC teams can explore the black powder option.

The avionics system, which triggers the separation events, was moved into the nose cone due to complications with establishing GPS connection from inside the carbon fiber body tubes. This simultaneously dropped the necessity of having an externally mounted antenna, and we worked with the Gloucester County Ameteur Radio Club to design and fabricate a dipole antenna. Additionally, the avionics team designed a PCB for a circuit which interprets signals from the avionics system and controls the release of CO2. The payload currently consists of a Raspberry Pi based system with a camera module and four measuring devices connected through an Analog-to-Digital Converter.

The avionics team have started to create the board for controlling the separation system, with the design being prepared in Flux.ai, a website for designing PCB. The other board that is needed on the rocket to control and store the data for the payload. The sensors that are being used have already been decided upon, so the PCB will be designed around those sensors. Communication with the rocket is key throughout the entire flight, so multiple tests have been run to see what ranges it will connect at. Eventually, it was found that the antenna that was being used was not the correct antenna, so a new one will be purchased. To begin this semester, the team had planned to use black powder for the separation system. However, using and storing black powder requires a lot of safety procedures and certifications that the team had trouble working with. A document has been made so that the black powder and fuel grain can be stored on campus safely, and is currently being reviewed by both Technologist Nick Bovee and the health and safety department for Rowan University. So, the separation system has been changed to pressurized CO_2, with some tests already being performed to test its power and reliability.

II. System Architecture Overview

In the sections following, the propulsion systems, airframe architecture, and payload configuration will be discussed in detail. The proposed design features a minimum diameter design and a student designed payload bay and structure.

A. Propulsion Subsystems

1. Overview

The propulsion subsystem utilized in this year's competition aircraft is a AeroTech N1975W-PS Reloadable White Rocket Motor. The casing and the propellant were COTS parts. In this rocket design, the propulsion system features a minimum diameter design, therefore removing the need of a thrust plate and centering rings. The figure below highlights the design of the propulsion system.

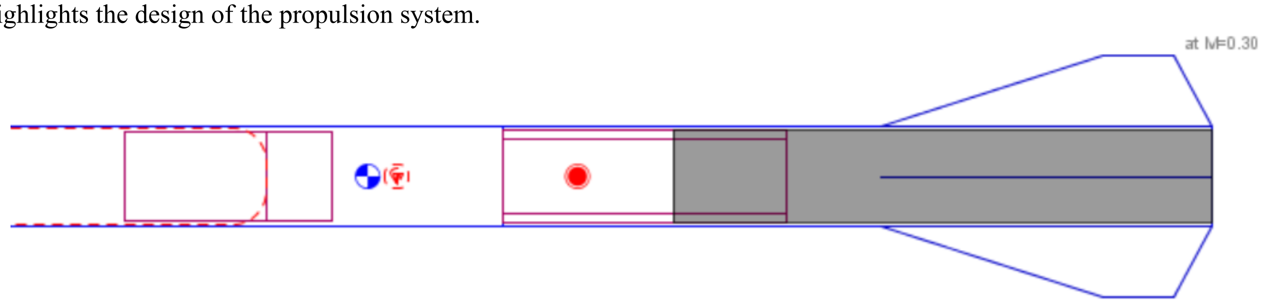

Figure 2. OpenRocket model of propulsion system

Featured in gray is the motor, which is fitted tightly into the aft body tube also containing the fins. To ensure there is no movement upon launch, the team intends to properly secure the motor casing likely using Raka 900 Resin and 606 Hardener. Further research will be carried out on resin options before a final decision is made at the start of next semester. In addition, a rocket motor subsystem will have a retainer seated in the front of the casing, which will also be secured in place with epoxy.

2. Casing

The motor casing was the CTI Pro98 Hardware Casing Set GEN 2 6G which is a COTS part purchased from Sunward1 hobbie group. The motor casing is a treated thin-walled aluminum tube, which houses the propellant. In the figure below, the technical drawings for the CTI PRO 98 Hardware is shown. Please be aware the team purchased the 6G version of the kit, as resulting dimensions can be read in the key.

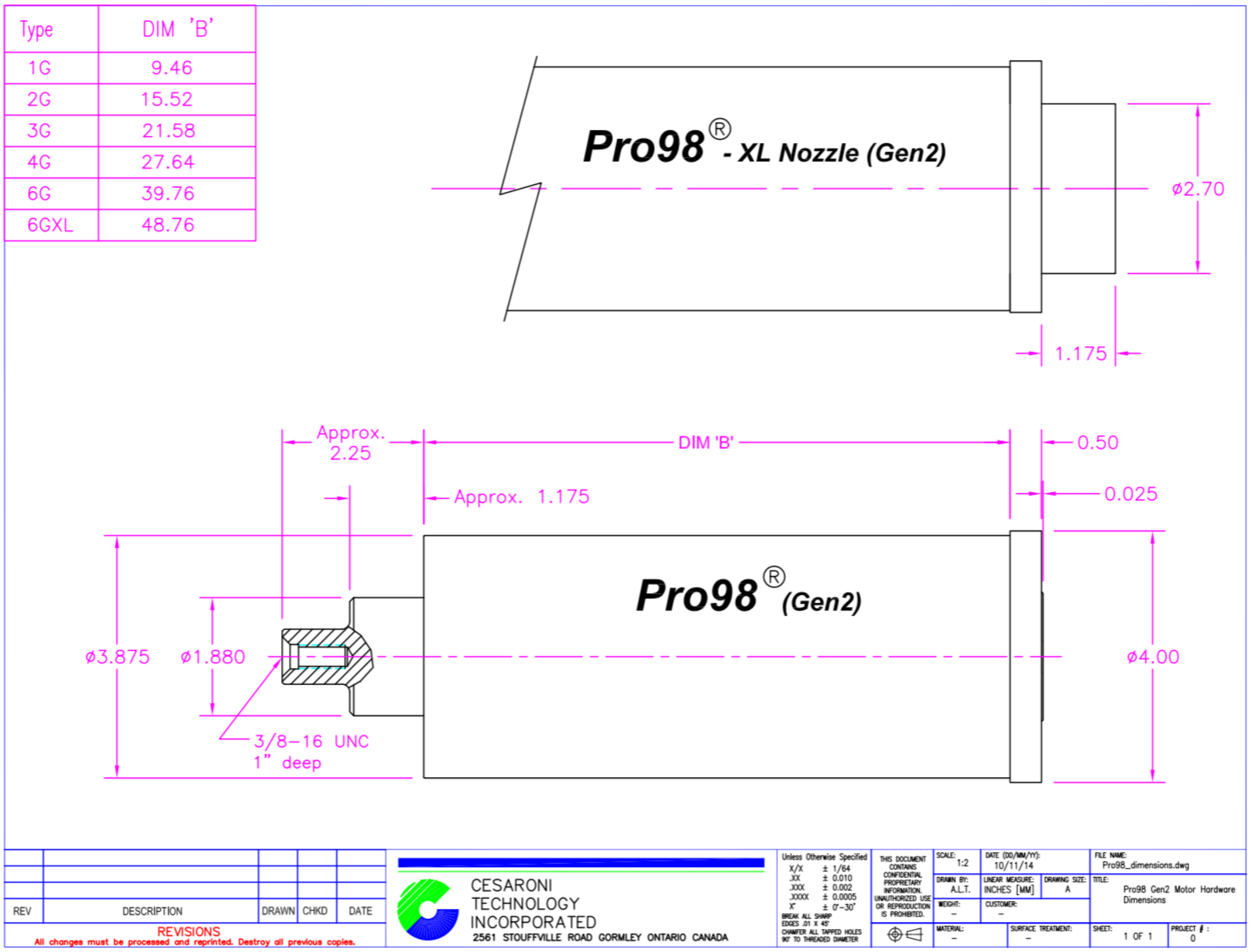

Figure 3. Engineering drawing of CTI PRO 98 6G engine casing and closures

The final price of the hardware was $559.95 cost to the team, and the reload for the AeroTech N1975W-PS cost $946.60. The final price to the team for these parts was therefore $1,506.55. Much of the design team's research was understanding the nature of a minimum diameter rocket design, and creating a design that would allow the team to reach 30,000 ft, while also operating on a budget. Much of the school year involved meetings and discussions with the SGA and the engineering college to procure enough funds to complete this project. As a result, the team settled on a minimum motor design to cut down on materials and cost.

3. Motor Retention

As previously stated, the motor casing will be secured with an epoxy and hardener, and a tight fit within the body tube. A retainer was also purchased to secure the propulsion system in place for launch. This part was a COTS part purchased from MadCow Rocketry, and will be secured with epoxy in the aft body tube of the airframe.

With the minimum diameter rocket design, the team needed to take a slightly unorthodox approach to securing the system. A few test samples were designed by students to determine the yielding strength of the selected epoxy and resin. As aforementioned, the most likely choice of epoxy and hardener is Raka 900 Resin and 606

Hardener. This is a marine grade resin which was surplus from the 2018-2019 rocket build, due to the lack of test data present samples were tested and their respective strengths in testing can be seen below.

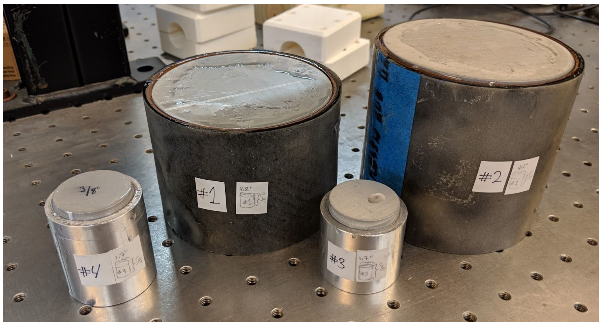

Figure 4A. Crush Samples

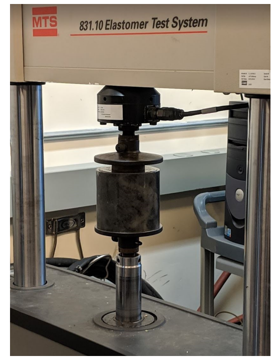

Figure 4B. MTS Elastomer Test Set-Up

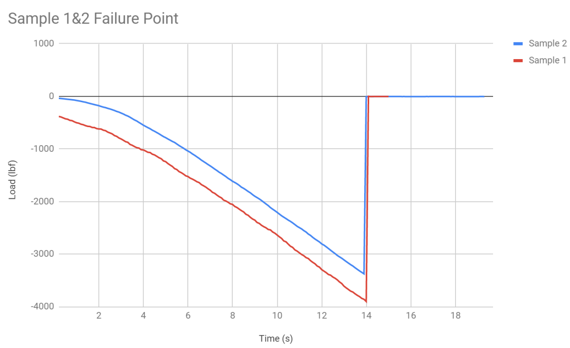

Figure 4C. Test Results of Carbon Fiber Samples (1&2)

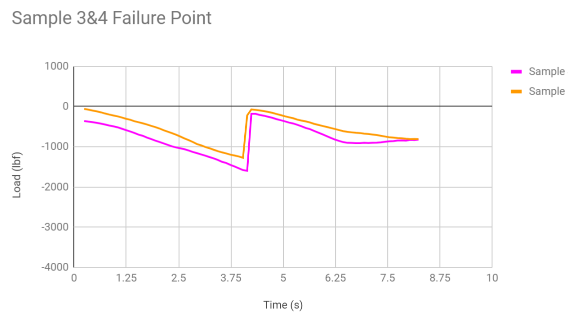

Figure 4D. Test Results of Small Al samples (3&4)

Following the testing, it was determined that this epoxy and hardener would be sufficient in holding the propulsion system in place during flight. The carbon fiber samples failed at approximately 4,000 lbf. This load will be distributed along the circumference and length of the purchased motor casing. Since the epoxy from the 18-19 team had expired a new supply will need to be acquired before construction on the retaining structure can begin.

B. Aero-structures Subsystems

1. Nosecone

After researching different designs, the two shapes that were considered were the Haack series Von Karman nose cones and the ogive nose cones. The Haack series nose cones are designed to reduce the drag, improve rocket stability, and increase maximum rocket altitude. However, for the dimensions that would be needed for a Haack series nose cone, it would need to be custom made. A custom made nose cone would be very expensive and isn't necessary for the rocket design to be successful. The shape that is most commercially accessible is the ogive shape. The tangent variation of the ogive shape, after simulations were performed on two different designs in OpenRocket, gave the best results. The geometry of a tangent ogive is a partial circle, where the desired length and radius are in a defined ratio to the radius of the circle.

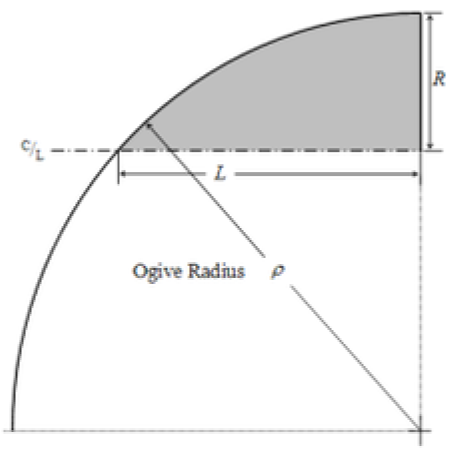

Figure 5. Geometrical interpretation of the ogive nose cone

The equation for the nose cone shape can be determined through a set of parameters from the rocket. The equation relies on the radius of the rocket, the ρ value (determined by the radial curvature of the circular profile), and the length of the nose cone. Completely symbolically, the equation is as follows:

$$y = \sqrt{\rho^2 - (L - x)^2} + r + \rho \quad (1)$$

Where:

$\rho = Radius\ of\ the\ circle$
$L = The\ length\ of\ the\ nose\ cone$
$x = The\ independent\ variable\ to\ create\ the\ curve$
$r = The\ outer\ radius\ of\ the\ rocket\ airframe$

For the team’s purposes, the equation above filled out as such:

$$y = \sqrt{65^2 - (16 - x)} + 2 + 65 \quad (2)$$

Below in Figure 6 is a geometric demonstration of our team's specific values for circle radius, nose cone radius, and nose cone length. This curve was modeled in an equation-driven spline curve in SolidWorks.

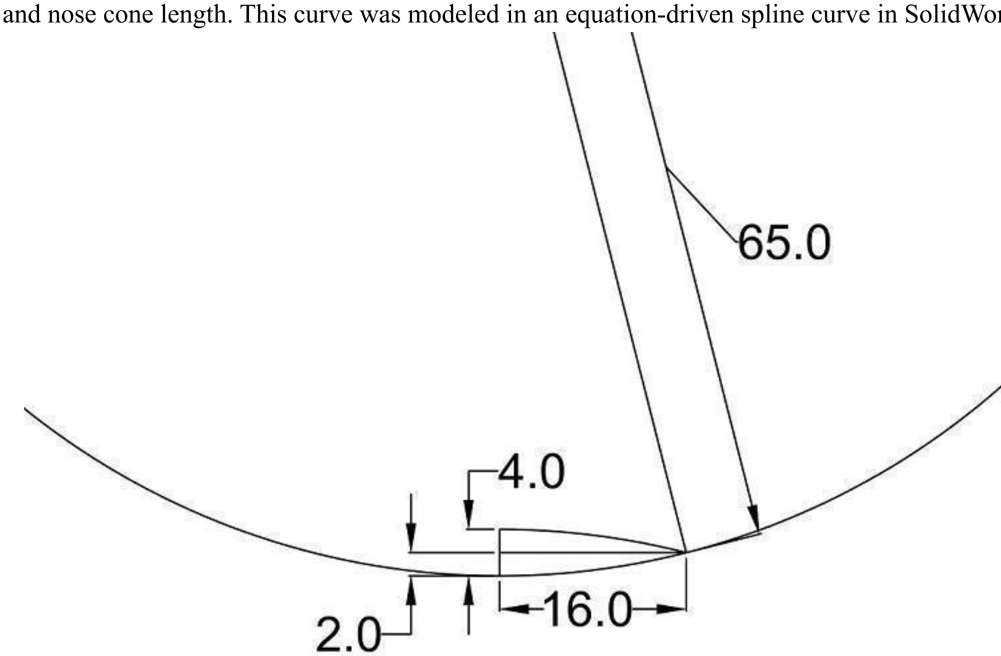

Figure 6. AutoCAD representation of nose cone geometry

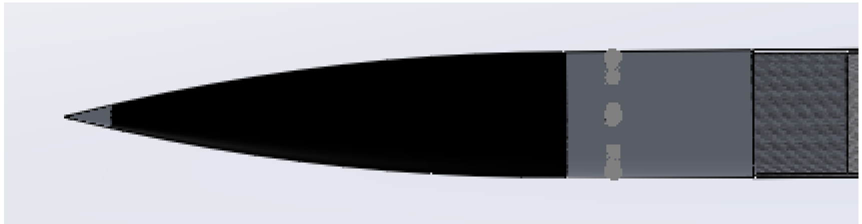

Figure 7A. SolidWorks rendering of nose cone (using equation driven spline feature)

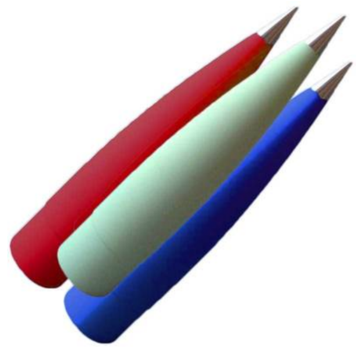

Figure 7B. Nose cone photo from Mad Cow rocketry

Figure 7 - Images of the team-selected nose cone

For the first simulation with a secant ogive shape the maximum altitude of the rocket was 25571 ft. However, when the tangent ogive shape was used the maximum altitude of the rocket was around 27285 ft. The team needed to select a nose cone that could cut through the air easily and lessen the drag forces that would be created at such a high speed. Since fiberglass has a high specific strength, it would be able to withstand the forces that the rocket will encounter as it makes its ascent. The fiberglass will also provide an RF window in the rocket for telemetry and GPS communication. Having an aluminum tip provides the rocket with slightly more stability, which means that the rocket's course should stay true

Running launch simulations in OpenRocket at each of these three lengths, a 16 in, 4:1 nose cone was determined to be optimal, giving a projected apogee of 12191 ft. The 3:1 ogive shape did produce a higher projected apogee in OpenRocket, but this goes against the aerodynamic theory which states that at speeds over Mach 1, a more pointed nose cone will be preferable.

Having an aluminum tip on the nose cone also means that this will also be the heaviest point on the nose cone. This helps to increase the stability of the rocket and will help with damage upon recovery. Having the tip carry more weight means that the rocket will be following the weight at the front, which is what is helping to guide the rocket through the air. Upon reaching its final apogee and starting its descent, the nose cone will want to land tip down, since that will be where the most weight is concentrated. Doing so will protect the thin fiberglass walls of the nose cone, and will increase the longevity of the part.

According to the vendor (Mad Cow Rocketry), the 5:1 Ogive ratio filament wound fiberglass model weighs approximately 1 lb. This does not include the weight of the 6-inch coupler section. Given that the team's desired Ogive ratio is 4:1, which would give it a length of 16 inches instead of 20 in for 5:1, the nose cone will weigh slightly less than this by a few ounces.

Nose Cone Stress Analysis

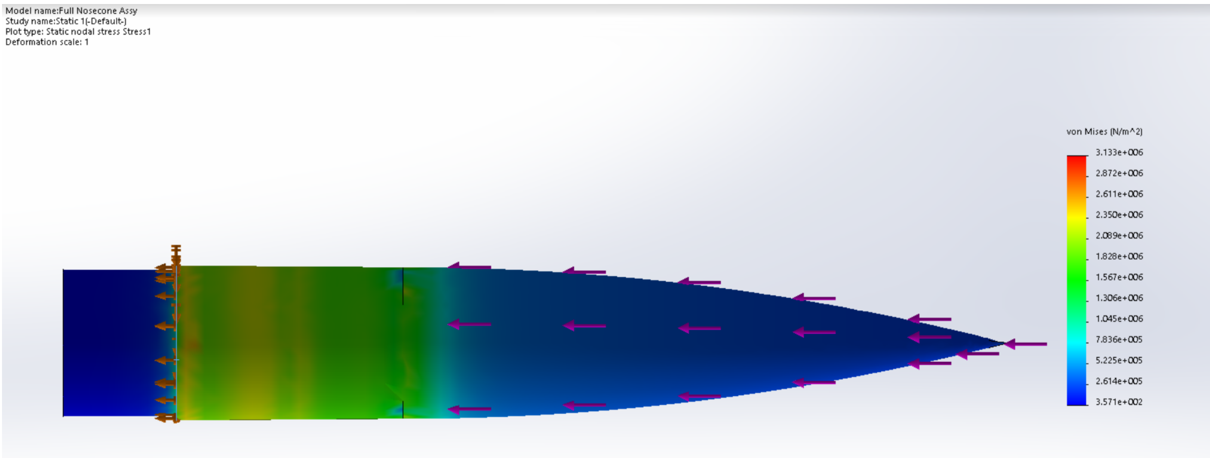

Figure 8A. Static Force Analysis on Nose Cone using SolidWorks

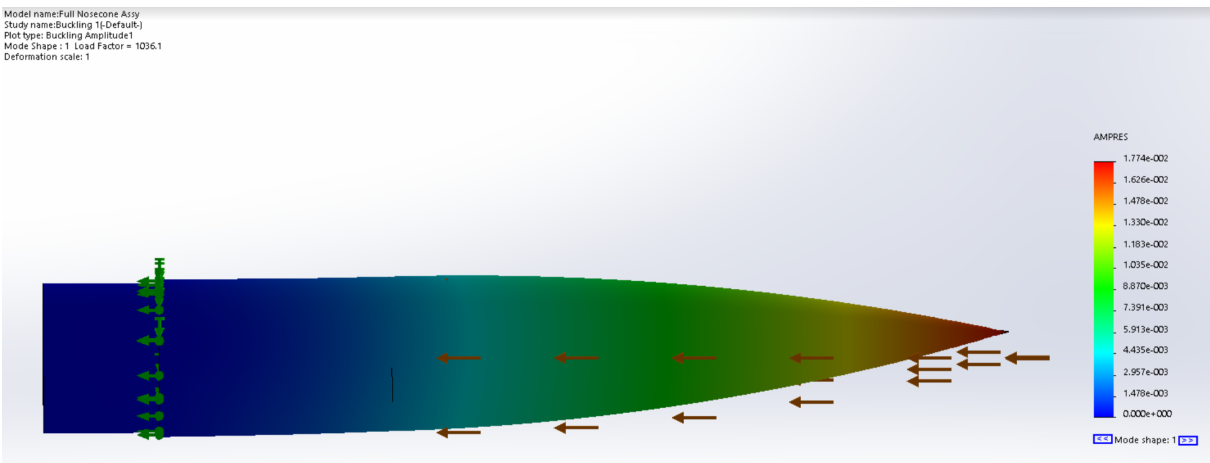

Figure 8B. Buckling Analysis on Nose Cone using SolidWorks

Figure 8. Static and Buckling Analysis on Nose Cone using SolidWorks

Based on the results of the SolidWorks stress analysis, the nose cone will hold up just fine when introduced to stresses from the flight of the rocket. The rocket should perform optimally for the team, while also saving the team from having to manufacture the part themselves.

2. *Avionics Mount*

The avionics devices will be mounted to a structure which slides into the nose cone and sits just above the 6 inch fiberglass coupler. This mount is a tapered structure made from four interlocking wooden pieces with tabs that fit into slots cut into two plastic bulkheads. This assembly will be held in place on the inside of the nose cone by a ¼"-20 threaded rod fastened into the aluminum tip. The strength of the materials for this mount was not of very high concern considering it will stay fastened in the nose cone for the entire flight and will not be exposed to any outside elements. A design with four interlocking pieces was chosen with respect to the four main components of the avionics bay, two avionics devices and two batteries.

Figure 9. SolidWorks Assembly of Avionics Mount

3. Airframe

The airframe design that the team used follows "The Jarvis Illustrated Guide to Carbon Fiber Construction." The design team and manufacturing team worked together to identify the airframe constraints that were needed during the design phase. The dimensions of the carbon fiber sheets and thickness of the phenolic tubes both played a part in the overall design of the rocket. The combined thickness of the five layers of carbon fiber that will be used is 0.045 inches. The final thickness of the rocket's body tubes will be 0.107 inches. This thickness was implemented in the OpenRocket simulation to obtain more accurate flight predictions.

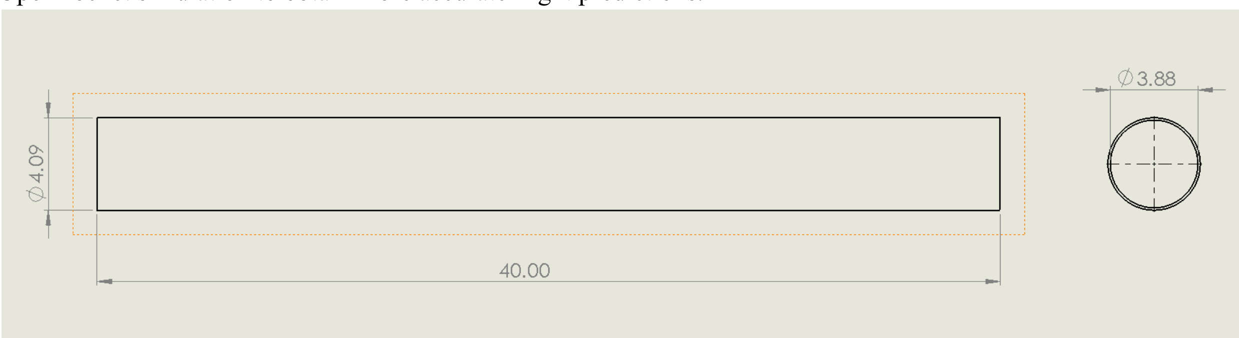

Figure 10A. Dimensions of middle/payload tube measured in inches

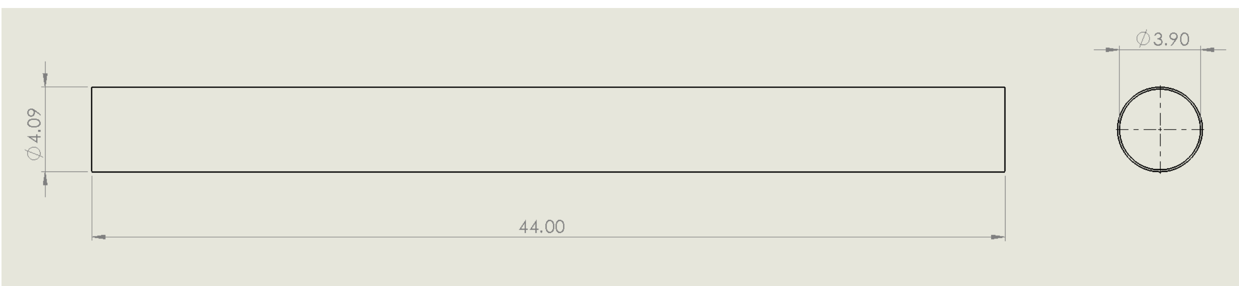

Figure 10B. Dimensions of sustainer tube measured in inches

A minimum diameter tube design doesn't require an internal structure because the motor kit fits tightly in the sustainer tube. A forward retainer will be used to secure the motor into the tube. After the fabrication process, the airframe will be strong enough to withstand the aerodynamic forces acting on the rocket as it ascends at roughly 90% the speed of sound. In addition to this 4 vent holes (⅛" Diameter) will be drilled through the payload bay body tube in TBD locations (these locations will be chosen based on sensor locations as well as focus on structural integrity). These holes are intended to equalize the barometric pressure within the payload bay and mitigate the effects of overpressurization during the rocket's extremely rapid ascent. Typically a single 1/8th or 3/16th inch hole is utilized for this, however, due to the high vertical acceleration, dramatic altitude change, and multiple onboard sensors specifically monitoring for various changes in air pressure, quality and temperature, four holes were chosen in order to maximize optimal conditions during ascent.

The airframe was manufactured in three parts, two being the carbon fiber phenolic tubing, and the third being the nose cone. For assembly of the finished rocket, couplers are required to connect the pieces and create one single streamlined rocket. Aluminum couplers were manufactured from a previous year but were set to be replaced by RF transparent 3D printed nylon couplers. After several setbacks with printing, including the loss of access to the specialized 3D-printer, an RF test determined that even without couplers on the airframe the carbon fiber will fully block out the signal requiring a redesign of the antennas. The aluminum couplers will be used in the final design of the airframe and the nose cone will house the components which require RF transparency.

4. *Payload Bay*

In order to ensure the safe retrieval of the electronics systems placed within the rocket, a rugged payload structure was constructed to mount all payload components and sensors to. The major design factors to take into account are structural integrity, contact with the airframe, modularity, and ease of access. Structural integrity and airframe contact are grouped because of their physical importance to the design. The structural integrity of the payload mount is important due to the fact that the electronics contained within the structure will be damaged if the structure fails, risking the loss of any collected data. The contact with the airframe is an important development within the IREC design process for Rowan's team given that in the 2018 IREC competition, the airframe cracked on impact due to the pressure points created by the payload structure. Modularity and ease of access are not necessarily important structural factors in the design, but they are a required focus as specified by the design constraints provided by the competition guidelines. The payload and all associated structures needed to be fully removable from the airframe in order to be properly weighed and reviewed, so it was important to make a design that could accommodate this fact. A modular structure would also make repairs and design alterations easier and allow the electronics to be removed completely from the structure to allow for easier access.

Avionics System

The function of the avionics system is to act as the recovery control system of the rocket. The avionics system will be centered around an Altus Metrum TeleMega flight computer, with an EasyMini flight computer in parallel to provide a layer of redundancy. These devices will measure altitude, acceleration, speed, tilt, temperature and GPS location. Using this data, it controls a dual deployment recovery procedure by detecting when the rocket has reached apogee to release the drogue chute and when the rocket has descended to 1,500 ft to release the main chute. The devices are both preconfigured to send the pulse signal to actuate the CO2 separation device at apogee and at 1,500ft vertical. Together the rocket trajectory will be measured and transmitted to the ground station to allow live monetization during launch

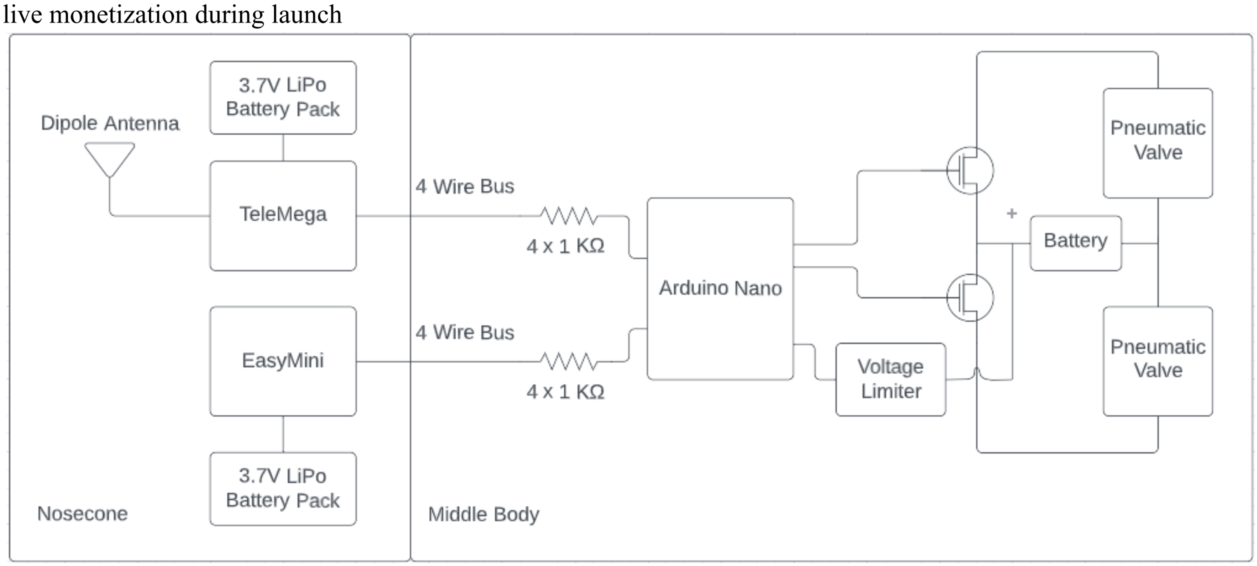

Figure 11. Block Diagram of Avionics/Separation System

1. *Avionics Bay*

This section will hold the TeleMega v4.0, referred to as the TeleMega, and the EasyMini v2.0, referred to as the EasyMini. The TeleMega was selected as the team's main avionics device for the breadth of functions it can perform. The EasyMini will be incorporated in parallel to the TeleMega to ensure success through true redundancy. The TeleMega had the advantage of having a range beyond our target apogee, meeting our physical requirements. As for the technical requirements the TeleMega meets the minimum needs for avionics; range tracking, and altitude logging. As well as many other readings such as recovery systems, barometric pressure, accelerometer, GPS receiver, along with being able to record data on board and transmit using a 70cm ham-band at 434.550 MHz frequency. The TeleMega is a device that needs almost no outside assistance to function aside from a 3.7V power supply and an antenna to transmit data.

2. *Signal Pathing*

The signals from the TeleMega and EasyMini were designed to light a simple e-match to trigger the activation of the separation system. The devices expect a low resistance connection between the positive and negative leads for each ignition circuit. In order to properly interpret the signals from each device and exercise true redundancy, the two wires for each ignition signal were passed through a 1 kΩ load. The voltage over each load was measured between two analog I/O pins on the Arduino Nano. If a detected voltage difference is over a set threshold (i.e the signal is detected), then the respective digital output on the Arduino will be raised high. Two digital output pins on the Arduino Nano are each connected to the gate of a MOSFET, which opens the respective pneumatic valve when activated. The full diagram of this circuit is shown in Figure 12 below.

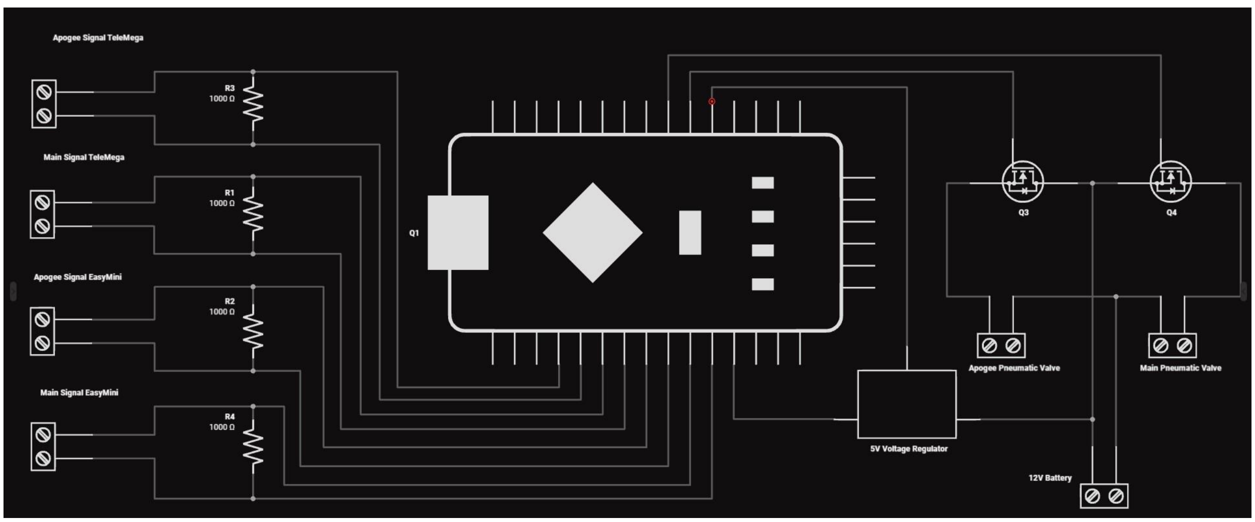

Figure 12. Schematic for Avionics-Separation System

Flux.ai was the program that was used to create the schematic and PCB for the circuit that interprets the signals sent from TeleMega and EasyMini to control the separation. The schematic above shows that the wires from the TeleMega and EasyMini will connect to the 1 kΩ load via 2-pin screw headers. The Arduino will act as a pulse extender/amplifier to control the MOSFETs. The battery and pneumatic valves will also connect to the board via 2-pin screw headers.

3. *HAM Radio Communications*

During flight, we will be able to monitor the status of the rocket via transmissions from the TeleMega. The TeleMega operates on the 70 cm HAM band at 434.550 MHz through a dipole wire antenna and communicates with our ground station which uses a 433 MHz three element Yagi antenna. The dipole antenna was chosen over a straight wire antenna with more traditional grounding radials because the dipole showed a lower Reflected Loss value on our Vector Network Analyzer. Additionally, the grounding radial on the dipole can be fastened more securely using a chassis mount SMA connector whereas the grounding radials on our straight wire antenna were soldered to the mounting pins on a through-hole SMA connector. Our most recent range test resulted in a stable connection from about a mile and a half away with obstructions. More testing and tweaking our dipole design in the spring will yield a stronger connection at further distances.

Payload Structure and Design

The payload structure's primary function is to house all of the rocket's electronics in a structurally sound and electromagnetically isolated space. The team achieved this function in a few ways, the first of which being the use of acrylic plates. These quarter-inch thick plates are what the electronics are directly mounted to, so to prevent any sort of unwanted conductivity, they are non-metallic. As for the structural side, there were a few design considerations to take into account when creating a functional structure. The first consideration was our rocket dimensions; because the airframe is too small to accommodate a CubeSat format payload, the structure was designed instead to make use of as much space as possible within the airframe whilst remaining rigid. The positioning of all of the structure's components are to ensure that nothing on the inside shifts or twists while in transit or in flight. While the payload has to meet the 8.8 lb payload weight requirement, the majority of the weight comes from the structure itself, so the structure was designed to be heavy but not so much that it weighs down the rocket unnecessarily. The team accomplished this weight goal by using steel threaded rods and eye nuts and aluminum divider plates. The threaded rods are designed to be the primary load-bearing members of the structure, as they will be the only pieces besides the eye nuts that are subjected to direct load from the parachutes. As for the divider plates, while important to the overall structure, these plates were chosen to be out of aluminum mainly to allow for easy machining. These disks won't be subject to the same forces as the load-bearing rods and as such the material does not have to be as strong. The same rationale goes for the aluminum brackets used to assemble the structure, since modifications had to be made to allow for proper nut clearance. As part of the requirements for the competition, the payload team decided to go with a camera feed from launch to touchdown. Our initial goal was to completely stream the flight of the video live from the inside of the rocket, but this proved difficult considering the RF suppression factor of the carbon fiber body; our current implementation has the camera feed being saved locally to an SD card.

C. Payload Subsystems

All subsystems of the student-made payload will be controlled by a Raspberry Pi. The Raspberry Pi will locally store all data on an SD card which will format the data in a spreadsheet storing measurements with a timestamp. The devices in the payload take measurements surrounding the theme of air quality analysis.

1. *Payload Module*

This section will hold the Raspberry Pi and its auxiliary devices which will analyze the atmosphere around the rocket during its descent. This module will be ejected from the payload body section of the rocket with the intent of collecting data on the air quality. The devices used include a standard arduino temperature sensor (DHT11), a temperature/altitude/pressure sensor (BMP180), an Ozone gas sensor (MQ131), and a methane gas sensor (MQ4).

2. *Temperature/Humidity Sensor*

The temperature sensor is a standard arduino temperature sensor, this will be used to read the temperature inside the rocket and how the ascent affects the inside temperature as well as at apogee and descent. This reading will help the team understand some of the constraints the electronics will face in the future.

3. *Temperature/Altitude/Pressure Sensor*

The use of the BMP180 will allow for various types of weather measurements such as temperature and barometric pressure while also allowing for altitude to be calculated using the pressure. The redundancy of the temperature sensors will allow for confirming of the results of each sensor, and the inclusion of the altitude will allow the data to be easily put onto the raspberry pi for viewing and using.

4. *Gas Sensors*

Our team decided to use two gas sensors for our payload design though more may be implemented later on given the time and resources. Our choices were the MQ131 Ozone sensor and the MQ4 methane sensor. While our rocket will only be going up to 10,000 feet, with the low concentration model of the MQ131 a noticeable difference in Ozone concentration should be observed. Also, as methane in the atmosphere is an indicator of fossil fuels and a contributor to climate change, an MQ4 was included to sense and display data on the methane concentration.

5. *Camera*

The on-board camera will be a Raspberry Pi Camera Module 2. For the ascent of the rocket, the camera will just have a view of inside the rocket; the team has not yet decided on the potential for an acrylic window to be installed in one of the couplers to allow the camera to view outside during ascent. The camera will then get a view from outside of the rocket once the payload module has been ejected during the first separation event. The footage collected from this camera will be stored on the SD card for viewing after the rocket is retrieved.

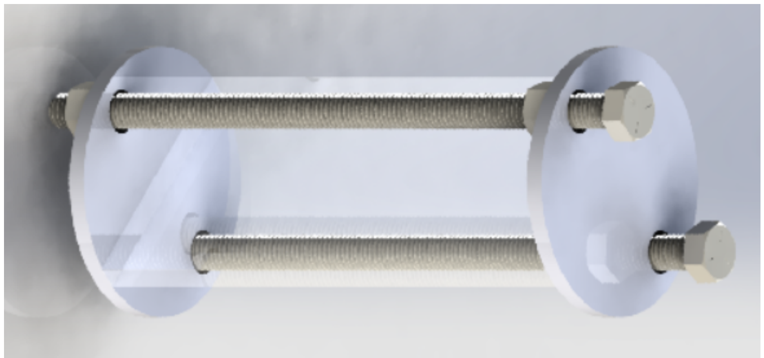

Figure 13. SolidWorks rendering of payload structure

D. Fins

There will be four main sustainer fins located directly above the back end of the rocket. The profile of these fins can be seen in Figure 11 below.

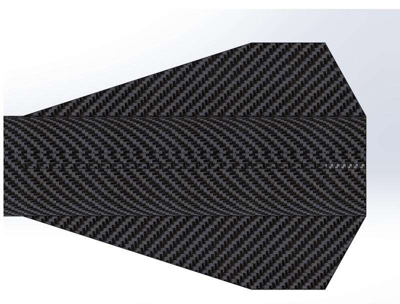

Figure 14A. SolidWorks sustainer Fins

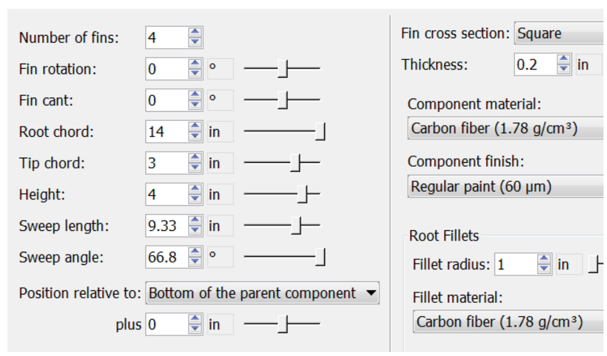

Figure 11B. OpenRocket sustainer fins measurements

Figure 14 - Solidworks rendering of sustainer fins (with dimensions from OpenRocket)

After discussing alternative options for the manufacturing of the fins with Dr. Schmazel and Dr. Haas, the team has decided the sustainer fins will be fabricated using additive manufacturing. In other words, the sustainer fins will be entirely 3D printed using a Markforged printer. The Markforged printer has the capability to print with nylon-carbon fiber chopped matrix filament, simply referred to as "onyx" by the company. The printer has a second head that is able to reinforce a print with fiberglass. Utilizing these materials together for the 3D printed fin will result in a higher quality, higher precision, and easily replicated fin than a hand wrapped fin at almost no cost to durability.

The team ran into a slight issue with the Markforged printer during the initial prints. The fiber nozzle jammed on one of the first prints resulting in a loss of time and materials. We began communication with Dr. Haas and the Tech team to try and find a solution to get the printer's fiberglass reinforcement capabilities running properly. The fiberglass reinforcement is essential as it introduces more stiffness and stability, as well as strength to the printed fin.

The team is currently in the process of finding a viable fin simulation software that will help accurately evaluate the structural analysis of the fin design. Complications with the original fin simulation software, AeroFinSim, has brought upon a need for further research into alternative options. We are exploring all options and working with advisors for the best solution for our needs. Once we have a fin simulation software, we are looking forward to the evaluation of our fins.

Attaching the fins will be the next step once fabrication and simulations are completed. Based on our research, we have concluded that through the wall (TTW) is the best method for attaching our fins to the fuselage. TTW will reduce movement of the fins when forces act on them throughout launch and flight. We plan on using epoxy adhesive to glue the tabs on the fin that go through the wall as well as the points where the fin and fuselage meet on the outside. A fairing-like structure will be created when applying the epoxy to the outside so there are more rounded edges. We are currently communicating with the lab technicians on the best method to drill through the carbon fiber wrapped fuselage for precision placement of the fins.

In early stages of the design, the original sustainer fins had a swept back shape, which extended past the back end of the rocket. This design provided the rocket with optimal stability to reach our goal apogee. However, since the back end of the airframe will experience significant amounts of force on impact upon recovery, a redesign of the fin shape was needed. The trapezoidal fin shape was used to keep the fins from protruding off the back of the rocket. With this design, the fin tips will not be taking the full impact, the impact will be distributed across the cross-sectional area of the bottom of the rocket. This design will provide the teams desired approximate two-caliber stability. The fins were designed with a very low profile to reduce the drag force during the rocket flight. However, they are not too low profile to compromise the rocket's overall stability.

Based on previous designs, the back up plan for the sustainer fins will be to cut them from G10 fiberglass plating and wrap it with seven layers of carbon fiber on each side of the plate, similar to the airframe design. Since each wrap is 0.009 in thick, the total carbon fiber thickness of each of these fins is approximately 0.126 in. In order to ensure the sustainer fins are strong enough to withstand the forces that will be undergone during launch, the total thickness has been increased to 0.251 in. The sustainer fins will be cut from 0.125 in G10 Fiberglass. Because the fin thickness is an extremely sensitive parameter, it is extremely important that they are constructed as precisely as possible. The tolerance is 0.001 in because of the dramatic changes in apogee of approximately 500 ft.

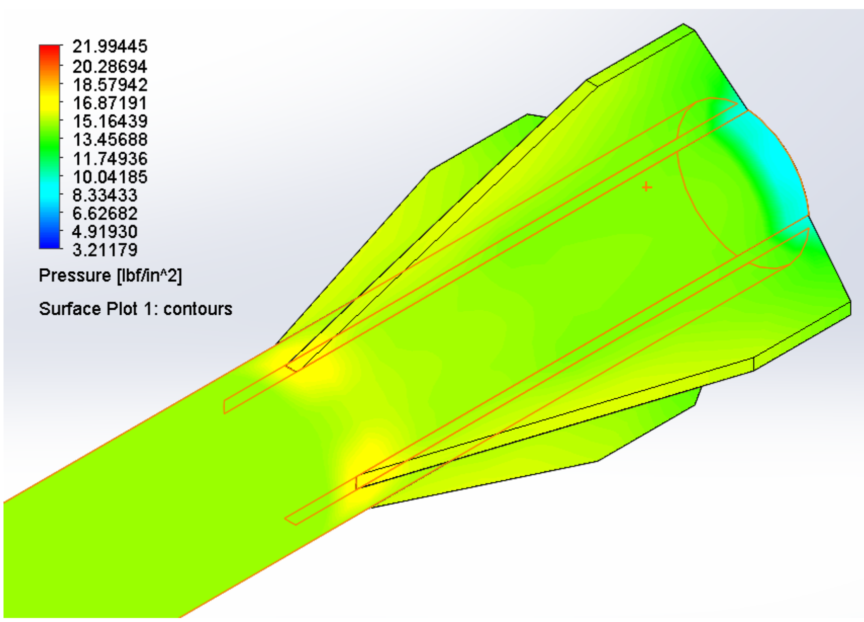

Figure 15 - Solidworks Flow Simulation of Air Pressure on Tail Section at 1670 Feet Per Second

It was determined that the pressure on the fins was between 13 and 16 pound-force per square inch (psi). The area of the frontal part of the fin is 2.46 in^2. Therefore, the force on the fin is 35.67 pounds. The epoxy chosen to attach the fins to the rocket was G5000 Rocketpoxy developed by Glenmarc industries. This rocketpoxy has a tensile strength of 7600 psi which is definitely strong enough to handle the force on the fins, but we plan to mix in 10% Miller fiberglass by mass to significantly improve the thermal and physical properties of the fins.

To practice laying carbon fiber, we cut out thin rectangles of G10 fiberglass and tested the hardness and strength of different carbon fiber laying methods. Through these tests, we have learned the perfect amount of epoxy required to wrap the fins in carbon fiber, and we have the ability to assess just how much the 10% milled glass adds to the properties of the epoxy. Before we conducted these tests, we researched the hazards of epoxy and milled fiberglass and bought the necessary PPE–gloves and masks–to start work on the G10 rectangles. We also opted to work within a fume hood to mitigate the amount of small milled glass particles the team could be exposed to.

We differ from the previous team in our wrapping methodology in one major way: we don't make use of an oven to cure the epoxy, instead opting to vacuum seal the fins while they cure. We accomplish this through the implementation of a vacuum sealer typically used in preserving food, but instead of storing food inside of the vacuum bags we simply slide in our G10 pieces and achieve the perfect seal we need. Moving forward, we will need to finish wrapping the fins prepared by the previous team and wait for the results of our new design idea before ultimately using plan B and attach them to the rocket body.

Recovery System

1. *Drogue Parachute*

The drogue parachute will be a 3 foot parachute with 20 feet of shock cord to separate the top section of the rocket. The drogue parachute will deploy at apogee when the TeleMega and the Easy Mini detect a maximum altitude. The drogue parachute will be used to slow the rocket to 34mph before the main parachute is deployed.

2. *Main Parachute*

The main parachute will be a 16 foot parachute with 30 feet of shock cord. This will ensure the two parachutes will not interfere with each other and the long length of shock cord can help prevent "zippering" on the airframe of the rocket, further increasing chances of having a reusable rocket. The main parachute will be deployed at 820 feet before the ground, allowing for the rocket to make contact with the ground at approximately 11mph. This parachute has yet to be ordered, as tests done with the previous parachute and bag showed difficulty in deploying under the restraints of the rocket.

3. *Shear Pins*

The stage separation method we plan on utilizing is shear pin separation. In previous iterations of the rocket, explosive bolts were used as the main separation method for the stages of the rocket, however due to the challenges of acquiring black powder, our team opted for CO_2 pressurized separation that shears plastic bolts connecting the different rocket stages. The material for the bolts will either be acrylic or nylon. These bolts will be sheared by the pressurized CO_2 system. Our team has calculated the amount of bolts needed for a successful stage separation for size M3, M2 and 2-56 bolts for both materials. However, we are still in the process of deciding the final material and bolt size. Nylon has a very narrow precise shear strength, allowing for a more predictable shear, but it is very ductile and could clog up the stage separation. Acrylic is much less ductile, creating a cleaner shear, however, it has a much less precise shear strength compared to nylon, causing its shear to be much less predictable. The final bolt will be decided on after extensive tests in the future.

III. Mission CONOPS (Concept of Operations)

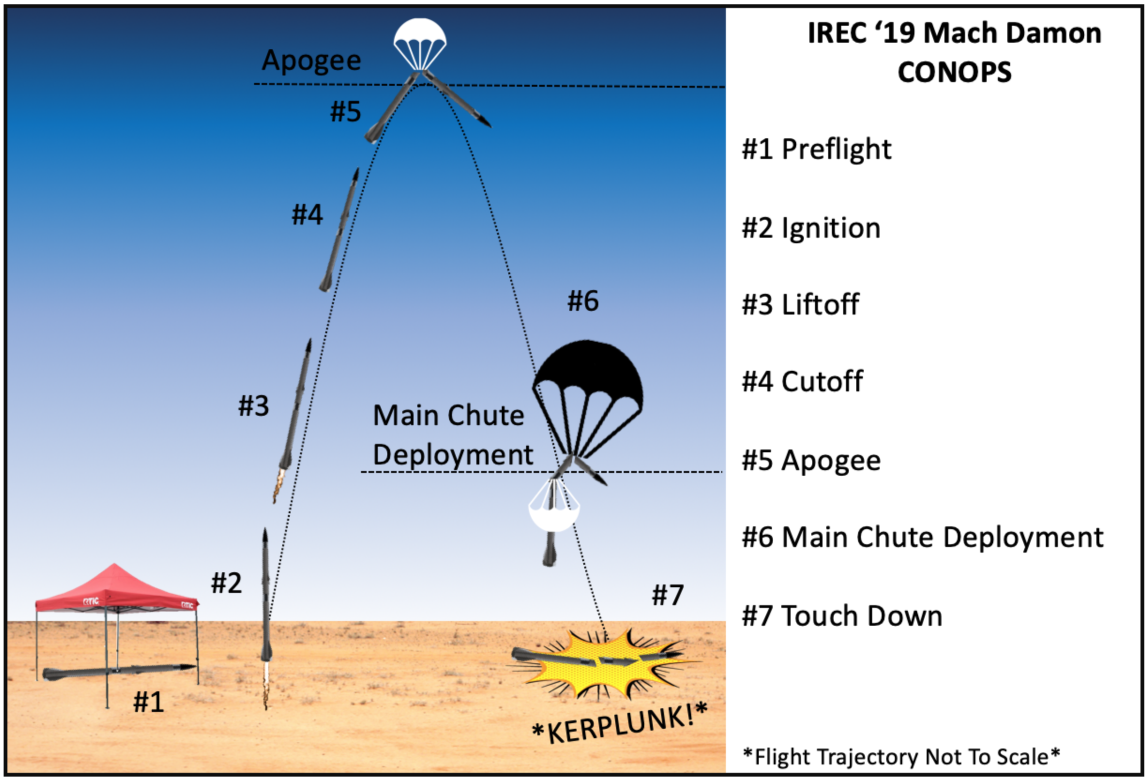

Figure 16. Mission Phase Diagram

Attached on the following page is a reference key explaining each mission phase, and phase signifier, as well as the subsystem activity at each respective phase.

Mission Phase	Phase Signifiers	Subsystem Status
Phase 1-Preflight	Rocket is prepared and installed onto the launch rail	**Motor:** *Standby* **Recovery:** *Standby* **Avionics:** *Manually Turned-on (Starting data collection and data transmission)* **Payload:** *Manually Turned-on (Starting data collection)* **Airframe:** *Final assembly complete and rocket loaded onto rail*
Phase 2-Ignition	Ignition is activated	**Motor:** *Ignition switch is engaged, rocket propellent burning* **Recovery:** *Standby* **Avionics:** *Active/Transmitting* **Payload:** *Active/Transmitting* **Airframe:** *Attached to launch rail*
Phase 3- Liftoff/Flight	Rocket lifts off and begins flight	**Motor:** *Burning* **Recovery:** *Standby* **Avionics:** *Active/Transmitting* **Payload:** *Active/Transmitting* **Airframe:** *Accelerating off rail/to apogee*
Phase 4- Cutoff	Motor cuts off	**Motor:** *Rocket fuel exhausted, engine cuts off* **Recovery:** *Standby* **Avionics:** *Active/Transmitting* **Payload:** *Active/Transmitting* **Airframe:** *Momentum carrying rocket towards apogee*
Phase 5- Apogee	0 Velocity reached and transition to free fall. Drogue deployment.	**Motor:** *Off* **Recovery:** *Drogue chute deployment* **Avionics:** *Apogee detected, signal sent to blow 1st stage ejection charges* **Payload:** *Active/Transmitting* **Airframe:** *1st Stage ejection charges blow, nose cone separation*
Phase 6- Main chute deployment	2nd stage separation. Main chute deployment.	**Motor:** *Off* **Recovery:** *Main chute deployment* **Avionics:** *Main chute altitude detected, signal sent to blow 2nd stage ejection charges* **Payload:** *Active/Transmitting* **Airframe:** *2st Stage ejection charges blow, payload bay separation*
Phase 7- Landing	Rocket touches down	**Motor:** *Off* **Recovery:** *GPS Tracking Signal Transmitting* **Avionics:** *Active/Transmitting* **Payload:** *Active/Transmitting* **Airframe:** Rocket gently lands atop a cozy pile of sand

Table 1. CONOPS Reference Key

IV. Conclusions and Lessons Learned

Rowan AIAA believes that "Newton's Fifth Law" demonstrates the strides we've made in our fourth, fifth, sixth, and now seventh years working on a competition rocket. Working with previous IREC members who were, the team set out to continue work on a new improved rocket based off of the previous years' designs. The lessons learned from the last rocket launched directly impacted several decisions that were made for the rocket that will be launched this summer. Removing the tapered section will decrease the overall drag produced during flight, something that was modeled on last year's rocket and is believed to have affected its maximum velocity and altitude. This will allow us to achieve higher speeds and greater altitudes, something that is necessary as we strive for future success and higher achievement. In addition to this, last launch year's airframe damage directly impacted the decision to not only use stronger airframe materials (carbon fiber), but to also produce a much lighter payload bay. This should greatly reduce the risk of damage upon landing. These and many other small tweaks were implemented directly because of the experiences at IREC 2018 and past years.

Due to the efforts of last year's IREC team, funding and material acquisition for the project hasn't been an issue. Despite the great work done by the previous IREC teams, this semester we struggled on properly understanding where the project actually was and what needed to be completed. We were not given a proper briefing coming into this term, and as we were a whole new team with no returning students, it took a lot of digging to figure out where to begin. It would have been beneficial to understand the entire scope of the previous team's vision and why they chose specific design and material choices. Due to so much work already being complete, we felt constrained to continue the previous group's plans, rather than introduce new solutions that might better help to complete the mission. For example, we now must tackle the issue of RF signal transparency as our body's carbon fiber shell and the aluminum couplers both block the signal between the ground and our payload. The alternate material chosen for the couplers, nylon-fiberglass filament, is also extremely difficult to work with given the resources available at the university. Of course as engineers it's our job to solve these kinds of problems, but they have definitely held up progress on the overall project. If need be, we will attempt to create a brief for next year's IREC team so that they can hit the ground running. We hope to continue on our legacy as a dynasty of participation in IREC as so many other schools have done with participation in over a decade of IREC competitions. We hope that hard work and dedication that was put forth on this year's rocket build will continue on to IREC 2023 and carry on the legacy of the forerunners that started the Rowan Rocket Team.

VI. Acknowledgments

First and foremost, we would like to thank the ESRA for the incredible work on growing and expanding this event to the magnitude that it has reached. It has been an amazing experience for a team that doesn't have much experience with aerospace in the curriculum at our university. We are extremely grateful for the mentoring and help we have received from the ESRA. We would also like to thank the dedicated and hardworking staff supporting our efforts at Rowan University including our advisor Dr. John Schmazel and finance coordinator Terri Sabatini. They were instrumental in helping us secure and utilize the capital funding the entire build and our continued participation this year is thanks to their dedication and assistance. Lastly, (and perhaps most importantly) we would like to thank our founder and former club president Tyler Harlow as well the previous team members before us who contributed to the Rowan Rocket Teams legacy. These forerunners laid the foundation of which ALL of our work is laid on and without their hard work, dedication, successes and failures this team would be launching model rockets on a farm field outside of Glassboro.

VII. References

"Fiberglass 4' Filament Wound (Select Shape)." *Madcow Rocketry*, www.madcowrocketry.com/fiberglass-4-filament-wound-select-shape/.

Appendix A- System Weights, Measures, and Performance Data

As stated on the final update from Rowan University, listed below is a table of values representing the final measurements of the airframe. Additional data listed on the final progress report.

Rocket Information		
Overall rocket parameters:		
	Measurement	Additional Comments (Optional)
Airframe Length (inches):	114	
Airframe Diameter (inches):	4.09	
Fin-span (inches):	4	
Vehicle weight (pounds):	28.45	
Propellent weight (pounds):	19.1875	
Payload weight (pounds):	10	*This will be closer to 8.8 pounds once final assembly after testing is complete.*
Liftoff weight (pounds):	57.9375	

Table 2. Measurements of Newton's Fifth Law

Appendix B- Hazard Analysis

Propellant grain for motor reload was shipped directly to competition grounds. Once picked up, care will be taken to keep propellant away from open flame, and other ignition sources. Propellant stored in a cool dry storage location and will be kept out of direct sun as much as possible. Fail-safes have also been implemented to ensure that the ejection charges do not go off prematurely.

Appendix C- Risk Assessment Appendix

Team	**Rocket/Project Name**	**Date**		
75 - Rowan University	"Newton's Fifth Law"	5/17/2019		
Hazard	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation Approach**	**Risk of Injury after Mitigation**
Explosion or fire of the solid-propellant rocket motor during storage, assembly, or setup of rocket.	Improper storage of propellent ------------------------ Open flame or smoking in critical storage areas or setup zones ------------------------ Sparks caused by metal-on-metal contact or outside sources	Low: Solid fuel propellant is being shipped directly to the competition to minimize time of HAZMAT storage. Propellant will also be stored in its packaging until assembly.	All team members will be briefed on safety risks and required precautions PRIOR to receiving the propellant into teams possession. --------------------- Assembly and setup areas will be treated as "sterile" and local risk mitigation will be conducted prior to the unpackaging of the propellant.	Low
Igniter fails to launch on command but, ignites as team approaches to troubleshoot.	Wiring malfunction/misfire in the leads ------------------------ Insufficient power provided to leads ------------------------ Leads attached to igniter improperly at the beginning	Moderate: Tests may be run prior to launch but equipment purchased may still be faulty	Check leads using a voltmeter and perform sample igniter test ------------------------ Perform calculations for necessary power requirements and perform sample test prior to launch ------------------------ Double check for sufficient attachment and ensure leads are not touching	Low
Fins detach from the rocket rocket	Epoxy used for the attachment of fins to	Moderate: Any small bubbles	Fill the fin attachment area with excess	Low

causing the rocket to become unstable and deviate from the projected trajectory.	the airframe doesn't hold. ------------------------ Rocket velocity is too high and fin material is unable to withstand shear force with the air rushing past it.	or cracks in the layer of epoxy could cause there to be a weak point and compromise the integrity of the attachment method.	epoxy to ensure that there is a larger area of the fins glued to the airframe	
Deployment occurs prior to apogee, ripping the parachutes out and causing the rocket to descend at too high a velocity, possibly causing injury	Portholes on the side of the airframe are not large enough for a barometric reading. ------------------------ Wiring malfunction/misfire ------------------------ Target deployment altitude programmed incorrectly into the system.	Moderate; Flight controller is manufactured and purchased from outside vendor and may not be repairable if malfunctioning	Calculate and double check the correct sizing of portholes and perform ground testing. ------------------------ Check leads using a voltmeter and perform ground test ------------------------ Double check settings in flight controller prior to every ground test and run rocket simulations to check for appropriate deployment altitudes	Low
Lose sight of rocket during launch and unable to receive data on location.	Low Cloud Coverage ------------------------ Telemetry fails to work after launch because the battery dies, or the power is lost in some way.	Moderate: Telemetry could have a manufacturing error or weather could be uncooperative.	Check weather reports for clouds and communicate with range safety to ensure safe flight conditions. ------------------------ Charge batteries and wait until the last possible second to turn power on to the electronics.	Low

Appendix D- Assembly, Preflight, and Launch Checklists

Assembly:

1. Unpack vehicle upon arrival at Las Cruces
2. Assemble propellant grain in grain sleeve
3. Grease O-rings
4. Seal casing with O-rings
5. Install propellant grain
6. Install nozzle with aft closure
7. Attach casing retainer
8. Attach lower parachute tether to engine retainer
9. Attach lower body tube to transition piece
10. Pack main parachute
11. Install main chute into lower body tube
12. Secure upper parachute tether
13. Pack drogue chute
14. Install drogue chute into upper body tube

Preflight:

1. Charge electronics prior to launch day
2. Check charge on electronics on launch day
3. Bench test electronics
4. Install electronics onto cubesat trays and mounts
5. Install payload bay into payload bracket
6. Install ejection charges for main and drogue
7. Connect ejection charge lines
8. Secure ejection charge lines
9. Connect upper and lower body tubes by avionics bay
10. Install shear pins
11. Attach nose cone

Launch:

1. Load onto launch rail
2. Power on electronics in flight mode
3. Install igniter
4. Secure igniter to launch stand
5. Test connection to GPS (telemega) as well as other electronics
6. FIRE!

Appendix E- Engineering Drawings

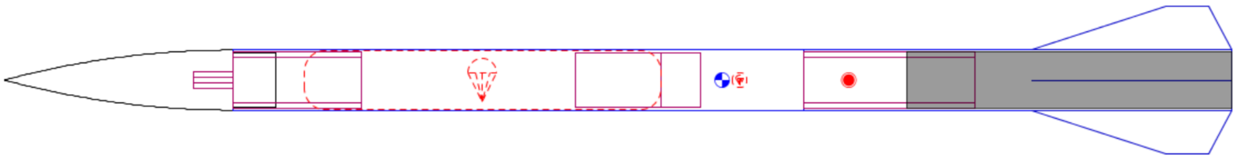

Figure 19. OpenRocket Drawing of Newton's Fifth Law

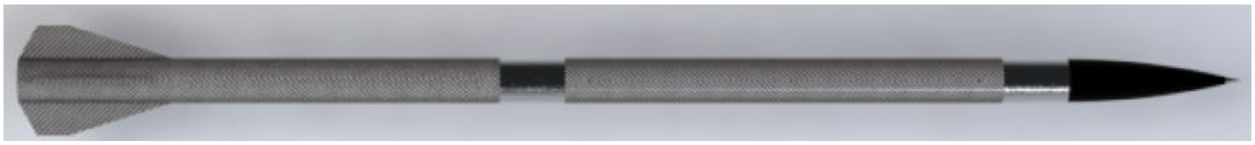

Figure 20. SolidWorks Rendering of Newton's Fifth Law

Figure 21. Exploded View of Newton's Fifth Law

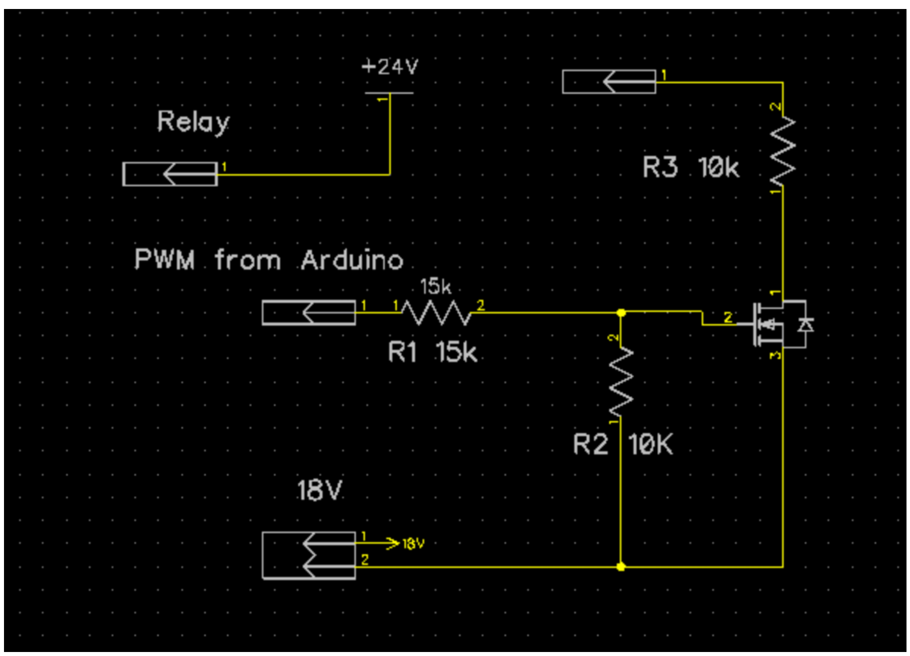

Figure 22. - Carbon Fiber Oven Circuit

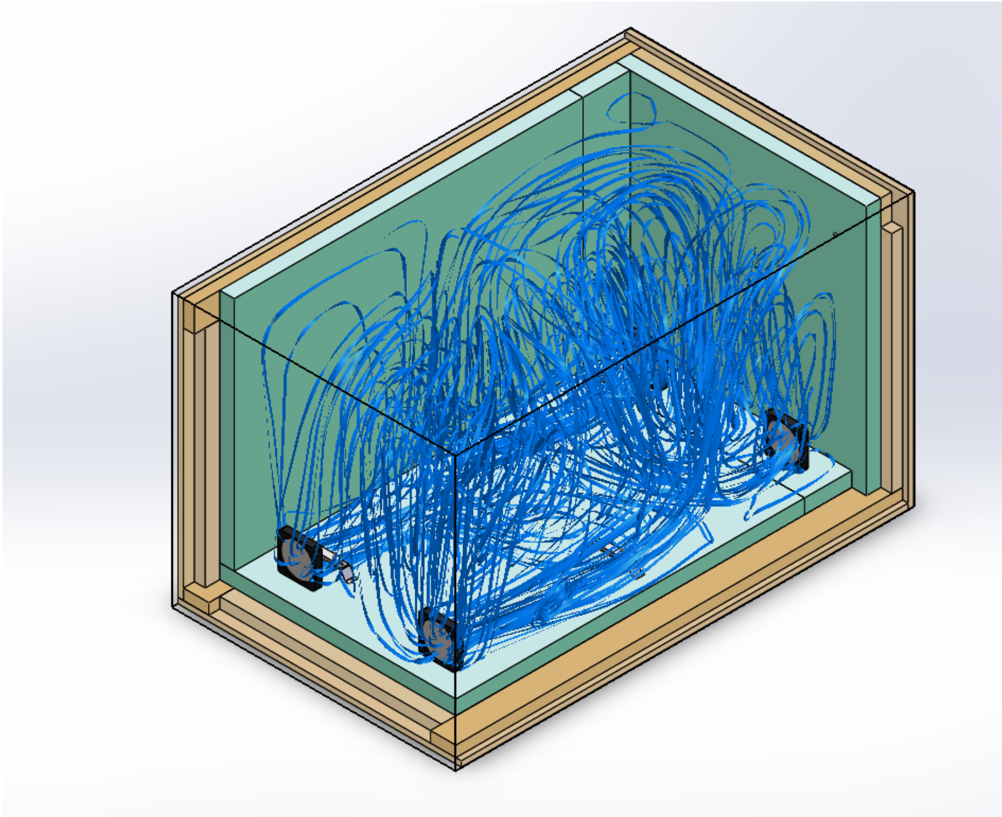

Figure 23. - Carbon Fiber Oven Simulation