University of Nebraska-Lincoln

2018-2019 Midwest High Power Rocketry Competition

Husker Rocketry Preliminary Design Report

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1 Executive Summary

The University of Nebraska-Lincoln Husker Rocketry Team will be competing in the NASA's Space Grant 2019 Midwest High-Power Rocketry Competition. The objective is to design an efficient supersonic rocket. The rocket is designed to minimize weight and drag. This will be accomplished using a minimum diameter design. The motor mount will be entirely internal, which further reduces drag. Additive Aerospace fly-away rail guides will be used in place of traditional rail buttons.

The rocket will be constructed from scratch-built carbon fiber tube. The fins will be G10 fiberglass, attached with reinforced epoxy fillets and a carbon fiber tip-to-tip layup. The nosecone will be a clear polycarbonate Von Karman housing an internal camera for the bonus challenge.

The first launch the rocket has a static stability of 1.79. It is predicted that the rocket will fly to an apogee of 5020 ft (1530 m) with a maximum velocity of 732 ft/s (223 m/s) and a maximum acceleration of 417 ft/s^2 (127m/s^2) on a Cesaroni I218 motor. These values are predicted to be 7650 ft (2332 m), 1143 ft/s (348 m/s) and 796 ft/s^2 (234 m/s^2) on a Cesaroni J430 motor on the second launch with a static stability of 1.54.

Safe recovery will be accomplished with a pair of Raven4 altimeters. They will be independently powered and connected to independent ejection charges. Both the main and drogue parachutes will be ejected with a single event, with the main parachute held by a Jolly Logic Chute Release until the set altitude of 1000 ft AGL.

The non-commercial sensor suite will contain sensors and transmitters capable of operating at the extreme accelerations of Mach 1 flight. They will be securely mounted to a custom PCB. The Raven4 altimeters will provide a comparison to the non-commercial sensor suite. The commercial GPS to be flown, Apogee's Simple GPS Tracker, will allow ground retrieval, should the non-commercial GPS fail.

2 Design of Rocket Airframe

The rocket fuselage is composed of a polycarbonate Von Karman nosecone, a scratch-built carbon fiber tube for the body and booster section, and a set of three trapezoidal fins. A minimum diameter design was chosen to minimize weight and drag. There is no additional internal motor mount tube, which eliminates the possibility for positive motor retention on the back of the rocket. The motor is instead held by an AeroPack minimum diameter motor retainer attached to the booster tube in front of the motor. The payload is housed in the nosecone and its shoulder, which is lengthened by a coupler section. To incorporate the switches and coupler for the payload bay, a small (~6 in) section of body tube is attached on the coupler and nosecone shoulder. The overall length is 36in (91.4cm).

2.1 Diagram of Rocket

Figure 1 is a visual cutaway of the rocket, with specific attention drawn to the centers of pressure and gravity of the rocket. The center of gravity of the unloaded rocket lies 16.420 in (41.7 cm) from the tip of the nose cone, and the center of pressure of the rocket lies 25.464 in (64.7 cm) from the tip of the nose cone.

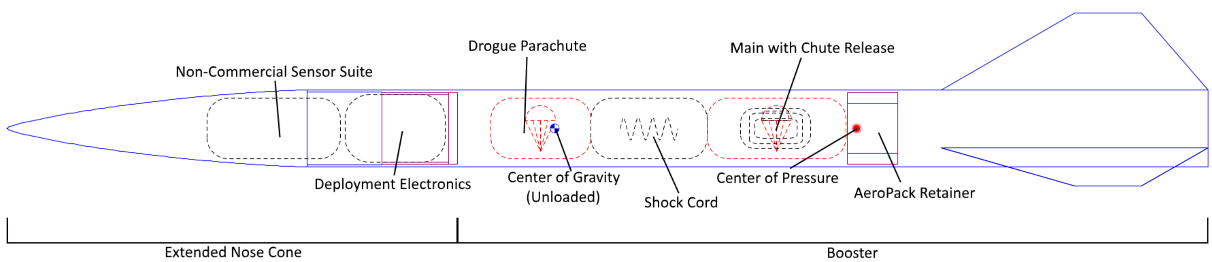


Figure 1: Diagram of the rocket with CG and CP.

2.2 Booster Section Specifications and Design

The booster section tube is a scratch-built, minimum diameter carbon fiber tube and has a length of 27 in (68.6 cm), an outer diameter of 2.3 in (5.8 cm) and a wall thickness of .074 in (.188 cm). The trapezoidal fin set consists of three fiberglass fins with carbon fiber reinforced epoxy fillets and tip-to-tip carbon fiber reinforcement, each possessing a root chord of 8 in (20.3 cm), a tip chord of 2 in (5.1 cm), a height of 2.3in (5.8 cm), a sweep length of 4 in (10.2 cm), and a sweep angle of 60.1°. Instead of a permanently attached rail guide system, a set of Additive Aerospace fly-away rail guides is used in order to minimize drag. Motor retention is provided by an AeroPack minimum diameter motor retainer. The fins, motor retainer, carbon fiber tip-to-tip reinforcement, and carbon fiber layers are all bonded with 635 epoxy resin from U.S. Composites, Inc.

2.3 Nosecone Section Specifications and Design

The Von Karman nosecone is made of polycarbonate and has a length of 9 in (22.9 cm), a base diameter of 2.25 in (5.6 cm), and a wall thickness of .0075 in (0.2 cm). It has a shoulder with length 2.25 in (5.7 cm), wall thickness .075 in (.20 cm), and diameter of 2.15 in (5.5 cm). A small (~6 in) section of body tube is fixed to the nosecone shoulder and a Bluetube coupler is fixed in the other end of this short body tube section. This creates the space needed for the payload. These components are bonded with 635 epoxy resin from U.S. Composites, Inc.

2.4 Propulsion System Specifications

The flight 1 motor is provided by the competition and is a Cesaroni 491-I-218-14A. This reloadable motor provides a maximum thrust of 294.2 N and an average thrust of 218.3 N. The burn will last for 2.3 seconds, providing a total impulse of 491.2 N·s. The dimensions of the motor are 54 mm in diameter and 153 mm in length. The motor consists of 580 grams total mass with 230 grams of propellant mass. The thrust curve for this motor is shown below in Figure 2 and obtained from the following link: http://www.thrustcurve.org/simfilesearch.jsp?id=1669.

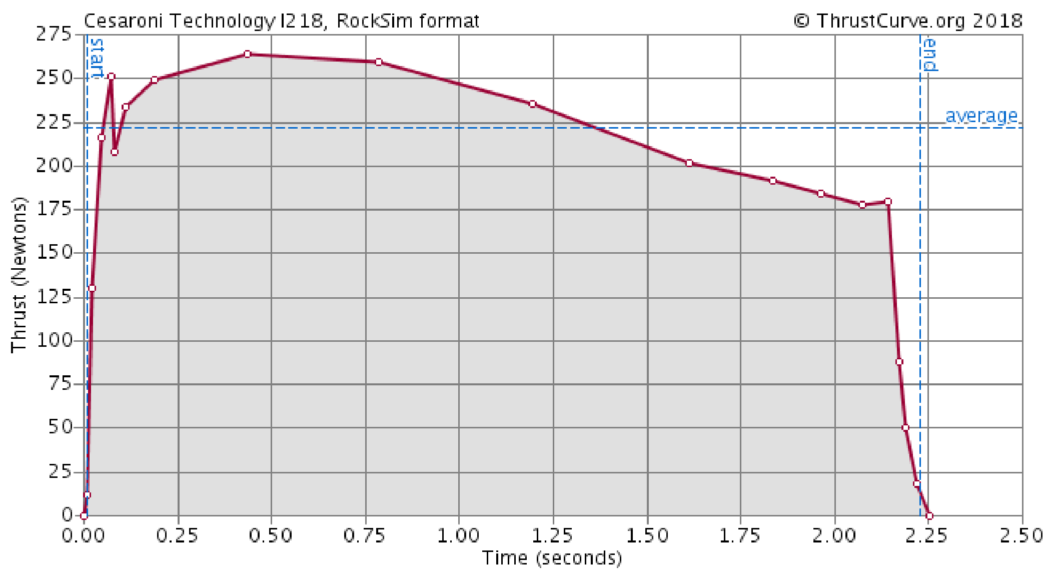


Figure 2: Thrust curve vs. time for the I218 rocket motor.

The flight 2 motor is a Cesaroni 821-J-430-18A. This motor provides an average thrust of 218.3 N, with a maximum thrust of 294.2 N. A total impulse of 491.2 N·s is provided through a burntime of 1.9 seconds. It is a reloadable 54 mm in diameter motor that is 153 mm in length. It has a total weight of 580 grams, 230 grams of which is propellant weight. Shown below in Figure 3 is the thrust curve for this motor, obtained from the following site: http://www.thrustcurve.org/simfilesearch.jsp?id=1868.

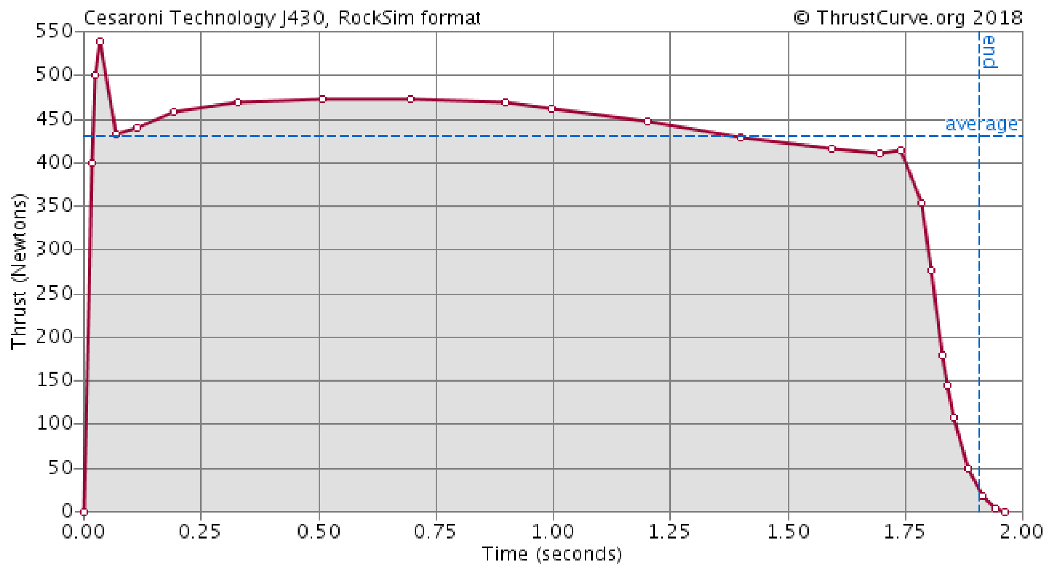


Figure 3: Thrust curve vs. time for the J430 rocket motor.

2.5 Planned Construction Solutions & Techniques

The specific construction procedure can be found in Appendix A. A unique aspect of the rocket is its scratch-built carbon fiber tubes and its minimum diameter design. Also, due to weight, space, and complexity concerns, separate sections for a payload can, parachute tube(s), and a booster tube is not included. Instead, one tube is used for the booster/body section, with a lengthened nosecone shoulder as outlined in section 2.3. The fins utilize wedge-shaped leading and trailing edges to enhance trans-sonic and supersonic performance. Normally a through-the-wall approach is used for fin attachment. However, the fins will be surface mounted due to the minimum diameter design. To ensure sufficient adhesion to the body tube, the tube and fin root edges will be significantly roughened.

A polycarbonate nosecone was selected to view lift-off. The polycarbonate is not initially very transparent and will have to be polished either mechanically or chemically. In order to house all the electronics, an extension to the nosecone will be made. This section of body tube is made of pre-glassed phenolic tube from Public Missiles. This material was chosen because transmitting devices are housed in this section.

For low-weight and high-strength, scratch-built carbon fiber tubes were chosen for the body tube. The tube was created through a wet layup technique involving a uniformly distributed load applied across the carbon fiber as it was wrapped around a mandrel. Excess resin was forced out of the carbon fiber with a plastic squeegee to improve strength and minimize weight. Mylar was used as a release film, to allow easy separation of the finished tube from the mandrel. This application of

Mylar was also used to set the inner diameter of the tube and give the tube a smooth finish.

2.6 Structural Analysis of Scratch-Built Parts and Risk Mitigation Analysis

The rocket design includes a scratch-built carbon fiber body/booster tube. Short sample sections of carbon fiber tubes were created in developing the process for making scratch-built tubes. These short sample sections were also used to test the strength. The max acceleration the rocket experiences was multiplied by the mass of the rocket to find a peak force of 262.8 lbf (1.169 kN). To test the structural integrity under a compressive load, one sample section was placed vertically on the ground and a weight of 441 lbs (1.96 kN) was placed on top of it. A sample section was then place horizontally on the ground and the hoop strength was tested with a weight of 350 lbs (1.56 kN). No measurable deflection or structural failure was observed.

3 Design of Payload and Electronics

3.1 Flight Avionics

The flight avionics package performs several functions critical for the collection of data for the bonus challenges and analysis. The flight package is driven by a Teensy 3.6 Microcontroller Unit (MCU). This is a powerful 32-bit microcontroller with support for a variety of hardware and software protocols. The Teensy also includes an onboard MicroSD card reader, MicroUSB connector, and support for up to 6 VDC external power. The Teensy platform is Arduino compatible, using a programmer plugin called Teensyduino. This allows easy modification and configuration of Arduino libraries for use with this microcontroller board. It will be powered by a 3.7 VDC lithium-polymer battery.

Acceleration, gyroscope, and magnetometer readings will be collected with a combination of an Adafruit BNO055 9 degree of freedom Inertial Measurement Unit (IMU) and an Adafruit ADXL377 High-G Triple axis accelerometer. These products were chosen due to their high rate of data collection, simplicity and compatibility in programming logic, and form factor. The High-g accelerometer is a necessary addition to the avionics package since the BNO055 IMU's max acceleration is 16g (156.8m/s^2) while the rocket's maximum acceleration during flight is around 24g (232m/s^2). This would mean that the IMU acceleration would be inaccurate during the burn time, so the ADXL377 accelerometer with a max acceleration of 200g (1960m/s^2) is necessary to take accurate data during flight. To collect altitude, temperature, and pressure data, a BMP180 barometer will be used. To calculate the final GPS location of the rocket, an Adafruit Ultimate GPS

Breakout sensor will be included in the custom sensor suite.

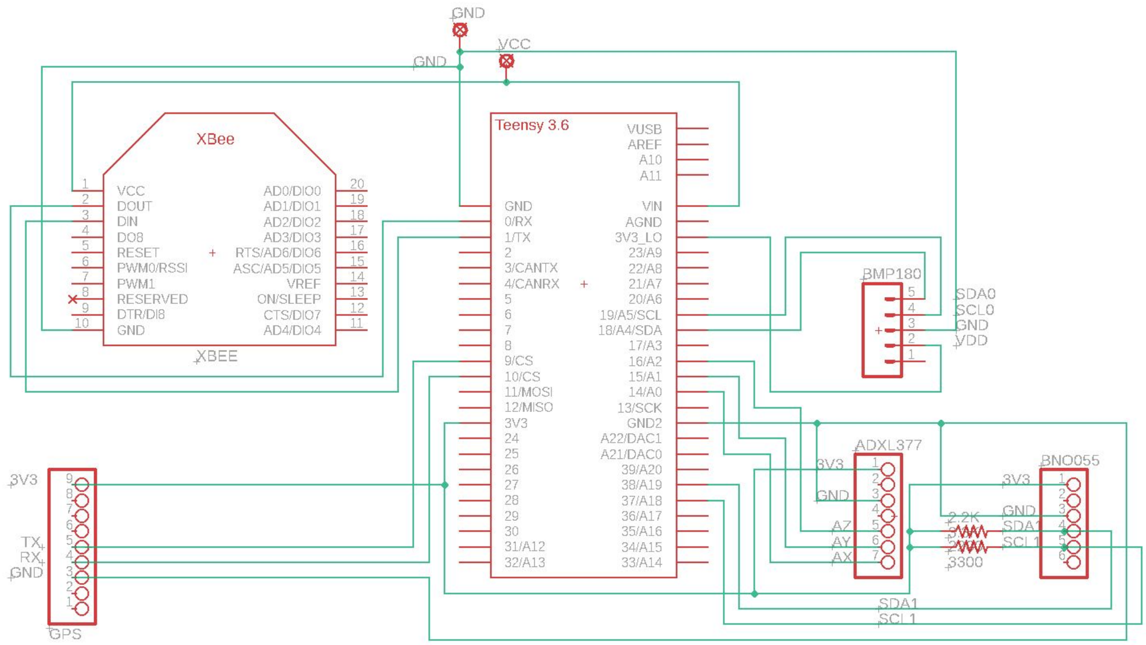


Figure 4: Flight Avionics electrical schematic

In order to detect which of the two black powder ejection charges separate the body tube and ejects the drogue and main parachutes, a detector will be constructed from 3 solid core wires with pin connections. One wire will be connected to the 3.3V output of the Teensy, while another will be connected to an analog logic pin. These two wires will extend from the body of the electronics sled to the bulkhead where a third wire, attached to the main body tube, connects the two wires. When an ejection charge successfully separates the two sections of tube, the third wire will separate and break the circuit, allowing the Teensy to record at which time and altitude the parachutes were ejected. This can then be compared to the different timings at which the two ejection charges are set to go off to determine which actually ejected the parachutes.

3.1.1 Electronics Sled and Organization

The avionics electronics, ejection electronics, telemetry systems, and one camera will be contained in one modular, 3D printed sled as shown in Figure 5. This sled will be bolted into place between the bulkhead above the parachutes and the coupler attached to the nose cone with epoxy resin. This sled extends from the bulkhead to the top of the nose cone. The top of the sled will incorporate a detachable, angled mount for the camera positioned in the nose cone. This detachable mount is designed to be 3D printed with multiple angles so that the camera can have its view angle altered quickly. The sled as a whole is designed for quick assembly and disassembly as well as open access to all electronics once removed from the rocket.

Figure 5: Avionics and Ejection Electronics Sled

To allow easy mounting, simplify wiring, and improve device integrity, all avionics devices will be mounted to a printed circuit board, shown in Figure 6. This device has been designed for devices mounted on the front and back sides of the board, as space is limited in the design of the electronics bay.

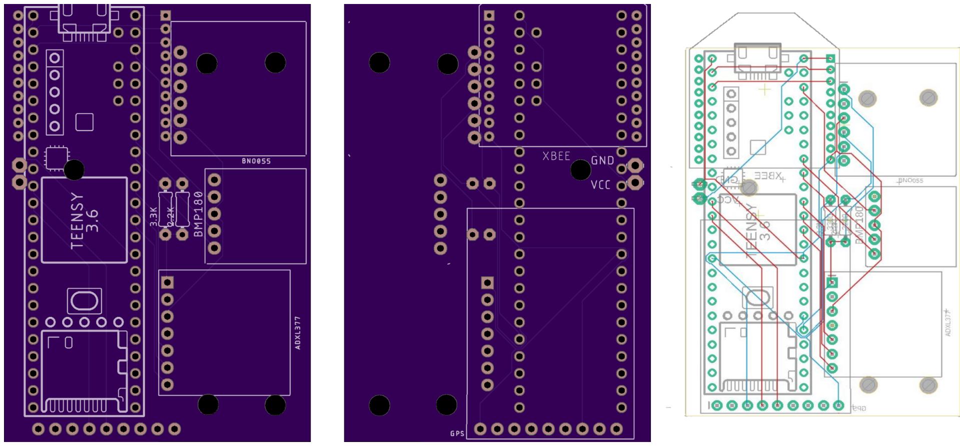


Figure 6: Flight Avionics PCB layout, front (left) and back (center); EAGLE trace schematic (right)

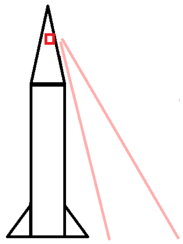
3.1.2 Camera selection and Mounting

Two QEBIDUL cube micro cameras will be used to capture all the necessary flight events for the bonus challenge. The camera is a minuscule cube with a side length of .95 in (2.4 cm). Its characteristics make it ideal for the tasks it needs to perform. Its tiny size allows it to fit in compact spaces such as the tip of the nosecone. Its wide angle lens enables it to view 140°, giving it a larger range to view and aiding in the ability to see multiple flight events. It has a self-contained battery as well as a removable microSD card. Both of these features are ideal since they eliminate the need for cables running to the camera from the teensy.

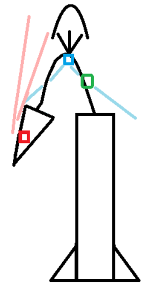
One camera will be in the clear polycarbonate nosecone of the rocket, and the other will attach to the bottom of the drogue parachute. The camera in the nosecone will be attached to the top of the electronics sled. The electronics sled will be printed multiple times and have different angles, to allow for testing to determine the best angle in order for the camera to most reliably capture the needed events. The camera will be able to view the takeoff out the side of the nosecone as shown in Figure 7a, and view the release of the drogue chute as the nosecone and body tube separate and the parachute deploys as shown in Figure 7b.

The second camera will be attached to the shock cord at the bottom of the shroud lines of the drogue chute. The goal of this camera is to capture another angle of the release of the drogue chute, record the release of the main chute, and to record the landing of the rocket. It will be pointing away from the opened parachute (towards the ground) and will see the release of the main chute below it as shown in Figure 7c, and capture the landing as shown in Figure 7d.

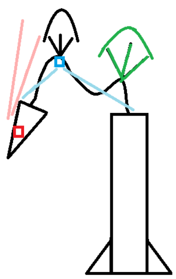
Figure 7: Camera angles showing how the four flight events will be captured.



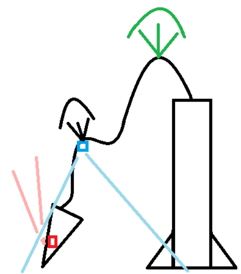
(a) Camera in nosecone (red) captures takeoff.



(b) Camera in nosecone (red) captures drogue chute deployment with main chute (green) in view of drogue camera (blue).



(c) Drogue camera (blue) captures main chute deployment from Jolly Logic Chute Release.



(d) Drogue camera captures touchdown.

3.2 Recovery System

A dual deployment parachute system comprised of a drogue and main parachute will be used to recover the rocket.

3.2.1 Recovery Hardware

Both parachutes are packed in the same space immediately below the nosecone electronics bay. The drogue chute is a Fruity Chutes 12" Elliptical Parachute with a coefficient of drag of 1.50. The drogue and main parachutes are tethered to each other via a 3/8 in tubular nylon shock chord with a length of 8 feet. The fore end of the shock chord is attached to a 1/4 in steel eye-bolt with a 500 lb linear capacity that is rigidly mounted to the electronics bay bulkhead. The aft end of the shock chord will be tethered to the eyebolt of the Aeropack Minimum Diameter Motor Retainer. Starting at the fore end of the rocket, the drogue chute will be attached to the shock cord first followed by the main chute beneath it. The drogue chute's inflation will aid in pulling the main parachute out of the body tube.

The parachutes will be ejected from the body tubes at apogee using a redundant electronic ejection system. Two independent black powder charges are mounted on the electronics bay bulkhead facing downward toward the parachutes. The first black powder charge will ignite at apogee. The second black powder charge will be set to ignite a predetermined time after apogee. The drogue will deploy once ejected, while the main parachute will remain closed until a predetermined height using a Jolly Logic Chute Release to meet competition requirements.

3.2.2 Recovery Electronics

The recovery electronics consist of two independent systems. Each system is comprised of a Raven4, a two-cell lithium polymer battery, and an e-match. The power from the batteries passes through a switch to break the circuit during assembly. The altimeters, batteries, and switch are housed in the electronics bay below the non-commercial avionics package. The switch is accessible from the outside when the rocket is completely assembled. Leads from the ejection terminals of the altimeter run to a terminal block on the other side of the wooden bulkhead. The e-matches are attached to the terminal block instead of running through the bulkhead directly to the altimeter. This allows for faster and easier launch preparation and prevents ejection gases from entering the electronics bay. One-half inch copper pipe caps hold the black powder ejection charges. The charges are tightly packed with cellulose wadding and sealed with painter's tape. A test is planned to experimentally determine the amount of black powder needed for ejection.

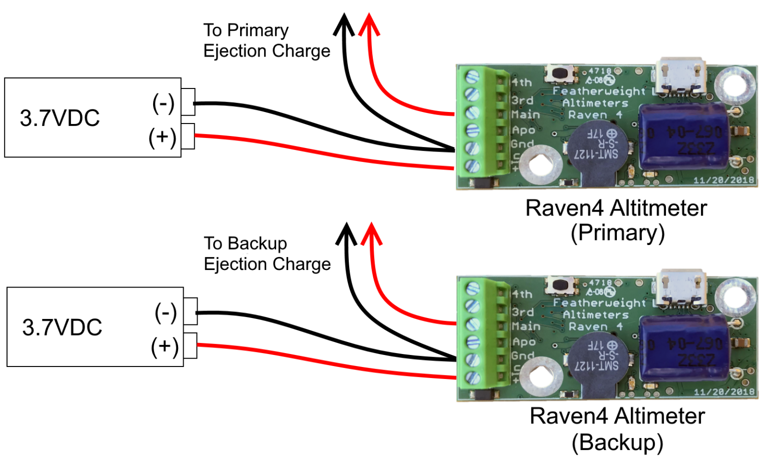


Figure 8: Parachute ejection device wiring diagram

3.3 Radio Telemetry and Tracking

To complete the bonus communication challenge, the flight avionics package includes a 900 MHz XBee radio communications module. This transmitter will be used to receive commands from the ground station before flight, and to telemeter data during the flight. The telemetry data will be transmitted in two packages: one to complete the first part of the bonus challenge to be shown to the judge before landing, and the second to complete the second part of the bonus challenge to be shown within 5 minutes after landing.

The Teensy is responsible for sending and receiving data from the XBee and performing the appropriate actions. The XBee is connected to the Teensy via simple serial communication and will operate at the highest Serial data rate that provides error-free, high-speed data telemetry. The Xbee is powered by the common 3.3 VDC line.

3.3.1 Ground Station

The ground station consists of another Teensy 3.6, an SD Card shield, a 900 MHz XBee (Digikey) Module, a 900 MHz hand-held antenna, and a laptop. This will allow ground control to collect and display telemetry data in real time for in-flight analysis. Data received through telemetry will be logged to the SD card and shown to the judges for submission.

3.3.2 Commercial GPS Tracker

An Apogee Simple GPS Tracker system will be included in the nose cone of the rocket, in addition to the radio telemetry system. This is to satisfy competition requirements and to provide confirmation of data received from flight telemetry.

4 Anticipated Flight Performance

Estimation of the rocket's performance is done using OpenRocket. Optimization of diameter, overall footprint, and simulation of wind scenarios were also completed using OpenRocket. The optimization showed that a minimum diameter design would be greatly beneficial to achieve a velocity of Mach 1 by lowering the mass and drag. The flight simulations can be found in Figures 9 and 10. High wind scenarios were compiled from NAR rules, accounting for a 10 percent deviation.

Figure 9: Flight simulation on I218 motor in metric units

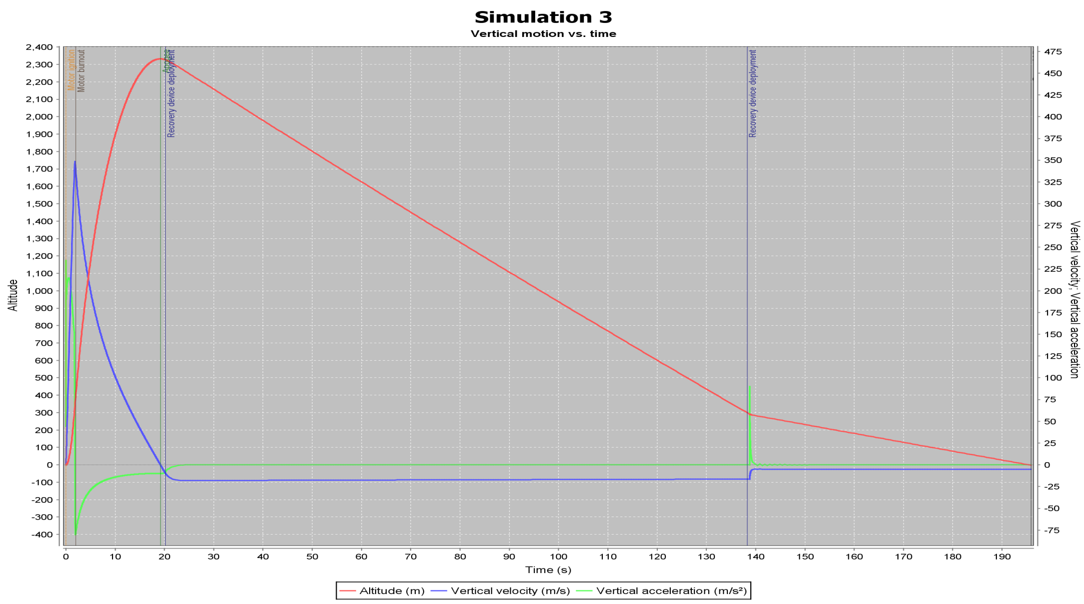


Figure 10: Flight simulation on J430 motor in metric units

4.1 Assumed Simulation Values

To accurately simulate competition conditions, flight parameter were assumed as follows:

- Launch Rod is 6 ft (1.83 m) long
- Average wind speed of 0 ft/s (0 m/s) unless otherwise stated

- Wind turbulence intensity 10.0 percent
- Temperature from 0.0 - 11,000 ft is 15.0°C with a pressure of 101.325 Pa
- Drogue parachute deployed at apogee, secondary chute at 1.5 seconds after apogee
- Chute release triggered at 1000 ft (304.8 m) AGL, main parachute inflation following

4.2 Ascension Phase Analysis of I218 Motor

During the boost phase, a maximum velocity of 732 ft/s (223 m/s, Mach 0.68) is reached after 2.22 seconds; at an altitude of 919 ft (280 m) AGL. The rocket then coasts for 14.48 seconds following motor burnout to a maximum altitude of 5020 ft (1530 m). The total ascent phase of the rocket lasts for 16.7 seconds from launch to apogee. A summary of these values at varying wind scenarios is provided in Table 1 below.

Table 1: Projected Performance Values

Wind m/s	Apogee ft (m)	Max Velocity f/s (m/s)	Max Acceleration ft/s^2 (m/s^2)	Apogee (s)
0	5020 (1530)	732 (223)	417 (127)	16.7
2	5002 (1525)	732 (223)	417 (127)	16.7
4.47	4977 (1517)	731 (223)	417 (127)	16.6
8.94	4868 (1484)	729 (222)	417 (127)	16.4

4.3 Ascension Phase Analysis of J430 Motor

During the boost phase, a maximum velocity of 1143 ft/s (348 m/s, Mach 1.03) is reached after 1.91 seconds; at an altitude of 1312 feet (400 m) AGL. The rocket then coasts for 17.29 seconds following motor burnout to a maximum altitude of 7650 ft (2332 m). The total ascent phase of the rocket lasts for 19.2 seconds from launch to apogee. These values are in Table 1 along with varying wind scenarios below.

Table 2: Projected Performance Values

Wind m/s	Apogee ft (m)	Max Velocity f/s (m/s)	Max Acceleration ft/s^2 (m/s^2)	Apogee (s)
0.00	7650 (2332)	1143 (348)	796 (234)	19.2
2.00	7635 (2330)	1142 (348)	769 (234)	19.2
4.47	7617 (2322)	1142 (348)	769 (234)	19.2
8.94	7524 (2293)	1140 (348)	769 (234)	19.0

4.4 Recovery System and Descent Phase Analysis of I218 and J430

The parachutes are deployed by the electronic ejection charge at apogee. A secondary black powder charge will ensure separation 1.5 seconds after apogee. For the main chute a Jolly Logic Chute Release is programmed to open at an altitude of 1000 feet AGL. This height will ensure the parachute has adequate time to slow the descent of the rocket. Open Rocket was also used to calculate decent velocities. When using the I218 motor, the rocket reaches a velocity of 262.5 ft/s (80 m/s) before the main parachute opens. After the parachute opens, descent velocity is reduced to 16.3 ft/s (4.98 m/s). When using the J430 motor, the rocket reaches a velocity of 295.3 ft/s (90 m/s) before the main parachute opens. After the parachute opens, descent velocity is reduced to 16.6 ft/s (5.07 m/s). The descent will also be effected by wind conditions which can be seen in Tables 3 and 4.

Table 3: J430 Motor Descent and Wind Conditions

Wind Speed m/s	**Deployment Velocity f/s (m/s)**	**Hit Velocity f/s (m/s)**	**Drift Distance ft (m)**
2	18.5 (5.63)	16.3 (4.97)	769 (234)
4.47	26.5 (8.07)	16.2 (4.94)	1241 (378)
8.97	43.8 (13.3)	16.2 (4.94)	2743 (836)

Table 4: J430 Motor Descent and Wind Conditions

Wind Speed m/s	**Deployment Velocity f/s (m/s)**	**Hit Velocity f/s (m/s)**	**Drift Distance ft (m)**
2	11.6 (3.54)	16.6 (5.06)	1220 (372)
4.47	14.7 (4.48)	16.6 (5.06)	1989 (606)
8.97	27.5 (8.39)	16.9 (5.15)	2017 (1224)

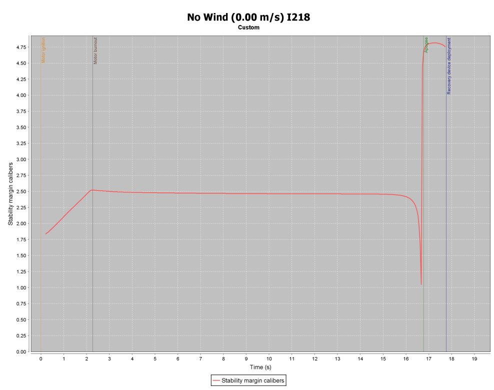
4.5 Stability Analysis

The rocket has a predicted static stability of 1.79 calibers with the I218 motor. The center of pressure lies 25.5 in (64.7 cm) from the tip of the nose cone, with the center of gravity at 21.3 in (54.2 cm).For the J430 motor, the rocket has a predicted static stability of 1.54 calibers. The center of pressure lies at 25.5 in (64.7 cm) from the tip of the nose cone, with the center of gravity at 21.9 in (55.7 cm). For both motors, minimum stability occurs immediately after launch rod clearance. Figure 11 and Figure 12 show the stability at various wind speeds for the I218 and J430 motors, respectively. Stability is lowest at 1.05 which is immediately before apogee. However, this does not represent a concern as this is due to the shifting of the center pressure. The center of pressure shifts when the rocket begins to turn while approaching apogee. Maximum stability occurs immediately after motor burnout and is predicted to attain approximately 2.68 calibers for all wind conditions. The stability condition is expected to be fulfilled for all points during the flight. OpenRocket calculates the stability margin in calibers by taking the distance between the CP and CG and dividing by the maximum body diameter of the rocket.

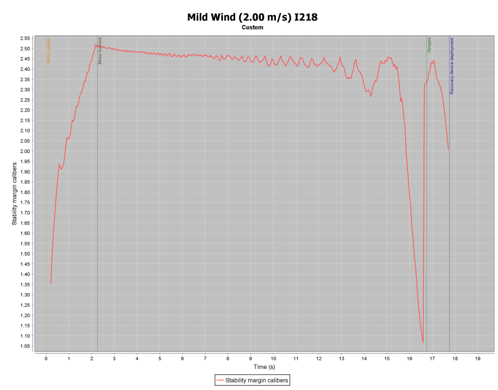
4.6 Environmental Analysis

Wind conditions on the launch date are unpredictable. A range of wind speeds demonstrates acceptable and safe performance for safe launch conditions. The average low temperature on May 18th and 19th in North Branch, Minnesota is 46°F (7.8°C), with an average high temperature of 70°F (21.1°C). Using the average low temperature instead of the ISA, apogee is decreased by approximately 52 ft (16 m) for the I218 motor, and approximately 102 ft (31 m) for the J430 motor. At the average high temperature, apogee is increased by 46 ft (14 m) for the I218 motor, and approximately 85 ft (26 m) for the J430 motor. The air density and viscosity does not change enough within this limited temperature range to have an appreciable impact on other flight parameters.

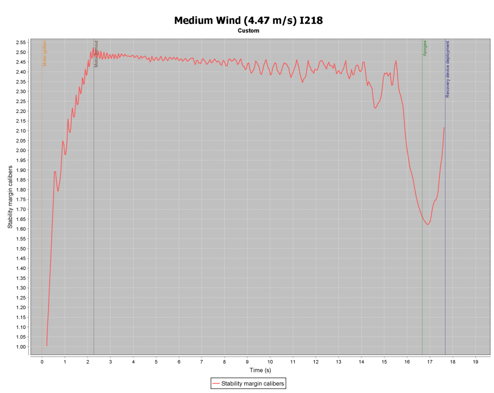
Figure 11: Performance of I218 motor with varying wind velocities.



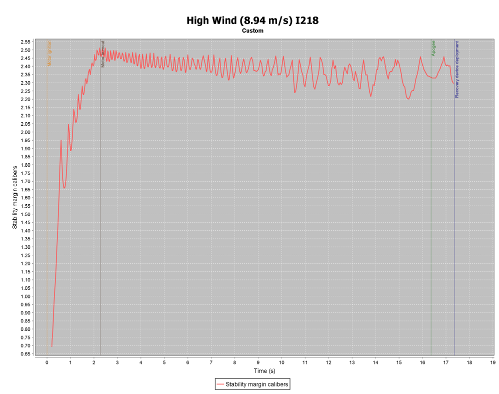
(a) I218 Performance with no wind



(b) I218 Performance with mild wind

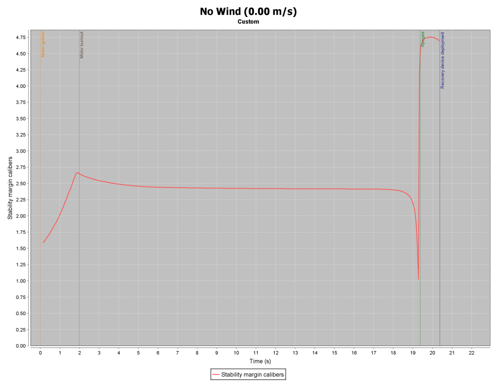


(c) I218 Performance with medium wind

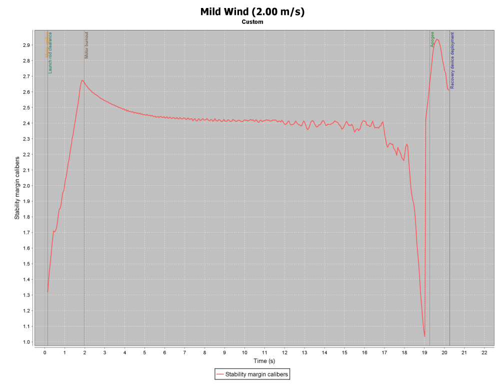


(d) I218 Performance with high wind

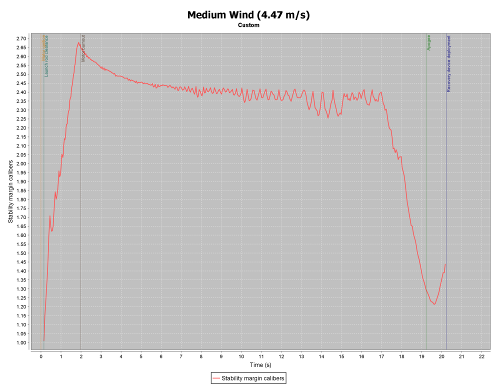
Figure 12: Performance of J430 motor with varying wind velocities.



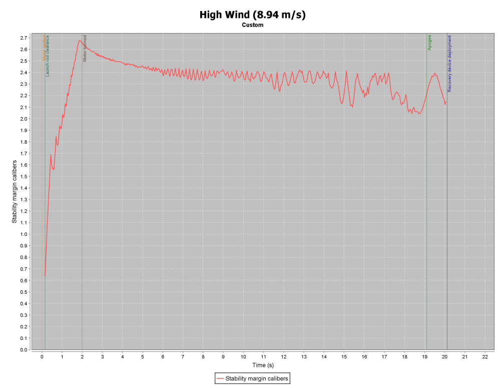
(a) J430 Performance with no wind



(b) J430 Performance with mild wind



(c) J430 Performance with medium wind



(d) J430 Performance with high wind

5 Safety

5.1 Model Rocket Demonstration

To demonstrate the ability to safely launch and recover a rocket, a pack of Estes Viking model rockets (Skill Level 1) were purchased. Four of the model rockets were built in groups of current members. Three were launched at The Heartland Organization of Rocketry's (THOR) October launch. Safety procedures were enforced before and after the launch. Weather conditions were nearly ideal: clear skies and minimal wind. The location, however, was not as ideal because the cleared area was relatively small. The corn in the surrounding fields were not yet harvested. One rocket was visually tracked in the sky, landed in a corn field to the East, and was lost. A photo of the rocket being placed on the pad can be seen in Figure 13.

Figure 13: Flight simulation on I218 motor in metric units

5.2 Hazardous Material Handling

The 635 epoxy resin is used for fiberglass reinforcement and carbon fiber manufacturing. The epoxy resin can cause skin, eye, and respiratory irritations which can lead to sensitization after prolonged exposure. As a preventative measure to reduce exposure to the epoxy resin, the resin is handled while in a well-ventilated area and while wearing appropriate personal protective equipment.

This year, carbon fiber air frame testing was resumed from last year. Because the manufacturing process includes carbon fiber and epoxy resin, appropriate personal protective equipment was required. Before conducting manufacturing tests with carbon fiber, the following items are worn to prevent damage to skin or clothing: protective body suits, face masks, safety glasses, talcum powder (to protect skin around the hands and forearms), and latex gloves. Once the members are prepared, the materials are moved to well ventilated area where they are to be used for manufacturing.

Figure 14: Team members safely cover their hands and wear protective gear before handling resin.

Black powder is also a hazardous material that requires certain safety protocols while handling. Black powder, used for ejection charges, is a highly explosive material. The black powder is stored in a non-flammable area and handled away from heat and other flammable materials. Only members who are trained to work with black powder are allowed to handle and load the black powder for the ejection charges. Other members are instructed to maintain ample clearance of those who are handling the black powder.

The level two motor, another potentially explosive material, is stored in a non-flammable environment before use. Only a NAR or Tripoli Level Two certified individual is allowed to handle and load the motor.

5.3 Assembly Procedures

Rocket Assembly Procedure

- Flight Computers
  - Verify flight computer configurations
  - Replace flight computer batteries
  - Check battery voltages
  - Check flight computer
  - Wire e-matches

  - Set charges

- GPS
  - Check battery voltage
  - Connect antenna to receiver
  - Mount antenna to receiver
  - Connect receiver to laptop serial connection

- Flight Video Telemetry
  - Mount cameras
  - Verify cameras' functionality

- Avionics Bay
  - Rewire flight computers to switches

- Recovery System
  - Insert Kevlar Wadding
  - Prepare main parachute
  - Connect main parachute to nose cone
  - Place drogue parachute to drogue tube
  - Gather shock chord to airframe
  - Position nose cone and insert shear pins

- Load Motor
  - Adjust ejection charge
  - Place motor in motor mount tube
  - Lock engine retainer ring
  - Confirm ignition system disconnected
  - Insert igniter and retain in place with nozzle cap
  - Disconnect leads and connect to ignition system

5.4 Pre-and Post-Launch Procedures

Pre-Flight Procedure

- Launch Procedure
  - Load rocket onto launch rail
  - Angle launch rail to vertical
  - Activate flight computers
  - Arm deployment charges
  - Clear launch pad
  - Confirm continuity
  - Signal launch readiness

Post-flight Procedure

- Visually mark touchdown location
  - If unable to visually determine touchdown location, use GPS tracking
- Deploy recovery team
- Guide recovery team to rocket
- Confirm recovery
- Fold and Assemble Parachute
- Connect Battery and SD card
- Inspect All Wiring Connections in Electrical Bay

6 Budget

The overall budget is presented in Table 5, with a total cost of $4807.42. Materials costs are itemized by category in following sections.

Table 5: Overall Budget

Category	Price Per Unit	Quantity	Cost
Lodging	500.00/night	3 nights	1500.00
Vehicle Rental	362.00/van	1	362.00
Gas	183.33/van	1	183.33
Construction Materials	673.36	n/a	673.36
Electronics Materials	1256.76	n/a	1256.76
Launch Materials	431.97	n/a	431.97
Registration Fee	400.00	n/a	400.00
		Total	$4807.42

6.1 Construction Materials Breakdown

The cost of the booster is $673.36. A itemized list can be found in Table 6.

Table 6: Construction Materials Budget

Item	Supplier	Quantity	Cost
4:1 Polycarbonate von Karman	Sunward	1	23.49
5.5:1 Filament Wound von Karman	Madcow	1	49.95
3/32in FR4 Sheet	ePlastics	2	21.80
2.1in Preglassed Phenolic	Public Missiles	1	96.99
1/4" Plywood	Aircraft Spruce	1	56.38
1/8" Plywood	Aircraft Spruce	1	33.88
54mm Minimum Diameter Retainer	Apogee	1	28.89
Pro54 Ejection Closure Adapter	Apogee	1	15.56
54mm Minimum Diameter Extension	Apogee	1	13.89
Flyaway Rail Guides	Additive Aerospace	2	99.00
30in Main Parachute	FruityChutes	1	126.85
12in Drogue Parachute	FruityChutes	1	50.58
5/8in Tubular Nylon Shock Cord	FruityChutes	2	46.10
U-bolt		1	10.00
		Total	$673.36

6.2 Electronics Materials Breakdown

The cost of the payload is $1256.76. An itemized list can be found in Table 7.

6.3 Launch Materials Breakdown

The cost of the launch materials is $431.97. An itemized list can be found in Table 8.

Table 7: Electronics Materials Budget

Item	Supplier	Quantity	Cost
Raven 4	Featherweight	2	310.00
QEBBIDUL Cube Camera	Amazon	2	39.96
Mobius Mini Camera	Amazon	2	149.90
32GB microSD Card	Amazon	4	33.96
Tattu 1s 800mAh Batteries	Amazon	6	21.99
Coax Cable and Adapters	Amazon	2	30.78
GPS Breakout	Adafruit	1	39.95
200G Accelerometer	Adafruit	1	25.95
36pin Female Headers	Adafruit	10	15.90
36pin Male Headers	Adafruit	4	1.90
Teensy 3.6	Adafruit	1	29.95
900MHz XBee	DigiKey	2	78.00
900MHz Antenna	DigiKey	3	23.52
PCB Printing	Oshpark	3	30.00
Simple GPS Tracker	Apogee	1	415.00
3D Printing Elec. Sled			10.00
		Total	$1256.76

Table 8: Launch Materials Budget

Item	Supplier	Quantity	Cost
FireWire Initiators	OffWeGo	20	40.00
Cesaroni 54mm Rear Closure	OffWeGo	1	39.95
Cesaroni 54mm Spacer	OffWeGo	1	12.95
Cesaroni 54mm Case	Apogee	1	69.19
Test Launch I218	Apogee	1	70.99
Test Launch J430	OffWeGo	1	72.95
Competition I218	OffWeGo	1	52.99
Competition J430	OffWeGo	1	72.95
		Total	$431.97

7 Appendix

A Construction Procedure

- Booster Section
  - Body tube
    - Carbon fiber wet-layup
    - Trim to length
    - Roughen surface for tip-to-tip reinforcement
  - Fins
    - Trace outline
    - Cut out rough shape
    - Sand to uniform dimensions
    - Sharpen leading/trailing edges
  - Mount retainer in body tube
  - Attach fins to body tube
    - Resin root edges to body tube
    - Fillet fin roots (with carbon fiber reinforcement)
    - Wet layup of carbon fiber tip-to-tip reinforcement
  - Finish surface of airframe
    - Fill pores
    - Sand surface smooth
    - Paint and clear coat
- Nosecone Section
  - Polish polycarbonate nose cone
  - Cutoff length of pre-glassed phenolic
  - Join Bluetube coupler, pre-glassed phenolic, and nosecone together